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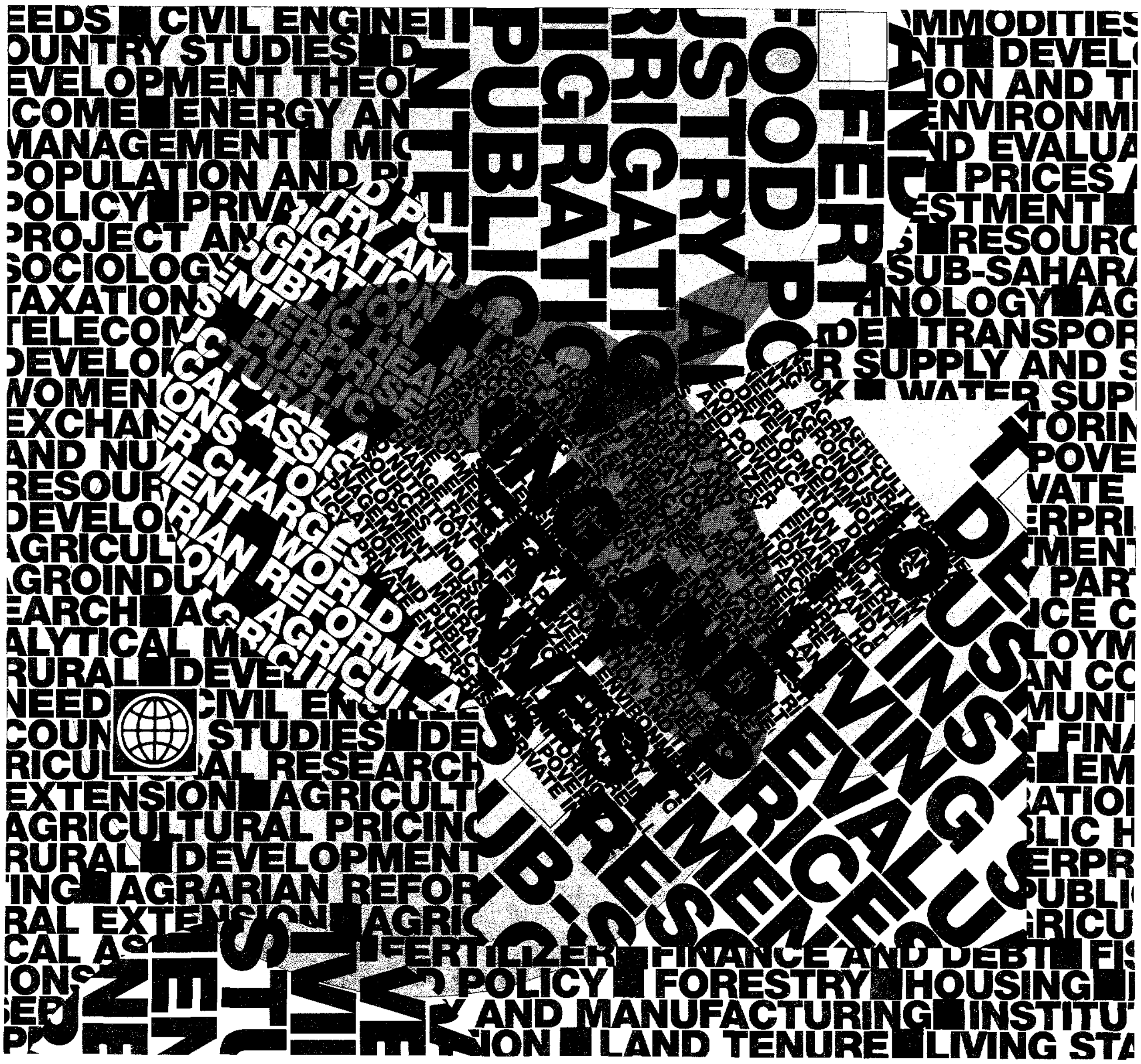
The Gezira Irrigation Scheme in Sudan

Objectives, Design, and Performance

Hervé Plusquellec



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(List continues on the inside back cover)

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CURRENCY EQUIVALENTS

		Official Rate	Commercial Rate
US$1 =	LS	4.5	12.1
Sudanese Pound (LS) =		US$ 0.22	0.082

WEIGHTS AND MEASURES

Feddan (Fd) = 0.42 hectare (ha)

Kantar (seed cotton) = 143 kilogram (kg)

ABBREVIATIONS

ARC	Agriculture Research Corporation
ELS	Extra Long Staple Cotton
EMC	Earthmoving Corporation
FOP	Field Outlet Pipe
GRS	Gezira Research Station
HRS	Hydraulic Research Station
GOS	Government of Sudan
MOI	Ministry of Irrigation
MS	Medium Staple Cotton
RPMU	Rehabilitation Project Management Unit
SGB	Sudan Gezira Board

Government of Sudan

Fiscal Year

July 1 to June 30

TABLE OF CONTENTS

FOREWORD

For the Sudan Gezira scheme, the eighties have been a decade of missed opportunities. Despite considerable momentum on rehabilitation, the scheme is operating well below its potential. Unless its key actors embark on a major reform of production arrangements in the scheme, Gezira will not be the engine of growth that Sudan desperately needs in the nineties. Placing the farmer at the center of the production process, with the Government and parastatal providing the enabling environment through a policy framework and basic facilities such as research, extension and investment promotion, is the key to Gezira's future. Efforts, such as the present case study, should assist decision makers in the task of realizing Gezira's potential in the nineties.

J. Shivakumar
Chief, Agriculture Operations Division
Eastern Africa Department
World Bank

PREFACE

This report is part of a series of case studies on the performance of irrigation systems in different countries. These studies focus on the extent to which the design of the irrigation system fosters effective water management and provides equitable, reliable, timely water distribution to farms (analyzes water efficiencies, the effectiveness of maintenance, and cost recovery).

