Irrigation Management in Sudan

Technical Report No. 3

Gezira Scheme

INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE

Contents

CHAPTER 1

Effective Farm Management Decision-Making in the Gezira Scheme

Muddathir Ali Ahmed[1]

1.1 INTRODUCTION

The Gezira Scheme is the largest farm in the heart of Africa. It extends a few miles south of Khartoum to about 25 miles north of Sennar. It comprises more than 2.1 million feddans and accounts for 50 % of the total irrigated area in the country. The soil of the Gezira Scheme is described as black cotton soil, rich in clay content, which when getting dry results in deep cracks. This property of the soil helps to maintain the soil structure and allows the free movement of irrigation water and air.

The Gezira Scheme slopes gradually from south to north, thus rendering gravity irrigation possible. The irrigation system intersects the scheme like a mesh, consisting of tens of thousands of kilometers of canals, escapes and surface drains and hundreds of thousands of kilometers of subsidiary field channels (Abu Ishreens and Abu Sitas).

The Gezira Scheme consists of the Gezira main and the Managil extension. Each of these Regions is divided into Seven Groups and subdivided into 53 Blocks. In the Gezira, there are 107 thousand tenants, 2805 employees, 10085 workers on a permanent basis and some 700,000 seasonal, temporary and casual workers. The scheme provides livelihood for more than two million citizens living within its boundaries.

The Gezira Scheme is often described as a socioeconomic example of democratic regional development. It is a blend of private and Government enterprises. It is a joint venture between the Government, the management and the tenants. Each party has specific duties and costs in the production process. The Gezira Scheme is specialized in the production of extra long and medium staple cotton, wheat, sorghum, groundnut and vegetables. Lately, livestock has been introduced at a limited scale in the Scheme. (Livestock is now introduced in the rotation of 13 Blocks, which includes Barakat and Dirweesh...)

The Gezira Scheme is managed by a board of directors called Sudan Gezira Board (SGB). It consists of 23 members and a Chairman. The Chairman of SGB is the Minister of Agriculture and Natural Resources. In the 1950s, after nationalization, the Board consisted of seven members only.

The present representation of the SGB is meant to be large to give all parties concerned a chance for participation. The members of SGB represent the executive management, the Tenant Union of the scheme, the scheme's employees, agriculturists and workers, top executives and professionals from the relevant ministries, corporations and institutions (recently, 50 % of the representation on the Board has gone to the farmers / tenants).

[1]Professor from the University of Gezira, Wad Medani.

In addition to the SGB, there is an executive administration with a Managing Director (under the new liberalization policy, the designation is changed to General Manager) on the top, assisted by a deputy and four main administrations. Other specialized units are attached to the office of the Managing Director. The four administrations (different administrations and commercial companies are being formulated under the new policy of the Government) are the Finance Administration, the Agricultural Administration, the Engineering Administration and the Administrative Affairs Administration. The specialized units are the legal unit, the internal auditing unit, the socioeconomic research unit, and the information and public relations unit. Parallel to these is the irrigation operations directorates, which are administered by a totally different body, the Ministry of Irrigation (MOI).

The SGB sets out the general policy of the scheme. It approves the work plans and programs prepared by the executive administration. It supervises implementation which is conducted by the executive administration. The administration works in a totally integrated manner with the general directorates for irrigation operations. These directorates (part of the MOI) provide irrigation water at the level of the minor canals and from that point onward, water distribution becomes the responsibility of the agricultural administration.

The Sudan Gezira Board and top administration body is assisted in running the scheme by different committees:

1. Administration Committee: It is composed of the Managing Director and his Deputy and the managers of four administrations. The committee looks into the different subjects submitted to the Managing Director. The Managing Director then decides on those subjects which need consultation of the committee.

2. Joint Committee: Its includes the concerned officials and Tenants Union representatives. It looks into the matters concerning agricultural policy and preparation for the different seasons. It also decides on reasonable compromises on different issues related to agricultural routine work.

3. Engineering Inputs Committee: Its concern is to make available all inputs needed by the different engineering departments so as to safeguard the production process.

4. Contracts Committee: This committee is to look into the different contracts needed by different works within the scheme. It evaluates all contracts and bids offered on the basis of the Scheme advertisement tenders.

1.2 THE OBJECTIVES OF THE GEZIRA SCHEME

The Gezira Scheme Ordinance of 1984 sets out the objectives of the scheme as follows:

(i) *The utilization, development and promotion of existing natural and agricultural resources, on commercial bases using the best available production methods to achieve maximum socioeconomic benefits.*

(ii) *The promotion of the social development and services in the scheme area for the benefit of the tenants and other persons living within it.*

The objectives are achieved through an exhaustive list of tasks and measures, and a multitude of key management performance actors all over the scheme.

The first of these key management actors is the Sudan Gezira Board. The main farm management decision taken by the SGB is to formulate the general policy of the scheme, approves its work plans and programs, and supervises their implementation. The formulation of these policies is made in line with the general country's socioeconomic strategy. The SGB translates these strategies into action.

The latest of these policies (1991/1992) meant to transfer the Sudan Gezira Scheme into a granary to achieve self food security, especially after the last two consecutive drought years, and refusal of international bodies to keep food out of the political game. The current agricultural policy reduced the cash crops and increased the food crops. The area of cotton for the season 1991/92 was reduced by more than 45% and that of cereals was increased by 100% of the average over the last ten years (1980 - 1989/90)[2]

Once this decision was taken about the area of different crops, the executive administration acts accordingly. Each of the four administrations takes the respective management decision to make these policies a reality. The decisions taken by the various administrations are interrelated with each other in terms of information and work to be accomplished.

1.3 ROLES OF THE THREE PARTNERS

To understand how the Gezira Scheme operates and the farm management decisions are taken, it is necessary to understand the role of each of the three partners (the government, the management and the tenants) in the production process and the associated cost that each party incurs as a result.

1.3.1 The Government

The Government is responsible for digging and maintaining the irrigation and drainage system and all irrigation operations in the scheme until the minor canals. In return, the Government receives proceeds collected from the water and land charges levied on the areas of the different crops grown in the Scheme.

This job accounts for the one-half of MOI's activities, as the area of the scheme is about 50 % of the irrigated sector in the Sudan. The irrigation operations in the Gezira Scheme are conducted via two irrigation operations directorates - - one for the Gezira and the other for the Managil Regions. There are seven divisions, twenty three subdivisions and seventy eight sections in each directorate under the MOI.

[2]Average cotton area = 435,448 feddans and average cereal area = 647,852 feddans.

The maximum area that can be irrigated during any one season is one-half of the Scheme. This means that the Scheme may irrigate a total of 1.5 million feddans each year (during the summer and winter seasons).

In addition to the above stated direct tasks and responsibilities, the Government is nationally responsible for the importation of all chemicals including fertilizers, insecticides, sacks, marketing of the cotton, and determining the cotton and wheat farm-gate prices to the tenants.

1.3.2 The Sudan Gezira Board

The Sudan Gezira Board represents the management of the Gezira Scheme. It performs two types of tasks: (i) on behalf of the tenants; and (ii) obligations towards the scheme. The first category includes tasks about cotton and wheat crops, the costs of which are debited to the tenant accounts. The other type of tasks are its own responsibilities towards the Scheme. The costs of the tasks under the second category are covered by the Board using its proceeds from the scheme.

The tasks performed on behalf of the tenants include the following:

(a) *Cleaning, levelling and preparing the land for cultivation, mainly using the scheme machinery.*

(b) *Digging and maintaining the subsidiary field channels (Abu xx and Abu vi).*

(c) *Distributing tenancies and charging tenants water and land charges as decided by the Ministries of Agriculture and Finance, Advisory Unit for Agricultural Corporations (AUAC), Ministry of Irrigation and the Gezira Tenants Union.*

(d) *Providing agricultural inputs to the tenants in time and place at cost.*

(e) *Supervising the tenants in their work and supplying them with the necessary guiding instructions to manage these inputs.*

(f) *Supervising other production operations including ginning, grading and transportation.*

(g) *Preparing and maintaining the Gezira Scheme fixed and movable assets.*

(h) *Conducting the socioeconomic research and studies which help promote the performance and welfare of the Scheme, its labor force and residents.*

The Sudan Gezira Board represented by its Finance Administration keeps all financial records of the Scheme and individual tenants accounts. At the end of each cropping season, it prepares individual profit and loss accounts of the tenants and the Scheme income statement.

The costs incurred by the SGB in accomplishing the tasks conducted on behalf of the tenants are debited to the tenants individual accounts. These expenses are deducted from each tenants proceeds as soon as the earnings are credited to the tenants' accounts. Moreover, the Board extends cash advances to the tenants for certain operations and these advances are treated in the same manner. In addition to the above costs, the Board will also deduct from each tenant's account the water and land charges due for the cultivation of the grown crops, plus a service charge which includes interest to the Bank of Sudan.

Starting with the season 1991/1992, the financing of the Gezira Scheme is done by a consortium of financial institutions instead of the Bank of Sudan. The Sudan Gezira Board acts as the coordinating body between the tenants and the consortium. It represents the tenants in the negotiations for the financing to the Scheme and repays these finances to the consortium after the cotton and other crops are sold.

Other duties performed by the SGB as specified in the 1984 Ordinance include the following:

(a) *Recruitment of employees and workers, revision of their terms of employment, in addition to training and other manpower development activates.*

(b) *Contracting with persons or agencies inside or outside the country on the basis of approved budgets and prevailing financial rules and procedures to import production inputs, machinery, implements or conduct services required by the Scheme.*

(c) *Disposition of any property not of use or fully salvaged and/or being redundant in accordance to the existing financial rules and procedures.*

(d) *The SGB has the right to form committees to help in executing its duties.*

It also has the right to invest any capital not in use, as well as to lend it to the central government. In return for the above duties, the SGB may receive a share in the water and land charges.

1.3.3 The Tenants

The tenants are a pivot in the production process. *They are the party who plant the seeds, irrigate the land and finally harvest the crops, using in this process all the inputs provided to them by the SGB or the Government.* There are many duties that the tenants perform and pay costs from their own or other resources.

In return, the tenants receive all the income above the costs made on their behalf. Any excess is put as a credit to their individual accounts and is paid to them before 30 June, or if in case of deficits, their individual accounts are debited and these debts will be deducted from the following years surpluses, if any.

1.4 FARM MANAGEMENT INFORMATION

Accurate and efficient management for decision-making requires extensive information concerning past costs, returns, inputs used and production, present financial and physical conditions, and future costs and returns. This information is acquired from the scheme records, which are compiled at the headquarters by the four administrations at the *Block* levels, and the socioeconomic research unit.

The Gezira Scheme represented by the different administrations uses these records to make production decisions, financial decisions, services decisions, and reorganization decisions. These records provide the basis for preparing reports for legal bodies, such as the General Auditor, the Council of Ministers, the Minister of Agriculture, etc. The data available are voluminous, but adequate for most of the decisions taken regarding crop production and financing. The management considers the scheme as one management unit, although many suggestions were raised for dividing it into several management zones, but this is not feasible at present for several economic and technical reasons.

1.4.1 Available Farm Management Information

Since 1911, the Gezira Scheme has accumulated production data on a time series basis according to the types of crops grown. This data include the physical inputs provided for each land unit cultivated with a crop and their costs. Data on cotton and wheat are more complete than on sorghum and groundnut.

The information needed to achieve the scheme objectives is numerous and varied in nature. It includes the following areas: (a) production; (b) finance; (c) policies; (d) economics; (e) social; (f) meteorological; (g) natural resources (irrigation); (h) international factors; and (i) manpower. The information from all these sources are compiled on a continuous time series basis and meshed together before it is used for farm management decisions.

The outcome of these data may include the following: (i) annual income statements (profit / loss); (ii) balance sheet statement; (iii) crops costs by agricultural operations; (iv) the physical input requirements and the crop sale proceeds; (v) an inventory of the Scheme assets; and (vi) a list of depreciation or replacement costs.

Availability of this information is important for the preparation of work plans and programs each year, which include current and development budgets of each Administration, department or unit in the Scheme. It is also important for writing annual reports on the performance of each unit, department or administration; annual report about the scheme; and reports for the General Auditor and Council of Ministers.

1.4.2 Socioeconomic Research Unit (SERU)

One of the specialized units in the scheme, which is responsible for the collection, compiling and disseminating the information and statistics of the scheme, is the socioeconomic research unit. It has been collecting and producing annual reports, such as the economic analysis for field crops, annual economic review, and Gezira current statistics for more than a decade.

The sources of these data and reports are the *Administrative Affairs Administration*, the *Agricultural Administration*, the *Finance Administration* and the *Engineering Administration*, the *Archives center* and the *Socioeconomic Research Unit's own staff* located in the field. The kinds of information already being collected by the Socioeconomic Research Unit include the following at the level of Agricultural Block, Groups and Regions:

1. Areas, yields and production of the main crops.

2. Quantities of inputs used for the cotton and wheat crops and their prices and costs (seeds, fertilizers, insecticides, herbicides and sacks).

3. Amount of labor used in the Gezira Scheme classified into family, local labor, imported labor, floating labor and an estimate of the total scheme requirements compared with the total available.

4. Costs of spraying herbicides and insecticides and number of sprays in case of cotton insecticide spraying.

5. All the agricultural operations performed on each crop and their costs. These include land preparation operations, agricultural operations, harvest and post harvest operations, service, water / land charges collected from each crop, and transport.

6. Prices of the different crops and for cotton these prices by grades and variety.

7. Quantities of other inputs used such as petroleum products, quantities received and quantities consumed, and also data on irrigation water requirements and deliveries in million cubic meters by months.

8. Also, in order to take the correct farm management decision, the Socioeconomic Research Unit sometimes conducts studies and/or surveys concerning certain problems.

In addition to this, the unit also conducts research on the effects of the social changes resulting from the economic development and social services provided to the people living in the scheme. The turn around time between the information collection and its conveyance after analysis is not long because of the computer facilities available at the Unit, which also may be used as a word processor.

It is worth noting that the constraints on the use of this information for management are not significant so far. An example of the usefulness of the data collected by the SERU, in taking the correct management decision, is that concerning the allocation of 230,000 feddans of cotton on the Gezira tenants during the year 1991/1992. The average area of cotton cultivated during the last ten years (1980 - 1989-90) was about 435,000. Therefore, the cultivation of 230,000 means a reduction of more than 45%. The question is whether the proposed area is to be proportionately allocated on all the tenants, or whether it is to be allocated to those tenants who historically are distinguished for their high cotton productivity.

In order to address the questions raised, management of the scheme asked the SERU to furnish it with the cotton productivity data of all Blocks for the last 16 years and also the profit and loss statements. On basis of these two sets of data, the management decided to allocate the 230,000 feddans on the productive Blocks and to exclude the non-productive Blocks. This decision would not have been feasible if the requested data were not available.

1.4.3 Information Difficulties

The Gezira Scheme has been in continuous operation for more than 75 years. During this period, many changes have taken place, especially to the soil, the canalization system, the agricultural environment, and the tenant himself as a factor of production. Studies on these issues need to be conducted to investigate the extent of change on the productivity and the social aspects of the farming community.

Agricultural productivity in the Gezira Scheme varies between and within the Agricultural Groups. It also varies between the Blocks and within the same Block, and even within the same number (land unit of 90 feddans). Factors affecting these variabilities are not yet completely investigated. It is with pleasure one notes that there are certain on-going programs on soil test analysis, deep plowing, canal desilting, etc. Yet, the results of these programs are not available in the form that can be used in making farm management decisions. How effective are these programs in increasing the productivity is still under investigation. It is highly recommended that the Gezira Scheme by now should have soil analysis maps, and productivity maps, superimposed on the soil maps with correlations between the soil nutrients and productivity, especially for the micronutrients.

An example of the waste that may take place from year to year as a result of a lack of information may be noted from an example given as under:

> *The provisions of insecticides for next season requires knowledge of the kinds of pests that may be dominant in that season. These types of pests are affected by the weather conditions that will prevail in the next season. Information on next year's climate is not available and is difficult to predict. Therefore, when deciding to import next season's insecticides, the management allows for both groups of pests (dry and wet). In this case, some of the imported insecticides may not be economically used.*

But the question is why the Gezira Scheme management does so. The answer is easy. It takes a long time to obtain approval for foreign exchange to open letters of credit and import the insecticides. If the Gezira Scheme management is assured of getting the foreign exchange needed to import the different inputs on time, then this waste would not have taken place. Nevertheless, it is cheaper to waste a few thousand dollars on some insecticides than to lose the whole crop. The problem of foreign exchange availability to the Gezira Scheme will remain one of the main deterrents to the progress of the Scheme.

1.4.4 Management Decisions Based on Rapid Information Collection

The management decisions which require the fastest collection of information are those which cannot be postponed and which need immediate action. In the Gezira Scheme, there are a few such management decisions which may be enumerated below:

1. *Crop protection operations that depend on the state of winds and irrigation of the crops.*

2. *Herbicide application which is closely tied to sowing and irrigation dates.*

3. *Sudden investigation of pests and crop diseases.*

4. *Water indents, water shortages, canals spilling over or breaking, especially during high demand.*

5. *Political decisions, the implementation of which needs much preparation in a very short time.*

6. *Inputs that need to be transported to and from the scheme stores on time, especially during the rainy season.*

7. *Labor shortages during the critical growing and harvesting periods.*

8. *Farm mechanical land preparations and desilting programs when interrupted for any reason.*

9. *Social information due to adoption of certain packages of technology.*

1.5 KEY MANAGEMENT PERFORMANCE CONCERNS

The key management performam concerns of the different actors in the Scheme may be divided into six main parts:

1. *The formulation of the general policy of the scheme and the main objectives.*

2. *Setting up of the work plans and programs that will achieve the main objectives and targets.*

3. *Approval of the work plans and programs by the Sudan Gezira Board.*

4. *Implementation of the work plans and programs after being approved by the SGB.*

5. *Supervision of the implementation of the work plans and programs.*

6. *Assessment of the results at the end of the business year.*

The cornerstone to the whole decision-making process is what the Sudan Gezira Board decides as general policy and objectives. This decision, once taken, is passed down to the executive administration to be translated into work plans, programs and targets. In doing this, all of the scheme administrations and their departments and units will be involved in setting up these plans and programs.

Each administration has a defined role to play in achieving the set objectives. The agricultural administration, for example, in order to grow the areas specified in the general policy of the scheme, need certain requirements to be met. The magnitude of these stipulations will be set by the specialized departments, Agricultural Groups and Agricultural Blocks. These include areas to be plowed, quantities of different inputs, seeds, herbicides insecticides, irrigation water, manpower and other services. These requirements, after being compiled and discussed at the Administrations and Joint Committee levels, will be passed on to the Finance Administration for translating the figures into physical quantities and cash.

The Finance Administration will furnish the needed inputs in the quantities demanded and at the time needed. The Engineering Administration will also get its agricultural machinery on time, well-maintained, and start preparing the land for the different crops and finish this job in good time before the beginning of the following operation. The Administrative Affairs Administration will make sure that each Block, or Group has its needs for manpower met. However, in performing all these activities, and in taking the appropriate decisions, one very important element is always kept in mind, that is the time factor. These management decisions should be taken at the proper time so that each administration concerned can react to what is required.

The approved plans and programs will be implemented by the units concerned, which know what to do. The work plans and programs are tightly scheduled and any delay at any stage of implementation will interrupt the smoothness of the overall implementation and may require some further management decisions.

Parallel to the operations performed by the Gezira administration, other complementary work is also performed by the irrigation operations directorates which belong to the Ministry of Irrigation. The role of the irrigation operations directorate is equally important. Irrigation water, being the limiting input in the Gezira Scheme, has to be provided in the quantities and times desired. To do this, a similar decision-making process is made. At the field level, water indents are ordered by the Field Inspector and passed to the Block Inspector, who consult with the canal ghaffir (gate operators) to make sure that the water indents correspond with the needs in time and place. Water indents may be changed daily during the rainy season and weekly at other times. Water indents are accepted mid-week. The irrigation operations directorate will provide the water as required up to the minor canal. From there, the Field Inspectors and tenants take over and distribute it into Abu xx and to the fields.

In addition to the units of the Gezira Scheme and Ministry of Irrigation, there are other important bodies involved in the decision-making process concerning the Gezira Scheme. These bodies include the Agricultural Research Corporation, the Ministry of Agriculture, the Gezira Scheme Tenants Union and their units such as the cotton variety committee, the field coordinating teams and the Joint Committee.

The Joint Committee is second to the Sudan Gezira Board as a farm management decision-making body and includes the Agricultural Manager, the executive office of the Gezira Tenants Union and representatives from Finance Administration, employees and workers unions. The task of the Joint Committee is to review the agricultural plans and programs before they are presented to the SGB, approve the rates of the agricultural operations, the rates and dates of the agricultural financial advances, and the policies of the labor recruitment in addition to all of the other issues concerning the tenants. The task of the Ministry of Agriculture and the Agricultural Research Corporation is mainly concerned with how much to produce and how to produce, including new production input packages, sowing dates and other operations recommendations.

Another important body, in the decision-making process, is the group production councils, which include the Group Inspector, representative of the Gezira Scheme Tenants Union, and representatives from the Blocks production councils. It helps the Group Inspector in the general supervision of the production operations and assists in solving any complaints raised by the individual tenants. The next is the Block production councils. They represent members from the village councils and the Gezira Scheme Tenants Union.

The last is the village production council, which represents the broad base of tenants participation in the decision-making process. They cooperate with the field inspectors in all aspects concerning the tenants. They are elected by free ballot.

The decision-making process in the Gezira Scheme is not simple and involves a large number of different degree of responsibilities. Starting with the highest position, there are:

1. Council of Ministers.

2. Minister of Agriculture and Minister of Finance.

3. The Sudan Gezira Board.

4. Three SGB specialized committees, Financial, Agricultural and Administrative Committees.

5. The Managing Director, they Deputy Managing Director and the Managers of the four Administrations.

6. The three Deputy Agricultural Managers, one at the Headquarters and two at the Agricultural regions (Gezira and Managil).

7. The managers of the departments of the engineering administration, the maintenance and workshops, the civil engineering, the mechanical engineering, the electrical engineering, the agricultural engineering and the telecommunication departments.

8. The managers of the ginneries and the Gezira railways.

9. The financial controller, the head of accounts and the managers of the supplies and stores, departments and their deputies.

10. The manger of the Socioeconomic Research Unit and his deputy and staff.

11. The managers of the specialized departments of the Agricultural Administration : crop protection, field affairs, animal production, extension and tenants affairs, seed propagation, horticulture, along with the services and the budget departments.

12. The Social Service Officer.

13. The Group Inspectors.

14. The Block Inspectors.

15. Members of the Joint Committee, the group production councils, the Block production councils and the village councils.

16. The Agricultural Research Corporation professional staff.

17. The organs of the Ministry of Agriculture.

18. The Irrigation Operation general directorate.

1.6 SUPPORTIVE ORGANIZATION INCENTIVES

The Gezira Scheme is a public corporation. As such, it is affected by the general terms of employment and government policies issued by the Ministry of Finance and Bureau of the Civil Service. It operates according to an approved annual budget. In this budget, the scheme annually submits proposals for overtime and bonus payments. The employees' terms of service and conditions (1986) furnish good intentions towards its employees. Item 3 of section 87 of the statute states the nature of these incentives.

The principle of incentives paid to the manpower with the intention to promote production is controversial. One view is that each person should be given a financial incentive at a certain rate for a particular job without any additional productive contribution being made. The proponents of this view want to avoid possible resentment in case of any fall in the incentives provided.

Another view is that incentives are like catalysts, and when adopted, result in more production. In this regard, numerous incentive schemes exist ranging from simple bonuses to profit sharing. One of these incentive schemes relates to planting operations. This may be applicable to certain operations, like land preparation, harvesting, hauling of crops and transportation, etc.

The quality of work is important and so is the care of the instruments used. Yet, this scheme produces fluctuations in monthly incomes and involves careful record keeping and supervision for quality control. In the Gezira Scheme, there are not yet any supportive incentives for the staff who participate in the achieving management objectives on a large group basis except on a very limited extent and only for those who participate in wheat production.

In fact, the Minister of Finance and National Planning has lately banned any incentive payments. In the past, these payments were given to workers in certain service units, like the ginneries and the Gezira railways. These incentives were meant to encourage these workers to finish their work before the rains.

But, as these incentives are not provided to other employees, such as field inspectors who supervise the production process, they do not feel that their efforts are appreciated, either by the administration or by the tenants. On the contrary, some tenants think that the post of field inspector is redundant. This is due to ignorance about the role of the field inspector in increasing productivity.

The present Managing Director (1991) is of an opinion that conditional incentives may work satisfactorily in the Gezira Scheme. If all inspectors are assured of getting a progressive share of incentives in increasing the productivity of cotton or wheat over a certain historical average, they will make extra efforts to achieve higher yields. Anyway, this proposal deserves to be studied and discussed at all decision-making levels.

1.7 HOW RAPID APPRAISAL COULD EFFECTIVELY BE CONVEYED TO MANAGEMENT AND INCORPORATED INTO THE MANAGEMENT DECISION-MAKING PROCESS

The management decision-making process in the Gezira Scheme is quite extensive and passes through a chain of the scheme, institutions and several stages of actions. Some of these decisions need to be taken before the beginning of the cropping season, others during the cropping season, with the remaining at the harvest and even post-harvest of seasons the different crops. The type of information needed for each decision-making is quite different. Some decisions need time series data, while other need current data. Some farm management decisions may wait for some time, but others have to be taken immediately.

It is, therefore, difficult to prescribe what each unit should do. On the contrary, each unit should demonstrate its capabilities regarding the kinds of goods it can deliver. Just to help them to do so, the following is suggested:

1. *There is need for several organized workshops to train decision-makers on how to use the Rapid Rural Appraisal (RRA) in management decisions.*

2. *Each administration should list the kinds of decisions it usually takes, classify them chronologically according to the type of information needed, and the turnaround time between the need for the information and the time for taking the decision.*

3. *Some decisions need inputs provided by external bodies (e.g. Ministry of Agriculture, Finance, Irrigation, Bank of Sudan, Cotton Sales Corporation, etc.) In this case it should be clearly specified what sort of inputs are needed and what is the shortest time required for such inputs.*

4. *The scheme should have a data bank with a central computer services and terminals located where such data are mostly used in the decision-making processes. A list of the information needed at regular time periods for the people concerned.*

5. *Rapid Rural Appraisal staff should be trained on how to use the system effectively.*

Means of supplying Rapid Rural Appraisal Information should be specified. Currently, the scheme has the best communication system. A few additions may be to provide helicopter services to the

Chairman of the Sudan Gezira Board and the Managing Director because the scheme is vast and during the rainy season is not easily accessible in addition to the fact that certain problems need to be solved at the site. The accessibility of the Managing Director to all parts of the Gezira Scheme at any time will make the staff at the field level continuously alert, especially if the incentive systems are being finally adopted.

CHAPTER 2

Performance of the Gezira Canals

M. S. Shafique[3]

2.1 BACKGROUND

2.1.1 Sudan

In terms of area, Sudan is the largest country in Africa (Figure 1). Its population in 1992 was estimated around 26.7 million and its total area is 250.6 million ha (EIU and FAO). The annual rate of population growth is 2.8 percent (Zaki 1992), annual GDP growth is 2.0 percent (EIU) and per capita annual income is estimated at $300 (PCGLOBE Software 1989).

The agriculture sector of Sudan accounts for 38 percent of GDP and provides employment to about 80 percent of the country's population. The sector contributes about 98 percent of total foreign exchange. According to Zaki(1992), the sector has the following four sub-sectors: (1) irrigated agriculture-1.68 million ha (FAO source reports 1.89 million ha is a better estimate); (2) mechanized rain-fed agriculture-2.52 million ha; (3) traditional rain-fed agriculture-4.2 million ha; and (4) livestock. After excluding livestock, the estimated contributions of the irrigated and rain-fed sub-sectors are about 45 and 55 percent, respectively.

2.1.2 Irrigation Schemes

At present, the total area within the irrigated sub-sector is about 1.89 million ha. The Gezira-Managil scheme alone occupies 0.882 million ha. Other major public sector schemes are New Halfa (0.151 million ha), Rahad (0.126 million ha), and Blue and White Nile Schemes (0.269 million ha). There are five sugarcane schemes with a command area of about 0.1 million ha. Other small irrigated public schemes are Es Suki (33.6 thousand ha), Abu Nama (12.6 thousand ha), and Northern Agricultural Production (NAPC) schemes (38.6 thousand ha). There are two main schemes outside of the Nile system: Gash and Tokar.

The private sector consists mainly of pump schemes, which are concentrated in the north. The estimated irrigated area in this sector is about 0.19 million ha (pre-mission working paper of the World Bank office in Khartoum, 1988).

[3]Head, Sudan Field Operations, IIMI.

2.1.3 The Gezira Scheme

The Gezira Scheme is huge in size and dominates the entire irrigated sector of Sudan. It is approximately 47 percent of the entire total irrigated area of Sudan and also the largest single management scheme in the world. It has been the backbone of the Sudanese economy: its share to total agricultural GDP is estimated to be 35 percent (Plusquellec 1990).

The Gezira Irrigation Scheme (0.882 million ha) is mainly gravity fed and lies between the Blue and White Niles south of Khartoum (Levine and Baily 1987). As shown in Figure 2, the irrigation system of the scheme is a huge network of main, major, minor and tertiary canals[4].