Case studies have been prepared by the Bank's Operations Evaluation Department (OED) in cooperation with the Agriculture and Rural Development Department (AGR) in two semi-arid countries, Mexico and Morocco, and two tropical countries, Thailand and the Philippines. A case study prepared by AGR on two irrigation districts in Colombia has been published (PPR staff working paper No 264). Other cases studies in South East Asia by the International Irrigation Management Institute (IIMI) are now starting. A report summarizing the results of the individual case studies based on the series of performance indicators and other observations will then be prepared. This report will draw some recommendations on the design of the physical infrastructure, institutional and organizational of irrigation systems and their impact on the management of these systems.

Because of the comparative nature of this study, this report on the Gezira scheme in Sudan makes only passing references to some specific but critical aspects of this project, such the capacity of the system to adapt to changing socio-economic conditions.

SUMMARY AND CONCLUSIONS

The Gezira Irrigation Scheme lies between the Blue and White Nile rivers south of Khartoum, and is fed principally by gravity irrigation from Sennar dam on the Blue Nile. It has grown from the original scheme cultivating 300,000 fd to the present irrigation area of 2.1 million fd (about 882,000 ha). The climatic conditions are favorable to year-round cultivation, and the physical properties of the impermeable clay soils show a tendency to water-logging which badly depress the yields. The quality of the Blue Nile water is excellent for irrigation. Despite 65 years of irrigation, salinity is not a problem with the exception of some fringe areas on drier zones near Khartoum. Blue Nile water is silt-laden during the flood season.

The flow of the Blue Nile is regulated by the Sennar diversion dam built in 1925 and the multi-purpose Roseries dam completed in 1966. The total live storage capacities of the two reservoirs represent only 5 percent of the average annual flow of the river (and 15 percent of the Nile water allocation to Sudan).

Farmers do not own their lands; they are tenants. The area is divided into 102,000 tenants with an average area of 20 fd (about 8 ha).

The Gezira scheme was designed in the 1920s after prolonged experiments had been carried out on a prototype scale. It was designed with the main objective of producing cotton, a single cash crop. It was thus a non-perennial scheme with monoculture. Other crops were initially grown to provide food for the tenant farmers, and to help in the maintenance of soil fertility. Cotton, wheat, groundnut/sorghum are now cultivated in a four-course rotation, including fallow. For many years the Gezira scheme has been the backbone of the Sudanese economy contributing around 35 percent of the total G.N.P.

The irrigation system was laid out to suit the size of tenancy and crop rotation. The flat and featureless topography was favorable to the adoption of regular gridiron layout. The basic unit is a group of four adjacent fields of 90 feddans each called numbers. One crop is grown on each number following the four rotation system. Each number is divided into 18 tenant fields of 5 fd (called hawasha). The tenants fields are in turn divided by a network of cross-bunds for irrigation by basins.

The irrigation system comprises twin main canals running from headworks at Sennar dam with a combined capacity of 354 m^3/s, a network of 2,300 kilometers of branch canals and major canals, and about 1,500 minor canals with a total length of over 8,000 kilometers. All canals are divided into reaches by cross-regulators which are the control points for the off-taking canals.

The main, branch and major canals are designed as regime conveyance channels. The minor canals are designed for storing water continuously flowing from the major canals at night. The rough rules of thumb developed for the operation of a scheme of such a large scale were the result of insufficient knowledge about the crop requirements under Gezira soil and climatic conditions. According to the design principle the field outlet gates serving the "numbers" are open 12 hours per day at a nominal flow of 116 l/s (5,000 m^3/12 hour).

The present drainage facilities are limited to major and collector drains. The existing 6,000 km of minor drains are completely silted up. Despite the absence of field drains, run-off disposal is seldom a problem either because of the open cracks in dry soils or traditional method of irrigation by basin.

Operation of the scheme is centrally controlled: The management is divided between the Ministry of Irrigation (MOI) which is responsible for the irrigation network and the Sudan Gezira Board (SGB) which is responsible for agricultural operation and for determining the irrigation water requirements. The water orders (or indents) are passed to the MOI engineers, summed out throughout the system up to headworks at Sennar dam. MOI delivers the required discharge at the head of the main canals, and SGB is responsible for the operation of the minor canals and the delivery of water to the tenants. Water flows from the major to the minor canals are controlled by movable weirs, which provide accurate and easy water measurements, but have the serious disadvantage to be highly sensitive to upstream variations of water level.

The Gezira scheme is not a sophisticated one by present day standards. It was designed before the development of modern canal water control technologies. The design, however, took the best advantage of some favorable and unique features of Gezira: (1) the flat topography, and (2) the adopted tenancy system i.e. the absence of constraints imposed by small, fragmented, field plots found in many developing countries. The adoption of the night storage system resolved the issue of night irrigation found in many schemes, and provide a remarkable solution to the complex problem of adjusting water releases at the headworks and at critical points of the system to the demand without excessive losses. A negative characteristic of the minor canal, which was probably overlooked, is its ability to trap the silt released into the system.

For about 40 years, the Gezira scheme was operated satisfactorily on the basis of the original design and operational concept. The management of the Gezira scheme ran into problems in the early 1970's shortly after the scheme reached its present extension.

The steady deterioration in the terms of trade in the Sudan, as in most other countries dependent on the export of agricultural production, led to shortages of financial resources. As a result, insufficient funds were available to finance the considerable recurrent operations and maintenance costs of the Gezira scheme and to replace machinery and equipment. This situation was aggravated by the total breakdown of the telephone system which was a crucial tool for communications between SGB and MOI staff, especially for the water indenting process.

The cropping intensity in the Gezira has increased from less than 40 percent in the early 1960's to the present 62 percent of the rotational area. This intensification combined with the increase of irrigated area resulted in a three-fold increase of water released through the irrigation system, and of the silt deposit into the canal system.

Because of the lack of financial resources, MOI was not able to cope with removal of silt and weed clearance. Poor maintenance led to a reduction in the transit capacity of canals, especially minors.

Crop intensification, expansion of the system, breakdown of the communication system, and insufficiently-funded maintenance critically resulted in improper use of the system and inadequate control. Due to the deterioration of the movable weirs and their sensitivity to the fluctuating water levels in the major canals, it became difficult to maintain the indented discharge into the minor canals. The degree of siltation of some minor canals is also such that little water reaches the tail numbers and some areas are now out of production. The tenant lost confidence in the timely operation of the system and, to some extent, took over the management of the minor canals. The original night storage system gave way to a continuous, 24-hour irrigation water delivery to the fields, which is not supervised by the tenants during the night. By adopting the continuous unattended irrigation, the tenants have considerably reduced labor costs for irrigation. They also appreciate the flexibility of the new system on which water is withdrawn on demand since they took control of the opening of the field outlets. The departure from the originally planned method of watering has given rise to some management and water application problems. It is the intention of MOI to re-establish the night storage system, which was based on a strict discipline of water scheduling.

The imposition of discipline and the re-institution of the old regulations may be counter-productive especially during the summer rains which disturb any pre-arranged schedule. In this period management should consist of day to day decisions, with proper field drainage deserving high priority.

The Gezira system operated under extreme difficulties for about 10 years until the recent installation of a new telecommunications system. This was achieved despite the slackening of flow control in the major and minor canals. However, the decline in the overall performance of the official system was matched by a rise in compensating informal management. The experience and expertise of a core of long-serving personnel employed on the scheme has certainly contributed to the maintenance of a reasonable level of service. However, the unique design of the system played a major role in the maintenance of irrigation service during that period, and in the adoption of a new management system. The minor canals playing the role of terminal reservoirs are the key feature in this adoption. Indeed, it is now demonstrated that water can be withdrawn from the minor canals based on a rigid or on a highly flexible scheduling as long as the indenting, which is nowadays made daily a large part of the irrigation season, ensures a sufficient replenishment of water in the minor canals.

The Gezira scheme is operated by over 5,000 staff from the Ministry of Irrigation (MOI) and the Sudan Gezira Board (SGB). A large part of MOI staff includes unskilled labor to operate the regulators manually. Since the SGB ghaffirs (ditchriders) have in practice turned over their responsibilities to the tenants, only operation of the conveyance and distribution system is controlled by a public agency. Again, the grid layout and the storage provided by the minor canals facilitate the de facto transfer of management to the tenants.

In summary, water distribution from the Gezira system to the fields is efficient, timely and reliable as long as the system is adequately maintained. There is no indication of rising of the groundwater table, and evidence of salinization is limited to fringe areas. The design was able to adjust to a major departure from the original management system thanks to the flexibility in operation provided by the minor canals. The main drawback of this unique feature of the Gezira scheme is its silt-trapping efficiency, and the high health hazards not only for tenants, but also for workers who until recently cleared the canals manually.

The field efficiency in the Gezira is estimated at about 75%[1/], and the overall efficiency 70%. This value is the highest found in surface irrigation projects (excluding projects at the scale of river basin system with a high degree of re-use of drainage flow, such as, the Nile System in Egypt). The high clay content of the soils in the Gezira plain and the design of the distribution systems are the two main reasons for this high efficiency. Provided that the major and minor canals are clean from silt and weed, there is a fairly equitable water distribution.

The operation and maintenance expenditures average US$ 11.4 per irrigable hectare over the last three years which is clearly below what is needed for adequate O & M activities of an unlined system located in a warm climate area, and served by highly silted water. A two to three times increase of O & M budget under the present maintenance practices should be necessary. Research on

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1/ Assuming usual definition of crop water requirements which exclude the field losses.

alternative methods of weed clearance by mechanical chemical and biological control, and desilting methods is under way and may result in some savings on O & M expenditures. Land and water charges are determined every year to recover, in principle, administrative costs of SGB and MOI, operation and maintenance costs of the irrigation system and part of capital replacements. These charges are collected by SGB through the tenant individual account system for cotton revenues set up in 1981. The collection rate for the last three years was between 70 and 80 percent. No repayment has been made by SGB to government account for MOI expenditures in recent years.

Despite the satisfactory water distribution in Gezira - assuming the system is adequately maintained - agricultural production is rather disappointing.

The average cropping intensity (60%) is 20% lower than the 75% intensity of the authorized four-crop rotation.

Yields of cotton and wheat, two of the main crops, are two to three times below the yields achieved in the research stations.

CONSIDERATIONS FOR THE MODERNIZATION OF THE GEZIRA SCHEME

i) Design of Minor Canals

A recent silt monitoring study has provided some valuable insights into the nature of sediment entering the Gezira system, the period of highest concentration and the sedimentation process. Most of the sediment are of silt and clay size and enters the system during a short period in July/August when the level in Sennar reservoir is at its minimum. Two thirds of the sediment deposit in the major and minor canals, mostly in their first reaches. An important outcome of the study is that slope limitation makes its impossible to design "regime" minor canals. The suggestion to narrow the minor canals to reduce weed and silt clearance costs would not solve the problem of siltation. It would eliminate the buffer storage in the minor canals, a critical feature in the design of the scheme, and would considerably increase the complexity of operation.

ii) Liberalization of the Cropping Pattern

Several changes in the official cropping pattern over the last 65 years have demonstrated the flexibility of the combined physical and institutional design of the Gezira scheme to respond to changing socio-economic conditions. The flexibility is provided by the geometric layout and the tenancy system. The Sudan Plantations Syndicate and then the Sudan Gezira Board have over the years diversified and intensified crop cultivation in the Gezira from the original mono-crop cotton production, and reallocated land plots to the tenants. These modifications have been imposed on the tenants who still have little choice in deciding which crops to grow, where and how. However the design of the system would make it possible to move from the highly centrally planned agriculture to a system based on farmer's individual choice and incentives. In the present four crop rotation for example, one "number" could be allocated to cotton, two to free crop cultivation and one fallow. The cultivation of 40,000 fd of tomatoes during the winter of 1989/90 is a move in this liberalization of the cropping pattern.