According to Plusquellec (1990), the following are the main features of the conveyance and distribution system of the scheme:

- *2 main canals of total length of 261 km with conveyance capacity ranging from 168 and 186 m^3/s at headwork to 10 m^3/s at the tail;*

- *11 branch canals of total length of 651 km with conveyance capacity ranging from 25 to 120 m^3/s;*

- *107 major canals of total length 1,652 km with a carrying capacity ranging from 1.5 to 15 m^3/s;*

- *1,498 minor canals of total length of 8,119 km with a delivery capacity ranging from 0.5 to 1.5 m^3/s;*

- *29,000 water courses called "Abu Ashreens" (Abu XX) of total length of 40,000 km with 116 l/s capacity; and*

- *350,000 field channels called "Abu Sitta" (Abu VI) of total length of 100,000 km with 50 l/s capacity.*

All canals have cross-regulators[5] which serve as *control points* (*CPs*) for off-taking canals. The stretch of canal between two regulators is called a *reach*. A segment of a canal comprising two or more reaches is defined as a *section*.

The above conveyance and distribution system is the one which is targeted here for assessing and quantifying the hydraulic performance in comparison with its design objectives. This paper, therefore, only deals with a selected portion of the physical system of Gezira Scheme. By making use of reliable existing secondary data, an effort is made to evaluate the system.

---

[4]In Sudan, major, minor and tertiary canals are called Majors Minors and Abu Ashreens respectively.

[5]Cross-regulators are of the following kinds: (i) Sluice gates, (ii) Pipe-regulators, and (iii) Butcher's weirs.

2.1.4 Why the Gezira Canal System?

The International Irrigation Management Institute (IIMI) established its field office in Sudan in the middle of 1989. Over the last more than four years, the Institute has brought the national and international experience to the doorstep of policy-makers and managers responsible for irrigated agriculture. To achieve this objective, dozens of seminars and workshops have been organized at different locations.

Field research is being conducted at two main locations: (1) the Rahad irrigation scheme where the performance of a selected canal system has been monitored over the last two years; and (2) the White Nile pump schemes with a focus on the comparison of different management modes introduced after the privatization of many pump irrigated schemes. Limited technical assistance has also been provided to the Kenana Sugar Company near Kosti.

For the Gezira Scheme, which is the largest and the forerunner of all major schemes in this country, IIMI's contribution was confined to the level of on-farm water management only. A senior advisor from IIMI remained associated with the Water Management Advisory Unit (WMAU) from 1990 to 1992. His main responsibility was to establish the Unit and provide training and technical assistance to the field staff of the scheme. According to the terms and conditions of his job, he concentrated more on water management issues below the field outlet pipe (F. O. P).

It is also well known that over the last 68 years of its existence, the Gezira scheme has been studied more than many schemes in the world. There is a long list of research papers, theses, reports and books written about the scheme. In other words, there exists a rich source of secondary data which can be exploited. The main irrigation system, however, did not receive enough attention till the 1980's.

2.1.5 Importance of Secondary Data

At many occasions, the management of IIMI and its many supporters have stressed the importance of making use of existing data in the field of irrigated agriculture. The proponents of this view feel that in many developing countries there exists a lot of data and literature which can easily be analyzed and reviewed to learn useful lessons. Also, reports based on such information provide cost-effective and faster means of knowledge generation and dissemination to many stakeholders.

In certain cases, financial difficulties hinder proper dissemination of generated information to all parties concerned. Due to such factors, information generated and reports written by national agencies, with or without outside help, stay confined to a few deep pockets. This restricted circulation of research findings deprives many researchers their due share of reward and recognition and others to benefit from it.

2.1.6 Source of Secondary Data

Although the Gezira scheme has been studied extensively, the main focus always remained on the on-farm activities. Farbrother, an FAO consultant, who spent more than a decade and half in Sudan is considered to be an authority on soils, crops and on-farm water management practices in the scheme. He contributed dozens of research papers, technical notes and reports. Farbrother's work is very much acknowledged and appreciated in Sudan. There are countless other researchers who contributed their share to enrich the knowledge about the scheme. However, in the past, the main conveyance and distribution subsystem attracted very little attention from many of the researchers and the focus remained on the on-farm subsystem.

In the 1980s, there came a pleasant change. The policy-makers and researchers started undertaking studies about the main conveyance and distribution system of the scheme. Partly, this change can be attributed to the rehabilitation program for the Gezira and Managil scheme which was initiated at that time.

After securing necessary research funds from the Gezira Rehabilitation Project, the Hydraulic Research Ltd, Wallinford, and Hydraulic Research Station, Wad Medani (MOI) conducted a collaborative research study in the scheme. The secondary data which will be used in this paper comes from a report entitled as *"Research for Rehabilitation: Study of the Reliability of Water Supply to Minor Canals."*

From this point onward, the report about the reliability of water supply to minor canals will be referred to as the *Main Data Source Report (MDS-Report 1991).* The data used in this paper is mainly tabulated in the second volume of the report.

2.1.7 Objectives

The design considerations for the Gezira canal system were to convey and distribute adequate, equitable and reliable water supplies regardless of time and location in the scheme. In line with the design criterion, the objective of this study is to *quantify the extent to which design objectives are achieved by assessing the hydraulic performance of the Gezira irrigation system under the following three categories: (i) Conveyance of Water Supplies, (ii) Utility of Water Supplies, and (iii) Maintenance of the Irrigation System.*

2.2 LITERATURE REVIEW

In this section, the following topics will be briefly covered:

1. Concept of performance.
2. Design objectives.
3. Variables required in the control of a conveyance and distribution system of the Gezira scheme.
4. Performance indicators which can use selected water control variables to determine the extent to which design objectives are achieved.

2.2.1 Concept of Performance

Performance is the degree to which a system achieves its objectives. But objectives differ for individual systems and may be reset from time to time by a management decision. IIMI's concern is with absolute standards of performance, consistent definitions and measurements of components of performance, including productivity, equity, reliability, sustainability, profitability and quality of life (IIMI's Strategy for 1990s, fifth draft)." IIMI has opted for this definition of performance as a guideline for the 1990s.

Abernethy (1989) has given the following definition of performance: *" The performance of a system is represented by its measured levels of achievement in terms of one, or several, parameters which are chosen as indicators of system's goals."*

Murray-Rurst and Snellen (1992) have commented that the above definition (by Abernethy 1989) is output oriented only. According to them, the definition totally disregards the resources utilized, and the environmental impacts in achieving the level of outputs.

Perhaps the definition given by Small and Svendsen (1992) does give due consideration to the points raised by Murray-Rust and Snellen (1991). This improved concept of performance is given as follows: *" Performance of a system as encompassing the totality of both its activities-inputs and the transformation of the inputs into intermediate and final outputs-and the effect of these activities on system itself and on its external environment."*

From a different angle, the definition of performance as given by Abernethy (1989) is simpler and more practical. The points raised and additions proposed could be considered as essential tools for the assessment of performance i.e., to determine whether the performance results are acceptable or not. However, performance as such appears to be more an output-oriented matter.

In this study, the performance monitoring is restricted to a component of an irrigation system generally called the main system. As dictated by the availability of secondary data, the focus is only on reporting the operating status of the main conveyance and distribution system. By no means was there any intention to ignore the importance of the on-farm part of the subsystem.

2.2.2 Design Objectives

In the context of water control, Johnstone (1926) states that the design of the Gezira scheme was intended to meet the following conditions:

1. No field irrigation at night was possible.

2. Disposal of water in excess of actual requirements was not possible after it had left the main canal.

3. Under the terms of agreement, actual requirement of the cultivating syndicate had to be satisfied.

4. Measurements of water under varying conditions and levels were necessary.

Similarly, Taj el Din et. al. (1982) also stated that the design of the operating system is to deliver the required quantities of water at the proper time at the farm level. In order to achieve such design objectives, the authors emphasize:*"It was necessary for the Ministry of Agriculture and Irrigation (MOAI) to ensure that water delivered in the main canals (Gezira and Managil canals) at Sennar (the dam serving the canals) is adequate for (satisfying) crop water requirements and the effective control of the water ensures that sufficient water is delivered at the correct time to the cultivators."*

The above referred literature clearly points out two design objectives: (i) adequate water supply, and (ii) reliability of water supply irrespective of time and location in the scheme. Also, additional emphasis is placed on the operational performance of the managing agency to ensure that the design objectives are being achieved.

Johnstone (1926) also reports that the scheme was originally designed for continuous irrigation. However, at the time of construction, the difficulty of irrigation by night was raised, which made it necessary to adopt a night storage system. A report by Euroconsult (1982) further elaborates on the irrigation management practices as follows: " *... block inspector and his staff have to operate the regulators between the successive reaches in such a way that distribution to tenants from head to tail in the minor is as equitable as possible irrespective of their locations on the minor. The equitable distribution can be obtained by relative opening of the gates in the night-storage weirs and the (partial) opening or closing of the FOPs (field outlet pipes)."* It is also quite clear that in order to have equitable water distribution at the Minor level, the main and major canals have to supply equitable water supplies to these minor canals.

The above discussion helps to identify the following design objectives:

(1) adequacy;

(2) dependability;

(3) equity; and

(4) operational effectiveness to achieve adequate, dependable and equitable water distribution.

2.2.3 Variables for Water Control

The selection of the variables is based on the data presented in the original report. According to this report, the variables are as follows:

1. Indents prepared by the SGB.

2. Crop water requirements.

3. Authorized releases (as determined by officials).

4. Actual deliveries.

As this paper is based on the referred MDS-Report (1991), the above variables will be used in deriving performance indicators for the selected Gezira canals.

2.2.4 Performance Indices

2.2.4.1 Hydraulic Performance Indicators

In order to establish the extent to which design objectives are being achieved, the above stated water control variables will be used to identify performance indices. The first set of such indices is taken from the Main Data Source Report(MDS-Report 1991) as given below:

1. Indent/Requirement Ratio (IRR): a measure of the accuracy of the indenting process and the assessment of demand (R1 in MDS-Report 1991).

2. Authorized Release/Indent Ratio (AIR): a measure of the adjustment of the indents (R2 in MDS-Report 1991).

3. Actual Delivery/Authorized Release Ratio (SAR): a measure of performance of the distribution system (R3 in MDS-Report,1991).

4. Management Delivery Ratio, Actual Delivery/Requirement (MDR): a measure of the performance of the whole process (MDR in MDS-Report 1991).

5. Reliability: the portion of the season during which performance is acceptable. This is equivalent to the probability that a given performance parameter, for example R3, lies within an acceptable range."

However, in MDS-Report (1991) there is no mention of any measure for an equity parameter. As a matter of fact, this aspect of water distribution was not considered in the report referred to at all.

Kuper and Kijne (1992) and Molden and Gates (1990) have proposed the following performance parameters for adequacy, dependability and equity:

Adequacy: A fundamental objective of irrigation systems in Sudan is to deliver the amount of water required to crops. To quantify the adequacy achieved, the authors have defined P_A[6] as

$$P_A = \frac{1}{T} \sum_T (1/R \sum_R P_a) \quad ---(1a)$$

and

[6]Attached figures show P_A as PA.

$$P_a = \frac{Q_d}{Q_r} \quad If \quad Q_d \leq Q_r \text{------} (1B)$$

$$P_a = 1 \quad otherwise \text{--------} (1c)$$

Where $P_a = Q_d/Q_r$ is the ratio of water delivered over water required. In the context of Sudan, the water demand can be either crop water requirements or indents placed. Equation 1 implies that Q_d and Q_r are defined for discrete locations where water is conveyed in a region R at finite time intervals within a period T.

Molden and Gates (1990) also proposed that a P_a value more than 0.9 is assumed to be good, between 0.8 to 0.9 fair, and below 0.8 poor (unsatisfactory as used in this paper).

When requirement provides the basis for a target discharge, the *Management Delivery Ratio (*MDR) is the same as the *Delivery Performance Ratio (DPR)* as defined by Bos et al. (1993) and Rao (1993). *Water Delivery Performance, WDP,* also provides similar information. Baily and Lenton (1984) described WDP as:

$$WDP = \frac{1}{n}\sum_{t=1}^{t=n} \frac{V(t)}{V^*(t)}$$

where V(t) is the total volume of water entering the headworks of the irrigation system during period t, $V^*(t)$ is the total target volume to be supplied in period t, and n is the number of periods in the cropping season. The authors have suggested the following condition for the above equation of WDP:

$$V(t) \leq V^*(t)$$

Supply-Indent Ratio (SIR) is another indicator presented by Shafique et. al (1993) for assessing adequacy in the context of Sudan. As the indented water quantities are the targets to be achieved, *SIR* also quantifies the conveyance or delivery performance of an irrigation system such as the Gezira System.

It is important to note that *MDR / DPR or SIR* are basically Q_d/Q_r where Q_d stands for an actual delivery and Q_r being a target discharge defined as per plan. Obviously, either such indicator can be an input to derive P_a and P_A as described by Eqs. 1a to 1c.

Levine (1982) has described the *Relative Water Supply (RWS)* as the most complete indicator for adequacy. The measure can be explained as below:

$$RWS = \frac{Irrigation + Rainfall}{Evapotranspiration + Seepage + Percolation}$$

As used in the MDS-Report (1991), the same parameter, RWS, is stated as *the ratio of irrigation and effective rainfall to canal water requirements.* The slight deviation from the standard definition of the index appears to have happened because seepage and percolation losses in Sudan are considered to be almost negligible. In the same context, when the measure is calculated for the normal growing period with very little rainfall, the resulting values are almost the same as given by MDR. Sakthivadivel et al. (1993) have proposed a cumulative relative water supply indicator (CRWS) with special reference to systems irrigating rice. Its usage for upland crops is yet to be tried.

Dependability: This performance measure indicates the uniformity of Q_d/Q_r over time. A system which achieves almost steady state is considered to be dependable. The dependability parameter is defined as follows:

$$P_D = \frac{1}{R}\sum_{R} CV_T \left(\frac{Q_d}{Q_r}\right) \text{-----} (2)$$

In this case, CV_T (Q_d/Q_r) is the temporal coefficient (standard deviation / mean) of variation of the ratio Q_d/Q_r over discrete locations in a region R, in a time span T.

Molden and Gates (1990) presented a performance standard for P_D[7] as given below:

P_D 0.0 to o.1--good,

P_D 0.11 to 0.2--fair, and

P_D over o.2--unsatisfactory.

Bos et al. (1993) have selected the following indicator of *Overall Reliability (O.R)*:

$$O.R = \frac{\text{Volume Delivered}}{\text{Target Volume}} \times \frac{\text{Actual Duration of Supply}}{\text{Target Duration of Supply}}$$

The above equation implies that if actual and target values are the same, then the parameter becomes one. This should also mean that the best indication of an overall reliable or dependable supply is the unit value of the index. However, the index would also become one if, for example, the actual volume is half of the target volume and the actual duration is double that of the target duration. For example, the Gezira Irrigation System is supposed to irrigate a total area of 37.8 ha (called ***Number*** or field of 90 feddans in the scheme) at a rate of 5000 M^3/day for 7 days. However, under an inequitable water distribution scenario, the same area gets irrigated within 14 days due to a low supply rate of only 1250 M^3/day. In such a case, the index of reliability may give a misleading indication.

Equity: As defined by Mohammed (1987), it indicates the ability of a system to uniformly deliver water. Molden and Gates (1990), and Kuper and Kijne (1992) have suggested the following performance indicator, P_E[8], for equity:

---

[7]Attached figures show P_D as PD.

[8]Attached figures show P_E as PE.

$$P_E = \frac{1}{T}\sum_T CV_R\left(\frac{Q_d}{Q_r}\right) \quad ----(3)$$

where $CV_R(Q_d/Q_r)$ is the spatial coefficient (standard deviation / mean) of variation of the ratio of delivered water to the required amount (Q_d/Q_r). This coefficient of variation is defined for a specific time over a region R.

In this case, Kuper and Kijne (1993) have proposed that the performance should be taken to be good if the equity parameter is between 0.0 to 0.1, fair if it falls between 0.1 and 0.2, and unsatisfactory if it exceeds 0.2.

Abernethy (1986) has proposed a relatively simple indicator, *Modified Inter-quartile Ratio (Modified IQR)*, for a quick view of overall equity. The index is based on DPR (or MDR) with the following interpretation:

$$ModifiedIQR = \frac{Average\ DPR\ of\ best\ 25\%\ of\ the\ system}{Average\ DPR\ of\ worst\ 25\%\ of\ the\ system}$$

For assessing equity of water distribution at canal levels, Vander Velde (1991) has suggested looking at the head-tail differences. The *Head:Tail Equity Ratio* (HTER) is expressed as:

$$Head{:}TailEquityRatio = \frac{Average\ DPR\ of\ upper\ 25\%\ of\ the\ system}{Average\ DPR\ of\ Tail\ 25\%\ of\ the\ system}$$

2.2.4.2 Maintenance Indicators

Bos et al. (1993) have described the following measures for maintenance performance:

$$Efficiency\ of\ Infrastructure = \frac{Number\ of\ Functioning\ Structures}{Total\ Number\ of\ Structures}$$

Another important indicator suggested by the same authors is aimed at assessing the impact of sedimentation and erosion on the physical irrigation system. The index, *Water Surface Elevation Ratio (WSER),* relates actual and target water surface elevations at full supply level (FSD):

$$WSER = \frac{Actual\ Water\ Surface\ Elevation\ at\ FSD}{Target\ Water\ Surface\ Elevation\ at\ FSD}$$

2.3 METHODOLOGY

2.3.1 Measurement Locations

The main data source report is based on information collected during two irrigation seasons: 1988-89 and 1989-90. The HRS and HR Wallingford decided to monitor a network of sites across the Gezira scheme.

Three major canals were chosen to document performance levels at the head, middle and tail areas of the Gezira main canal. Zanda (abbreviation of Zananda), Gamusia and Kab El Gidad (KEG) are the head, middle and tail Majors, respectively. The head Major obtains water from the main pool at Kilo[9] 57 (main pool) and not the Gezira main canal, which has the same source. The middle major canal has its offtake at Kilo 114 of the main Gezira canal. The tail Major receives its share from the main canal at Kilo 194. On each major canal, three minor canals located at the head, middle and tail sections were selected. Figure 1-C provides a schematic layout of the selected canals.

2.3.2 Data Collection

During the two irrigation seasons, 1988-89 and 1989-90, monitoring started on 1 July and ended on 10 March. This exercise included direct measurements, such as monitoring of sluice gates, movable weirs, fixed crest weirs and well head regulators; and indirect information about indents, authorized supplies and planting dates and areas of crops. The latter information was needed to calculate crop water requirements for the selected command areas. Using head-discharge relationships, the direct measurements were converted into actual supplies at different selected control points.

The entire information is tabulated in the MDS-Report (1991) by averaging the values of the selected variable on a bi-weekly basis (total of 19 readings each season i.e., 38 weeks). The Volume 2 of the MDS-Report (1991) presents a set of monitored data about the Gezira main canal and its 3 Majors and 9 Minors. Also, actual and authorized discharges at the heads of four Managil canals were recorded regularly.

2.3.3 Use of the Secondary Data

As the recording of actual supplies of the Gezira main canal started from 28 August during the first irrigation season, the monitored data for all of the selected canals were considered only from that date onward. This implies that the information from 1 July to 28 August 1988 recorded at other canals was not included in the analysis of the secondary data. As the irrigation requirements are abnormally low and unpredictable just after the planting time (July and August) due to minimum crop-water needs and rains, ratios such as MDR become too high to be used in determining an average trend during the normal growth period anyway.

Towards the maturity stage of the main crops (mid-February to March) water demand drops causing MDR to become explosive, so that the last two bi-weekly readings during both seasons were also dropped (i.e. only normal growth periods were considered). During the second irrigation season (1989-90), as the rainfall was very low and actual supplies to the main canal were monitored from 1 July, only the first bi-weekly information was dropped.

Although during the second season, the bi-weekly information was considered from 15 July 1989-90, still a couple of MDRs for the Minors at the head of the Major became too abnormal in the third week of August due to rain. These corresponding data points were also ignored. However, the stated difficulty

---

[9]Km in Sudan is commonly referred as Kilo.

suggests that MDR is an erratic ratio which should be used carefully to avoid misleading results. In this context, perhaps the Supply-Indent Ratio proposed by Shafique et al. (1993) seems a relatively safer index in the context of Sudan.

2.3.4 Indicators Selected for Analysis

The following indicators as presented in the literature review can be adopted either as such, or with some modifications, for evaluating the hydraulic performance of the selected Gezira irrigation system according to the following three categories:

A. *Conveyance of Water Supplies*
(1) Management Delivery Ratio (MDR)
(2) Supply-Indent Ratio (SIR)
(3) Supply-Authorized Release Ratio (SAR)

B. *Utility of Water Supplies*
(1) Parameter for adequacy, P_A (Eqs. 1a to 1c)
(2) Parameter for dependability, P_D (Eq. 2)
(3) Parameter for equity, P_E (Eq. 3)
(4) Modified Inter-quartile Ratio
(5) MDR and SIR

C. *Maintenance of System*
(1) Water Surface Elevation Ratio (WSER)

Also, there are some additional indicators that could be adopted, which would further help to develop an understanding for the performance of the Gezira Irrigation System. These measures are either being proposed for the first time, or derived from the ones listed above. These indices are also grouped into three categories:

A. *Conveyance of Water Supplies:*

A general conveyance indicator is used to evaluate the conveyance performance of the Irrigation Operation Department of MOI responsible for the Gezira Scheme as:

$$Conveyance\ Index\ (CI) = [MDR\ /\ SIR\ /\ SAR]_{period} - 1$$

In this case, the ratio of actual and target supply could be either of the following indicators: MDR, DPR or SIR, etc. The selection of any particular indicator will depend on the way that the target supply is defined. In this report, the following arbitrary criteria based on CI is used to describe the level of conveyance performance in the Gezira Scheme:

0.0 to 0.1 = Excellent
0.11 to 0.2 Or 0.0 to-0.05 = Good
0.21 to 0.3 Or-0.06 to-0.10 = Fair
> 0.3 or less than-0.10 values = Not satisfactory

B. *Utility of Water Supplies:*

(1) Parameter for adequacy concerning an individual locale (PAI). The value of the index is derived by taking
R = 1 in Eq. 1a. Two other equations, Eqs. 1b and 1c, will be used as such for calculating PAI[10]. It is interesting to note that PAI becomes similar to WDP.

(2) Parameter for dependability regarding an individual locale (CVt). The index is derived by considering R = 1 in Eq. 2.

(3) Depending upon the choice of conveyance indicators, an *equity ratio for head and tail (ERHT)* components of a distribution sub-system is defined as:

$$ERHT(MDR) = \frac{\frac{1}{n}\sum_{t=1}^{t=n} MDR_{Head}}{\frac{1}{n}\sum_{t=1}^{t=n} MDR_{Tail}}$$

$$ERHT(SIR) = \frac{\frac{1}{n}\sum_{t=1}^{t=n} SIR_{Head}}{\frac{1}{n}\sum_{t=1}^{t=n} SIR_{Tail}}$$

$$ERHT(SAR) = \frac{\frac{1}{n}\sum_{t=1}^{t=n} SAR_{Head}}{\frac{1}{n}\sum_{t=1}^{t=n} SAR_{Tail}}$$

where t is the time period and n is the number of periods monitored. The choice of conveyance indicator may depend on availability of data and preferences, etc.

---

[10]PAI is quite similar to WDP (Baily and Lenton, 1984).

It is desirable that researchers and irrigation managers of a particular irrigation system should jointly decide some ranges for ERHT to categorize results as excellent, good, fair or unsatisfactory. However, for this paper, an arbitrary set of such limits is proposed:

0.9-1.1	Excellent
0.8-0.89 and 1.11-1.20	Good
0.70-0.79 and 1.21-1.3	Fair
Less than 0.7 or more than 1.3	unsatisfactory

Note: In some cases, it is possible to expect ERHT less than 1 at certain stages of an irrigation season. Such a situation may be unique but possible. For example, tail reaches of many systems in Sudan, contrary to the official position, are used to dispose of excess water.

C. *Maintenance of System:*

(1) *Water Surface Status (WSS)*: The index is defined by measuring actual water surface at peak discharge, or mean water level recorded in a period from a reference point fixed at a unit depth below the full supply level. A value of the measure less than one is likely to indicate an erosion problem or over-capacity of a canal resulting from imprecise dredging or cleaning activity. If, on the other hand, WSS is more than one, then it is possible to have a rise caused by siltation and / or weed infestation in a canal.

(2) *Supply-Designed Capacity Ratio (SDR):* This measure can be used to determine the extent to which seasonal or periodic actual supplies compare with designed canal capacities. If the ratios for two or more seasons, along with those determined during maximum demand periods, stay low, it may indicate a maintenance problem. As actual supplies at the heads of many canals are usually recorded, the proposed measure seems a very convenient and cost-effective tool.

(3) *Authorized Release-Designed Capacity Ratio (ADR):* In some countries, information regarding authorized releases may not be available. However, for a country like Sudan, such practice is an essential part of canal operations. If ADR values are low, it may indicate a possibility of excessive siltation or vegetative growth in a canal. This assertion is based on the hypothesis that field officials responsible for canal operations usually give serious consideration to the existing canal capacities in determining authorized releases for different canals.

2.4 DATA ANALYSIS AND DISCUSSION

This section provides results by analyzing the secondary data in the form of indicators about the hydraulic performance of the selected canals of the Gezira scheme. These indicators are presented under the three performance categories described earlier. Under each grouping of indicators, a discussion furnishes the author's explanation of the results. At first, each component of the main system is discussed separately by analyzing the data based on: (I) control points (CPs); and (ii) sections. In the case of Gamusia, middle Major, the analysis is also extended to different canal reaches. This follows with a comparison of different levels of the system. At the end, these results for the Gezira main canal system are compared with one in Pakistan studied by Kuper and Kijne (1992).

2.4.1 Conveyance of Water Supplies

2.4.1.1 Conveyance Index (CI)

A. Main Gezira Canal

Table 2.1 below presents a summary of results for the main Gezira canal. The conveyance index, CI, is calculated based on MDR values collected at the head, middle and tail control points. The data are also analyzed based on head middle and tail sections.

Table 2.1. The Conveyance Index for the Main Gezira Canal.

Location/ Position	Type of Values	1988-89		1989-90	
		CP-based	Section	CP-based	Section
HEAD	Maximum	0.16	0.78	1.17	2.80
	Minimum	-0.38	-0.39	-0.30	-0.26
	Seasonal	-0.05	0.12	0.10	0.47
MIDDLE	Maximum	0.09	0.10	0.63	0.66
	Minimum	-0.41	-0.40	-0.45	-0.45
	Seasonal	-0.20	-0.19	-0.15	-0.16
TAIL	Maximum	0.10	0.10	0.31	0.31
	Minimum	-0.61	-0.61	-0.47	-0.47
	Seasonal	-0.34	-0.34	-0.09	-0.09

Note: CP stands for control point.

The main canal serves a total command area of about 414,400 ha. As the information collected at a control point pertains to the entire downstream stretch of a canal, the seasonal result at the head control point, Kilo 57, gives an average CI of -0.05 and 0.10 during 1988-89 and 1989-90, respectively, for the whole Gezira main canal. These values, as per the proposed criteria for evaluation, suggest that the conveyance performance is good to excellent. This also implies that the actual releases at the head gate quite well match with crop-water requirements.

As one moves away from the head to the middle and tail control points, the seasonal conveyance performance deteriorates. At the middle, Kilo 114, and the tail, Kilo 194, the canal supplies are aimed to serve their respective command areas which are 51 and 3.4 percent, respectively. The seasonal Conveyance Index indicates an unsatisfactory performance at these CPs during both seasons, with the only exception being an improvement at the tail in 1989-90.

Other presented information relates to the differences between maximum and minimum values of the conveyance index. As the data for the tail CP and section are the same, the resulting numbers are obviously going to be the same. But, it is interesting to note that the spread determined by maximum and minimum CIs based on CP and section analysis is almost the same at the middle and tail during the respective monitoring periods. However, the same cannot be said for the head CP and head section where the referred difference is more than double. It implies that the head section received excess supplies relative to a command-average determined by the head control point.

Moreover, when the above stated differences during 1988-89 are compared with the related outcome of 1989-90, there is also a doubling trend except for the tail where the range is almost the same. It points to an increase in supply in the second season, which has improved seasonal averages at different control points. However, analysis based on section suggests that the conveyance performance deteriorated for the head section as the CI increased from 0.12 to 0.47. There is a slight improvement at the middle, but the index is still within unsatisfactory limits. However, the excess supply which trickled down to the tail contributed to improving the conveyance performance from unsatisfactory to marginally fair. As a matter of fact, the saving of 1 percent from the middle section representing 47.6 area pushed the performance up for the tail section from -0.34 to -0.09 because of the area being only 3.4 percent of the total canal command.

Before initiating a discussion about the conveyance performance for the selected Majors, it is important to keep in mind the results of the main canal. Following are the main points to be remembered:

(1) As per data collected at the head control point, the conveyance index for the entire command of the Gezira main canal is within the excellent range.

(2) Seasonal average for the head section was good in the first season, but declined in the second due to excessive supplies.