This shift would not require special modifications to the existing physical infrastructure but a greater flexibility in water distribution rules i.e. in the opening of the FOP gates as presently practiced by the tenants.

iii) Silt and Weed Clearance

The infestation of canals with emerged and submerged weeds and the deposition of silt have become the most serious problem in the Gezira scheme, reducing the transit capacity of canals. Silt removal is contracted by MOI to a parastatal body, Earthmoving Corporation (EMC), formerly a division of MOI. There is scope to improve the performance of EMC in terms of quality and quantity of work. Serious consideration should be given to break the de facto monopoly of EMC by involving the private sector in maintenance works.

iv) Institutional Arrangement for Operation and Maintenance

No change is suggested in the share of responsibility between SGB and MOI in the operation and maintenance of the irrigation scheme, especially of the minor canals. However it is recommended to increase or formalize the participation of the farmers in the operation of the FOP gates and water allocation within the blocks.

v) Research on Farm Irrigation Practices

How much of the potential of the Gezira scheme can be achieved depends on several factors including irrigation management, fertilizer application, pest control and other farming practices. Good irrigation management, which aims at providing the crop with enough water to avoid stress while at the same time avoiding overwatering and waterlogging is difficult to achieve in the soil and climatic condition of the Gezira scheme. The clay soils are prone to waterlogging; cultivation of sorghum and cotton, two crops highly sensitive to waterlogging, especially at the development stage, takes place during the rainy season. A further difficulty is the low degree of regulation of the Nile water by Roseires dam with the result that the cropping calendar is still dictated by the natural flow of the river. The irrigation season keeps pace with the onset of the Nile flood flows and the rains.

Experiments on cotton cultivation conducted at Gezira Research Station (GRS) and at Tambul pilot farm on the right bank of the Nile in the early 1970's demonstrated the advantages of i) early sowing; ii) furrow irrigation versus the traditional basin method; iii) shorter length of irrigation period; and iv) pre-irrigation.

The paramount advantage of early sowing associated with pre-irrigation is the undisturbed establishment of crops, including thinning before the rains start. Other advantages include maximum use of radiation, ripening before the cool nights and the appearance of white fly.

By contrast to the standard method of basin irrigation which promotes waterlogging, furrow irrigation is self-draining. Further research on the method to convey water from the field ditches to the furrows is needed before its adoption, given the limited head available from the minor canals.

A reduction of the length of irrigation periods may have a favorable effect on the quality of cotton.

The heightening of Roseires dam, now under consideration, which will increase its live storage by almost three times, will offer opportunities for the development of irrigation in Sudan. Benefits are expected not only from development of new irrigated areas but also from the changes in irrigation management which will be possible on existing irrigation areas. The possibility to run the Gezira system at or near full-supply year round, especially during the low flow dry season, will make it possible to adopt an optimal cropping calendar dictated by climatic (temperature and rainfall) considerations. Timely pre-irrigation and early sowing of cotton for establishments before rainy season would have an enormous impact on crop yields. Sowing of groundnuts could be advanced by 4 to 6 weeks, which again will reduce the risk of depressing yields due to early rains. Crop diversification through the introduction of spring crops, such as safflower, may be possible. However to achieve full benefits from the above changes in field water management and cropping patterns, dramatic improvements would have to be made: a) to reduce the risk of waterlogging through the conversion from the inherited basin irrigation to furrow or other methods and b) implementation of a complete drainage system of an all-weather road system. These would be associated with profound institutional reforms in production relationship, tenancy system, marketing, credit and so forth.

COMPARATIVE STUDY

OF PERFORMANCE OF IRRIGATION SYSTEMS

GEZIRA SCHEME

SUDAN

I. THE PROJECT AREA

The Gezira Irrigation scheme in Sudan covers an area of some 2.1 million feddans[2/] (about 882,000 ha) fed principally by gravity irrigation. The Gezira plain is located in the triangle land between the Blue and the While Nile south of Khartoum. The original irrigation system comprised the Gezira main canal to serve approximately 300,000 fd of cultivable land. Extensions to the initial scheme were carried out in the late 1920s and early 1930s and subsequent smaller extensions steadily increased the command area to around one million fd by the early 1950s. In 1957, work commenced to bring the planned area of around 800,000 fd of the Managhil extension under irrigation. By the mid-1960s, the Managhil was fully operational. At present, after further small extensions, the irrigated area stands at 1.2 million fd in Gezira and 0.9 million in Managhil.

The land holds the best conditions for water delivery systems with a general slope of 15 cm per km towards the White Nile.

The soils are faily uniform, and consist mainly of sediments of the Blue Nile, which are classified as vertisols that crack widely, have a clay content of 50-60% and a high exchange capacity. Movement of water in the soil is very

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2/ One feddan (fd) = 0.42 ha.

slow. At depths of a few meters or more soil moisture content has been observed to be virtually constant and there are no indications of a downward percolation of irrigation water. Where soils crack to good depth, water penetrates to be followed by roots. These soils generally show a tendency to waterlogging attended with bad aeration and yield reduction.

The climate of the area is arid and continental characterized by a low average annual precipitation and considerable fluctuations from year to year in the magnitude intensity and distribution of rainfall. There are three distinct seasons: a short rainy season from July to September, during which the temperature is moderate and the humidity high; a cool dry winter season from November to February; and a hot summer from April to June. March and October are transitional months. The mean annual rainfall ranges from 472 mm at headworks near Sennar to about 160 mm near Khartoum, and is distributed over six months from May to October. The relative humidity fluctuates from 20% to 70% and temperature varies from 5^{o} C in December to over 46^{o} C in April, with an annual mean of 28^{o} C. The evaporation, Eo (Penman), at Wad Medani varies from 5.5 mm per day in December to 9 mm per day in June, with an annual average of 2,632 mm (Table 1).

Water Supply

The Blue Nile is the source for the water supply for the Gezira Scheme. The river is known for its marked seasonal and annual variations. It has an average annual flow of 50 milliard m^3 and contributes about 68% to the yield of the Nile. The seasonal variation of its discharge ranges from over 10,000 m^3/s

at the peak of a high flood to 60 m^3/s in a very low year. Analysis of water quality shows that the Blue Nile water is suitable for irrigation. The electrical conductivity of 0.20 mmohs and the SAR of 0.35 places the Blue Nile water in the C1-S1 class (excellent irrigation water). The annual suspended load of the Blue Nile is about 60 million ton. Silt content can reach about 10 kg/m^3.

II. PROJECT DESCRIPTION

STORAGE DAMS

Sennar Dam. The Sennar dam is situated on the Blue Nile some 260 km southwest of Khartoum. The dam, completed in 1925, was built to supply the Gezira irrigation scheme by gravity from head works on the left bank of the river. The total storage capacity of the reservoir created by Sennar dam was 930 million m^3. The total length of the dam including embankments is just over 3 km, of which the central section, built of masonry, is 600 m long with a maximum height of 26 m. This latter section contains 80 low level sluices and a 300 m spillway which can be closed off by steel panels when the flood has passed. The top water level of the reservoir is at 421.7 m and the minimum level in the reservoir to maintain maximum flows in the Gezira canal is 417.2 m.

Reseires Dam. The Roseires dam is situated on the Blue Nile approximately 250 km upstream of Sennar dam. The dam, with a design reservoir retention level of 480 m, completed in 1966, was constructed to provide storage for irrigation in the low water season and for hydropower generation. The total storage capacity of Roseires reservoir was 3,000 million m^3 and the live storage was 2,400 million m^3.

The dam is a concrete buttress type about 1 km long, flanked on either side by earth embankments 8.5 km long to the west and 4 km long to the east. For sedimentation control in the reservoir the dam has five deep sluices set at the lowest possible level in the main river channel. The discharge through the dam is normally passed through these deep sluices which are equipped with radial gates for control purposes. A gated spillway, with a crest level set at the minimum drawdown level of 467 m, augments the deep sluices when the peak flood is passed.

Silt has influenced the design and operation of the two dams. In spite of the fact that filling of the reservoir takes place after the elapse of the flood, siltation has resulted in reducing the live storage at Sennar from 600 to 480 million m^3 and silted up the dead storage of Roseires reservoir. The present storage capacity is just sufficient to meet the present irrigation demand in a year with an 80% reliable flow. In 1984/85, for example, the low river yield resulted in cutting out wheat from the rotation for insufficiency of water supply. Raising of Roseires retention level by 10 meters to elevation 490 is under consideration. The heightening of the dam would increase the live storage almost three times to about 7,000 m^3. This additional storage will offer large possibilities to modify the calendar and cropping pattern in the Gezira scheme.

CONVEYANCE AND DISTRIBUTION SYSTEM

The irrigation system comprises twin main canals running from the headworks at Sennar to a common pool at the cross-regulator at km 57. The Managhil main canal of 186 m^3/s design capacity was constructed in parallel to the old Gezira main canal of 168 m^3/s capacity, to serve the Managhil extension. The water distribution system includes:

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

- 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 Ashreen" (Abu XX) of total length of 40,000 km with 116 l/s capacity;

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

Downstream of the first common cross-regulator at km 57 the main canals are divided into reaches, which vary in length from 5 km to 22 km, by further cross-regulators. These regulators are the control points for the branch and major distributary canal offtakes. The branch canals are similarly divided into reaches by cross-regulators and major distributary canals are grouped at these regulators. The major canals are divided into reaches of around 3 km and minor canal offtakes are generally grouped at the cross-regulators. There is normally no irrigation offtake direct from the main canals, branch canals or major canals.

The carrying capacity of the conveyance system (0.39 l/s/ha) can meet the maximum demand on the system at full rotational cropping of 75%.

The main, branch and major canals are designed as regime conveyance channels, with water flowing continuously day and night. The minor canals are designed for night storage delivering water directly to the water courses.

Canal Regulators

The control structures are designed to maintain a constant upstream level and the discharge is controlled by manually operated means.

The two main classes of regulator gate in use are the vertical lifting sluice gate and the movable weir. There are a number of different types of sluice gate (gantry operated sluice gates, rack and worm gates, roller sluice gates). The system of water control throughout the distribution system relies on a knowledge of the discharge characteristics of the regulator gates. The flow through sluice gates is estimated from calibration charts requiring readings of gate opening and upstream and downstream levels.

Moveable Weirs

Moveable weirs are installed as head and cross-regulators on major canals and at most head regulators on minor canals for discharge up to 5 m^3/s. They comprise a moveable weir plate and frame with a downstream plate sloping at 1:5 set in a masonry or concrete structure.