(3) Actual supplies for the middle and tail sections were less than target supplies during both seasons. The conveyance performance remained unsatisfactory for the two sections during both seasons except for an improvement to a marginally fair level in the tail section (having only 3.4 percent of the total command) during the second season.

B. Major Canals

The head, middle and tail Majors have command areas of 8520, 19002 and 5817 hectares, respectively. The head Major and the main canal have a common source, whereas the middle and tail Majors receive their supplies from the head and middle sections of the Gezira main canal. There was no Major selected from the tail section of the main canal.

Table 2.2 presents results about the conveyance index for the head Major. In 1988-89, the Major received supplies for its entire command of about 17 percent more than targeted amounts. This percentage does not change at the middle control point. However, it drops to 5 percent at the tail control point. During the first season, the analysis on CP-basis indicates that the performance at the first two control points was fair and at the tail control point it became excellent.

Table 2.2. The Conveyance Index for the Head Major (Zananda).

Location/ Position	Type of Values	1988-89		1989-90	
		CP-based	Section	CP-based	Section
HEAD	Maximum	0.91	0.97	2.52	2.24
	Minimum	-0.12	-0.14	-0.12	-0.31
	Seasonal	0.17	0.07	0.56	0.74
MIDDLE	Maximum	0.89	1.74	3.23	2.80
	Minimum	-0.17	-0.20	-0.25	-0.34
	Seasonal	0.17	0.48	0.50	0.54
TAIL	Maximum	0.88	0.88	3.43	3.43
	Minimum	-0.35	-0.35	-0.43	-0.43
	Seasonal	0.05	0.05	0.51	0.51

The ICs derived from section-data shows that the performance of head and tail sections lies in the excellent range. However, the middle section received 48 percent more supplies than required; hence, its performance is classified as unsatisfactory. One explanation for the drastic difference lies in the fact that estimated crop-water requirements for the head section were 22.5 and 6.5 percent more than for the middle and tail sections, respectively. During 1989-90, the conveyance performance based on both types of analyses can be termed unsatisfactory. This is mainly due to actual supplies on the average being 56 percent more than target supplies. Also, the differences between maximum and minimum values are about 2.5 times more in the second period as compared to the first one. This is another indication for the stated deterioration.

The middle Major has about 33 percent more command area than that of the head and tail Majors combined. It gets its supplies from the first section of the main canal at Kilo 114 from Sennar Dam.

The results of the data analyzed based on control points and sections are displayed in Table 2.3A. The analysis shows that the conveyance index lies in an excellent range at all control points during 1988-89. As the actual deliveries at the tail CP serve the tail section only, the performance index is obviously going to be the same. The results of two analyses at the middle point show similar performance (i.e., excellent as per the arbitrary suggested limits). However, the head section extracts a relatively greater share of water as compared to an average determined at the head control point.

Table 2.3A. The Conveyance Index for the Middle Major (Gamusia).

Location/ Position	Type of Values	1988-89		1989-90	
		CP-based	Section	CP-based	Section
HEAD	Maximum	0.47	1.44	2.50	1.61
	Minimum	-0.31	-0.67	-0.21	-0.63
	Seasonal	0.05	0.21	0.29	-0.06
MIDDLE	Maximum	0.54	0.99	2.79	3.87
	Minimum	-0.27	-0.30	-0.13	-0.55
	Seasonal	0.02	0.04	0.42	0.43
TAIL	Maximum	0.99	0.99	2.72	2.72
	Minimum	-0.34	-0.34	-0.41	-0.41
	Seasonal	0.01	0.01	0.43	0.43

During 1989-90, the Major follows the trend set by the head Major with few exceptions. An average CI derived at the head CP and for the head section indicates performance within a fair range, which is better than the head Major. However, the performance at the middle and tail CPs and sections is similar to the first Major (i.e., unsatisfactory), but CIs are slightly on the lower side. Another similarity is that the differences between maximum and minimum values of the index for 1989-90 are 2 to 3 times higher than those monitored in 1988-89. This measure also shows the extent to which the responsible agency is serious about matching actual supplies with target quantities. As the spread widens, so does the gulf between *what it is* and *what it ought to be*.

In case of the middle Major, data were available to extend the analysis on a reach basis, the only exception being the last reach, Reach-5, which cannot be termed a reach as it is, rather, a tail section instead. So, data related to the tail-CP and the resulting indices are the same for the tail section and Reach-5.

According to the author's opinion, canal reaches are the basic units of water distribution. Any data set analyzed either on CP or a section basis may hide many unpleasant features of water distribution because of so called *averaging* or *lumping* effects.

Table 2.3B presents information about conveyance performance of the middle Major based on data analyzed on a reach basis. As discussed earlier, the Major received on average 5 percent (at head CP) more supplies than targeted for its entire command during 1988-89. The distribution which appeared to be excellent as per CP-data has turned out to be marginally good in one case and marginally fair in three other cases. The tail reach / section, however, received supplies almost matching those required.

Table 2.3B. *The Conveyance Index for Middle Major.*

SEASON	TYPE	REACH-1	REACH-2	REACH-3	REACH-4	REACH-5
1988	Maximum	1.48	3.33	1.71	0.75	0.99
to	Minimum	-0.63	-0.94	-0.72	-0.95	-0.34
1989	Seasonal	0.26	0.18	0.22	-0.10	0.01
1989	Maximum	1.04	2.26	5.53	5.05	2.72
to	Minimum	-0.89	-0.98	-0.71	-0.97	-0.41
1990	Seasonal	0.18	-0.31	0.84	0.21	0.43

Note: Tail Control Point, Tail Section, and Reach-5 have common data.

During the monitoring period of 1989-90, the reach-base analysis shows the conveyance performance being good to fair for Reach-1 and Reach 4, respectively. However, the other reaches either received too much or too little supply against their targets and performance is classified as unsatisfactory. As the first two reaches (Reach-1 and Reach-2) form the first section and the second two reaches (Reach-3 and Reach-4) make up the second section, which shows that with CP or section-base analysis, one would not be able to identify short supplies for Reach-2 and fair conveyance performance at Reach 4.

Another interesting comparison relates to the spreads-the difference between maximum and minimum CIs-derived using analyses based on CPs, sections or reaches. By dropping the common tail results, the following are the spreads during 1988-89: (i) 0.78 to 0.81, (ii) 1.2 to 2.11 and (iii) 1.7 to 4.27 for CPs, sections and reaches, respectively. Similarly, the differences for CPs, sections and reaches during 1989-90 are: (i) 2.71 to 2.92, (ii) 2.24 to 4.42, and (iii) 1.93 to 6.24 in the same order. This clearly supports the earlier statement about the averaging effect. This may provide sufficient justification for considering the analyses done on aggregate levels (Baily and Lenton 1984; Levine and Baily 1986) insufficient for evaluating an irrigation system.

The off-take of the tail Major is located at Kilo 194 of the main Gezira canal. It is interesting to note that the tail Major receives its supplies from the middle section of the main canal which, as discussed before, did not perform well during 1988-1990. The middle section of the main canal managed only 19 and 16 percent less deliveries against its targeted amounts during the two monitored irrigation seasons.

Table 2.4 provides different values of the conveyance index about the tail Major during the two years, 1988-90. Contrary to the short supply situation at the source section of the main canal, it is interesting to note that the tail Major received excess supplies as compared to its target amounts. Whether it be a coincidence, a routine occurrence or a deliberate effort, the fact remains that the tail Major provides a trend of extra supplies. It is also contrary to a general belief the tails are usually bound to receive lower supplies because of obvious location- or position-related disadvantages.

Because of the long monitoring periods, it is difficult to support the premise that the excess supply situation resulted from mere coincidence. Perhaps there are other more significant factors to be considered.

The premise of routine occurrence is also very logical. The proponents of this idea argue that the agricultural officers of SGB[11] over-indent their requirements. The MOI officials adjust these indents quite often according to their perception of water requirements, status of sedimentation, potential threat of rains, availability of water, and the current capacities of their canals. If for some reason, upstream managers do not take his or her requested share, the excess supply ends up at the tail.

Table 2.4. The Conveyance Index for the Tail Major.

Location/ Position	Type of Values	1988-89		1989-90	
		CP-based	Section	CP-based	Section
HEAD	Maximum	0.56	0.38	1.27	1.21
	Minimum	-0.14	-0.60	-0.02	-0.27
	Seasonal	0.17	-0.06	0.47	0.16
MIDDLE	Maximum	0.66	0.62	1.67	1.23
	Minimum	-0.19	-0.39	-0.10	-0.31
	Seasonal	0.29	0.07	0.67	0.24
TAIL	Maximum	1.38	1.38	2.54	2.54
	Minimum	0.08	0.08	0.17	0.17
	Seasonal	0.61	0.61	1.40	1.40

On the other hand, it is also possible that there was a deliberate effort to effect the supply situation for the tail Major. In this context, there could be two reasons for the effort:
(i) there is a common belief, which is informally used as an indicator of the system performance, that if the tail is satisfied, then the entire system should have been performing well; and (ii) knowing the nature of the study, there might have been an effort in this direction to influence the outcome.

The above stated relatively excess supply at the tail Major is shown by different values of the conveyance index in Table 2.4. It is evident that during 1988-89 the Major received on an average 17 percent more water than was required at the head control point. The amount increases at the middle point to 29 percent, indicating that the head section did not extract proportional supply (6 percent less than target). The index further went up at the tail CP (0.61) to mean that the middle section also drew relatively less by having actual deliveries 7 percent more than targeted quantities.

[11]Sudan Gezira Board , a parastatal agency for the Gezira Scheme.

According to the chosen criteria, the conveyance performance for the head and middle section falls in the good and excellent ranges, respectively. This can be compared with CP-based values which show good and fair conveyance levels according to head and tail control points. When the tail CP and section are the same, the performance is unsatisfactory due to 61 percent supplies over the required targets.

During 1989-90, the CP-data shows the index being always in the unsatisfactory range. However, as the index increases from head to the tail (0.47 to 1.4), most of the excess supplies are delivered to tail and conveyance performance results are fair for both head and middle sections. This is another example how the head, middle and tail CP-analysis can hide the actual performance of different sections. It is the author's opinion that the section analysis similarly has the potential to hide the actual situation in the reaches because of the so called averaging phenomenon.

Before discussing the conveyance performance at the level of Minors, it seems appropriate to list the main findings about major canals. Following is a summary of the results:

(a) Based on CP-analysis, the average conveyance performance (derived at the head control point) during 1988-89 for the head and tail Majors is found good and excellent for the middle Major.

Similarly, during 1989-90, the average performance results are unsatisfactory for the head and tail Majors, but marginally fair for the middle Major.

The above statements also signal that the head and tail Majors received more supplies relative to the Middle Major when deliveries are compared with their respective targets.

(b) The conveyance performance during 1988-89 at the level of tail CPs / sections of the head and middle Majors falls in the excellent range, but the tail of the tail Major shows unsatisfactory performance due to oversupply.

During 1989-90, the tails of all three Majors indicated an abundance of actual supplies being 43 to 140 percent more than their requirements and hence the performance is unsatisfactory.

(c) With one exception, the head and middle sections of all Majors have shown the conveyance index doing very well during the first monitoring year. However, the performance of these sections is mixed in the following year.

C. Minor Canals

There were a total of nine Minors selected for the study. At each Major, three Minors were chosen to represent the head, middle and tail positions. The command areas of these canals range from 375 to 1150 ha, with the average being 760 ha.

In the case of Minors, the data collection was not extended to all control points or reaches along the canals. Rather, the heads of all Minors along three Majors were monitored. This implies that the data collected can only provide information about overall average conditions at this secondary canal level. The analogy of such measurements can be drawn with the information represented at head control points in the cases of main and major canals. As found from the above discussion, indices derived from such data may conceal many discrepancies that occur along a canal. As a matter of fact, it is even more important to study the Minors on a reach basis as these canals serve as the interface between the MOI and SGB, and for all practical purposes, such a network of 1498 secondary channels lies in *no man's land*.

Table 2.5 furnishes different calculated values of the conveyance index for all nine Minors over two monitoring periods: (i) 1988-89; and (ii) 1989-90. In spite of the above comments, the current data set and related results are still very helpful in presenting the following observations:

Table 2.5. The Conveyance Index for the Selected Minors and Majors.

Source	Type of Values	1988-89			1989-90		
		Head Minors	Mid. Minors	Tail Minors	Head Minors	Mid. Minors	Tail Minors
HEAD MAJOR	Maximum	2.80	2.32	0.60	3.03	2.40	3.61
	Minimum	-0.53	-0.62	-0.49	-0.30	-0.34	-0.38
	Seasonal	0.24	0.12	-0.11	0.56	0.36	0.34
MIDDLE MAJOR	Maximum	0.70	0.95	0.98	1.92	3.27	3.68
	Minimum	-0.42	-0.34	-0.72	-0.63	-0.43	-0.58
	Seasonal	0.15	0.26	0.14	0.03	0.60	1.28
TAIL MAJOR	Maximum	1.30	2.82	1.93	1.74	1.77	5.00
	Minimum	-0.89	-0.14	-0.13	-0.36	-0.43	0.15
	Seasonal	0.09	0.63	0.83	0.69	0.23	2.09

(a) During 1988-89, all Minors of the head and middle Majors performed well and the resulting values of CI are in either the good or fair categories. On the other hand, performance of the head Minor of the tail Major is excellent, but the other two secondary canals-middle and tail Minors-indicate unsatisfactory conveyance performance.

(b) Almost contrary to (a), all Minors show unsatisfactory performance (with only two exceptions) during 1989-90.

(c) Maximum oversupply occurs at the tail Minor of the tail Major, about 83 and 209 percent more than required for the first and second year, respectively. This occurrence also indicates that unutilized deliveries are pushed to the tails.

(d) Another interesting piece of information relates to the difference between maximum and minimum values of the conveyance index for the nine Minors. During 1988-89, the average differences corresponding to each set of three Minors of head and tail Major are equal and almost double when compared to the Minors of the middle Major. In the following period, the average differences of Minors located at the head, middle and tail Majors are almost the same. However, when compared to the results of the previous year, they are 50 to 100 percent more.

D. Comparison of Conveyance Performance at Different Levels

The comparison is mainly based on results given in Table 2.6. However, some information from the preceding discussion will also be used. The CI values of the table below are the average of CPs, sections and reaches. Such an aggregation is bound to level off many sharp differences because of the averaging of values calculated for head, middle and tail positions.

However, for comparison purposes, it seems prudent to have one value for each level to avoid confusion. This has been done by using the seasonal average of the *Management Delivery Ratio (MDR)* in deriving an average conveyance index for each canal level. But this does not exclude utilizing relevant results for each component of the Gezira canal system discussed so far in detail. This is the setting in which the following statements for comparison are made:

(1) During 1988-89, the results based on CP-analysis present on the surface a baffling anomaly: on the one hand, the conveyance performance of the main canal is unsatisfactory because actual supplies are 20 percent less than target ones, while on the other hand, the conveyance performance of the tail Major and its Minors is also unsatisfactory but the reason is reversed i.e., 36 and 52 percent excess supply for the Major and Minors. Moreover, all the other major and minor canals show performances from excellent to fair and no average conveyance index indicates any instance of short supply. A similar trend is found based on section analysis. However, in the latter case, the performance of the tail Major is slightly improved to a fair level, but still shows a situation of excess supply.

(2) During 1989-90, the derived values of the conveyance index follow the trend established in the first monitoring period (i.e., abundance of water supply for almost all Majors and Minors) but relatively less supply at the primary source. In the second monitoring period, conveyance performance of all major and minor canals is unsatisfactory when CP-based results are considered. However, the performance of the Middle Major on average improves to a fair level when calculations are based on sections or reaches. *A point to be noted is that the selected Majors and Minors were receiving lavish supplies at a time when the main canal was barely meeting its targets.*

The situation described above may appear to be puzzling, but in reality it is not. It should be borne in mind that it is possible to manage excess supplies for only 3 out of 107 Majors and a mere 9 out of 1498 Minors from the huge Gezira scheme? The same can also be said about the Gezira main canal, but the difficulty lies in the fact that there are only two main canals in the scheme.

Table 2.6. An Average Conveyance Index for Different Canal-levels of the Gezira Canal System.

CANALS	CP/ Section	1988-89			1989-90		
		Max.	Min.	Mean	Max.	Min.	Mean
Main Canal	CP	0.06	-0.39	-0.20	0.70	-0.41	-0.05
	Section	0.08	-0.31	-0.14	1.26	-0.34	0.08
Head Major	CP	0.78	-0.18	0.13	3.06	-0.26	0.52
	Section	1.08	-0.13	0.20	2.48	-0.17	0.59
Mid. Major	CP	0.56	-0.24	0.03	2.42	-0.25	0.38
	Section	0.59	-0.33	0.09	2.48	-0.24	0.26
	Reach	0.65	-0.35	0.11	2.62	-0.35	0.27
Tail Major	CP	0.84	-0.07	0.36	1.73	0.02	0.85
	Section	0.57	-0.10	0.21	1.37	0.01	0.60
Head Major	Minors (HMT)	0.90	-0.37	0.08	2.55	-0.28	0.42
Mid. Major	Minors (HMT)	0.82	-0.22	0.19	2.23	-0.27	0.64
Tail Major	Minors (HMT[12])	1.65	-0.16	0.52	1.97	0.0	1.0

(3) In general, the difference between maximum and minimum values of CI increases from the main canal to Majors and Minors. These difference are maximum at Minors: 3 to 5 times more when compared with majors and 6 to 11 times with respect to the main Gezira canal. *It appears that these differences have an inverse relationship with the management-level of canal operations.*

[12]HMT stands for head, middle and tail locations.

2.4.2 Utility of Water Supplies

2.4.2.1 Parameter for Adequacy (PAI)

The parameter for adequacy concerning an individual location, PAI, is first applied to find the adequacy status from location to location (i.e., control points, sections or reaches of a selected canal). This indicator is adopted from Molden and Gates (1990) with minor adjustment. Later on, the original indicator, P_A, suggested by the authors will be used to compare different levels of the Gezira canal system.

A. Main Canal

Adequacy of water supplies should not be a problem in Sudan as its irrigated sector, at the present stage, is only able to utilize 70 percent from its share of the Nile waters (Zaki 1992). However, it is possible to expect inadequacy at certain locations due to problems concerning the distribution of irrigation supplies.

Results derived at a control point represent average conditions below that point. It implies that values based on data collected at the head control point of the Gezira main canal represent average conditions below that point (i.e., the entire command of the main canal). So, with reference to Figure 3 (A and B) and performance criteria suggested by Molden and Gates (1990), it is evident that the average adequacy level during the two irrigation seasons (1988-89 and 1989-90) for the entire command of the main canal is good.

However, during both seasons, the adequacy parameter for about 51 percent of the canal command (below the middle CP) indicates a slightly unsatisfactory adequacy level. In case of the area below the tail CP, the parameter shows a very unsatisfactory situation during the first season, but reaches the fair category in the second season.

The command area, actual supplies and water requirements below the tail control point are the same as for the tail section. Therefore, adequacy levels will obviously be the same in both cases during the monitoring periods. The head and middle sections have a similar performance as discussed for the head and middle CPs, with slight improvements as section-bases parameters are derived only for their respective actual supplies and requirements.

The distribution which creates some location specific changes in the adequacy levels can be understood better by comparing management delivery ratios (MDR) with relevant PAIs. For example, the differences between MDR and PAIs (oversupply fractions) are minimal at the middle and tail sections. However, these differences for the head section are 0.16 and 0.49 during the first and second periods and caused slight inadequacy for the other sections.

B. Major Canals

Head Major: According to Figures 4A and 4B, the parameter of adequacy at all control points and sections during the monitoring periods is generally more than 0.9; thus, there is a good adequacy level at the head Major. Only the head section in the first period has a slightly less than good level.

The oversupply fractions have higher values than observed at the main canal and they are quite consistent for all CPs and sections. In case of abundant supply, these fractions only point to mismanagement of available irrigation supplies which could have been effectively used at other deprived locations.

Middle Major: According to results presented in Figures 5A, 5B and 5C, average values of PAI at the head control point during the two periods show that actual supplies were enough to achieve a good adequacy of water distribution for almost the entire command of the middle Major. The CP-based data does not show any localized inadequacy very clearly because of the prevailing oversupply and averaging effects. However, the section and reach-base data point to some shortcomings regarding adequate water distribution.

For example, the adequacy level during 1988-89 for all sections (values for all tail segments are to be the same) is fair, but Reach # 2 and Reach # 4 show unsatisfactory performance. Again, in 1989-90 the parameters for the head section indicate a barely fair level, with the remaining sections falling in the good category. However, it is interesting to note that Reach # 2 and Reach # 4 again are distinguished by very unsatisfactory performance. Perhaps, it is difficult to identify trouble spots with the other two procedures used for data analysis.

The oversupply fractions are almost the same as in the case of the head Major. However, the reach-based values show sharp variations, signaling mismanagement of water supplies at the reach levels.

Tail Major: Figures 6A and 6B present values of PAI and MDR based on CP and section data. The CP-analysis indicates that the adequacy level is within the good range irrespective of location and monitoring period. A similar trend is found in the case of section-wise water distribution, with the only exception being the head section which secured a fair instead of good level of performance.

The most interesting point is the oversupply fractions. As evident from the figures referred to, these fractions explode toward the tail of the Major. Such a consistent sharp increase toward the tail of the tail Major does not seem to be a mere case of mismanagement of available water supplies-it appears more to be an informal management style for canal operations.

C. Minor Canals

The results in terms of MDR and PAI for the Minors of the head, middle and tail Majors are shown in Figures 7A, 7B and 7C. In general, the values of all PAIs indicate either fair or good adequacy levels of water distribution. This pattern persists irrespective of time and place.

As expected, PAIs of all Minors of the tail Major fall in the good classification. However, the oversupply fractions, especially for the tail Minor of the tail Major, indicate trends similar to those established at its source. This further supports the earlier statement about the informal management style.

D. Comparison of Adequacy of Water Distribution at Different Levels

In order to compare different levels of the Gezira main canal system, values of adequacy at each level are derived using a *Parameter of Adequacy,* P_A, as defined by Eqs. 1a to 1c (Molden and Gates 1990). As the proposed method results in a single average value for each component of the system (i.e., main canal, Majors and Minors), it is helpful in getting a distinct picture about the performance at different levels.

The resulting values of the above mentioned parameter of adequacy, P_A, are displayed in Figure 8A. These values are derived according to control points, sections, reaches and heads of minor canals. In order to demonstrate the kind of differences which could appear just by analyzing data based on different arrangements, adequacy levels for the middle Major are plotted according to control points, sections and reaches (Fig. 8B).

The values of P_A for the main canal show that the adequacy level during 1988-89 can be described as either marginally fair or marginally unsatisfactory. For the same year, the adequacy of water distribution at the Major and Minors is generally good, with a few cases of performance near the top of the fair range. During 1989-90, the adequacy level is improved at the main canal level due to an average annual increase of water supply of 5.2 percent at the head. The performance for the main canal falls in the upper half of the range chosen for fair distribution. During the period, adequacy levels for all the Majors and Minors, without exception, lie in the range termed as good.

However, it is interesting to look at data presented about the middle Major. As given by Figure 8B, based on CP-data, the adequacy level is at the top of the fair range or good; as per section data the adequacy is at the top of the fair range or marginally good; and data analysis based on reaches reveals that the level is marginally fair and unsatisfactory for the first and second seasons, respectively. This change can also be attributed to the *averaging* effect on the resulting parameters. For example, if one section has two reaches with MDR being 1.6 and 0.4 for say every time interval t. Using Eqs. 1a to 1c, the average adequacy level for the two reaches will come to 0.70 and the section will have a perfect value of P_A as 1. A similar argument can be made to an additional *lumping* effect from sections to control points.

Going back to the comparison among different components of the system, one can draw a parallel with the findings discussed under the section on *Conveyance of Water Supplies*. If the selected segments of the system are not the *best* among all, the former explanation under the referred section is also applicable in this case.

However, it has to be noted that in the MDS-Report (1991) the crop water requirements were transformed into canal water requirements only by considering canal water losses due to evaporation. Seepage losses were assumed to be negligible for the heavy clay soils of the scheme. There is no mention of evaporation losses from the water which stands in fields for days, unofficial but widely practiced surface drainage, water which is turned to the field roads, conveyance and application losses.

2.4.2.2 Parameter for Dependability (CVt)

The parameter **CVt** is adopted from Molden and Gates (1990) to determine an indicator for dependability of irrigation supplies at one particular location along a system over a time period t. The main parameter for dependability, P_E, proposed by the authors will be used to get single performance values for each component of the system.

A. Main Canal

Figures 3C and 3D provide values of **CVt** at different control points and sections, respectively. The analysis based on CP-data illustrates that the dependability levels at the head and middle control points are in the (marginally) fair range during the first monitoring period. However, while the tail control point shows unsatisfactory performance in this respect, the area below this point is only 3.4 percent of the total command. The same performance during the following period drops to an unsatisfactory level with some improvement at the tail control point.

The analysis based on data related to sections shows that during both of the monitoring seasons, the values of **CVt** for the head and middle sections indicate an unsatisfactory level, with the exception that the value of **CVt** for the middle section during the first period falls in a marginally fair range. Because the data set is the same, the values of **CVt** for the tail control point, or tail section, are going to be same. In the latter case, during the first period, the performance is low (unsatisfactory level) but it improves in the following monitoring season.

B. Major Canals

The resulting levels of the parameter for dependable water supplies for all three Majors are presented in Figures 4 to 6. The values of **CVt** are derived by basing analyses on data collected at control points, sections and / reaches.

Generally, all Majors show unsatisfactory levels of performance in the context of dependable water distribution. The **CVt** values are very high in the case of head and middle majors, but relatively lower for the tail Major. Again, the **CVt** values for the first season are relatively lower when compared with those of the second season. This may result because the management practices are less intensive at Majors as compared to the level of main and branch canals.

Figure 5F illustrates the resulting values of the parameter when data analysis is done according to canal reaches. As is evident from the figure, Reach #2 and Reach # 4 produce the maximum values of **CVt**. It is interesting to note that the highest values correspond to the lowest values of **PAI** for the same reaches. This may have happened due to erratic supplies to these segments of the Major and less attention being paid to these trouble spots.

C. Minor Canals

The parameter **CVt** is derived for the selected 9 Minors described before. Based on the data about actual supplies and their respective water requirements, **Management Delivery Ratios** for the two monitoring periods have been used to derive the seasonal values of the parameter at each head of the minor canal. These results are presented in Figures 7A, 7B, and 7C. Each figure displays information for three Minors of each Major for two periods - - 1988-89 and 1989-90.

As is evident from the referred figures, the values of parameters in each and every case indicate an unsatisfactory level of performance in terms of dependable water distribution. The results also show that the unsatisfactory levels of **CVt** are higher for the Minors of the head Major as compared to the Minors of the middle and tail Majors. Had the evaluation been planned according to CPs, sections or reaches of each Minor, the resulting levels of the parameter might have been even higher.

D. *Comparison of Dependability of Water Distribution at Different Canal Levels*

Instead of looking at the results for specific locations, as is done by calculating values of **CVt** at different points, a **Parameter of Dependability (P_D)** as suggested by Molden and Gates (1990) is applied to derive only one value for the selected three Minors of each major canal. Figure 9A exhibits the results for each component of the Gezira canal system.

The performance in terms of dependable water distribution is unsatisfactory at each level. However, each component of the system has its position based on the corresponding value of P_D either high or low. A comparison of the results indicates that the parameter has its relatively low values for the following canals: (i) main canal; (ii) tail Major; and (iii) Minors of tail Major. The rest of the canals show a higher level of undependable water distribution.

In the case of the main canal, the relatively low values of the parameter, P_D, or in other words, the better performance in terms of dependability can be attributed to the higher level of attention paid and efforts directed to the management of canal operations. It seems quite possible that if some more attention is paid at the level of the main canal, at least fair water distribution can be secured.

The tail Major and its Minors also have relatively lower values of P_D within an unsatisfactory range. While it is true that the Majors get relatively less attention for their operations as compared to the main canal and that the Minors lie in *no man's land* anyway, the above mentioned trend toward the tail appears to be surprising. However, when the abundance of actual supplies throughout the monitoring periods at the tail Major and its Minors is compared with other corresponding canals, it appears to be possible to have such results.

Figure 9B provides a visual display about the differences in the resulting values of the parameter for dependability based on data collected according to control points, sections and canal reaches. The P_D values based on reach data are 50 to 100 percent more than those based on CP data while section-related results lie in the middle. However, these numbers, more or less, all indicate that water distribution over time is quite unsatisfactory.

Bos et al. (1993) have mentioned that if supplies are undependable, farmers may be less efficient in water use and also reluctant to apply optimal quantities of other inputs. Perhaps, the scale of the impact referred to may vary from one context to another. For example, undependability of water distribution can result under two obvious circumstances: (1) short and fluctuating supplies over time; or (2) excess and fluctuating supplies over time. The third context would be a case where a government or semi-government agency provides and or applies inputs. It may mean that while reliability is a crucial concern for a country like Pakistan, it is of less importance for the Gezira scheme in Sudan.