The characteristics of these weirs are:

(i) provided the upstream level is kept constant, they give a very accurate discharge from a formula requiring the value of the head of water over the weir only;

(ii) the discharge is independent of the downstream water level;

(iii) being overshot, they are very sensitive to fluctuation in upstream level.

Field Outlet Valves

The original field outlet valves, in abbreviation FOP gates, discharging into the Abu XX through field outlet pipes (FOP) consisted of a chopper-type valve. The flow was controlled by rotating the chopper gate about hinge pin. This valve was very subject to stealing. Virtually all valves have been replaced by oil drum bottoms, bags or other local materials - or not replaced at all.

Escapes

The Gezira scheme is characterized by a very limited capacity for escapage of surplus water. Very large areas on the periphery of the scheme have no escape possibility at all.

The total escape capacity is 67 m^3/s, which is less than 20% of the capacity of the main canals, and is intended primarily to allow for emergency spillage due to sudden decreases in irrigation demand following rainfall.

As a result of the low escape capacity combined with the long length of supply canals, farmers are often required to continue to take water into their fields for some time, even when they are already flooded by heavy rain.

Minor Canals

The minor canals are a key feature of the Gezira canal irrigation system. They are overdimensioned in relation to the flow they have to convey, especially in the downstream reaches, since they have been designed to act as night storage reservoirs. In two experiment units in the early 1920s the minor canals were designed as regime channels with continuous flow. The night storage reservoir concept was introduced in the design of the first 300,000 fd in the mid 1920's when it was realized that tenant were opposed to irrigation at night. It was decided that the field outlet pipes would be closed at night and the continuous discharges into the heads would be stored within the minor canals until the morning. The dimensions of the cross section vary from a bed width of about 6 to 4 meters and a depth of 1.30 to 0.80 meters going downstream. The standard distance between two successive minors is 1.42 km.

The total length of a minor canal can be as much as 20 km. Each minor is divided into reaches with a length varying from 1 to 4 km depending on the slope of the land. The reaches are separated by night-storage regulators consisting of a brickwork well and sluice gate or, in the lower reaches, by a gated pipe.

The minor canals are primarily designed to command land for direct application of irrigation water to the field. The design criteria are a command of 20 cm above the highest parts of the field. The water level corresponding to these criteria is known in Sudan as full supply level (FSL), which differs from the definition used in most countries, i.e., the water level in the canals when running at maximum flow capacity.

Since the banks are set further apart than what would be required for carrying the required flows, there is sufficient material for their construction. At intervals of 292 m along the minor canal, field outlet concrete pipes take off at right angles, each feeding a 90 fd field called number. These pipes - 12 meters long and 0.35 m diameter - are buried at least 60 cm below the service road of the minor canals.

Field Irrigation System

The uniform slope of the land in the Gezira Scheme has permitted a very regular layout of fields. The typical layout is shown in figure 1.

The field irrigation system is designed to serve standard units of 90 fd (Numbers) measuring 1,350 x 280 m and irrigated by water courses known as Abu Ishreen (Abu XX). This unit is divided into eighteen 5-fd plots (called hawasha) watered by secondary water courses called Abu Sitta (Abu VI) taking off from water courses.

A "number" is normally planted with one crop (cotton, wheat) or divided between simultaneous crops (groundnut, sorghum).

The Abu XX had originally a design bed width of 1.00 m and a depth of 0.40 m and a design command of about 0.20 m. The Abu XX is nowadays rebuilt by a special ditcher pulled by a crawler tractor, and its new section is dictated by the plant used for construction. Its theoretical capacity is 116 l/s (5,000 m^3 in 12 hours).

In the standard field layout, the hawasha is further divided into fourteen angayas by small ditches and the angayas, in turn, were divided into 10 smaller basins called hods. This subdivision has been abandoned because too demanding from the tenants in time and energy. Irrigation water distributed from the Abu VI is now distributed to the angayas until there is free standing water throughout the field.

Drainage System

The original design of the Gezira irrigation scheme recognized that because of the nature of the soil and absence of a high water table, there was no need for, and indeed no means of providing, subsurface drainage of the fields. The only need for drainage, therefore, was for dealing with surface runoff from rainfall or excess irrigation.

The present surface runoff drainage system consists of minor surface drains of total length of about 6,000 km and major drains totalling about 1,500 km in length. Minor drains run parallel to minor canals. These discharge into the major or collector drains which generally follow the lines of natural drainage and lead the runoff water to outfalls. Although there are no field drains parallel to the Abu XX to take runoff from the fields runoff disposal is seldom a serious problem. At the time of the heavy showers a large part of the total area is fallow or has not yet been planted. The rains fall on dry cracked fields which can absorb a large part of it. With the angaya system of irrigation, each small plot retains some of the non-absorbed rainfall. In this system retention facilities are automatically built-in, the disadvantage is frequent waterlogging.

The major drains ideally outfall beyond the cultivation boundaries to natural drainage lines and thence to the Blue or the White Nile. However, in much of the Gezira this does not happen. Several drains terminate in large local depressions and so runoff water either has to be pumped into nearby canals, or is allowed to pond up and then evaporate, usually on land which is unsuitable for agriculture. The lands so flooded are left uncultivated deliberately but often are used unofficially for labor townships.

III. DESIGN OPERATIONAL REQUIREMENTS

Water Requirements

The Gezira scheme was the first large-scale irrigated agricultural developments in Sudan and at the initial planning and design stage, there was little information concerning local crop requirements. Criteria were largely based on experience in Egypt and some pumped irrigation scheme in Sudan and certain asumptions had to be made, particularly concerning the capacity of the main canal. After commissioning, as a result of the close involvement of management in the agricultural operations and the need to avoid wastage of water, empirical values of crop water requirements were quickly established, and a number of rules of thumb for the operation of the scheme were developed.