2.4.2.3 Parameters for Equity

In order to assess the ability of a system, or any part of the system, three types of indicators have been selected: (i) **Parameter for Equity, P_E**, as proposed by Molden and Gates (1990); (ii) **Modified Inter-quartile Ratio, Modified IQR,** suggested by Abernethy (1986); and (iii) **Equity Ratio for Head and Tail, ERHT.** All three parameters are used to understand different aspects of the status of water distribution within the command of the main canal.

(a) Parameter for Equity, P_E

This parameter describes an equity concept in terms of the spatial coefficient of variation of a selected ratio such as MDR. It gives an average situation over the selected region but does not pinpoint the *pockets* within a region which may need special attention to improve the equity of water distribution.

Based on this concept, Figures 10A and 10B display results for different components of the Gezira canal system. The values of $\mathbf{P_E}$ for all components either fall in the fair or unsatisfactory ranges depending upon the way data were collected, arranged and analyzed.

The CP-based data analysis shows that the equity of water distribution for the main and major canals can generally be classified as fair (Fig. 10A). It is also evident that there is very little difference between the parameters corresponding to the two monitoring periods - - 1988-89 and 1989-90. This aspect is contrary to the findings discussed earlier about adequacy and dependability of water distribution.

The section-based data analysis, however, shows the values of the parameters, indicating that relevant performance is unsatisfactory for the main and major canals (Fig. 10A). These results are almost the same during the two monitoring seasons.

The above stated differences in the resulting values of the parameter, $\mathbf{P_E}$, extend further support to the earlier findings in this context. Another example for the trend is given in Figure 10B. This is a case of the middle Major exhibiting striking differences in values of the same parameter, with the only difference being the way the data are analyzed based on selected segments of water distribution (i.e., control points, sections and canal reaches).

In the case of Minors, the performance is found unsatisfactory as expected. This may result due to *unattended* operations and the generally bad condition of control structures along these canals.

(b) Modified Inter-quartile Ratio

The Modified IQR, on the other hand, quantifies the extent to which data averages of the top and lower quarters of a system vary. In many cases, these differences can be associated with the head and tail of a system. However, in a country like Sudan, this may not always be true.

Table 2.7 provides **Modified Inter-quartile Ratios** for all the selected components of the main canal network of canals.

These ratios are derived from CP and section data. The ratios are found with a range of 1.5 to 3.0 for the entire system. As is evident from the table, these ratios are relatively low during 1988-89 for the following canals: (i) main canal; (ii) tail Major; and (iii) the Minors of the tail Major. Except for the main canal, when the ratio is derived from section analysis, the same trend is repeated during 1989-90. Other canals have relatively higher values of the ratio.

At present, there are no criteria set to evaluate the equity of water distribution based on these ratios. However, as a first cut, the following ranges for good, fair and unsatisfactory performance can be considered: (i) 1.0-1.5; (ii) 1.5-1.75; and (iii) 1.75 or more, respectively.

If the above arbitrary criteria are accepted, then the performance in terms of equity of water distribution of the main canal and tail Major can be categorized as fair. The rest of the canals fall in the last performance category.

(c) Equity Ratio for Head and Tail (ERHT)

The third parameter has its main focus on the equity for head and tail at different levels of a system. This indicator can help to identify head and tail differences at each level of the system or subsystem, and hence, to address problems accordingly.

Table 2.7. Inter-quartile Ratio for the Gezira Canals.

CANALS	CP/ Section	1988-89	1989-90
Main Canal	CP	1.55	1.89
	Section	1.62	2.78
Head Major	CP	1.86	3.06
	Section	1.88	2.70
Mid. Major	CP	1.84	2.76
	Section	1.89	2.76
	Reach	1.95	3.00
Tail Major	CP	1.72	1.79
	Section	1.52	1.59
Head Major	Minors	2.54	2.86
Mid. Major	Minors	2.02	3.08
Tail Major	Minors	1.96	2.21

Table 2.8 present **Equity Ratios for Head and Tail** corresponding to different canals of the system. It is interesting to note that there are 10 numbers in the table which are less than 1. These numbers imply that MDR ratios of the tails are higher than their respective heads. These results are contrary to a general concept about the head and tail syndrome. This phenomenon is not indicated by the values presented in Table 2.7.

There is a clear trend from 1988-89 to 1989-90; the values of ERHT generally decrease during the second season. This may have happened due to 5.2 percent extra supply provided at the head of the main canal. Also, the ERHT values derived from section data are generally higher than those related to control points.

Table 2.8. Equity Ratios for Head and Tail for Different Canals.

CANALS	HEAD and TAIL DATA	1988-89	1989-90
Main Canal	CP	1.44	1.21
	Section	1.70	1.48
Head Major	CP	1.13	1.03
	Section	1.02	1.15
Mid. Major	CP	1.04	0.90
	Section	1.20	0.66
	Reach	1.25	0.83
Tail Major	CP	0.72	0.61
	Section	0.58	0.48
Head Major	Minors	1.39	1.16
Mid. Major	Minors	1.01	0.45
Tail Major	Minors	0.60	0.55

The performance of the main canal is unsatisfactory, particularly during the first period as the head received relatively more water than the tail. On the other hand, the unsatisfactory level of the tail Major and its Minors results from reverse reasons. During 1989-90, the middle Major and its Minors follow a similar trend. It is, however, quite possible that the excess supply at the identified tail-ends may end up in surface drains.

2.4.3 Maintenance of System

Bos et al. (1993) have suggested that maintenance should accomplish the following three purposes: *(i) Safety; (ii) keeping water control infrastructure in working condition; and (iii) keeping canals in sufficiently good condition to minimize losses and sustain designed discharge-stage relationships.* Recently, the researchers, like the authors referred, to above and Mao Zhi (1989) have proposed some indicators to assess performance in terms of maintenance of irrigation infrastructure. But, at the current level of the activity, a lot more remains to be done.

In the context of the Sudan Gezira Scheme, the type of available data does not allow discussion of all maintenance related aspects of the Gezira canal system. Moreover, the main concern for the main system managers is the rapidly decreasing canal capacities due to a serious problem of siltation and weed infestation in the channels. As the phenomenon has a direct bearing on the water distribution in the scheme, the selection of the maintenance indicators is intended to address this identified concern only.

2.4.3.1 Water Surface Status (WSS)

The first indicator selected in this case is **Water Surface Status (WSS).** The values of the indicator are presented in three tables (Tables 2.9 A to C). The resulting numbers are based on mean and peak levels measured from a unit depth from full supply levels (FSL) on the upstream of headgates of various canals in the Gezira scheme. This index can help to assess if the rise or drop in WSS indicates that maintenance measures are required.

At this stage, however, it is difficult to recommend a specific value of WSS to serve as a tickler for initiating a maintenance activity. It may require consultations with the main system managers, investigations based on long-term relevant data, timing of maintenance activity, and impacts of maintenance on mean and peak discharge levels. Once such threshold levels are determined, the indicator can become a useful tool for the main system managers as the needed information is usually recorded on a regular basis at different levels of many irrigation systems.

In the case of certain canals, with time and mainly because of siltation, the bed levels rise. For example, Niaz Beg distributary in Punjab (Pakistan) has its bed level either equal or higher than designed FSL for a section about 20 kilometers toward its tail end (WAPDA 1984). Similarly, the rise in bed levels of the head, middle and tail Majors in this study is reported to be 1.3, 1.2 and 0.6 meters, respectively (MDS-Report,1991). This implies that corresponding canal banks have also been raised to keep the system running. Under such circumstances, one needs to consider the indicator, WSS, with the existing bank and full supply levels before deciding to undertake a maintenance activity.

Tables 2.9A and 2.9B compare the values of WSS based on mean levels for the main canal, 3 Majors and 9 Minors. In general, the Minors need attention as the numbers in the tables are relatively on the higher side. The tail Major also shows a similar trend. However, these higher values do not necessarily point to a maintenance problem. There is a possibility that some such canals are receiving supplies beyond their design limits.

Table 2.9A. Water Surface Status (WSS) for the Main Gezira Canal and Head, Middle and Tail Majors (Mean Levels Basis).

CANALS	1988-89			1989-90		
	Head	Middle	Tail	Head	Middle	Tail
Main Canal	1.34	1.19	1.36	1.37	1.14	1.37
Head Major	1.34	1.01	0.75	1.37	1.04	0.90
Mid. Major	1.19	1.52	1.08	1.14	1.44	1.10
Tail Major	1.36	1.62	1.47	1.37	1.75	1.37

Note: Depth from the defined depth is taken in meters.

Table 2.9B. Water Surface Status (WSS) for the Minor Canals of Head, Middle and Tail Majors.

CANALS	1988-89 (Based on Mean Levels)			1989-90 (Based on Mean Levels)		
	Head Minors	Middle Minors	Tail Minors	Head Minors	Middle Minors	Tail Minors
Head Major	0.82	0.73	1.53	0.94	0.90	1.92
Mid. Major	1.47	1.45	1.45	1.37	1.49	1.40
Tail Major	1.70	1.55	1.00	1.80	1.49	1.05

Note: Depth from the defined reference is taken in meters.

Table 2.9C provides results from 4 Managil canals based on mean and peak discharge levels. Except for the Managil Old, all the numbers corresponding to other canals indicate siltation or weed infestation causing the water levels to rise. It is also reported that the peak discharge levels of Managil New and Fahal branch canals were either equal to, or higher, than their respective designed bank levels (MDS-Report 1991).

Table 2.9C. Water Surface Status (WSS) at the Head of Managil Branch Canals.

CANALS	1988-89		1989-90	
	Mean Level Basis	Peak Level Basis	Mean Level Basis	Peak Level Basis
Managil Old	0.57	1.02	0.63	1.02
Managil New	1.25	1.88	1.27	2.04
Shawal	1.23	1.51	1.03	1.57
Fahal	1.80	2.09	1.36	1.96

Note: Depth from the defined reference is taken in meters.

However, it is also possible to have these higher levels if diverted supplies are more than the design capacity of a canal. It implies that the above results should be studied, together with information about supplies diverted and intended, and design capacities of different canals being studied.

2.4.3.2 Supply-Design Capacity Ratio (SDR)

Figure 11 shows different **SDR** values for the Gezira and Managil canals. The data illustrate that the main Gezira canal (GMC), Managil New (M-New), Zanda Major (head Major), and Gamusia Major (middle Major) have almost identical average supply-design capacity ratios in a range of 0.70 to 0.80 for both the monitoring periods. The tail Major, however, has attained higher ratios of these parameters, than any other canal (i.e., 0.82 to 0.96 during 1988-89 and 1989-90). If October and November are selected as peak discharge periods, then the following are the resulting SDRs:

YEAR	GMC	MANAGIL	NEW ZANDA	GAMUSIA	KEG
1988-89	0.80	0.90	0.79	0.85	0.92
1989-90	0.80	1.04	0.86	0.90	1.12

The above high ratios partly explain the higher upstream levels as determined by WSS. However, as there are only two cases when SDR is found to be slightly more than 1, the high values of WSS still signal siltation and weed infestation to a degree in these canals.

Figure 11 also illustrates that the average SDRs (seasonal mean values) for the following three canals are very low: (i) Managil Old (M-Old); (ii) Fahal; and (iii) Shawal. The ratios for these canal lie within a range of 0.2 to 0.5. There could be three possible explanations for such low ratios: (i) too little supply was diverted; (ii) the carrying capacities of these canals were drastically reduced due to siltation and weed infestation; and (iii) a combination of both factors.

Even the SDRs of the above three canals, corresponding to the selected peak discharge months, are low. These values are tabulated below:

PERIOD	MANAGIL OLD	SHAWAL	FAHAL
Oct. and Nov. 1988-89	0.56	0.37	0.26
Oct. and Nov. 1989-90	0.64	0.40	0.30

When the SDRs of these three canals are compared with corresponding values of WSS, it appears that Managil Old may have some reason other than maintenance for these low ratios. However, Shawal and Fahal branch canals, which have high WSS levels with low SDRs (i.e., a combination of low deliveries with respect to their design capacities and higher water levels at their heads) provides a strong reason to suspect reduced carrying capacities and a need to consider corrective measures.

2.4.3.3 Authorized Release-Design Capacity Ratio (ADR)

This ADR is selected on the following hypothesis: *"the field managers of the main system base their decisions for authorized releases mainly on the existing capacities of various canals."* However, there could also be other reasons such as: (i) sediment load in canal waters; (ii) irrigation demand; (iii) availability of water at the source point; and (iv) intentional increases or reductions for certain locations such as tails, trouble spots, heads of canals, etc.

The ADRs and SDRs presented in Figure 11 for different canals follow each other very closely. So, the ADRs also support some of the tentative observations about such canals as Fahal and Shawal.

Although the proposed package of the above three indicators appears to be a reasonable selection, it is too early to suggest that it could be used as a tickler system for initiating a maintenance activity. Though it may be insufficient, it is surely a serious effort in the right direction.

2.4.4 Comparison with Other Countries

Comparisons across countries needs careful presentation of basic assumptions used to derive even similar indicators. Similarly, different climatic and soil conditions will also change the resulting performance indices. Moreover, the size of a main system, and the way data is arranged for analysis, may give different results. For example, the indices may differ if they are calculated based on data according to control points, canal sections, or reaches.

At this stage, data are not available for all types of hydraulic indices. However, Table 2.10 provides examples from three countries for indicators belong into the performance category: *utility of water supplies*. These countries are: (1) Sudan; (2) Pakistan; and (3) Sri Lanka. Both Sudan and Pakistan have large gravity irrigation main canals as compared to Sri Lanka. In the case of the latter, the selected main canals are very similar to the Minors in the irrigated schemes of Sudan. As compared to Sri Lanka, which is a humid country, Sudan and Pakistan are classified as arid / semi-arid regions.

Table 2.10. Comparison of the Water Utility Indicators for Performance at Main Canal Levels across Sudan, Pakistan and Sri Lanka.

Indicators	CPs / Sections	Year	GMC (SGB) (SD)	Fordwah Branch (Pak)	Minneriya (SL)	Kaudulla (SL)
P_A	CPs	1988-89	0.78	0.67 (91-92)	0.79 (1987)	0.85 (1987)
		1989-90	0.86			
	Sections	1988-89	0.80			
		1989-90	0.88			
P_D	CPs	1988-89	0.22	0.47 (91-92)	0.59 (1987)	0.55 (1987)
		1989-90	0.29			
	Sections	1988-89	0.25			
		1989-90	0.35			
P_E	CPs	1988-89	0.19	0.63 (91-92)	0.64 (1987)	0.76 (1987)
		1989-90	0.13			
	Sections	1988-89	0.25			
		1989-90	0.24			

From the table, it is evident that the performance in terms of adequacy of water distribution at the Gezira main canal is similar to the two systems monitored in Sri Lanka. It is better than the case of Fordwah Branch from Pakistan. However, it should be noted that the Pakistani irrigation system is not designed for adequate water distribution; it aims at equitable but short supplies.Moreover, the calculations related to the parameter of adequacy for GMC consider only evaporation losses to convert crop water requirements into water requirements, whereas in the case of Fordwah, a conveyance efficiency of 60 percent is used.

The other parameters such as P_D and P_E indicate relatively better performance of the Gezira main canal as compared to the examples chosen from the other two countries. Many factors could have contributed to achieving relatively better performance. In addition to Sudan's management style for its irrigated agriculture and factors such as tight heavy clay soils of the Gezira, as well as availability of needed irrigation supplies, a crop-based demand system (in spite of the weakness associated with the indenting procedure), etc.

Other components of the system are not compared because of the incompatibility of indices derived for Fordwah distributaries and the absence of secondary canals in the cases of the Minneriya and Kaudulla systems. In the first case, the parameters for adequacy and dependability are based on ratios of actual deliveries to designed discharges for the secondary canals.

2.5 CONCLUSIONS AND RECOMMENDATIONS

Based on the secondary data analyzed and discussed, plus the canal operations observed in the Gezira scheme, a set of practical recommendations is presented for implementation. The package is mainly based on making use of already available data, the current institutional provisions for routine data collections and canal operations, and some readjustments and redefined roles for the existing departments and institutions in the scheme. The following recommendations also identify important research and monitoring activities aimed at improving the hydraulic performance of the Gezira scheme:

2.5.1 Activities Recommended for Improved Hydraulic Performance

1. At present, water levels and gate-openings are routinely recorded at all control points along the main canals and heads of Majors. It is recommended that the same practice should also be extended to include all control points of majors canals. In order to improve the credibility of the daily information reported by the gate-operators, it is essential to have a serious mechanism for counter-checking the accuracy and reliability of the information recorded.

2. Even if the reporting of water levels and gate-openings is accurate and reliable, or made so with a little more attention, it is still not an end in itself. In the context of improving the water distribution performance, it is strongly recommended that the reports should be translated into actual deliveries daily at all control points to be compared with targeted quantities. If the distribution is not found as planned, instructions should be conveyed to the person concerned

on the same day. With the available telephone facility in the scheme, it is possible to exchange such information rapidly. For the main and branch canals, the two directorates of irrigation operations in the scheme can be made responsible. For Majors, the offices of relevant divisional engineers can be entrusted with the responsibility.

Based on the findings of this paper, it is strongly recommended that the evaluation of water distribution should be based on canal reaches as they are basic hydraulic units for water distribution for the main system.

(3) After a short time period of interruption, the responsibility for Minors is back with the agricultural administration of the Gezira scheme. The Water Management Advisory Unit (WMAU) of the SGB should train and assist the agricultural field staff of the scheme in monitoring, evaluation and taking corrective measures for improving the water distribution at Minors.

(4) The official schedule at a tertiary level is to have a *number* (37.8 ha) irrigated within a week. However, the existing unattended irrigation practices at this level are far from the formal procedure reported in the books. It may take 4 to 5 days in some cases and 20 to 25 days in other cases to irrigate a *number*[13]. Such a distorted water distribution at the end point needs immediate attention. It is, therefore, recommended that the WMAU / SGB should advise and provide necessary assistance to the tenants for ensuring proper distribution at the tertiary level.

(5) Canal siltation and weed infestation is a very serious problem in the irrigation schemes of Sudan. It is recommended that the field irrigation managers should make use of the suggested maintenance-related indices in this paper. Such an additional suggested use of the routine daily recorded information at control points along the main and branch canals would add another purpose to a *ritual* that is of little use at present.

(6) The Minors get silted faster than any other component of the main system. This phenomenon is the cause of serious problems of water distribution at the Minors as reported in this paper. At present, the maintenance responsibility of Minors lies with the Ministry of Irrigation. In addition to financial problems of the Ministry, there are inter- and intra-agency bureaucratic procedures. For such reasons, the desilting of the Minors suffers. It is, therefore, recommended that farmers should be made responsible for pursuing this activity. Farmers should be free to choose and pay directly for all options available to them for the desilting of Minors.

[13]personal communication with Mr. Izzel din El Mekki, former managing director of the Gezira Scheme.

2.5.2 Recommended Facilities

2.5.2.1 Arrangements for Data monitoring

1. Generally, the control points of the main, branch and major canals are equipped with sluice gates. At present, there are no gauges installed to measure the head difference across these gates. For an effective monitoring of flows, it is strongly recommended that such gauges should be installed immediately as the provision of such convenient means does not require a large financial commitment from the Ministry of Irrigation.

2. The current practice to measuring gate opening is based on the number of screws turned up or down with respect to a reference point. Such *screw-based* measurements are difficult to make and may not be very transparent and accurate. In the context of canal operations, many supervisors hardly bother to count screws to verify their instructions were implemented or not. It is, therefore, suggested that either gauges should be installed or painted to read gate openings directly.

3. The gauges of structures, such as Butcher's Weir, should read flow in thousand m^3/day directly instead of the usual graduations in centimeters or meters. This should facilitate confirmation of whether the actual supplies are matching with requested indents at a particular point. This should also help the officials of SGB to verify if their water request / indents are being met when compared with actual deliveries.

4. For remote locations where the Gezira telephone link is not available, then *walkie-talkie* type equipment should be provided to the relevant staff.

5. For quick data analysis and record, computers should also be provided, at least to the two directorates for irrigation operations in the scheme.

2.5.2.2 Training of Relevant Staff

1. The agricultural officials of the Gezira scheme are not trained to undertake monitoring and evaluation of water distribution at the Minors. It is suggested that the Water Management Advisory Unit of SGB should offer short training programs for its field staff.

2. It is also recommended that The Ministry of Irrigation should organize local training programs for its staff. Such training activity should aim at providing necessary skills for the evaluation of the hydraulic performance of the main system and use of the proposed (and other) indices for such assessment.

2.5.2.3 Research

1. Sudan is an extremely flat country. Installation of flow measuring structures in the existing canals will be a difficult and expensive job. For most places, it may even be impossible. It is, therefore, suggested that a regular program for field calibration of irrigation control structures should be entrusted to the Hydraulic Research Station (HRS) of MOI. In order to have accurate information on which to base daily decisions about canal operations, it is also desirable to keep updating the older calibrations of structures in the scheme.

2. Due to the heavy clay nature of the soils of the Gezira scheme, the seepage losses are very low. However, it is considered appropriate for HRS to conduct a study aimed at identifying conveyance losses due to, say, evaporation, seepage and human interference, etc. Proper estimates of conveyance losses are expected to improve the ability of the Ministry to deliver appropriate water supplies at desired locations as per plans.

3. A considerable amount of irrigation water ends up in surface drains in the scheme. Although such *leakage* is usually denied by officials, it is a well acknowledged reality in the scheme. It is recommended that a study should be conducted in the scheme to quantify the drainage over time. Where surface drains are not available, water is disposed of to fallow fields and roads, etc. It will be useful to know the quantities in order to determine the net quantity delivered to the fields.

4. A study should be conducted to devise a tickler system for the maintenance of canals. A package of indicators is proposed which can be applied to the available long-term data with the Ministry. The resulting indices can show the maintenance-related conditions over time, as well as changes in the values of the indices which occurred after a maintenance activity. A detailed study in this context is recommended to further improve the suggested mechanism.

5. In order to encourage relatively more meaningful interaction between the officials of SGB and MOI at their inter-face (i.e., the level of minor canals), it suggested that researchers should devise and field test simple and practical management tools and interventions. This package should be targeted at the field staff and tenants of the scheme to verify if the deliveries are provided according to mutually agreed indents.

6. The secondary data used in this paper was collected from the main canal to the *headgates of minor canals only.* In other words, the effort was confined to a level which is relatively well supervised. However, the management controls for the canal operations below the headgates of Minors are hardly applied. From the analysis of data and absence of any serious management control at the Minors and Abu Ashreens, it is hypothesized that the hydraulic performance of the lower water distribution subsystem is expected to be extremely unsatisfactory. In order to document the current status of this performance, it is recommended that the water distribution at Minors and *Abu Ashreens* be studied in detail.

7. One of the most important finding of this report is that the traditional concept of performance evaluation based on head middle and tail conditions at different canal-levels is not satisfactory. It is strongly recommended that future research should base such evaluations on canal reaches instead.

8. The respective command areas should be used as weighting factors for determining seasonal averages for a component of a system.

2.6 REFERENCES

Abernethy, C.L. 1986. Performance measurement in canal water management. ODI-IIMI Irrigation Management Network Paper 86/2d.

Baily, Charles and Roberto Lenton. 1984. A management tool for Gezira irrigation system. In: Conference proceedings about " Water Distribution in Sudanese Agriculture, Productivity and Equity" edited by Osman A. Fadl and Chales R. Baily, University of Gezira, wad Medani. PP. 59 to 68.

Bos, M.G., D.H. Murray-Rust, D.J. Merrey, H.G. Johnson, and W.B. Snellen. 1993. Methodologies for assessing performance of irrigation and drainage management. Paper prepared for presentation at the "Workshop of the Working Group On Irrigation and Drainage performance" at 15th International Congress of the ICID at the Haigue, The Netherlands, 30 August-11 September 1993.

EIU 1993. Country Report: Sudan. The Economist Intelligence Unit (EIU). 40 Duke Street, London WIA IDW, United Kingdom.

Euroconsult. 1982. Gezira Rehabilitation and Modernization Project I. Final report (draft). Volume IV-Annexes E and F.

Johnstone, Harmood Victor Carruthers. 1926. The Gezira irrigation scheme: Canalization of the Gezira. Paper No. 4665.

Kuper, Marcel and Jacob W. Kijne. 1993. irrigation management in the Fordwah Branch command area south east Punjab, Pakistan. In: Advancements in IIMI's Research 1992. Irrigation Management Institute, Colombo, Sri Lanka.

Levine, Gibert. 1982. Relative water supply: An explanatory variable for irrigation systems. Technical report No. 6; The Department of Irrigation Project Problems in Developing Countries. Ithaca, NY: Cornell University.

Levine, Gilbert and Charles Baily. 1987. Water management in the Gezira scheme. Water resource Development Vol 3. Number 2.

MDS Report. 1991. Research for Rehabilitation: Study of reliability of water supply to minor canals. Joint report by Hydraulic Research Ltd, Wallingford, and Hydraulic Research Station, Wad Medani. Final Report: January 1991. Volumes 1 and 2.

Mao Zhi. 1989. Identification of causes of poor performance of a typical large sized irrigation system in south China. Asian Regional Symposium on the Modernization and Rehabilitation of Irrigation and Drainage Schemes. Published by Hydraulic Research. Wallingford, England, ADb and NIA.

Mohammed, Robert Ali. 1987. A theory for monitoring the irrigation system. Unpublished Ph.D. thesis. Department of Agricultural and Chemical Engineering, Colorado State University, Fort Collins, USA.

Molden, David J. and Timpothy K. Gates. 1990. Measures of evaluation of irrigation delivery systems. In: Journal of Irrigation and Drainage Engineering, Volume 116, No. 6, ASCE.

Murray-Rust, D. Hammond and W. Bart Snellen. 1992. Performance assessment diagnosis. Final report (draft). IIMI and ILARI.

Plusquellec, Harve. 1990. The Gezira irrigation scheme in Sudan: objective, design, and performance. The World Bank.

Rao, P. S. 1993. Review of selected literature on indicators of irrigation performance. Forthcoming IIMI Paper.

Sakthivadivel R., Douglas J. Merrey and Nihal Fernando. 1993. Cumulative relative water supply: A methodology for assessing irrigation performance. Irrigation and Drainage Systems 7: 43-67, 1993.

Shafique, M. S. Abdel Bagi A.Y. Algam and Magdi A. Tawadrous. 1993. Rapid appraisal of irrigation water distribution in Rahad. The News-F. O. P. of IIMI, February-March 1993, Volume 2.

Small, L.E. and Mark Svendsen. 1992. A framework for assessing irrigation performance. Washington, D. C., International Food Policy Research Institute.

Vander Velde, Edward J. 1991. Performance assessment in large irrigation system in Pakistan: Opportunities for improvements at distributary level. Improved Irrigation System performance for Sustainable Agriculture. Proceedings of the Regional Workshop organized by FAO, 22-26 October 1990, Bangkok. Rome: FAO.

WAPDA. 1984. Behavioural analysis of channels in Punjab under the Command Water Management Project. Alluvial Channel Observation Prject (ACOP) / Water and Power Development Authority (WAPDA), Lahore, Pakistan.

Wallach, Bret. 1988. irrigation in Sudan since independence. Reprinted from Geographical Review Vol. 78, No. 4, October 1988.

CHAPTER 3

On-Farm Water Management Practices and Crop Production Indicators in Selected Areas of the Gezira Scheme

K. Azharul Haq, Gamar D. Khatib, Ahmed A. Salih[14]

3.1 INTRODUCTION

In the Gezira Scheme cotton and wheat are the major crops. In recent years, however, wheat has become the principal crop replacing cotton. The area planted to wheat has been increasing significantly over recent years and it is expected that by the mid-decade it will reach 300,000 ha if the present trend of sacrificing the cotton area in favour of cereals continues and adequate water can be diverted at the Sennar dam. On the other hand, the cotton area has registered significant decreases over the last few years and the trend is continuing. Data related to acreage and yield of wheat and cotton are given in Figures 1 and 2.

Figure 1. Trend in Wheat and Cotton acreage in the Gezira Scheme.

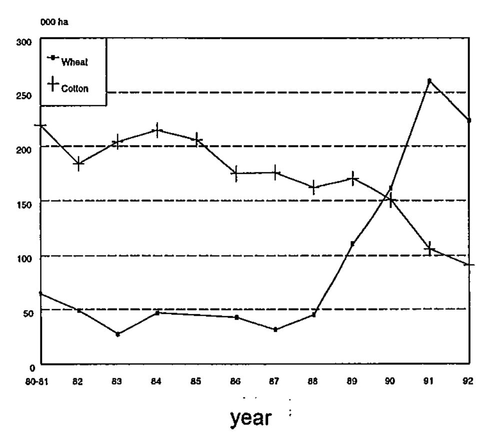
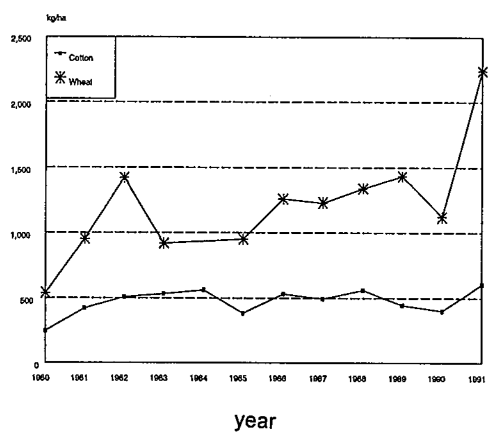


Figure 2. Yield trends for Cotton and Wheat.