The empirical method which has given satisfactory results from the management point of view for more than 40 years is still in use. The empirical method estimates the requirements of all crops at 30 m^3/fd per day inclusive of field losses (at the head of the Abu XX). This is equivalent to 420 m^3/fd per fortnight (100 mm application depth). The quantity to be applied to a 90 fd "Number" will then be of the order of 5,000 m^3/12 hours for an open FOP based on a 7-day application. For this discharge, (116 l/s), the head loss in the FOP should be 0.15 m. In practice it is far less.

In the late 1960s, research was carried out to determine the values of crop water requirements according to the Penman method, to meet the needs of irrigated agriculture in the Sudan under the soil and climatic conditions of the central plain. The work was entrusted to the Agricultural Research Corporation which runs the Gezira Research Station and has been responsible for agricultural research throughout the history of the scheme. Values of crop water requirements for all main crops grown on the scheme were determined for the local conditions at field outlet pipe level. The crop factors which have been determine by field measurements at GRS cover all losses below this level. The crop factors assumed for each crop are given in Table 2. The average monthly evaporation and rainfall at Wad Medani is shown in Figure 2. Average monthly water requirements for the four main crops are given in Table 3. Annual requirements vary from 12,700 m^3/ha for ELS cotton to 6,400 m^3/ha for wheat, a winter crop. The net irrigation requirements after deduction of effective rainfall and including canal transit losses are given in Table 4 for the 5 years during the period of 1983-88. The net water demand vary between 5,300 and 6,100 million m^3 during that period.

It should be noted that the definition of crop water requirements in the Gezira which include all field losses below the fielt outlet pipe differs from the normal practice used in other countries. The reason given for the adoption of this definition was that the field losses were considered small. Indeed percolation losses are negligible in the Gezira plain but operational losses during irrigation including evaporation and seepage from field channels, lateral movements through crack (hedge effect), release of excess water to neighbouring fallow numbers, increased field evaporation due to prolonged surface soil wetness are relatively important. (See Figure 3).

Indenting

The indent is a request for water passed at intervals from the Block Inspector of the Sudan Gezira Board (SGB) to the Sub-Divisional Engineers of the Ministry of Irrigation (MOI). Indents are rendered weekly by block inspectors to MOI assistant engineers on Tuesday with minor adjustments on Saturday in order to avoid unnecessary level fluctuations in the system.

The Block Inspector makes up a watering schedule of the Numbers on each minor canal, each Number being fed by one Abu XX.

When the MOI Sub-Divisional Engineer has received the indent for all the minors in his Sub-Division from the Block Inspectors, he sums them up to give the required discharge at each control point on the System in his Sub-Division and to give the total required from the next Sub-Division upstream. The indent is passed from Sub-Division to Sub-Division up the System with corrections for canal conveyance losses until the total is passed to the headworks of Sennar dam who adjust their gates to give the discharge required. As the revised discharged becomes available all other regulators downstreams are adjusted in turn.[3/]

The irrigation water entering the Abu XX is distributed over the Number in one week. According to the original recommendations the four head 10-fd hawashas are irrigated simultaneously for three days. The remaining group consisting of five hawashas further down the Number will take another four to

3/ The entire process could now be greatly improved by the use of computers and modern communication systems.

five days to irrigate, bringing the total irrigation period of the Number to approximately seven days. The irrigation interval has been determined as fourteen days.

Prior to the start of each irrigation season, the SGB and the MOI must reach an agreement on the overall planning of the cropping for the forthcoming season to ensure maximum efficiency in use of the water, land and irrigation facilities. It is then necessary for the MOI to ensure that the water diverted in the main canals at Sennar is adequate for crop requirements and that effective control of the water ensures that sufficient water is delivered at the correct time to the farmers.

IV. MANAGEMENT OF THE GEZIRA SCHEME

The management of the Gezira is divided between the Ministry of Irrigation (MOI) and the Sudan Gezira Board (SGB) a parastatal corporation which replaced the Sudan Plantations Syndicate in 1950. According to the agreement between the Government and the Syndicate, the government was to operate the whole irrigation system down to and including the Abu XX. Before the system came into operation (likely when the continuous irrigation method was abandoned) it was decided to confine the task of the Irrigation Department to operating the irrigation system down to the minor heads only and the Syndiate would be responsible for the operation of minor canals and field outlet valves. The Irrigation Department would be responsible for the maintenance of the main, branch, major and minor canals and the Syndicate for the Abu XX. This division of responsibilities between the Ministry of Irrigation and the Gezira Board is still in practice today. It is justified on the ground that the SGB agricultural blocks are regarded as consumers of water and as such they should be in charge of the operation of the minor canals to ensure the appropriate delivery to field. No change is proposed in the share of responsibilities between SGB and MOI regarding the operation and maintenance of the scheme. However, consideration should be given to increase, or "officialize", the participation of the farmers in the operation of the FOP gates and water allocation within the blocks.

Ministry of Irrigation

The Headquarters of the Ministry of Irrigation for operating and maintaining the Gezira scheme is located at Wad Medani. Moi is organized into two Directorates -- one for the Main Gezira and the other one for Managhil extension located at Gorashi -- and seven Divisions. These Divisions are divided into 23 subdivisions under the control of an Assistant Divisional Engineer (ADE). The Subdivisions are further divided into 56 sections each run by an Assistant Engineer.

Each Subdivision controls an average area of around 90,000 fd. The staff of each Subdivision consists of a senior engineer (ADE), head of the unit, a senior assistant engineer, three assistant engineers heading the sections, two technical assistants, four to six clerical staff and a labor force of about 50 to 150.