[14]Irrigation Specialist, International Irrigation Management Institute, Colombo, Sri Lanka, Manager, Water Management Unit, Sudan Gezira Board, Medani, Sudan and Soil Phycist, Agricultural Research Corporation, Medani, Sudan respectively.

In the 1991-92 crop season 228,288 ha was planted to wheat as compared to 260,000 ha in the 1990-91 crop season. This 12% decrease in area was a direct consequence of the loss of nearly 17,000 ha (approx. 7% of the area planted) due to a shortage of irrigation water during the previous year. Though there has been a significant increase in wheat area (45% increase in 1991-92 over 1980-81), the yield has been quite unstable. Taking 1980 -81 as the benchmark year, the yield of wheat increased from 0.50 t/ha to 1.60 t/ha in 1989-90, an increase of nearly 350 percent. The wheat yield in recent years has, however, have shown erratic trend. As compared to the previous season, wheat yields increased by about 110 percent (in 1991-92 over 1990-1991), whereas in 1990-91 the average yield declined by about 21% over 1989-90.

During the same season 92,000 ha were planted to cotton as compared to 105,000 ha in the 1990-91 crop season, a 13% decrease. Though cotton area showed a general decline over the whole period, the most significant reduction, 40%, took place between 19989-90 and 1991-92. This decrease can be attributed to a government policy to move cotton to rainfed areas and increase cereal acreage in the irrigated schemes. Another important reason is that, for this export crop, farmers were paid at the official conversion rate, which was only 10% of the "street" price. Like wheat, cotton also went through the cycles of high and low yields with the 1991-92 harvest producing an all time high of 2.28 t/ha, an increase of 52% over the previous season and 144% over the benchmark year.

Both wheat and cotton cultivation in the Gezira Scheme is nearly fully mechanized except for cotton picking which is done manually. Until recently, like cotton, wheat was also the "State Crop". The Government, through the Gezira Board, provided all the inputs and services and after the harvest the cost of production was reclaimed from the tenant. It was also mandatory for the tenant to deliver all of his production to the government at a price previously determined by the authority, except that the tenant was allowed to keep 95 kg/ha for domestic consumption. From 1991-92 crop season, the government has decided to deregulate wheat production. But cotton continues to be the state crop.

During the 1991-92 season, studies were conducted in 8 and 7 "Numbers" (Number is generally a 38 ha block of contiguous farm land) for wheat and cotton, respectively, belonging to three "Minors" at: 1 the Pilot Farm located in Tayba Block of Messelmia Group; and 27 and 17 "Numbers" for wheat and cotton, respectively, in the Mikhashfi Group (Figure 5), to quantify and evaluate the effect of agronomic and water management parameters on their production. For wheat, 3 additional Numbers were also included from the Wad Habouba Group.

Both primary and secondary data were collected for the study. Primary data were collected on soil moisture(wetting and depletion characteristics), plant density (for wheat), volume of dead storage, irrigation frequency and duration, and yields. All other data were collected from relevant SGB offices.

3.2 WEATHER

The weather data have been collected from the Wad Medani weather station (200 km south east of Khartoum), which is presented in Figures 3 and 4. The data indicate that both the seasons experienced extreme weather conditions. The 1990-91 crop year received less than average rainfall, experienced higher temperatures, and high wind-runs. The wheat season (November-April) was also characterized by high temperatures. Both the average maximum and average minimum temperatures were higher by 2-3 degrees from the 10-year average, as well as from those of the previous year (1989-90). This adversely affected seedling establishment, as well as vegetative growth, including tillering. The temperature, however, cooled off from early January and was quite favourable during the rest of the growing season. Worst affected were the fields that were planted at the recommended optimum time. Due to colder temperatures during the months of January, February and March, the late planted areas produced better yields than the scheme average.

By contrast, the 1991-92 crop year was extremely favourable in terms of both water and weather. A well distributed rainfall pattern in the project area, as well as in the catchment, coupled with reductions in cotton, groundnuts and wheat acreages, ensured a relatively adequate water supply during the entire crop year, especially during the wheat season. The growing environment during the wheat season was near perfect. Water adequacy, combined with better crop husbandry and improved management, resulted in significant increases in both cotton and wheat yields in 1991-92 compared with the previous season.

3.3 CROP PRODUCTION PRACTICES

3.3.1 Agronomic Practices

Agronomic data were collected from the SGB Block offices through questionnaires. In the whole of the study area, only two varieties, Debiera for wheat and shambat for cotton, were planted. Seed was machine drilled at the rate of 142 and 26 kg/ha for wheat and cotton, respectively.

For wheat, nitrogen (N) at the rate of 190 kg/ha in the form of urea (87.6 kg N), and phosphorus(P) at the rate of 95 kg/ha as TSP, were applied as basal during land preparation. P was applied with the first plowing whereas N was applied during the final land preparation. For cotton, only urea was applied at the rate of 190 kg/ha.

Wheat was harvested by combine harvesters and the yield estimates were made from the harvesters grain tank. Cotton yields were estimated from farmers "cotton yards".

3.3.2 Irrigation and Water Management

The layout of the water application system of a typical "Number" is shown in Figure 6. From the "Minor", water is supplied to a "Abu Ashireen" which has an average carrying capacity of 116 l/sec and serves one "Number". The "Number" is sub-divided into 18 "Hawashas" of 2.10 ha and each "Hawasha" is served by an "Abu Sitta"(50 l/sec capacity). Each "Hawasha" is further sub-divided into seven "Angaya" having an area of 0.3 ha each. Irrigation water to each "Angaya" is delivered through a small field channel called

"Gadwal" (7 1/sec capacity). A small field divider called "Tagnet" divides the "Angaya" into two equal halves, whereas each "Angaya" is supplied by two "Gadwals". Furrow and basin methods of irrigation are practiced for wheat and cotton cultivation, respectively. For better water management, the present recommendation is to divide each Hawasha into 42 plots of equal size.

The "Abu Sitta" runs perpendicular to the "Abu Ashireen" and both the "Gadwal" and "Tagnet" run parallel to the "Abu Ashireen". The existing practice is to irrigate half of the "Number" at one time. Originally, the on-farm water management practices called for applying irrigation water first to the tail end. But due mainly to unreliability, this is not practiced.

Water is supplied by the Ministry of Irrigation (MOI) based on the "indent" submitted by the Assistant Block Inspectors of the Sudan Gezira Board(SGB). The SGB is responsible for the operation of the "Minors" and "Abu Ashireenn". This responsibility has since been transferred to the MOI. On-farm water management is the responsibility of the tenants. Water is usually supplied to each "Number" in rotation on a fixed volume(5000 cu.m per day) over a fixed time interval (14 days).

3.4 RESULTS AND DISCUSSION

3.4.1 Agronomic Practices

Earlier, it has been mentioned that the crop production system is standardized and the cultural operations are carried out by the SGB. The variations appear to occur in the dates of planting and harvesting. The discussion will, therefore, be limited to these two parameters.

Over the last decade, planting dates for wheat have considerably changed. The recommended optimum dates at present is from the last week of October to the end of November. Planting upto mid-December, however, has become acceptable. During the year-long study on 35 wheat "Numbers", the monitored data indicated that the entire area was planted during the recommended period. Planting dates ranged from October 31 to November 30 (Table 3.1).

Planting dates monitored by other researchers (Hydraulic Research Ltd, 1991) in 1988-89 and 1989-90 reported that planting was delayed in both seasons by about three weeks. The date of planting did not have any significant impact on the trend of yields, though there was a wide range of variation from 0.48 t/ha to 3.33 t/ha. Yield variation was probably due to factors other than irrigation.

During the 1991-92 season, cotton was also planted within or near the optimum range in the majority of the Numbers monitored (Table 3.2). The planting date was spread from 05-07-91 to 28-07-91. In 1988-89, planting occurred upto two weeks before the official dates for minors at the head of the scheme, whereas at the tail end areas of the scheme planting was extended upto two weeks beyond the end of the recommended period (July 15 through August 15). In 1989-90, the spread was much reduced. Like wheat planting, the date also did not show any significant trend on cotton yields, though there was a wide variation in yields from 1.14 t/ha to 2.45 t/ha.

Table 3.1. Agronomic practices and their impact on wheat yield.

Serial No.	Location	Number	Date of sowing	Date of harvesting	Field duration (Days)	Yield T/ha
1	Tayba Shimal (Tayba)	2	11.06.91	04.08.92	154	3.09
2	Tayba Shimal (Tayba)	6	11.04.91	04.01.92	147	3.33
3	Ibrahim (Tayba)	2	11.21.91	04.16.92	147	1.95
4	Ibrahim (Tayba)	12	11.19.91	04.21.92	154	2.09
5	Ibrahim (Tayba)	17	11.07.91	04.10.92	155	2.36
6	Sunni (Tayba)	3	11.28.91	04.15.92	139	2.14
7	Sunni (Tayba)	11	11.04.91	04.08.92	156	2.62
8	Sunni (Tayba)	14	11.06.91	04.10.92	156	2.48
9	Saadiya (Huda)	1	11.02.91	04.10.92	159	1.93
10	Saadiya (Huda)	7	11.20.91	04.10.92	141	0.98
11	Saadiya (Huda)	10	11.26.91	04.10.92	135	1.38
12	Kareima (Huda)	1	11.12.91	04.12.92	151	1.48
13	Om Husan (Huda)	1	11.03.91	04.16.92	163	1.36
14	Om Husan (Huda)	7	11.08.91	04.16.92	159	1.09
15	Om Husan (Huda)	12	11.05.91	04.16.92	162	1.09
16	Garash (A.Gani)	1	11.24.91	04.29.92	156	2.33
17	Garash (A.Gani)	7	11.25.91	04.29.92	155	1.93
18	Garash (A.Gani)	10	11.26.91	04.28.92	153	1.81
19	Hamdnall (A.Gani)	1	10.31.91	04.04.92	157	2.55
20	Hamdnall (A.Gani)	7	11.06.91	04.05.92	150	2.71
21	Hamdnall (A.Gani)	9	11.07.91	04.05.92	149	2.52
22	Abdalla Yousif (A.Gani)	7	11.02.91	04.10.92	159	2.59
23	Abdalla Yousif (A.Gani)	21	11.30.91	04.16.92	137	2.57
24	Abdalla Yousif (A.Gani)	31	11.30.91	04.16.92	137	3.19
25	Garab (Abrag)	39	11.15.91	04.17.92	153	2.19
26	Garab (Abrag)	36	11.13.91	04.17.92	155	2.31
27	Garab (Abrag)	33	11.10.91	04.15.92	156	1.81
28	Garab (Abrag)	7	11.04.91	04.05.92	152	2.64
29	Garab (Abrag)	10	11.05.91	04.05.92	151	2.64
30	Garab (Abrag)	63	11.20.91	04.20.92	151	1.55
31	Garab (Abrag)	1	11.01.91	04.05.92	155	2.5
32	Garab (Abrag)	54	11.20.91	04.20.92	151	2.4
33	Um Sayala (Istrahna)	3	11.20.91	03.20.92	121	0.98
34	Elwalie(Istrahna)	23	11.01.91	03.01.92	121	0.92
35	Hieloat(Istrahna)	10	11.15.91	03.15.92	121	0.83

Table 3.2. Agronomic practices and their impact on cotton yield.

Serial No.	Location	Number	Date of sowing	Date of harvesting	Field duration (Days)	Yield T/ha
1	Tyba Shimal	3	05.07.91	23.12.92	170	2.46
2	Tyba Shimal	9	08.07.91	12.12.92	156	2.00
3	Sunni	4	15.07.91	08.12.92	145	1.83
4	Sunni	8	14.07.91	27.12.92	165	2.17
5	Sunni	12	20.07.91	30.12.92	162	2.26
6	Ibrahim	8	28.07.91	19.01.92	174	1.57
7	Ibrahim	14	15.07.91	28.12.92	165	2.31
8	Gorash (A/Gani)|	2	08.07.91	21.12.91	165	1.91
9	Gorash (A/Gani)	5	10.07.91	22.12.91	164	1.83
10	Gorash (A/Gani)	11	15.07.91	22.12.91	159	1.30
11	Adb alla yousif (A/G)	2	16.07.91	24.12.91	160	1.63
12	Adb alla yousif (A/G)	11	18.07.91	24.12.91	158	1.57
13	Hamadnalla (A/G)	2	16.07.91	24.12.91	160	1.97
14	Hamadnalla (A/G)	11	13.07.91	20.12.91	161	1.57
15	Adb alla yousif (A/G)	25	21.07.91	27.12.91	158	1.57
16	Hamadnalla (A/G)	5	16.07.91	23.12.91	159	1.63
17	Om Husan (Huda)	13	27.07.91	25.12.91	150	1.37
18	Om Husan (Huda)	5	22.07.91	22.12.91	152	1.57
19	Om Husan (Huda)	2	20.07.91	22.12.91	154	1.97
20	Kariema	12	18.7.91	22.12.91	156	1.14
21	Kariema (Huda)	5	15.7.91	22.12.91	159	1.71
22	Saadiya (Huda)	10	15.7.91	20.12.91	157	1.43
23	Saadiya (Huda)	2	10.7.91	21.12.91	163	2.17
24	Kariema (Huda)	2	17.7.91	22.12.91	157	1.37

Note: Harvest date indicated is the date of 1st picking. Cotton is generally picked 3 times and after each picking Irrigation is applied. Two to three weeks gap between picking is a usual practice.

Yields are in seed cotton.

3.4.2 Irrigation Water Management

3.4.2.1 Water Supply

Earlier, it was mentioned that water is supplied by the MOI against an indent submitted by the SGB Block Inspectors. The procedure for indent is very simple. Every Inspector demands 5000 m3/day (12 hrs) per "Number" for the duration of irrigation, which is usually 14 days. This demand remains constant during the whole year, irrespective of type of crop grown, stage of crop growth, or the season at which crops are being grown. An analysis of this magic number indicated that 5000 m3/day/Number seems to be the peak requirement for groundnuts, which are grown during June-October period. The peak crop water requirement of groundnuts has been estimated at 1207 m3/fd in June, which translates to about 4000 m3/Number/day (source GRP: Staff Appraisal Report). This higher and blanket type of indenting is probably done to play safe and should now be replaced by indents for specific crops and specific seasons. Estimates of monthly water requirements for different crops of the Gezira scheme are available, which should be utilized (Table 3.3). It can be seen that, depending on the growth stages, water requirements vary widely between crops during the same months. For example, the crop water requirements for ELS(extra long staple) and MS (medium staple) cotton is 475 m3/ha during the month of July as against 1666 m3/ha and 1420 m3/ha for groundnuts and sorghum, respectively. Similarly, during October, the water requirement for ELS cotton and MS cotton nearly peaks to 2100 m3/ha and 2420 m3/ha, respectively, as compared with 960 m3/ha and 435 m3/ha for groundnuts and sorghum. The above discussion amply demonstrates the need to realistically prepare indents to meet actual crop water requirements.

Except for groundnuts and sorghum, the water requirements for other crops are comparatively lower during the first three months, which incidentally brings nearly 60% of the silt load into the system. A better matching of deliveries to demand will prevent the diversion of unnecessarily large supplies, and hence, will reduce the silt problem (6 to 7 million tons of silt are carried into the system every year).

3.4.2.2 Frequency and Duration of Irrigation

Table 3.4 indicates that, for wheat the frequency of irrigation has followed more or less the recommended 14 day interval, in most of the cases. Yet, in some cases, the frequency was stretched to 28 days (Saadiya/Huda; Number 1) between the first and second irrigation. The lowest irrigation interval of 7 days was experienced by Number 1 of Kariema/Huda between the 2nd and 3rd irrigations. The total number of days of irrigation application also varied significantly between the "Numbers" (Table 3.5). "Number" 17 of Ibrahim/Tayba received water for the highest number of days, which was 88. The total number of days of water application varied from 44 to 88 days.

Table 3.3. Monthly crop-water requirements in the Gezira scheme (m^3/ha).

MONTH	COTTON ELS	COTTON MS	WHEAT	GROUND-NUT	SORGHUM
January	724	150	799	0	0
February	150	0	23	0	0
March	105	0	0	0	0
April	0	0	0	0	0
May	0	0	0	0	0
June	0	0	0	1.207	806
July	200	200	0	700	598
August	565	576	0	868	910
September	548	753	0	924	936
October	884	1.016	257	404	435
November	889	915	657	0	0
December	822	569	737	0	0
Total	4,887	4,179	2,473	4,103	3,685
M3/ha	12,678	10,447	6,388	9,722	8,759
Mm	(1270)	(1045)	(640)	(972)	876)

Source: Gezira Rehabilitation Project, Staff Appraisal Report.

Note: Crop requirements are at field outlet pipe taking into account the staggered planting dates and requirements for initial irrigation.

Crop requirements are calculated using the crop factor based on GRS field measurements (GRS 1979) and the Penman EO at Wad Medani.

FAO recommendation for wheat:450-650 mm.

Table 3.4. Date of first and last irrigation, irrigation frequency and interval - a case of wheat crop during 1991-92.

SERIAL NO.	LOCATION	NUMBER	DATE OF FIRST IRRIGATION	IRRIGATION INTERVAL (DAYS)						
				2ND	3RD	4TH	5TH	6TH	7TH	8TH
1	Tayba Shimal (Tayba)	2	11.15.91	14	16	16	15	14	16	-
2	Tayba Shimal (Tayba)	6	11.18.91	18	14	16	15	14	12	-
3	Ibrahim (Tayba)	2	11.28.91	13	12	14	14	15	-	-
4	Ibrahim (Tayba)	12	11.23.91	13	14	14	15	16	12	-
5	Ibrahim (Tayba)	17	11.17.91	18	14	15	13	16	14	-
6	Sunni (Tayba)	3	12.02.91	16	15	12	14	14	-	-
7	Sunni (Tayba)	11	11.14.91	13	13	11	13	14	14	-
8	Sunni (Tayba)	14	11.17.91	12	12	14	16	11	14	-
9	Saadiya (Huda)	1	11.08.91	28	15	15	15	15	13	-
10	Saadiya (Huda)	7	11.22.91	14	17	16	17	18	19	-
11	Saadiya (Huda)	10	12.01.91	18	15	16	16	16	17	-
12	Kareima (Huda)	1	11.20.91	18	7	15	14	14	18	-
13	Om Husan (Huda)	1	11.21.91	18	14	14	17	15	14	-
14	Om Husan (Huda)	7	11.14.91	17	17	15	16	13	16	-
15	Om Husan (Huda)	12	11.16.91	17	15	17	15	16	15	-
16	Garash (A.Gani)	1	11.29.91	18	15	14	13	14	14	-
17	Garash (A.Gani)	7	12.01.91	18	14	14	15	14	14	-
18	Garash (A.Gani)	10	12.03.91	18	14	14	13	14	15	-
19	Hamdnall (A.Gani)	1	11.17.91	18	15	14	14	16	-	-
20	Hamdnall (A.Gani)	7	11.10.91	18	16	14	17	17	16	-
21	Hamdnall (A.Gani)	9	11.20.91	18	15	15	14	14	16	-
22	Abdalla Yousif (A.Gani)	7	11.14.91	19	14	16	14	16	14	-
23	Abdalla Yousif(A.Gani)	21	11.03.91	21	13	15	14	14	17	-
24	Abdalla Yousif(A.Gani)	31	12.05.91	18	14	14	14	13	14	-
25	Garab (Abrag)	54	11.22.91	18	17	16	15	17	14	-
26	Garab (Abrag)	39	11.20.91	20	14	15	14	15	16	-
27	Garab (Abrag)	36	11.17.91	19	16	16	15	15	15	-
28	Garab (Abrag)	33	11.15.91	18	14	17	15	17	16	-
29	Garab (Abrag)	7	11.12.91	18	14	16	16	14	16	-
30	Garab (Abrag)	10	11.15.91	19	14	16	15	16	15	-
31	Garab (Abrag)	58	11.25.91	16	16	14	15	16	16	-
32	Garab (Abrag)	63	11.29.91	11	15	16	14	15	16	-
33	Um Sayala (Istrahna)	3	11.20.91	15	15	10	16	15	16	-
34	Elwalie (Istrahna)	23	11.01.91	14	15	12	14	15	10	16
35	Hieloat (Istrahna)	10	11.15.91	14	17	14	16	15	-	-

Table 3.5. Date of first and last irrigation, irrigation frequency and interval - a case of cotton crop during 1991-92.

	Location	Number	1st Irrig Date	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	Last Irrig Date
1	TS	3	08/7/91	14	14	24	15	15	14	15	15	15	13	23	01/01/92
2	TS	9	10/7/91	15	15	14	14	16	14	15	15	14	15	14	18/12/91
3	Sunni	4	18/7/91	15	14	16	15	14	13	16	17	16	13		14/12/91
4	Sunni	8	17/7/91	18	16	15	15	17	14	15	14	17			05/01/92
5	Sunni	12	23/7/91	17	14	17	13	14	15	16	15	13	13	15	31/12/91
6	Ibrahim	8	02/8/91	18	18	18	16	12	22	18	18	16	20		25/01/92
7	Ibrahim	14	17/7/91	16	15	17	16	13	15	16	14	14	15	22	05/01/92
8	Gorash (A/Gani)	2	05/7/91	Rain	Rain	Rain	14	14	15	14	14	15	14	16	26/12/91
9	Gorash (A/Gani)	5	08/7/91	Rain	Rain	Rain	14	16	14	15	14	14	13	16	28/12/91
10	Gorash (A/Gani)	11	12/7/91	Rain	Rain	Rain	14	16	15	14	14	15	16	15	02/01/91
11	Adb alla yousif	2	14/7/91	Rain	Rain	Rain	14	13	14	15	14	16	15	15	31/12/91
12	Adb alla yousif	11	15/7/91	Rain	Rain	Rain	14	14	14	15	15	15	14	15	30/12/91
13	Hamadnalla	2	14/7/91	Rain	Rain	Rain	15	14	14	14	15	14	14	12	24/12/91
14	Hamadnalla	11	12/7/91	Rain	Rain	Rain	14	14	14	14	14	14	14	14	22/12/91
15	Adb alla yousif	25	18/7/91	Rain	Rain	Rain	14	14	16	14	15	14	15	16	06/01/92
16	Hamadnalla	5	15/7/91	Rain	Rain	Rain	14	14	14	15	14	14	14	15	30/12/91
17	Om Husan (Huda)	13	27/7/91	Rain	Rain	Rain	14	13	14	16	14	14	17	16	10/01/92
18	Om Husan (Huda)	5	20/7/91	Rain	Rain	Rain	14	15	14	14	14	14	14	15	03/01/92
19	Om Husan (Huda)	2	18/7/91	Rain	Rain	Rain	14	14	14	14	14	14	15	17	04/01/92
20	Kariema (Huda)	12	14/7/91	Rain	Rain	Rain	14	14	14	15	14	14	14	15	31/12/91
21	Kariema (Huda)	5	15/7/91	Rain	Rain	Rain	24	12	14	14	15	15	15	15	04/01/92
22	Saadiya (Huda)	10	15/7/91	Rain	Rain	Rain	15	14	14	14	14	14	13	14	25/12/91
23	Saadiya (Huda)	2	08/7/91	Rain	Rain	Rain	16	14	15	14	16	16	16	15	01/01/92
24	Kariema (Huda)	2	15/7/91	Rain	Rain	Rain	15	13	14	15	14	14	15	15	29/12/91

For cotton, all of the Numbers (No. 1-7) of the Pilot farm received 12 irrigations. The Numbers in the Mikashfi groups received 9 irrigations; three irrigations were skipped because of rainfall. The irrigation interval ranged from 12 to 25, and 12 to 24 days, respectively, in the Pilot farm and Mikashfi Groups. The total number of irrigation days ranged from 55 to 78 and 74 to 83 in the pilot farm and Mikashfi Groups, respectively.

A common practice among the researchers is to correlate the crop yield with the number of irrigations applied. From the above discussion, it is quite evident that this approach, in many cases, may lead to erroneous conclusions because there could be a wide difference in the volume of water applied between fields, even if the number of irrigations is identical. Table 3.6 indicates that, even with a lower number of irrigations, an area can receive significantly larger amounts of water.

Primarily, this is possible due to two reasons: 1) uncontrolled flow; and 2) increased hours of operation. The number of irrigations can be correlated to yield only if the flow rate and irrigation time per unit area can be kept constant, which is extremely difficult to achieve in a vast irrigation system like Gezira. The total depth of actual water application was significantly higher than the estimates available for the area. Table 3.3 presents estimates of the evapotranspiration requirement of wheat for the Gezira scheme.

3.4.2.3 Crop Water Requirements and Actual Application

Estimated crop water requirements for major crops in the Gezira scheme are presented in Table 3.3. These fall within the range recommended by the FAO (cotton is 700-1300 mm; Dura is 450-650; and wheat is 450-650 mm; Irrigation and Drainage Paper No. 33). In 1990-91, the average depth of application for wheat ranged from 667mm to 993mm (Haq, K. A., 1991). In 1991-92, the data computed from 35 Numbers indicates that the range was from 661mm to 1380 mm (Table 3.6) with an average value of 848 mm. All values are significantly higher than the recommended value of 640 mm. The actual depth of irrigation application for cotton was computed for the 1991-92 season only. Water application for cotton ranged from 932 to 1908 mm with an average of 1200 mm (Table 3.7) as compared with the recommended 1045 mm.

All the application depths have been computed without accounting for the rainfall. With rainfall, the average application for cotton will increase by 99 and 163 mm for the Pilot Farm and Mikashfi Groups, respectively, thus decreasing both the application depth and the WUE further.

Table 3.6. Irrigation frequencies, irrigation days, depth of application and - a case of wheat crop.

Serial No.	Location	Number	Area ha	Irrig. nos.	Irrig. days	Depth applied (mm)	WUE kg/m3
1	Tayba Shimal (Tayba)	2	29	8	44	759	0.41
2	Tayba Shimal (Tayba)	6	29	8	66	1138	0.30
3	Ibrahim (Tayba)	2	32	7	73	1141	0.17
4	Ibrahim (Tayba)	12	38	8	80	1053	0.20
5	Ibrahim (Tayba)	17	34	8	88	1294	0.18
6	Sunni (Tayba)	3	38	7	80	1053	0.20
7	Sunni (Tayba)	11	38	8	78	1026	0.25
8	Sunni (Tayba)	14	38	8	77	1013	0.24
9	Saadiya (Huda)	1	37	7	65	868	0.22
10	Saadiya (Huda)	7	28	7	56	987	0.10
11	Saadiya (Huda)	10	19	7	53	1204	0.26
12	Saadiya (Huda)	1	36	7	56	771	0.19
13	Om Husan (Huda)	1	38	7	57	754	0.18
14	Om Husan (Huda)	7	38	7	58	767	0.14
15	Om Husan (Huda)	12	38	7	57	754	0.15
16	Gorash (Abdel Gani)	1	37	7	52	703	0.33
17	Gorash (Abdel Gani)	7	38	7	50	661	0.29
18	Gorash (Abdel Gani)	10	38	7	50	661	0.27
19	Hamdnall (Abdel)	1	28	6	46	811	0.31
20	Hamdnall (Abdel)	7	38	7	57	754	0.36
21	Hamdnall (Abdel Gani)	9	13	7	55	784	0.32
22	Abdalla Yousif	7	38	7	55	727	0.36
23	Abdalla Yousif	21	38	7	53	794	0.37
24	Abdalla Yousif	31	38	7	53	701	0.46
25	Gorab (Abrag)	54	35	7	56	808	0.30
26	Gorab (Abrag)	39	38	7	55	714	0.30
27	Gorab (Abrag)	36	38	7	58	754	0.30
28	Gorab (Abrag)	33	38	7	56	741	0.24
29	Gorab (Abrag)	7	38	7	55	714	0.36
30	Gorab (Abrag)	10	38	7	55	727	0.36
31	Gorab (Abrag)	58	38	7	55	727	0.36
32	Gorab (Abrag)	63	21	7	50	1380	0.13
33	Um Sayala	3	38	7	65	855	0.11
34	Elwalie	23	38	8	73	965	0.10
35	Hieloat	10	38	6	64	842	0.10

Table 3.7. Irrigation frequencies, irrigation days, depth of application, crop yield and WUE - a case of cotton crop.

Serial No.	Location	Number	Area ha	Irrig. nos.	Irrig. days	Depth applied (mm)	Yield t/ha	WUE kg/m3
1	Tyba Shimal	3	29	12	87	1500	2.46	0.17
2	Tyba Shimal	9	29	12	71	1224	2.00	0.16
3	Sunni	4	34	11	115	1690	1.83	0.11
	Sunni	8	38	10	118	1552	2.17	0.12
5	Sunni	12	38	12	142	1868	2.26	0.12
6	Ibrahim	8	38	11	123	1618	1.57	0.10
7	Ibrahim	14	38	12	145	1908	2.31	0.12
8	Gorash (A/Gani)	2	38	10	79	1040	1.91	0.18
9	Gorash (A/Gani)	5	38	10	78	1026	1.83	0.18
10	Gorash (A/Gani)	11	38	10	71	934	1.30	0.14
11	Adb alla yousif	2	38	10	76	1000	1.63	0.16
12	Adb alla yousif	11	38	10	76	1000	1.57	0.15
13	Hamadnalla (A/G)	2	28	10	55	982	1.97	0.20
14	Hamadnalla (A/G)	11	13	10	31	1192	1.57	0.13
15	Adb alla yousif	25	30	10	60	992	1.57	0.16
16	Hamadnalla (A/G)	5	36	10	76	1055	1.63	0.15
17	Om Husan (Huda)	13	38	10	81	1065	1.37	0.13
18	Om Husan (Huda)	5	38	10	80	1058	1.57	0.15
19	Om Husan (Huda)	2	38	10	78	1032	1.97	0.19
20	Kariema (Huda)	12	19	10	41	1080	1.14	0.10
21	Kariema (Huda)	5	19	10	42	798	1.71	0.16
22	Saadiya (Huda)	10	19	10	41	1078	1.43	0.13
23	Saadiya (Huda)	2	37	10	83	1123	2.17	0.19
24	Kariema (Huda)	2	37	10	74	998	1.37	0.14

3.4.2.4 Soil Moisture Profiles

Soil moisture profiles for both cotton and wheat during the 1991-92 crop season were determined by using the neutron probe from four successive depths of the root zone (15, 30, 45 and 60 cm). For wheat, 27 sets of data were collected from the study area on moisture depletion characteristics, which are presented in Figure 7. Soil moisture data were collected from one Hawasha each from three Numbers of the Pilot farm area. These represented the head, middle and tail Hawashas of Tayba Shimal, Sunni and Ibrahim minor canals. Samples were collected from 9 points in each "Number". For cotton, profiles were constructed from eight locations of two Numbers (i.e., Number 12 of Sunni minor and Number 7 of Ibrahim minor). Data were collected from the soil profile after the standing water disappeared from the soil surface. The data indicate that, throughout the growing season the soil moisture content, in most of the areas monitored, was maintained well within the appropriate range. For Gezira soils, the field capacity (FC) and wilting percentages (WP) are 42% and 18%, respectively. The average moisture depletion in the study area ranged from 10% to 15% in a two-week period. This means that if the soil moisture in the root zone was brought to the field capacity, the moisture content will be lowered to around 27% in two weeks which is well above the WP of 18%. The findings indicate that the possibility exists to increase the irrigation interval from the now practiced 14 days.

3.4.2.5 Crop Yield and Water Use Efficiency

The wheat crop in the Gezira Scheme is harvested mechanically by combine harvesters. Yields were estimated from the grain hopper of the combine. During the wheat harvest, it was observed that the harvesters were leaving behind a sizeable quantity of unharvested wheat, which was being collected by a large number of women and children trailing the harvesters. Though this grain ends up in the family grain basket, yet it is not reflected in the yield estimate. The unharvested yield was estimated to be around 10% of the harvested amount. The average yield of wheat in the study area was 2.0 t/ha. This is nearly double the average yield of 1.12 t/ha obtained in 1991. The reason for this higher yield can be attributed to a very good weather year coupled with a reduction in planted area (which provided adequate water) and the season experienced near optimum growing conditions. The yield, however, was still significantly lower than the potential of the variety (5.0 t/ha) as well as those obtained in the research farm. The reasons can be many, including low fertilizer uptake by the plants, weed infestation, 2-3% area of Numbers remain unplanted due to machine sowing, another 2% of high lands receiving less than adequate moisture, less than optimum plant population, loss due to shattering, other machine losses, etc.

Yield, water use efficiency (WUE) and related data have been presented in Tables 3.6 and 3.7. The WUE for wheat ranged from a low of 0.10 to 0.46 with an average of 0.26. Even the highest value obtained is significantly lower than the recommended WUE of 1, which should be achieved for sustainable and profitable wheat production. The highest yield, as well as WUE, were obtained by applying 701 mm of water in 7 irrigations with 53 days of application. The lowest WUEs were obtained in three Numbers with 842, 965 and 1380 mm depths of application (the last figure is one of the highest depths applied) in 7 irrigations, with 50 days of water delivery. The preceding analysis clearly demonstrates that both wheat and cotton have increased over the years, yet they are well below the recommended standard of 4.5 t/ha for wheat and cotton, respectively. Therefore, it is essential to review the crop production processes in the Gezira Scheme, not only to improve the WUE, but also to reduce the gap between the higher and lower performing areas.

For cotton, WUE values ranged from 0.10 to 0.20 with an average of 0.15 as compared to the recommended range of 0.40 to 0.60. The ratio between actual and potential value is 0.37 as compared to 0.32 for wheat. This indicates that cotton utilized irrigation water more effectively than wheat. The average yields and WUE for both the crops, however, continue to remain extremely low. To further improve this situation, not only the irrigation application should be matched more precisely with crop requirements, but management of the entire crop production system should be improved.

3.5 CONCLUSIONS AND RECOMMENDATIONS

1. Flow control and regulation should be strengthened by recalibrating structures, especially those at majors and below. Studies conducted by other researchers indicate that though the total volume of water entering the system is adequate to meet the crop water requirements, yet serious distributive inequity exists between different areas of the scheme, as well as in different "Numbers" of the same area, with the tail ends being universally deprived of their fair share. Determined efforts should also be made to construct flow measuring devices at the Abu Ashreen levels.

2. Due to siltation, weed growth and malfunctioning hydraulic structures, the conveyance characteristics of the canals have changed from those of the original design. Till these are restored, the system should be operated not by the strict design specifications, but by the existing conveyance conditions. That means personnel responsible should supervise the water distribution system more closely and intensively, while regulating the flow as per existing conditions, which may demand operation of the structures in ways significantly different than those prescribed in the manual. Water flowing well over/under the regulator and overtopping of the canal banks are increasingly becoming common in the scheme. At the present time, the only way to avoid this is to keep an eye on the situation and regulate the flow accordingly.

3. Though conveyance losses in the scheme are very low (< 10%), yet significant amounts of water are lost due to dead storage and overtopping of the canals. Dead storage losses quantified in the "Abu Ashreens" and "Abu Sittas" of three "Numbers" in the Pilot farm indicated losses of 1000 to 1200 m^3 per irrigation per Number. Effective ways, including manual pumping of water, should be adopted to use this water. If 75% of the 29000 "Numbers" are cropped, and an average of 8 irrigations are applied, a total volume of 210 million m^3 of water will be lost through dead storage,

which is equivalent to 40% of the average monthly supply during January, when the water requirement for wheat is the maximum and constitutes about 3.4% of the average annual release of 6100 million m^3 for the entire system.

4. Water management within the "Hawasha" is far from desirable. Two types of edge effects have been observed, both contributing to yield reduction. The high lands within the Hawasha estimated to be 5% suffer from water stress and the low lands and furrow ends from waterlogging.

   To irrigate high lands near the edges of the Abu Ashreens, the tenants raise the water level above the 'freeboard' by constructing cross dams on the Abu Ashreens. This practice reduces the gradient between the minor and Abu Ashreen that reduces flow and, depending on the duration of high-land-irrigation, tenants may lose a substantial amount of their share of water. High lands should preferably be irrigated by (a) using the water from the dead storage of Abu Ashreens and Abu Sittas, and (b) constructing deeper furrows for row crops and deeper corrugations for small grains (like wheat). For wheat, after the first irrigation, the 42 standard basins should be re-adjusted or fine-tuned following the wetting pattern of the land or the contour.

   Over/under irrigation results from a lack of knowledge about the cut-off time. Tenants use their judgement to turn off irrigation water. Some guidelines should be provided to the tenants on the duration of irrigation. They should be made aware that over-irrigation is often more harmful than under-irrigation.

5. To save irrigation water, row crops (cotton, dura, onion, etc) may be irrigated by alternate furrows (i.e., every furrow should service two rows). Alternately, if the existing method of furrow irrigation is used alternate furrows should be irrigated every time water is applied. It is estimated that upto 30% of the water can be saved without sacrificing the yield. In the 1990-91 crop season, yield trials on cotton were conducted on the Pilot farm by using the "one-furrow-service-two rows" method. There was no significant difference in yield as compared to the conventional furrow method. The study unfortunately did not consider water as a variable.

6. Limited studies conducted in June, 1992 in collaboration with ARC on moisture distribution from "naked" furrows (uncropped) indicated that moisture distribution is somewhat uniform up to about 1.5 m on both sides of the furrow when water is allowed to infiltrate for nearly 24 hrs. This opens up the possibility of irrigating upto three rows between furrows. Further studies are needed to confirm this. If successful, this would be expected to reduce the volume of water required, as well as reduce weed growth because the wetted area will be reduced.

7. Furrow irrigation practiced in the scheme is really controlled flood irrigation because the field is normally flooded by introducing the water through the furrow. This exposes the plant to prolonged and undesirable ponded water condition. This is especially injurious when the crop is in the early

stages of vegetative growth. Furrow irrigation in its true form should be practiced, except when fertilizer is applied on the ridges.

8. At present, the Abu Sittas takes too much time to convey water along their entire length of 280 m and this contributes to low application efficiency. It is, therefore, recommended that pilot studies be conducted by relocating the Abu Ashreens through the middle of the Number. This will reduce the length of the Abu Sitta by 50% and irrigation can be completed in a shorter time duration. For this, no new Abu Ashreens needs to be constructed. Half the area of the Numbers on either side of the Abu Ashreen will constitute the new Number. This new arrangement is also expected to discourage the construction of "Nacus" (unauthorized Abu Sitta) by the tenants. Some people will argue that the slope of the Gezira may not permit this practice. But, the very existence of a large number of "Nacus" nulls this hypothesis. Also, the slope is so small (5 to 10 cm per kilometer), which can be adjusted without making a major investment.

9. Investigations should also be made to assess the possibility of conveying water from the minor to the Abu Ashreens on both sides. This is being practiced in certain areas of the scheme where the slope is favorable. As has been mentioned earlier, the gentle slope of the scheme may not prove to be a major constraint. During the 1991-92 crop season, tenants of Number 12 of Sunni minor were in fact drawing water both from the Sunni and Ibrahim minors. One-third of the area was being supplied from the unauthorized Ibrahim minor. Where night storage is employed, a few hours in the mornings will be the optimum time to irrigate.

   Normally such arrangements will require resectioning of the minor. But, in the Gezira scheme, the minors also act as night storage reservoirs; hence, the minors expected to accommodate the increased volume without much difficulty. Also, if night irrigation (which is already being practiced by the tenants) is formalized, the minors will be able to carry the required capacity to serve both sides.

10. Night storage systems (NSS), introduced over half a century ago for social reasons rather than technical reasons, seem to have lost their relevance and tenants in many areas of the scheme are irrigating their hawashas at night. This practice should be encouraged and at the same time be institutionalized. This will have the following advantages:

    1. The larger volume will increase the velocity, thereby resulting in decreased sediment deposition in the minors, which at present accepts over 30% of the sediment entering the system. The sediment will be transferred to the Abu Ashreens and will be easier to manage if the responsibility for the maintenance of the Abu Ashreens are transferred to the tenants and each tenant is asked to maintain his portion of the canal. Some researchers have expressed concern that sediment diverted to the Abu Ashreens may

increase the elevation of the farm land. The 10 million m^3 of sediment entering the system every year will increase the field levels by about 1 mm in 1 year.

2. Night storage weirs will no longer be required. This will also reduce sediment deposition in the majors, which also gets 30% of the sediments carried into the system. Repair and maintenance of these structures will also be eliminated as these will no longer exist.

11. During the 1991-92 crop season, data collected from the study areas indicated that though the average plant density was near optimum, the variation was highly significant. This was especially true for wheat. Plant counts from three Numbers of the Pilot farm indicated that the average densities for wheat were 522, 490 and 648 per m^2 in Sunni Minor (Number 11), Ibrahim Minor (Number 18) and Tayba Shimal Minor (Number 2), respectively. For the same Numbers, the maximum and minimum densities were 284 and 828, 252 and 808, and 412 and 928 plants per m^2, respectively. This type of density distribution decreases yield in areas that are overcrowded and also in the sparsely populated areas. Improper adjustment of the seeder, and lack of experience on the part of the operator, are two major contributing factors. Also, observations showed that 3 to 5% of the areas in these Numbers did not have any plants at all. Agronomists from ARC and SGB should investigate and identify the exact causes for the abovementioned situations and recommend remedial measures.

12. Nearly a third of the scheme area is fallowed every year for improving soil fertility in order to increase crop yields, especially those of cotton. But the unstable trend in cotton yields over the years have negated this hypothesis. If water were made available, there is a high likelihood that the cropping intensity could be increased to 100% without further sacrificing yield. This was supported by most of the field staff. Therefore, a strong recommendation that is the potential for conjunctively using surface and ground water be pilot tested for technical feasibility, economic viability and farmers acceptance.

13. Distributive inequity was also observed at the micro-level (i.e., at the Hawasha level) in 1990-91. The soil moisture content in different parts of the same Hawasha varied more than the recommended 20%, which demonstrates the need for better distribution by improving leveling and control of water delivery.

14. Water depletion profiles computed for cotton and wheat in the 1991-92 season indicated that the soil moisture content in the effective root zone was much higher than the allowable depletion limit before the next irrigation was applied. This indicates a possibility for extension of the irrigation interval.

16. The Gezira soil is low in organic matter content (0.35 to 0.40). Higher organic matter content is expected to improve soil structure, water holding capacity, infiltration rates, etc.

In the early days, when chemical fertilizers were non-existent, nitrogen fixation by leguminous crops (dolicos lablab) and fallows in the rotation were the only ways to high soil fertility levels and ensured availability of essential nutrient for cotton (Burhan and Mansi, 1967). At the present time, despite heavy fertilization of the crops in the intensified rotation--3N as urea for cotton, 2N for Dura and 2N for wheat-- the yield of all the crops either continued to decline or showed no definite trend of increase. Therefore, to restart the use of organic manure is becoming increasingly important.

There are several cheap and abundant sources of organic matter, such as agricultural residue, animal manure (it is estimated that there are over 1.2 million animals in the scheme area and another 2 million graze through the scheme every year). The third source would be the growing of green manure crops during the lean season.

Based on the recommendation made in 1991-92, experiments have already been initiated for composting cotton residue. It will take several years before scientists can make recommendations on the amount needed per unit area (tons/ha), optimal size of the pit that can be easily constructed and maintained by the tenants, number of crops one application of organic matter will sustain, and the extent of possible reductions in the application of chemical fertilizers.

Raising a green manure crop during the fallow rotation offers a good potential for organic manuring. The best time for planting the crop would be just after the first significant rainfall of the season (> 15 mm) and biomass should be incorporated after 40-45 days. In the rice growing areas of south Asia, the rice crop preceded by a green manure crop increased yield by about 1 ton/ha and at the same time reduced the application of chemical fertilizer (N) by 50%. In the process, a total of 15 t/ ha of green biomass was incorporated into the soil. Studies should, therefore, be initiated to select suitable green manure crop(s) and the amount of biomass to be incorporated (t/ha) for increased, sustainable and economically attractive yields. In selecting the green manure crops, researchers should ascertain what kind of materials are available off-the-shelf that have relevance to the field conditions. Some new varieties of cowpeas developed at the International Institute for Tropical Agriculture (IITA) can be used for green manuring after the crops have been harvested. These are said to be good as cattle feed as well.

Determined efforts must also be made to effectively use animal manure for improving soil fertility and soil characteristics, including those affecting water movement through the soil. A good starting point would be to encourage farmers to use animal manure who very soon will be growing 50,000 fd (21000 ha) of citrus. Later, the practice could be transferred to field crops.

Though organic manuring is not generally practiced in the Gezira scheme, yet some of the progressive farmers, the ones producing the highest yields, are using all kinds of organic residues, including animal blood.

17. Studies conducted during 1990-91 and 1991-92 found that the water use efficiency (kg of yield per m^3 of water) for the major crops, cotton and wheat, are very low. In 1990-91, the water use efficiency (WUE) in three selected numbers ranged from 0.14 to 0.39 as against the recommended values of 0.80 to 1.00. In the 1991-92 season, even with a significant increase in wheat yield over 1990-91, the WUE efficiency continued to remain low and ranged from 0.10 to 0.46.

18. In 1991-92, some crops, especially wheat, were left unharvested after the crop was ready for harvest and the optimum harvest time was exceeded by a minimum of 31 days and a maximum of 52 days. This was also true in the 1990-91 season, even on the Pilot farm. To reduce shattering losses, it has been recommended that timeliness in the harvest be ensured.

19. Until 1992, the SGB was responsible for operation and maintenance of FOPs and Abu Ashreens. Responsibility has now been transferred to MOI. Like most of the distribution system, these have also departed significantly from their designed specifications. It is strongly recommended that farmers be increasingly involved in the operation and maintenance of the FOPs and Abu Ashreens. FOPs should be calibrated in such a way so that farmers are able to quantify the volume of water entering into their systems. For easy maintenance of the Abu Ashreens by the tenants, brick-lined reference sections should be constructed every 200 meters for two meter lengths throughout the entire length of the Abu Ashreens.

References

Doorenbos, J. and A.H. Kassam. 1981. Yield Response to Water. FAO Irrigation and Drainage Paper No. 33. P. 170.

Farbrother, H.G. 1979. Irrigation Practices in the Gezira. Cotton Research Corporation, London. No. 89.

Gill, H.S. and J.S. Kollar. 1981. Weed Control in Rice. Progressive Farming. Vol. XII, No. 10. Punjab Agricultural University, India. P.6.

The Herbicide Roundup. 1989. Monsanto, Europe.

Plusquellec, H. 1990. The Gezira Irrigation Scheme in Sudan: Objectives, Design, and Performance. World Bank Technical Paper No. 120.

World Bank. 1983. Sudan Gezira Rehabilitation Project. Staff Appraisal Report No. 4218. SU.

CHAPTER 4

Rotation by Minors[15] in the Gezira Scheme

Prof. Hussain S. Adam[16]

4.1 INTRODUCTION

The Gezira Scheme Irrigation System had been operated as a Night Storage System (NS) up to the mid-sixties. At that time, only cotton was catered for and when water exceeded the cotton requirements, dura (sorghum) was irrigated. The system worked very well because the operation matched the design. The cotton numbers were irrigated alternately every 14 days. The number was completely irrigated in 7 days, then the irrigation was shifted to the alternate number. The area of the number is 90 feddans. The irrigation duty is 400 m^3 per irrigation. So, the number takes 36,000 m^3 per irrigation. This amount is delivered in 7 days, so the discharge rate required is about 5000 m^3 day^{-1}, which matched the design discharge of the 35 cm diameter Field Outlet Pipe (FOP) feeding the ***Number***.

After intensification and diversification due to the introduction of groundnut and wheat, the NS system could not cope. The alternate watering of numbers did not work anymore, because more than 50% of the gross area on each minor was irrigated at the same time, which did not confirm with the design.

The major problem has been the overlap of the groundnut and wheat crops. For many years, the Sudan Gezira Board (SGB) promised that the sowing of groundnuts will end by 20 June so that water to groundnuts will be stopped by 31 October before the 1st water allocated for wheat is given. But every year, the sowing of groundnuts mostly took place in July and continued to the end of July. As a result, the watering of groundnut continued into November and some areas were irrigated up to December. This has always created a water shortage in November.

There are a number of reasons for the delay in sowing of groundnuts. One of them is the continuing argument between the SGB inspectors and the Ministry of Irrigation (MOI) engineers. The SGB claim they will start their sowing program only when they see the water in the canals, while the MOI staff respond by saying that unless they see that land preparation is finished they will not fill the canals. An additional reason is the reluctance of tenants to plant early. This may be a tradition from the rain-fed past, that they wait for the rains to break the hard cloddy soil.

---

[15] A secondary canal in Sudan.

[16] A former FAO expert.

All efforts to overcome this problem have failed so far. The objective of this paper is to suggest a rotation which will put an end to this overlap between the groundnut and wheat crops.

4.2 THE ROTATION

The simple suggestion is to separate groundnuts from wheat. The suggested rotation always puts groundnut and wheat on different minors. In the main Gezira, the tenant has his tenancies in four ***Numbers*** on the same minor. It is suggested here that he has two of his tenancies on one minor and the other two on a neighboring Minor. On one Minor, he will have sorghum as a summer crop and wheat as a winter crop. On the other Minor, there will be cotton and groundnuts in one ***Number*** and fallow and winter fodder in the other ***Number***. As sorghum has a shorter growing season, it is much easier to achieve the completion of all irrigations by 31 October. Thus the overlap problem may be solved. Such a Minor can then be easily operated under the old system with 50 % cropping. During the wheat season, there will be only one crop, which can be irrigated as cotton was irrigated in the past with alternate ***Number*** watering.

However, this system limits the areas of both sorghum and wheat to a quarter of the gross area in the main Gezira. The other Minor irrigates cotton and groundnut as summer crops and fodder as a winter crop with a fallow area. The rotation becomes: **W F S C W F S G**

4.3 ADVANTAGES OF THE NEW ROTATION

The fact that wheat follows cotton and groundnuts provides ample time for land preparation for wheat (May-Oct.). The same goes for sorghum following a fallow or a winter fodder. Similarly cotton and groundnuts follow sorghum, which again gives ample time for land preparation for cotton and groundnuts (Jan.-June).

Another advantage of this rotation is that it would be possible to dry the canals every other year. The season when only cotton, groundnuts and winter fodder are grown on a certain minor canal, the water can be stopped by the end of February and that canal can be dried for at least three months.

A third advantage is that tenants will now share two Minors and this will reduce the conflict at the Major. For example, if four Minors take off from a Major, in the past there would be four groups of tenants competing for water from that major. With the suggested rotation, there will be only two groups. The same applies to maintenance. A priority program will be easier to execute under the suggested system because a different set of crops will be grown in the two minors. The Engineer will decide on the priority depending on the crops being irrigated by each of the Minors.

4.4 DISADVANTAGES

The disadvantages are that tenants will have to work on two Minors. Accessibility to the tenancies for the tenants and their laborers will be more difficult, especially for those who are settled on the present tenancies.

The rotation is not that recommended by Agricultural Research Corporation (ARC). However, the alternatives should be weighted. In the last years, water has always been the most important single factor affecting the yields of crops. If the suggested system solves the irrigation problems, the other problems arising from its adoption could also be solved.

4.5 RECOMMENDATIONS

This paper invites the irrigation engineers, the SGB staff, the research workers from ARC, and the tenants Union to consider this suggested rotation. Then, it may be tried in one block where four minors take off from the major and see how the water management is affected by the new rotation.

A committee from the SGB, MOI and ARC should be formed to study the suggested rotation in detail and develop a sound recommendation that weighs very carefully the advantages and disadvantages of the suggested rotation.

CHAPTER 5

Water Availability and Cropping Pattern in the Gezira Scheme

Omer Mohd. Ahmed Elawad[17]

5.1 Water Availability from the Blue Nile

The Blue Nile is the source of irrigation water for the 2.1 million feddans of the Gezira scheme and some other 0.8 million feddans or so in other existing schemes. The present average annual consumption of irrigation water by these schemes is around 8.8 milliards cubic meters (Table 5.1). In addition to this, the Blue Nile flow is used for hydro-power generation and for drinking water supplies.

Table 5.1. Existing schemes irrigated from the Blue Nile.

Schemes	Gross Area 1000 Feddans	Cropped Area 1000 Feddans	Water Use 10^3 m^3
Gezira	2080	1600	5540
Rahad	300	304	1100
Suki	90	85	250
Gunaid	38	24	255
N.W. Sennar	32	36	355
Abu Na'ama	30	42	10
Blue Nile Schemes	235	162	540
Private (U/S Sennar)	25	22	230
Private (D/S Sennar)	55	52	512
Total	2885	2327	8792

[17]Senior Engineer, Hydraulic Research Station, Wad Medani.

In spite of the fact that the present water consumption constitutes only around 18% of the average annual river yield of 49.2 milliard cubic meters, it is still water and not land which limits the expansion of the area irrigated from the Blue Nile. The reason for this is the lack of the required storage facilities that would allow a higher exploitation of the river flows.

The Blue Nile is characterized by a marked seasonality in its flow pattern. Of its 49.2 milliard cubic meters, 80% occurs in the four months from July to October and only 10% occurs in the seven months from December to June. The seasonality of the Blue Nile flow pattern has created a situation whereby the natural flow by far exceeds the water demand during the flood months from July to October and falls short from December to May. The primary objective of the two storage reservoirs constructed on the Blue Nile at Sennar and Roseires was to help in smoothing out the river flow pattern by storing some of the flood flows to supplement the natural flow during the low-flow months.

The present combined storage capacity of the two reservoirs is 2.62 milliards cubic meters (2.20 at Roseires and 0.42 at Sennar). Although this constitutes only 5.3% of the natural river flows, it contributes some 30% of the irrigation water demands on the Blue Nile. This limited storage facility is a major factor in determining the areas which can be placed under cultivation during the river low-flow period from November onwards.

The two reservoirs are usually kept at their minimum level during the flood season to allow the heavy silt laden flood water to pass downstream. Filling of the reservoirs is usually carried out during September and October. Abstraction from the reservoirs usually starts in late November or early December. The reservoirs contents are used to supplement the natural flows in satisfying the irrigation and other demands (such as hydro-power generation and maintaining a minimum flow downstream of Sennar) in such a way that the reservoirs contents are not to be exhausted before 10 June, the time by which the flood of the next year will start. The exact date of the start of filling and abstraction from the two reservoirs varies from one year to the other, depending on the flood magnitude and the rate at which the river is falling after the flood.

5.2 Water Availability for the Gezira Scheme

With the present cropping calendar, the irrigation season in the Gezira scheme starts by the beginning of June and continues to the end of March. During April and May, irrigation demands are small and canals are virtually closed for annual maintenance.

During the first 10-day period of June, the river flood will have usually started and some water could be made available for irrigation in the Gezira and other schemes. Preliminary analysis indicates that during 90% of the years, up to 15 million cubic meters per day can be made available for the Gezira scheme.

From the second 10-day period of June to late-November/early December (when abstraction from reservoirs starts), the river natural flow usually exceeds the water demands for all purposes. During this period, water is diverted to the scheme as run-of-the-river. The maximum amount which can be diverted is determined by the combined carrying capacity of its twin main canals. At present, this is equal to 31.05 million cubic meters per day (14.52 in the Gezira old canal and 16.53 in the Managil new canal). However, during June, July, August, and sometimes early September, because the water level in the Sennar Reservoir is kept at its minimum level, the maximum discharge which can be passed into the headworks of the main canals is limited to 25 million cubic meters per day. From late September and onwards, the water level in the reservoir will be raised. This will enable the full main canals carrying capacity of 31.05 million cubic meters per day being diverted.

From mid-November/early-December, the river natural flow falls below the water demands and abstraction from the storage reservoirs is usually started. The Gezira Scheme has to compete with other schemes and other water uses in the available water resource. The water available for the Gezira Scheme then depends on the expected river flows, storage volume, and the competition from other uses during the particular season. Preliminary analysis using the present demand pattern indicated that in 80% of the years it is possible to make available 31.05 millions cubic meters per day for the Gezira scheme until the end of January, 25 millions per day throughout February and then 21, 15 and 10 millions per day during the first, second and third 10-day periods of March.

To operate the hydro-power facilities of the Roseires Dam during April and May a minimum of 17 million cubic meters per day have to be discharged. Preliminary analysis indicated that, after satisfying the minimum flow requirements downstream from Sennar Dam and N.W. Sennar Sugar and other small private schemes, some 5 million cubic meters per day could be made available for the Gezira Scheme.

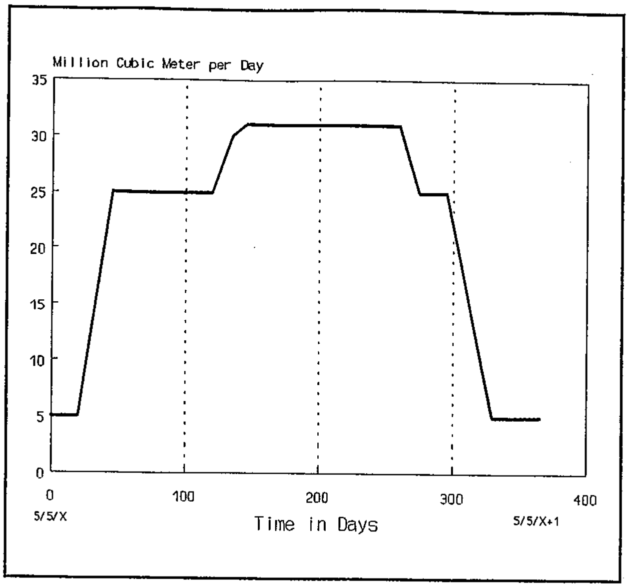
The above account shows that the water availability for the Gezira scheme can be taken to be as shown in Figure 5.1 and Table 5.2 in four out of five years.

The heightening of the Roseires Dam is expected to make available additional water for the period from February to early June if required.

Table 5.2. Water availability for the Gezira Scheme in million cubic meters per day.

Month period	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1st	15	25	25	25	31	31	31	31	25	21	5	5
2nd	25	25	25	25	31	31	31	31	25	15	5	5
3rd	25	25	25	30	31	31	31	31	25	10	5	5

Figure 5.1. Water availability pattern for the Gezira Scheme.



5.3 Water Use in the Gezira Scheme

5.3.1 Calculations of the Scheme Water Use

To calculate the water use in the Gezira Scheme, a micro-computer based model was prepared in Lotus-123. The model calculates the crop water demands of the scheme for each 10-day period throughout the year. The idea was to use the model for planning purposes at the scheme-wide level. The same model can be used at the major or minor level for the same purpose.

The use of the model does not require a knowledge of computers. The user needs only to input the area for each crop and the model automatically calculates and plots the pattern of water demand variation with time throughout the year. In addition, the model calculates the following: (i) total seasonal demand; (ii) abstraction from the storage reservoirs; and (iii) abstraction during the heavily silt laden flow (This is the period from July 10, to August 20. Abstraction in this period is particularly undesirable as, on average, 65% of the silt entering the scheme is diverted during this period).

The model described above was used for calculating the water use pattern for three scenarios of cropping patterns and intensities. The next subsections show the results and compare the water use pattern with the water availability.

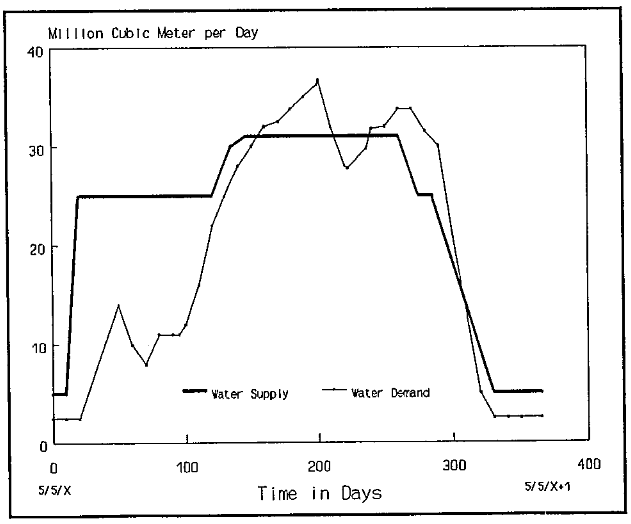
5.3.2 Last 4-Course Rotation

The last 4-course rotation (3-course rotation in the Managil extension) was adopted in the scheme in the 1975/76 season. The design cropping pattern and intensity for the whole scheme was as follows:

ELS Cotton	608333 feds.
Wheat	608333 feds.
Dura	304167 feds.
Ground Nut	304167 feds.

Figure 5.2 shows a comparison between the water availability and demand patterns. Clearly, the water demand exceeds the water availability for a large part of the irrigation season. In fact, the designed cropping pattern and intensity had never been achieved in the 15 years during which the rotation was adopted. Areas for all crops fluctuated considerably below their potential, with the exception of dura (sorghum), which in some years exceeded its design area.

Figure 5.2. Water supply and demand pattern based on 4-course rotation.



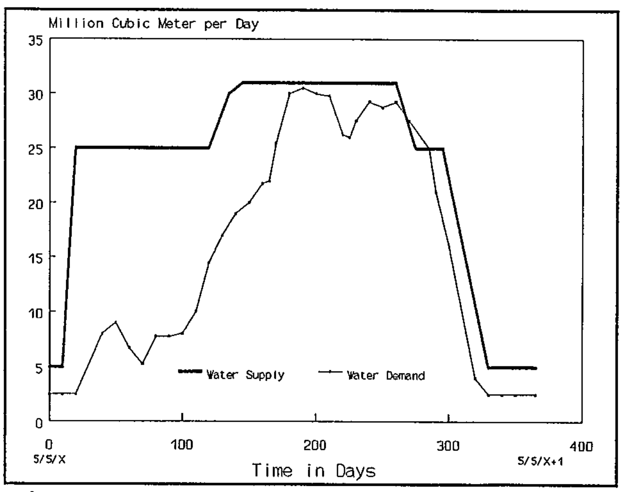
5.3.3 Original Proposed 5- Course Rotation

The original proposed 5-Course rotation was as follows:

ELS Cotton	420000 feds.
Wheat	420000 feds.
Dura	185000 feds.
Ground Nut	185000 feds.
Rot. Gardens	50000 feds.
Mixed fodder	210000 feds.
Serial Fodder	210000 feds.

Figure 5.3 depicts the relationship between water demand and availability. Clearly, the match is better than the previous 4-course rotation with demand exceeding supply in only one decade in the first period of February. However, there is a large quantity of water unused during the first half of the season.

Figure 5.3. Water supply and demand pattern based on the original 5-course rotation.



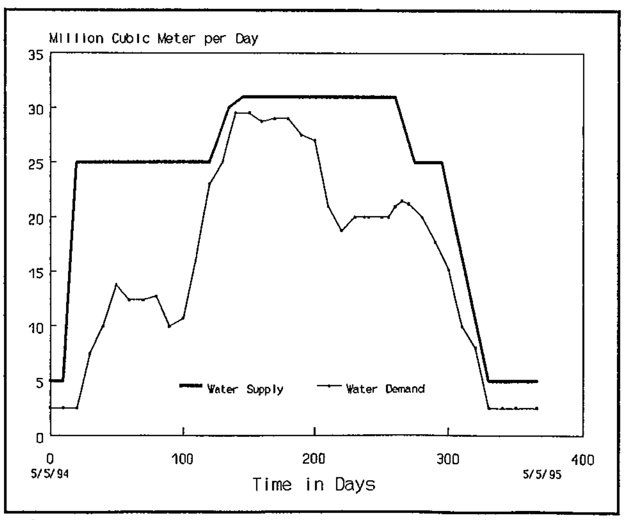
5.3.4 The Proposed 1994/95 Season Pattern

For various reasons, the originally proposed 5-course rotation was not adopted as designed during the last few seasons. The proposed 1994/95 season cropping pattern is as follows:

ELS Cotton	100000 feds.
MS Cotton	192995 feds.
Dura	425717 feds.
Ground Nut	228952 feds.
Wheat	500000 feds.
Sun Flour	10000 feds.
Rot. Gardens	50880 feds.

Officials of the agricultural administration of the scheme indicated that the cropping pattern in the scheme will follow this norm at least in the foreseeable future. Figure 5.4 shows the water demand and availability patterns for this season. The match is clearly better than in the originally proposed 5-course rotation. However, there is still a large quantity of available water unused during July and August and again during December and January. In practice, the unused excess water in July and August is reflected in the large areas which are usually unofficially cultivated with dura and irrigated using the scheme water. The December - January excess is reflected in the large quantity of water usually drained during this part of the season.

Figure 5.4. Water supply and demand pattern under the new 5-course rotation.



CHAPTER 6

Crop Rotational Challenge of Change in the Gezira

Dr. Mohamed Gamer El Deen el Khateeb[18]

6.1 INTRODUCTION

Throughout the history of the Gezira Scheme, the utilization of land and water to produce rotational crops has witnessed profound changes that ranged from the adoption of simple and open rotations to more complex and diversified ones. Several factors and objectives were considered, which include the following:

1. Control of pests, diseases and weeds;
2. Restoration of soil fertility;
3. Maximum utilization of land;
4. Maximum utilization of water;
5. Diversification of crops;
6. Integration of livestock; and
7. Increasing the tenants income.

To comply with set of plans and targeted objectives, the rotation observed over time has both various shapes and crop intensities, which are summarized as follows for the different periods:

1) 1925/26 - 1930/31
   A six course rotation with 66.6% cropping intensity
   Cotton, Dura/Lubia, Fallow, Cotton, Dura/Lubia, Fallow

2) 1931/32 - 1932/33
   A six course rotation with 33.3% cropping intensity
   Cotton, Fallow, Fallow, Cotton, Fallow, Fallow.

3) 1933/34 - 1960/61
   An eight course rotation with 50% cropping intensity
   Cotton, Fallow, Dura, F/Lubia, Fallow, Cotton, Fallow, Fallow.

[18] Senior official of the Sudan Gezira Board.

4) 1961/62 - 1974/75
An eight course rotation with 75% cropping intensity
Cotton, Wheat, Fallow, Cotton, Lubia, G/Nuts/Dura, Dura, Fallow

5) 1975/76 - 1990/91
A four course rotation with 86% cropping intensity for Gezira, and Managil 100%

6) 1991/1992
A 5 course rotation with 80% cropping intensity
Cotton, Wheat, G.Nuts/Dura, Fodder, Fallow.

A comparison between the 3, 4, and 5 course rotations is shown in Table 6.1.

Since the establishment of the Managil Scheme, a 3 course rotation was adopted with 100% cropping intensity; while the Gezira followed a 4 course rotation with 75% cropping intensity, with the whole cropping intensity being 86%.

Due to the deterioration of land productivity in Managil, a comparison with the Gezira 4 course rotation was thought to be suitable to relieve the land and also water utilization to match with Gezira. Hence, the crop intensity has dropped to 75% for the whole scheme.

The change to a 4 course rotation did not achieve its targeted goals. This is mainly due to various agro, socio-economical problems, and other factors namely:

1. The decline in the relative importance of cotton;
2. The drought conditions during the eighties;
3. The growing demand for animal production has stimulated the tenants to care more for their animals; and
4. The attention of the Government to food crops and the slogan of self-sufficiency became a major political aim.

These factors led to the adoption of the 5 course rotation and its implementation faster than originally planned. This was a sound solution for the critical situation that faced agricultural production in the Gezira. The main worries expressed by the concerned parties was that the 5-course rotation might create problems regarding water supply, weeds and cropping pattern.

6.2 IRRIGATION AND ROTATIONAL CROPPING

The irrigation system of the Gezira scheme, with its 30 million cubic meters per day canal capacity, is designed to supply water at one time for 50% of a gross area of 2.12 million acres to which 1.16 is located in the old Gezira and 0.96 in the Managil extension.

To ensure the timely and adequate delivery of water to the field crops, certain negations, measures and practices need to be strictly adhered to for the proper operation of the system and the normal growth and development of the crops. These include:

1. A balanced rotation of crops which is well distributed in time and space;

2. As the system is designed for night-storage, water should be allowed into the fields during the day hours so that a commendable storage level is built during the night;

3. The sowing dates and field operations schedules should be adhered to and programmed to allow for the termination of the irrigation cycle for summer crops by the end of October in order to avoid the competition between crops when water demand is at its peak;

4. The CWR is calculated at 30 cubic meters per feddan per day, which amounts to 420 cubic meters per feddan fortnightly and this should govern the organization of the indenting system; and

5. The F.O.P. are designed to deliver 5000 cubic meters of water per day, which is sufficient to irrigate 12 acres per day and a crop number of 90 acres in 7.5 days. Accordingly, the on and off of the FOP should be organized to match the 14-day irrigation cycle.

Theoretically, the design should perform in a satisfactory way, but the various and continuous agro, socio, economic and institutional problems, and constraints that prevailed and accumulated over the years, led to a reasonable decline in the water use efficiency in the cropping intensity and in the land productivity. The impact of this on the 5-course rotation, which is now under implementation, will be dealt with by comparing the land utilization and water requirements for the 3,4 and 5-course rotations adopted in the schemes and a similar comparison for 5 scenarios of the 5-course rotation

A comparison between the land utilization and water requirement for the three rotational regimes (Table 6.1) gives:

1. Managil 3 course + Gezira 4 Course rotations with a cropping intensity of 86%.

2. The scheme 4 course rotation with a cropping intensity of 75%.

To improve productivity, the cropping intensity has been decreased from 86% to 75%. As land utilization was decreased, water requirements also decreased.

6.3 THE FIVE COURSE ROTATION

The five course rotation will increase the cropping intensity from 75% to 80% in the whole scheme. This will increase the water requirement inevitably, as the land utility has increased by 5%, so the scheme increase from 1.59 to 1.69 million feddans.

The fodder crop may be adjusted from fully grown in summer, or having half grown in the summer and another half during winter.

The water requirements are always based on the full utilization of 50% of the gross area. This is not what is happening as Table 6.2 shows that the cropping intensity in actuality is less than the attainable intensity. An increase in cropping intensity is only possible with increased areas of a crop like sorghum, a summer crop which is dependent on rainfall rather than irrigation water for its development. From this, a conclusion may be considered that the 5 course rotation will not necessarily worsen the situation; on the contrary it might improve (or likely to improve) the extent of land utilization. This depends mainly on the size of the fodder area and its sowing date, as well as the length of the crop period. Scenarios are many that could be utilized for the success of the 5 course rotation.

6.4 RECOMMENDATIONS

1. With the recent implementation of the 5-course rotation, close and intensive coordination is needed between ARC, SGB and the MOI to improve water use efficiency.

2. Since the proper adoption of the 5-course rotation by the tenants will be slow and erratic, feedback from the field administration is essential for the final evaluation of the experience and for future plans.

3. ARC and SGB should work together to establish a system in which the types and areas of fodder crops and their sowing and harvest times are clearly specified and adhered to.

4. There is always a need for training to improve knowledge and create the general awareness among field inspectors, and irrigation engineers about the impact of water on crops and vice versa.

5. Since farmers generally compete for water, rather than cooperate, training at this level is of paramount importance for the benefit of the whole system.

6. Extension and the media should concentrate at this stage on acquainting the end users about the appropriate water management aspects and its benefits for them.

7. As the failure or success of any system is determined by the available resources and facilities, special attention should be given to this area regarding SGB, MOI and ARC staff.

Table 6.1. Land and Water Utilization Under 3 Rotational Regimes Area in '000 acres.

	COTTON	WHEAT	GN/ DURA	FODDER	FALLOW	SUM	WIN.	LAND USED	GROSS AREA	% INTENSITY
1. GEZIRA 4-COURSE + MANAGIL 3-COURSE ROTATIONS										
GEZIRA	290	290	290	-	290	580	580	870	1160	75
MANAG.	320	320	320	-	-	640	640	960	960	100
SCHEME	610	610	610	-	290	1220	1220	1830	2120	86
2. SCHEME 4-COURSE ROTATION										
GEZIRA	290	290	290	-	290	580	580	870	1160	75
MANAG.	240	240	240	-	240	480	480	720	960	75
SCHEME	530	530	530	-	530	1060	1060	1590	2120	75
3. SCHEME 5-COURSE ROTATION										
GEZIRA	232	232	232	232	232	696	464	928	1160	80
MANAG.	192	192	192	192	192	576	384	768	960	80
SCHEME	424	424	424	424	424	1272	848	1696	2120	80

Table 6.2. The Five Course Rotation Production Scenarios Area in '000 Acres.

SCEN.	COTTON	WHEAT	G/NUT	FODDER		FALLOW	SEASON		LAND USED	GROSS AREA	% INTEN SITY
				SUM	WIN.		SUM	WIN.			
1	424	424	424	212	-	424	1060	848	1484	2120	70
2	424	424	424	-	212	424	848	1060	1484	2120	70
3	424	424	424	424	-	424	1272	848	1696	2120	80
4	424	424	424	-	424	424	848	1272	1696	2120	80
5	424	424	424	424	424	424	1272	1272	1696	2120	80

CHAPTER 7

The Macro-Economic Perspectives of the Crop Development Systems in the Gezira Scheme

Dr. M. A. A. Dingle[19]

7.1 INTRODUCTION

7.1.1 The Setting

Agriculture in Sudan falls into three distinct modes; irrigated, mechanized rain-fed and traditional rain-fed. Closely with these modes there is a development of wide-scale traditional livestock raising. With about 4.3 million feddans (1.8 million hectares) under irrigation, the country has the largest irrigated area in Sub-Saharan Africa. Out of this area under the prevailing crop rotations, about 3.5 million feddans, (1.5 million hectare) is grown annually representing about 14% of the total cropped area under the three farming modes.

The main crops grown in the irrigated Sub-Sector are cotton, sorghum, groundnut and wheat, while the major products in both the mechanized and traditional rain-fed areas are sorghum and sesame. In 1991/92, the irrigated areas represented 11.1% of the cereals area, 4.7% of the oilseeds area, 79.2% of the cotton area, and the entire area grown by vegetables, fruits, legume fodder and pulses, (Appendix 1). Irrigated agriculture in Sudan is still considered as an area of emphasis in the strategy for agricultural development to satisfy both food security and export promotion goals.

Further expansion is thus expected in order to use an additional four million cubic meters of water per day (the remaining portion of the water-sharing agreement with Egypt) to develop one million feddans (0.42 million hectare). Other plans towards more diversified and intensified agriculture are part of the agricultural development strategy.

---

[19]Senior Agricultural Economist, IIMI-SUDAN.

7.1.2 The Organization of the Irrigated Schemes

Most of the irrigation schemes were developed under public control. They follow a standardized organizational system giving the Ministry of Irrigation (MOI) the responsibility of the construction,, operation and maintenance of the irrigation facilities, while entrusting the agricultural corporations with the agricultural activities. In each scheme, the management has to keep an individual account for each tenant against which the cost of inputs and services, including the irrigation fees, have to be charged. This system was introduced in replacement of the joint account system based on share-cropping arrangements between the Government and the tenants governing the production of cotton.

By this change in the production relationship, the Government shifted from being a partner sharing costs and revenue of the cotton crop to the position of an owner of an irrigation system collecting only fees for land and water use. In spite of this change in the Government role, the organizational system remained unchanged. The new circumstances encouraged relaxation of applying the rules of order and discipline designed to control land and water use. The rules identify the responsibilities and functions of the different partners in the scheme. They help in implementing the crop production plans under the suggested rotations.

7.1.3 The Cropping Pattern and Water Utilization

The area planted during any season is related to a cropping rotation which is still determined by the scheme management according to the recommendations of the Agricultural Research Corporation (ARC). The management is to formulate an annual working plan to facilitate input availability and assure the delivery of services in a timely manner. It has to pursue the financial related matters and maintain good relationship between the tenants and the financing and marketing agencies.

Watering practices in these schemes follow the requirements of the crop rotations. Both MOI and the Corporation meet at the beginning of each season to discuss the cropping plans and approve its water requirements. Based on the sowing and harvesting dates of each crop, the appropriate watering schedules will be designed. MOI engineers are responsible for setting of the water balances in relation to indents presented by the block inspectors of the Corporation. These indents are based in the requirement of the numbers under crops (a number is a rectangular ninety-feddan field bounded by two minor canals and two channels "**Abu Ishreen**"). Each number is divided into smaller parts watered from a tiny ditch **"Abu Sitta"** that takes water from an **"Abu Ishreen"**. Tenants were laid down in each number as narrow rectangular plots parallel to a minor canal.

7.1.4 The Gezira Scheme and the Decision-Making Process

One-half of Sudan's total irrigated area is in the Gezira Scheme. That is why the scheme is playing a key role in Sudan's economy. It produces 65% of the cotton, 12% of sorghum, 25% of groundnut and 65% of wheat.

Cotton production in the Gezira continues as the main export crop, giving the country a considerable portion of its foreign exchange earnings. The crop occupied 25% of the area in Gezira main (1.2 million feddan) when it was operating at 50% cropping intensity since 1930s till the implementation of the diversification policies at the beginning of the 1960s. The cropping intensity was increased to 67% and the cotton continued to occupy 25% of the area. During this period, the Managil extension (0.9 million feddan) and because of 100% cropping intensity, cotton used to occupy 33% of the area. Later, at the end of the 1980s, Managil also adopted a 75% cropping intensity and cotton started to occupy 25% of the area.

Only at the beginning of the 1990s, and after the change in the cropping intensity (70 -80%), the cotton crop occupied only 20% of the area, at best, both in Gezira and Managil. The cropping intensity, as assessed from the beginning of the 1980s, follows the changes in the crop rotations in Gezira and Managil as follows:

Gezira Main Rotations

(1)	Cotton	Wheat	(Sorghum	G/nut)	Fallow	
	25%	25%	12.5%	12.5%	25%	
(2)	Cotton	Wheat	(Sorghum	G/nut)	Fodder	Fallow
	20%	20%	(10%	10%)	20%	20%
(3)	Cotton	Wheat	(Sorghum	G/nut)	(Fodder Fallow)	Fallow
	20%	20%	(10%	10%)	(10% 10%)	20%

Managil Rotations

(1)	Cotton	Wheat	(Sorghum	G/nut)		
	33%	33%	(17%	17%)		
(2)	Cotton	Wheat	(Sorghum	G/nut)	Fallow	
	25%	25%	12.5%	12.5%	25%	
(2)	Cotton	Wheat	(Sorghum	G/nut)	Fodder	Fallow
	20%	20%	(10%	10%)	20%	20%
(3)	Cotton	Wheat	(Sorghum	G/nut)	(Fodder Fallow)	Fallow
	20%	20%	(10%	10%)	(10% 10%)	20%

Each crop, in each of the above crop rotations, has a different yield target. Based on the target areas during the season, the production programs are to be formulated. On the other hand, each crop has a different combination of inputs. The aggregate of these combinations represents the set of a consumption program for a particular rotation in a particular season. These combinations of inputs are developed within different production technologies for the different crops. Based on the latest technical package developed and recommended by the researchers, a set of organizational programs are to be initiated and implemented for the annual operations to start.

The actual outlay of these production, consumption and organizational programs shape the decision-making process within the system. The policy maker should draw the incentives and dis-incentives structures in which these systems can work successfully to achieve the overall objectives of the economic development strategy. The planner in his capacity, guided by the macro-economic indicators, should know the contribution of the system to economic growth (mainly the effects on income generation and employment).

7.2 THE OBJECTIVE AND THE SIGNIFICANCE OF THE STUDY

Since the diversification and intensification policies have been introduced in the Gezira at the beginning of the 1960s, and reached the peak in the mid 1970s and thereafter, many diagnostic efforts were directed towards assessing their impact on the production and income levels. Although they were useful in providing the inherent basic facts about the system, they fell short in putting a focus on the macro-economic perspectives of the crop development systems in this major irrigated scheme. Although the materials available to the researcher might not help in elaborating on this issue, the significance of this study is to reach some findings towards this goal. So, the objective of the study will be to examine the crop development systems of the scheme during the period 1980/81 to 1993/94. To be more specific, it will highlight the distribution related effects of costs and benefits of the main crops-- cotton, wheat, sorghum and ground-nuts-- and examine the services of the agricultural growth. At the end, it will help in bringing some realistic measures that will include efficiency in resources use, improve the tenant's income and the system viability.

7.3 THE GEZIRA CROP DEVELOPMENT SYSTEMS

7.3.1 The Factors Affecting the Decision-Making Process

Recognizing that the land and water resources are common goods to be collectively utilized by the tenants in the Gezira Scheme, the starting point will be to understand how the local capacities, including tenants and public management agencies, are managing these resources.

During the thirteen years that followed the change in the production relationship in 1981/82, tenants became more aware of risk evasiveness and continued in suing their bargaining position for changing the cropping plans. The factors behind this behavior could be due to poor harvest of one or more crops in the last season, or due a to increased input expenses, or the overall price movements that increase household consumption and reduce their savings.

Researchers are worried from the slow adoption of the recommended technical packages, as well as the accompanying fluctuation in the yields. In some cases, they express their dissatisfaction with the limited funds committed to research and the discouraging low salary scale.

Managers are forced, in many cases, to implement programs they did not formulate and expand their duties beyond the available means. They also feel that they are underpaid. Equally frustrated are the staff of the irrigation agency; being a government department, it is tied with strict rules and regulations while Its finance position is determined and controlled by the Ministry of Finance. Within its jurisdiction to supply water, it could be trapped in a situation of uncertainty, whether the budget allocations will not meet the requirements.

The government in its turn is often pushed to fight many evils at the same time; the prolonged state of unrest in southern Sudan, the repeated occurrence of drought, the continued budgetary and trade deficits, and trying to restructure the economy within this status of instability.

With an understanding of the above features, the economic decision framework under which the Gezira scheme is operating is the result of the interaction of many factors. There are roughly 42 thousand tenants in the Gezira main and 60 thousand tenants in the Managil extension. The standard tenancy in the Gezira main is 40 feddans, but what is prevailing is mostly half this size. In the Managil, the standard size is 15 feddan. According to the crop rotation, the tenants are placed in equal plots at different numbers (90 feddan rectangular plots) i.e. three numbers for three course rotation, four numbers for four course rotation, etc..

The crop calendars and irrigation schedules are as follows:

		Sowing	Irrigation Schedule (400 m^3 every 14 days)
Cotton	M.S	15 July - 31 July	12 irrigation.
Cotton	L.S	End July - 10 August	15 irrigation.
Sorghum		01 July - 15 July	4 irrigation.
G/nut		End April - Early June	10 irrigation.
Wheat		Mid October - End Nov.	8 irrigation.

In practice, there are certain rules which are to be followed for irrigation management in the Gezira scheme. These rules are based on the fact that water released at the headworks of Sennar Dam and conveyed in the main canals of the Gezira and Managil are adequate for crops grown in half of the area of the Gezira system. The boundaries of the responsibilities and functions are as follows:

a) Crop water requirements are based on the recommendations of the Agricultural Research Corporation (ARC).

b) The actual field requirements are based on indents prepared by SGB.

c) The authorized releases are organized by the Gezira Irrigation Operation of MOI.

d) The actual deliveries from the minor canals are controlled by SGB water gaffirs under the supervision of field inspectors who inform the tenants by the time of deliveries to attend their fields.

At the beginning of each season, the cropping plan is approved by the Ministry of Agriculture (MOA), the SGB and MOI determine the crops water requirements. SGB will further look on managing other resources expressed as capital and labor requirements, specially for the cotton and wheat development programs. The magnitude of these two programs and their requirements continued throughout the study period to be decided by the Government and imposed on the system, in spite of the policies and programs pursued towards the liberalization of the economy.

To follow any of the crop development programs, each tenant will be entitled to a package of inputs and services delivered by the scheme management. The only area that is left to the tenants decision is the hiring of labor required for some farm activities.

7.3.2 The Change in the Crop Development Components

A. The Change in the Cropped Land and Productivity

The cropped area and land use intensity in the Gezira for the period 1981/82 - 1993/94 is shown in Appendix 2. Land use intensity varies from 53% in 1983/85 to 75% in 1991/92. The contribution of each crop, as a percentage of the cropping pattern in each year, is calculated in Table 7.1. The continuous reduction in the cotton area and the steady increase in the area of both wheat and sorghum, explain the tendencies towards food security.

To analyze the data on the crop development systems, the period is divided into four segments, with the initial period 1981/82 -1983/84 taken as base period. For comparison, the trend factors were established for area, yield and production in Tables 7.1, 7.2, 7.3, and 7.4, respectively.

Table 7.1. The cropping pattern (%) in the Gezira during 1981-94.

Year	Cotton	Wheat	G/nut	Sorghum	Vegetables	Fod. & oth.
81/82	32.3	19.9	19.6	25.5	2.7	
82/83	42.6	13.7	13.0	28.2	2.5	
83/84	37.0	19.7	10.1	30.5	2.7	
84/85	41.4	-	18.9	37.4	2.3	
85/86	29.6	17.9	7.6	42.7	2.2	
86/87	33.8	14.6	12.3	36.4	2.9	
87/88	31.3	20.6	13.0	31.8	3.3	
88/89	32.1	21.7	8.8	33.8	3.6	
89/90	27.0	29.6	6.0	33.2	4.2	
90/91	17.0	41.7	2.7	34.4	4.2	
91/92	13.6	33.5	2.2	44.6	2.8	3.3
92/93	11.5	33.7	10.7	40.7	3.2	0.2
93/94	10.4	35.9	12.8	37.5	3.0	0.4

Source: Calculated from Appendix 2.

Table 7.2. The crop areas in the Gezira Scheme.

PERIOD	COTTON		WHEAT		G/NUT		SORGHUM		VEGETABLE		TOTAL LAND-USE	
	Ave Area	Trend Factor	Ave Area	Trend Factor	Ave Area	Trend Factor	Ave Area	Trend Factor	Ave Area	Trend Factor	Ave Area	Trend Factor
81/82-83/84	472453	1.00	229742	1.00	183013	1.00	358543	1.00	33425	1.00	1227175	1.00
84/85-86/87	426798	0.90	211183	0.92	155481	0.85	482275	1.34	30584	0.92	1235927	1.01
87/88-89/90	381842	0.81	306286	1.33	116652	0.64	449253	1.17	47508	1.42	1271641	1.04
90/91-93/94	198267	0.42	545757	2.38	106469	0.58	596320	1.66	49644	1.49	1511347	1.23

Source: Calculated from Appendix 2.

Table 7.3. The crop yields in the Gezira Scheme.

PERIOD	COTTON		WHEAT		G/NUT		SORGHUM	
	Av. Yield Ka/Fed	Trend Factor	Avr Yield Ton/Fed	Trend Factor	Avr Yield Ton/Fed	Trend Factor	Avr Yield Ton/Fed	Trend Factor
81/82-83/84	4.53	1.00	0.436	1.00	0.48	1.00	0.392	1.00
84/85-86/87	4.50	0.99	0.423	0.97	0.55	1.15	0.433	1.10
87/88-89/90	4.63	1.02	0.564	1.29	0.58	1.21	0.451	1.15
90/91-93/94	4.33	0.96	0.600	1.37	0.77	1.60	0.690	1.76

Table 7.4. The crop production in the Gezira Scheme.

PERIOD	COTTON		WHEAT		G/NUT		SORGHUM	
	Avr Yield Ka	Trend Factor	Avr Yield Ton	Trend Factor	Avr Yield Ton	Trend Factor	Avr Yield Ton	Trend Factor
81/82-83/84	2130528	1.00	100397	1.00	87846	1.00	140549	1.00
84/85-86/87	1930012	0.91	89330	0.89	85515	0.97	208825	1.49
87/88-89/90	1765966	0.83	172745	1.72	67658	0.77	202613	1.44
90/91-93/94	663190	0.41	327454	3.26	81981	0.93	411461	2.93

B. *The Change in the Foreign Exchange Requirement*

The two crop development programs that rely heavily on imported inputs are the cotton and wheat programs. Based on the 1992/93 prices, and the technical coefficients in Appendix 7, the overall foreign exchange requirements were calculated for both the initial period (1981/82 - 1983/84) and the final period (1990/91 - 1993/94). The estimates are as follows:

	The Cotton Program	**The Wheat Program**	**The two programs**
	F. E. Requirement (US $ 000)	F. E. Requirement (US $ 000)	F. E. Requirement (US $ 000)
Initial period	55325	12888	68213
Final period	23236	30616	53852

C. *The Change in the Demand for Water*

Using the crop water requirements shown in Appendix (8), the total water demand was calculated as an average for each period (Table 7.5). The general trend gives a slight increase in the final period, while it stayed at the same level in the other periods. If the total demand is compared to total supply, expressed as annual releases from Sennar Dam (Appendix 9) at a conveyance efficiency of 87%, the overall water balance looks satisfactory.

Table 7.5. The changes in the demand for water (000 m^3).

Period	Cotton	Wheat	G/Nut	Sorghum	Vegetable	Total	Trend Factor
81/82-83/84	2124000	586790	750849	1101053	318813	4863505	1.00
84/85-86/87	1921500	521803	636585	1478294	299491	4857673	1.00
87/88-89/90	1719000	756738	480051	1377083	463728	4796600	0.99
90/91-93/94	891000	1351896	434918	1827932	483050	4988856	1.03

D. The Changes in the Demand for Labor

If the farm business coefficients are used as shown in Appendix (10), the demand for labor estimates for each crop, and the total demand, then Table 7.6 shows a steady reduction in the use of labor with changes in cropping pattern during the studied period. An overall reduction of 22% is detected in the final period (equivalent to more than fifty thousand job opportunities calculated at an annual rate of 200 man-days for each hired individual). This reduction is attributed mainly to the reduction in the cotton areas. Of course, the implications will go also to other sectors if it is taken into consideration that the cotton sector used to absorb almost 15% of the total labor force in its various activities.

Table 7.6. The changes in the demand for labor (000 Man-Days).

Period	Cotton	Wheat	G/Nut	Sorghum	Total	Trend Factor
81/82-83/84	30680	1495	8912	11739	52876	1.00
84/85-86/87	27755	1372	7549	15761	52437	0.99
87/88-89/90	24830	1989	5698	14682	47199	0.89
90/91-93/94	12870	3549	5162	19489	41070	1.78

7.4 CROP COSTS AND BENEFITS

Efficient and widespread income generation is the most important role of the economy. Therefore, the important issue resulting from growing a crop is the size of the income stream that is realized. It is very important to have favorable macro-environments in which the micro-decisions are to be made. In other words, one can say that the macro policies condition the structure of crop costs and benefits.

After assessing the changes in the crop development components in the preceding section, the costs and benefits of the initial period 1981/82 -1983/84 with the final period 1990/91 - 1993/94 can be compared as shown in Table 7.7 and Table 7.8.

Table 7.7. The crop costs & benefits during 1981/82 - 1983/84 (L.S).

CROP	COST	GROSS RETURN	NET RETURN	NET RETURN PER FEDDAN
COTTON	8929362	13848432	4919070	10412
WHEAT	1984971	2509925	524954	2285
GROUND NUT	1322818	1474407	151589	828
SORGHUM	2115404	1686588	(428816)	(1196)
TOTAL	14352555	19519652	5167097	4328

Table 7.8. The crop costs and benefits during 1990/91 - 1993/94 (L.S).

CROP	COST	GROSS RETURN	NET RETURN	NET RETURN PER FEDDAN
COTTON	3747246	5610735	1863489	9399
WHEAT	4715340	8186350	3471010	6360
GROUND NUT	769558	1375969	606411	5696
SORGHUM	3518288	4937532	1419244	2380
TOTAL	12750432	20110586	7360154	5035

The parameters used in the analysis are those of the farm business estimates in Appendix 10.

7.4.1 Cotton Costs and Benefits

Cotton has the best chance for giving the highest net return per feddan both in the initial period and the final period. Clearly the slight reduction in profitability is due to the slight reduction in yield. Another important result is that while the profitability of cotton was four-and-one-half times that of wheat in the initial period, it is only one-and-one-half times in the final period.

7.4.2 Wheat Costs and Benefits

Wheat production in the Gezira is qualifying itself to a higher ranking position among the Gezira crops. The profitability (73.6%) is already more than doubled when comparing the final period with the initial period. Beyond the level fixed in the five course rotation (20% of the area), wheat will compete with cotton. The decision of more wheat and less cotton should always be weighed against their competitiveness.

7.4.3 Groundnut Costs and Benefits

There is a sharp increase in the profitability obtained in the final period when compared with the initial period. This is mainly attributed to the high yield realized in the final period. Actually, this pushed profitability from 11.5% to 78.8%.

7.4.4 Sorghum Costs and Benefits

In the initial period, the sorghum development program was operated at a loss, while in the final period it's profitability was assured but at a magnitude less than the other three crops. Many theses were developed in the past to reject keeping sorghum within the irrigated sector. But lately, with the development of hybrid sorghum and improvements in some of the local varieties, the tendency is towards grabbing the opportunity of the high yielding varieties and increasing the contribution of the irrigated sector in the production of the main staple food.

7.5 ASSESSMENT OF AGRICULTURAL GROWTH AND ITS SOURCES

7.5.1 The Sources of Agricultural Growth

In the present study, information on agricultural growth and its sources will help to highlight the growth path due to changes in crop rotation, while seeing the effects of these changes on resources use. The estimates calculated for the initial and final periods will be used for this purpose. They will be used to calculate the change in the net return realized for each crop in relation to the different growth sources.

a) That due to change in the area planted with the yield held constant.
b) That due to change in yield on the area planted in the initial period.

The average growth of crop production in the two studied periods, related to each source, were then calculated using the sources of growth expressed in absolute terms and change in percentage which are shown in Table 7.9.

7.5.2 The Analysis of the Growth Rates and Interpretation

The calculation of the growth rate of the studied factors for each crop is shown in Table 7.10.

The expansion of food crops in the irrigated sector at attractive yield levels is reasonable to expect. The other thing is that it is also reasonable when the area under cotton is reduced then expanding the area under wheat to use the excess stored water during winter is also reasonable. But it is also clear that 93.4% of the reduction in the total return of the cotton program, estimated as 62.1%, can be attributed to the reduction in cotton area estimated as 58.0%. The slight reduction in cotton yield had a minor effect. Therefore, the cotton program could easily expand to its limits in the rotation with the possibility of adding to the total return of the overall program. Generally, at higher cropping intensities, with adequate program requirements, a higher return is expected. From the calculations in Table 7.9, the total return changed is 42%, while the total area changed by only 16.3%. About 38.5% is attributed to the change in area, while 52.9% is attributed to the change in yield. This return supports the argument that low input, or even zero input, at lower intensities does not help the objective of improving agricultural growth and farm income. Crop development programs at higher intensities and adequately supported with improvement technologies, are the ones that have to be pushed to achieve higher contribution towards income levels and the balance of payments.

Table 7.9. Sources of growth in absolute terms and change in percentage.

Crop	Initial Period Area Feddan (1)	Final Period Area Feddan (2)	Growth Feddan (3) %	Initial Period Net Ret/Fed L.S. (4)	Final Period Net REt/Fed L.S. (5)	Growth L.S. (6)	Initial Period Total Return L.S. (7)	Final Period Total Return L.S. (8)	Growth L.S. (9) %
COTTON	472453	198267	-274186 -38.0	10412	9399	-1013	4919070	1863489	-3055581 -62.1
WHEAT	229742	545757	316015 +137.6	2285	6360	4075	524954	34710	2946056 +561.2
GROUNDNUT	183013	106652	-76361 -41.7	828	5696	4868	151589	606411	454822 +300.0
SORGHUM	358543	596320	237777 +66.3	1196	2380	3576	428816	1419244	1848060 +431.0
TOTAL	1243751	1446996	203245 +16.3	4154	5087	937	5167097	7360154	2193057 +42.0

The estimates of the growth rates will include the following:

$\Delta A^iY_o^i$ Effect of change in area with yield held constant = Column(3) x Column (4) ÷ Column (9)

$\Delta Y_iA_o^i$ Effect of change in yield on the area planted in the initial period = Column (1) x Column (6) ÷ Column (9)

ΔY^iA^i Effect of change in yield on the change in the planted area = column (3) x Column (6) ÷ Column (9)

ΔV^i Change in the net return of the crop = $\Delta A^iY_o^i + \Delta Y^iA_o^i + \Delta Y^iA^i$

Table 10: Calculations related to agricultural growth rates by crop (%).

Crop	$\Delta A^i Y_o^i$	$\Delta Y_i A_o^i$	$\Delta Y^i A^i$	Total
Cotton	-93.4	-15.7	+9.1	100.0
Wheat	+24.5	+31.8	+43.7	100.0
Groundnut	-13.9	+195.9	-81.7	100.3
Sorghum	-15.3 (2)	69.4	46.0	100.1
Total	38.5	52.9	9.8	

7.5.3 The Agricultural Growth and the Effect on Water Use

To relate the crop performance with water use, it is important to estimate water use efficiency for the two studied periods. If the vegetable program is excluded, the total net return as estimated for the other four crops will be compared with the total demand for water.

First, the initial period

The total net return = 516709 (L.S. 000)
The total demand for water = 45544693 (m^3 000)
The net return per m^3 of water = 1.145 L.S.

Second, the final period

The total net return = 7360154 (L.S. 000)
The total demand for water = 45058063 (m^3 000)
The net return per m^3 of water = 1.633 L.S.

The result of this analysis indicates that the crop development program for the final period was more remunerative for the water resource used.

7.6 THE MACRO-ECONOMIC PERSPECTIVE

7.6.1 The Structure of the Irrigated Sub-sector

The economy regards agricultural growth as the main source for employment, income generation, and external and internal fiscal balances. In spite of that, there has been periods of decline resulting from insufficient services and negligence of maintenance and replacement of assets, especially in the irrigated sector. Therefore, any improvement in macroeconomic policy will provide better incentives to the stakeholders in the irrigation systems.

From the recent national accounting estimates, irrigated crops contribute with about 58.8% of the total crop production, 34.2% of the agricultural GDP and 11.6% of total GDP. Under favourable conditions, their share in the annual growth rates is the highest compared with the product of other sub-sectors.

The relative importance of irrigated agriculture should be compared to other sectors that provide more stable levels of income and employment opportunities. The shift from cotton to food crops may not have unfavorable impact on income levels, but it disturbs the balance of employment levels.

When analyzing policy options in irrigated agriculture, the decisions to be taken on incentives to foster agricultural growth, and create the required impact on income generation and employment, should be emphasized. This will be followed by well targeted programs for implementation.

7.6.2 The Impact of the Crop Rotations in the Gezira

The crop rotations to be studied are the four course and five course rotations. The main parameters used for comparison are the impact on food self-sufficiency, foreign exchange earnings, and employment opportunities, with the following assumptions: (a) all the wheat, sorghum, fodder and cotton seed produce will be consumed locally; (b) all the cotton lint and the groundnut will be exported; and (c) fodder and sorghum will be treated as similar on the technical coefficients and value of produce. Based on these assumptions, the hypothetical example set for comparison is as follows:

Five Course Rotation	Four Course Rotation	Four Course
Cotton	420000	525000
Wheat	420000	525000
Sorghum/Groundnut	420000	262500
Fodder/Fallow	420000	262500
Fallow	420000	525000
Cropping intensity	70%	75%

Yield estimates relevant to this hypothetical example are as follows:

	5 Course Rotation	4 Course Rotation
Cotton lint	1.4 bale/feddan	1.2 bale/feddan
Cotton seed	0.5 m ton/feddan	0.5 m ton/feddan
Wheat	0.8 m ton/feddan	0.7 m ton/feddan
Groundnut	1.5 m ton/feddan	1.2 m ton/feddan
Sorghum	1.0 m ton/feddan	1.2 m ton/feddan

The expected output will be as follows:

	5 Course Rotation	4 Course Rotation
Cotton lint	588000 bales	630000 bales
Cotton seed	42800 ton	44600 ton
Wheat	336000 ton	367500 ton
Groundnut	315000 ton	315000 ton
Sorghum	420000 ton	315000 ton

A. The Impact on food self-sufficiency

The total human consumption of cereals is 3855000 m.tons and 11800 tons of vegetable oil based on a population of 2570000 (1993 census).

Per capita consumption of cereals is 150 kg (100 kg sorghum 40 kg wheat, 10 kg millet).

Per capita consumption of vegetable oil is 7 kg.

Therefore, the contribution of the Gezira Scheme will be:

	Cereals	Vegetable Oil
Five Course Rotation	19.6%	23.8
Four Course Rotation	17.7%	24.8

B. The Impact on Foreign Exchange Earnings

The gross export earnings from cotton and groundnut are based on the price of US$250 for a bale (average quality) and the same for a ton of groundnut. The expected earnings will be:

	Cotton	Groundnut	Total
Five Course Rotation	US$ 147,000,000	US$ 78,750,000	US$ 225,750,000
Four Course Rotation	US$ 157,500,000	US$ 78,750,000	US$ 236,250,000

The foreign exchange saving from producing wheat and sorghum and cotton seed are calculated as follows:

	Five Course Rotation (000 man-days)	Four Course Rotation (000 man-days)
Wheat	336000x140=47040000	367500x140=51540000
Sorghum	420000x100=42000000	315000x100=31500000
Cotton	42800x50=2,140,000	44600x50=2,230,000
Total US $	91,180,000	85,270,000

	Five Course Rotation (000 man-days)	Four Course Rotation (000 man-days)
Cotton	420000x67=28140000	52500x667=57750000
Wheat	420000x47.5=19950000	525000x47.5=24937500
Groundnut	210000x16.5=34650000	262500x16.5=4331250
Sorghum	4200000x23=9660000	262500x23=6037500
Total US $	61,215,000	70,481,250

Five Course Rotation 316,930,000 - 61,215,000 = US $ 255,715,000

Four Course Rotation 321,520,000 - 70,481,250 = US $ 251,038,750

C. *The Impact on Employment Opportunities*

	Five Course Rotation (000 man-days)	Four Course Rotation (000 man-days)
Cotton	420x65=273,000	525x65=43,125
Wheat	420x6.5=2,730	525x6.5=3,413
Groundnut	210x48.7=10,227	262.5x48.7=12,784
Sorghum	420x23.7=13,734	262.5x32.7=8,458
Total	53,991	58,775

If we consider the total rural force in the Gezira State of 760,000 persons (27% of the country's rural labor force), and a level of agricultural force in the Gezira State estimated as 450,000 persons, then the contribution of the Gezira crop rotation is expressed as follows:

Five Course rotation = 53,911,000 ÷ 200 = 270,000 persons
Four Course rotation = 58,775 ÷ = 294,000 persons

The five course rotation will contribute to 50% of the Gezira State population and the four course rotation to 54%.

D. *The Impact on Water Saving Opportunities*

The total demand for water for the two sets of crop rotations is calculated as follows:

	Five Course Rotation (000 m^3)	Four Course Rotation (000 m^3)
Cotton	420x4500=1,890,000	525x4500=2,362,500
Wheat	420x2473=1,038,660	525x2473=1,298,325
Groundnut	210x4103=861,630	262.5x4103=1,077,038
Sorghum	420x3067=1,288,140	262.5x3067=805,088
Total	5,078,430	5,542,952

With the application of the amended five course rotation (70% cropping intensity), there is a chance of saving about 464.5 million m^3 of water than when applying the four course rotation (75% cropping intensity).

The general rating from the comparison of the impact of the two studied crop rotations is as follows:

	Five Course Rotation (A)	Four Course Rotation (B)	The Higher Score for
1. Food Self-sufficiency A.1 Cereal A.2 Veg Oil	 19.6% 23.8%	 17.7% 24.8%	 A B
2. Foreign Exchange earnings	US$ 256 Million	US$ 251 Million	A
3. Employment Opportunities	54.0 million man-days	58.8 million man-days	B
4. Water Saving Opportunities	5.08 milliard m^3	5.54 milliard m^3	A

The five course rotation is better, if the expected improvements in yield capabilities are maintained at the levels presented in the hypothetical example. The gap in the employment opportunities will be bridged if higher intensifications are realized according to the original design of the five course rotation (80% cropping intensity). This move towards realizing the 80% cropping intensity should only be taken with firm commitment to the crop sequence. This should be implemented without creating water management problems at any stage of each of the crop development programs.

7.7 SUMMARY AND CONCLUSIONS

The irrigated sector is a major contributor to economic growth in Sudan. The Gezira Scheme stands as its most important irrigation system. On the other hand, the economy regards agricultural growth as vital to generate income and create employment opportunities. To achieve agricultural growth, the macro-economic environment that encourages the use of production improvement technologies is necessary. This implies well-targeted crop development programs be implemented.

Within the Gezira crop rotations, various crop development options were tested during the studied period 1981/92 - 1993/94. Assessment of the macro-economic perspectives was the main theme of the study on the agricultural growth path in the Gezira.

The link of agricultural growth to the changes in area and yield of cotton, wheat, groundnut and sorghum, and the distribution related consequences of costs and benefits, were studied. Cotton was found to be the production possibility with the highest return.

The conclusion that can be derived is that there is still room for yield improvement opportunities, but this could only be structured under favourable macro-economic conditions with incentives to use improvement technologies for achieving higher income levels. At the same time, it was found justified to expand food crops in the irrigated sector at attractive yield levels, but this should always be weighed with other competing crops.

Within the contest of the Gezira crop rotation, the five course rotation at 70% cropping intensity (leaving 50% fallow in the fodder leg of the rotation) has better opportunities than the four course rotation to attain the overall objectives of the economic development strategy. Further increases in cropping intensity are recommended, with the condition that water management problems are avoidable.

References

Ali, M.A. (1984), Economic Growth and Water Allocation in the Gezira (Ph. D. thesis) University of Ghent, Belgium.

Bret, Wallach (1988), Irrigation in Sudan since Independence. American Geographical Review. Vol 78, No. 4.

Doyal Barker (1992), The Inability of farming Systems Research to deal with Agricultural Policy. ODI/92/35. ODI Agricultural Administration Network, London.

Hassan R. M. nd Faki H. (1993), Economic Policy and Technology Determinants of the Comparative Advantage of Wheat Production in Sudan. CIMMYT Economics Paper 6.

IBRD (1990), Sudan Toward an Active Plan for Food security. World Bank Report No. 8167-SU.

Johnston P.F. nd Clark W.C. (1982), Redesigning Rural development. A Strategic Perspective. The Johns Hopkins University Press Baltimore and London.

APPENDIX (1)

Agriculture in the Sudan

The situation of the Crops Sub-Sector—Season 1991/1992

	Irrigated *	Mechanized Rain-fed	Traditional	Total
CEREALS				
Sorghum	1394	11277	2130	14,801
Millet	7	183	5250	5,440
Wheat	898			898
Maize	53	4	3	60
Sub Total	2,352	11,464	7,383	21,199
OILSEEDS				
Groundnut	135		640	775
Sesame		1303	705	2,008
Sunflower		77		77
Sub Total	135	1,380	1,345	2,860
OTHER CROPS				
Cotton	351	87	5	443
Vegetables	175			175
Fodder	150			150
Fruits	118			118
Beans	102			102
Lentils	7			7
Sub Total	903	87	5	995
TOTAL	3,390	12,931	8,733	25,054

* Excluding the sugar plantations which represent about 6% of the irrigated farming.

Source: The Advisory Unit for Agricultural Corporations, Ministry of Agriculture Khartoum.

APPENDIX (2)
THE GEZIRA SCHEME
CROPPED AREA AND LAND-USE INTENSITIES

SEASON	COTTON	WHEAT	G/NUT	SORGHUM	VEG	FODDER	SUN FLOWER	TOTAL GROWN	%
81/82	435314	267863	264245	343899	35811			1,347,132	63
82/83	484315	155538	148182	320940	28774			1,137,749	54
83/84	497729	265824	136611	410791	35689			1,346,644	63
84/85	464792	0	212859	420068	25566			1,123,285	53
85/86	400528	242497	102535	578758	30050			1,354,368	64
86/87	415074	179869	151050	448005	36136			1,230,134	58
87/88	383037	252313	159562	390295	40849			1,226,056	58
88/89	404506	274247	110814	426810	45787			1,262,164	59
89/90	357984	392297	79580	440953	55889			1,326,703	62
90/91	251047	613305	39860	506577	61138			1,471,927	69
91/92	215504	532813	35452	709640	45194	29556	21181	1,589,340	75
92/93	174701	514093	163814	621736	49245	733	2100	1,526,422	72
93/94	151815	522817	187146	547329	43000	5333	655	1,458,095	69

Source: Socio-economic Research Unit, SGB.

APPENDIX (3)
GEZIRA SCHEME
COTTON AREA YIELD & PRODUCTION

AREA	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	93/94
ACALA	55425	104955	151120							82377	104483	64726	57174
BARKAT	379889	379360	364609	345298	376109	328443	237992	223281	254876	116364	52946	86438	43791
SHMBAT					24419	56639	145045	181224	103109	52306	58075	23538	50850
TOTAL	415314	484315	515729	464792	400528	415082	383037	404505	357985	251047	215504	174702	151815
YIELD													
ACALA	4.5	509	6.4	7.2						4.1	5.8	3.9	4.2
BARKAT	3.8	4.3	4.3	4.4	3.4	4.7	3.9	4.1	3.7	2.9	5.0	4.4	3.7
SHMBAT					5.4	5.5	5.7	6.5	5.1	5.0	5.8	4.1	3.6
TOTAL	4.9	4.7	4.8	5.1	3.5	4.9	4.6	5.2	4.1	3.7	5.6	4.1	3.9
PRODUCTION													
ACALA	242887	645402	974118							336923	610178	249194	240131
BARKAT	1442634	1611974	1474568	1506894	1271248	153319	920096	920993	936055	332776	262402	378859	161396
SHMBAT					131863	476515	830383	1176762	522610	263099	337999	96743	183060
TOTAL	1685521	2257376	2448686	2372217	1403111	214709	2014709	2097755	1458665	932798	1210579	724796	584587

APPENDIX (4)

THE GEZIRA SCHEME

WHEAT: AREA (FED), YIELD (T/FED) & PRODUCTION (TON)

SEASON	AREA	PRODUCTION	YIELD
81/82	267863	87483	0.327
82/83	155760	92969	0.597
83/84	265864.5	103100	0.388
84/85			
85/86	242497.5	97388	0.402
86/87	179869	79918	0.444
87/88	252314	119568	0.474
88/89	274247	154127	0.562
89/90	392297	256955	0.655
90/91	613305.5	269854	0.440
91/92	526814	494152	0.938
92/93	514033.5	269868	0.525
93/94	522817	261408	0.500 (Est)

Source: Socio-Economic Research Unit, SGB.

APPENDIX (5)

THE GEZIRA SCHEME

GROUNDNUT: AREA (FED), YIELD (T/FED) & PRODUCTION (TON)

SEASON	AREA	PRODUCTION	YIELD
81/82	264245	97771	0.37
82/83	148182	60755	0.41
83/84	136611	91529	0.67
84/85	212859	108558	0.51
85/86	102535	55882	0.55
86/87	151050.5	91083	0.60
87/88	158728.25	958978	0.60
88/89	110864	66518	0.60
89/90	79580	42973	0.54
90/91	39860.25	29018	0.73
91/92	35452	28362	0.80
92/93	163418	116027	0.71
93/94	187146	153460	0.82

Source: Socio-Economic Research Unit, SGB.

APPENDIX (6)

THE GEZIRA SCHEME

SORGHUM: AREA (FED), YIELD (T/FED) & PRODUCTION (TON)

SEASON	AREA	PRODUCTION	YIELD
81/82	343899	89414	0.260
82/83	320940	125167	0.390
83/84	410791	216076	0.526
84/85	420068	147024	0.350
85/86	578753.5	318315	0.550
86/87	448005	179202	0.400
87/88	394456.5	141287	0.358
88/89	426810	215112	0.504
89/90	440953.25	216067	0.490
90/91	506577.25	267979	0.529
91/92	725306	477977	0.659
92/93	621736	480602	0.773
93/94	547329	437863	0.800

Source: Socio-Economic Research Unit, SGB.

APPENDIX (7)

INPUT REQUIREMENTS AND 1992/93 PRICE

(FOR THE GEZIRA COTTON AND WHEAT PROGRAM)

	UNIT PRICE US $	UNIT / FEDDAN
A. COTTON		
Fertilizer	200/m ton	80 kg
Insecticides	1.5 per feddan	5 sprays
Herbicides	10.0 per feddan	All area
Land Preparation	10.0 per feddan	All area
Sacks and B. hoops	18.6 per feddan	All area
B. WHEAT		
Fertilizer	200/m ton	100 kg
Insecticides	12.5 one spray	2 sprays
Herbicides	5.3 per feddan	All area
Land Preparation	6.8 per feddan	All area
Sacks and B. hoops	3.0 per feddan	All area

Source: Advisory Unit for Agricultural Corporations, Ministry of Agriculture, Khartoum.

APPENDIX (8)

THE GEZIRA SCHEME

CROP WATER REQUIREMENTS

CROP	M^3/FEDDAN
E1S-Cotton	4887
MS-Cotton	4100
Wheat	2473
G/Nut (Ashpord)	4103
Sorghum	3067
Fodder	6486
Vegetable	9661

Source: ARC -Wad Medani.

APPENDIX (9)

ANNUAL WATER RELEASED FROM SENNAR DAN

FOR THE GEZIRA SCHEME (Mm^3)

	Annual Releases[1]	Adjusted at Conveyance Efficiency of 87%	Average
1981/82	6164	5363]	
1982/83	6157	5357}	5388
1983/84	6258	5444]	
1984/85	6086	5295]	
1985/86	5714	4971}	5061
1986/87	5153	4918]	
1987/88	5659	4923]	
1988/89	5752	5004}	5118
1989/90	6244	5432]	
1990/91	6483	5623]	
1991/92	6165	5364]	5390
1992/93	6050	5264]	
1993/94	6102	5309]	

(1) Adjusted from annual releases calendar basis to crop season basis

Source: MOI, Wad Medani.

APPENDIX (10a)
THE GEZIRA SCHEME
COST OF PRODUCTION DATA 1992/93 (LS/FEDDAN)

CROP ITEM	COTTON	WHEAT	GROUNDNUT	SORGHUM
Land Preparation	1562.64	828	728	650
Agric Operations	1239.64	635	1608	1280
Materials Used:				
Seeds	446.4	870	745	100
Fertilizer	1990.1	2300	-	660
Pesticides	9166.27	800	-	-
Sacks	690.29	345	907	490
Sub-total	12293.06	4365	1652	1250
Harvesting & Post harvest	1294.83	1067	2044	1540
Land & Water charge	1400	960	900	9000
Transport	1000.22	790	297	280
Others	109.87	55	-	-
TOTAL	18900.26	8640	7228	5900

Source: Socio-Economic Research Unit, SGB

APPENDIX (10b)

THE GEZIRA SCHEME

THE FARM BUSINESS COEFFICIENTS

A. LABOR

Cotton	65 man-days/feedan
Wheat	6.5 man-days/feedan
G/Nut	48.7 man-days/feedan
Sorghum	32.7 man-days/feedan

B. FARM GATE PRICES (1992/93)

Cotton	L.S. 6500/Kantar seed cotton
Wheat	L.S. 25000/M. Ton
G/Nut	L.S. 16784/M. Ton
Sorghum	L.S. 12000/M. Ton

C. COST OF PRODUCTION (From Appendix 10a) (1992/93)

Cotton	L.S. 18900/Feedan
Wheat	L.S. 8600/Feedan
G/Nut	L.S. 7228/Feedan
Sorghum	L.S. 5900/Feedan

Source: SGB - Barakat.

CHAPTER 8

"IMPACT OF CROP ROTATION ON WATER MANAGEMENT IN THE GEZIRA SCHEME"

WEDNESDAY 27 APRIL 1994
HRS MEETING HALL

RECOMMENDATIONS

1) Integration of livestock is a very positive trend considering the socio-economic impact.

2) Five course rotation has certain advantages over four course rotation, as shown in the presented papers and the accompanied deliberation in the workshop.

3) Five course rotation has far greater outreaching impact; for successful implementation, a multidisciplinary approach is imperative.

4) Positive farmers' response is crucial for the success of any profitable production process.

5) The present constraints of the irrigation system are recognized, but these should not impair forward thinking by trying non-traditional and innovative options (e.g., rotation by Minors).

6) Production in absolute terms is not an end in itself. Optimizing production per unit of resources in a way to maximize the return for the farmer should be the target goal.

7) In order to reach the above targets, human resource development should be given priority.

8) Every effort should be made to exploit the media to promote the extension service for improved and efficient management of irrigated agriculture.

9) To encourage, by all possible means, intensive interaction among all parties concerned with the management of irrigated agriculture.

10) Rotation regimes are to be evaluated on socio-economic grounds.

11) Further studies are recommended to complete the picture about five and four course rotations.