Within the Subdivision, the responsibility for water control in response to the indents lies with the ADE assisted by the SAE. Maintenance work is usually under the daily direction of the Assistant Engineers and Technical Assistants.

The total number of MOI staff involved in the management of the scheme is about 3,200 of whom 20 are university graduates, and 78 are technician engineers and technicians with an in-service practical training. To this number should be added the staff of the Mechanical-Electrical Department (231) and Administrative Department (480) of MOI prorated to the area of the Gezira scheme. The total MOI staff directly and indirectly involved in the operation and maintenance of the scheme is therefore around 4,900 (one for about 173 hectares). However it should be noted, as discussed in Chapter V, that most part of maintenance activities of public schemes in Sudan, including silt clearance, are carried out by two parastatal corporations, totalling nearly 4,000 staff.

Staff in MOI for Gezira - Managhil Scheme

Under Secretary	1
Director	2
Engineer (University Graduates)	18
Technician Engineer	24
Technician	54
Clerk	220
Storekeeper	4
Accountant	26
Skilled Labor	2,861
Total	3,210

Sudan Gezira Board (SGB)

The Sudan Gezira Board, a large centrally managed corporation, is responsible for the agricultural management of the scheme. SGB determines crop rotations and prepares the land for cotton. For cotton, SGB is responsible for application of fertilizer and pesticides, seed propagation and distribution and ginning. It is also responsible for the maintenance of the infrastructure, which includes a railway network of 1,050 km in length, used for transporting cotton. SGB is responsible for field level water management including the operation of FOP gates.

For agricultural and water management purposes, the irrigated area is divided up into 14 Groups and further subdivided into 107 Blocks of variable size averaging about 20,000 fd each, the size and location of Blocks being dependent on topographical and geographical factors. Each Block is under control of a Block Inspector who is responsible for preparing the indent to pass to the ADE of MOI.

The SGB employs roughly 1,900 water watchmen called ghaffirs whose job should be to control the opening and closing of night storage weirs and field outlet pipes on the minor canals. They are distributed evenly over the whole scheme, which means that there is about one watchman for every 1,200 fd (about 500 ha). One ghaffir is responsible for about 13 field outlet pipes serving 13 numbers and two reaches of the minor canal on average. Given the present de facto control of the FOP gates by the tenants, the role played by the SGB ghaffirs is now questionable (Chapter V). Agricultural activities with the farmers are the responsibility of 365 field inspectors under the blocks.

The role of the Ministry of Irrigation is confined to ensuring the delivery of water into the minor heads as indented by the block inspectors provided that the water demands are within the canal carrying capacities. The system demands the closest possible contact between the SGB inspectors and the MOI engineers who control the sources of supply.

Farmers

Farmers do not own their lands; they are tenants. The area is divided between 102,000 tenancies with an average of about 20 fd. The original size of a regular tenancy was originally 40 fd, but a number of tenancies have been converted to half-tenancies over the years. Tenants supply or hire labor, tend the crops, pick seed cotton and transport it to ginnery collection centers. They are responsible for land preparation for crops other than cotton. Other crops are marketed privately and tenants have more latitude in their cultivation than for cotton. For wheat land preparation, planting and harvesting are all done mechanically, with the private sector providing most of the services.

Tenancy System

The tenant system designed in the 1920s has become increasingly unsatisfactory as social and economic changes have evolved. Tenants continue to have little say in what they grow and how they grow it. Tenancies were originally designed to be worked by the tenant and his family, but hired labor has always been important on the scheme. Currently about 15% of labor requirements are met by family labor, 29% by hired resident labor and 56% by migrant labor. Tenant participation in agriculture has fallen over two generations of rising living standards and better education, and it is estimated that over half of all tenants are now no longer involved in farming and most of those who are still involved, have an outside job. There is a need for major structural reforms in the nature, size and pattern of holdings of tenancies.

V. ACTUAL PERFORMANCE

The present management of the Gezira scheme departs substantially from the originally design which was used satisfactorily for 35-40 years. Factors which have contributed to that departure include:

(a) the nearly two-fold increase of the irrigation area between 1957 and 1965;

(b) the rapid crop intensification over the 7-year period 1963-1970 following the completion of the Managhil extension. The cropping intensity increased from 45% in the early 1960s to 62% in 1970 in the main Gezira (Table 5); and

(c) the volume of irrigation water released at Sennar headworks in the system increased three-fold from above 2,000 million m^3 in 1957-58 to nearly 6,000 million m^3 in 1970-71. The silt deposited in the system also increased in the same proportion. This rapid extension and crop diversification would have required an increase in the operation and maintenance activities of the Gezira scheme.

Unfortunately, the economic situation in Sudan deteriorated in the 1970s as in most countries dependent on the export of agricultural production. Because of the shortage of financial resources, insufficient funds become available to finance the recurrent operation and maintenance costs of the Gezira and to purchase necessary replacement of machinery and equipment. Inevitably, this led to a deterioration of the efficiency of irrigation.

The close control of water in the irrigation network which was made possible by a telephone system became quite difficult after this system became totally inoperative in the 1970s. The block irrigators and the sub-divisional engineers faced extreme difficulties in establishing contacts regarding the indents. The communication system was re-established recently in 1987 through the installation of a modern telecommunication network.

OPERATION ACTIVITIES

Present Practices of Operation

From the mid-1960s the tenants have adopted field methods which enabled them to keep pace with intensification and later to cope with the deterioration of water supply due to the poor maintenance. The larger cropped areas required greatly increased amounts of water and the time required for the water distribution on the field became onerous for the tenants. As a result, tenants started to leave field outlet gates open 24 hours.

At present, continuous watering is prevailing in the scheme without any attendance by the farmers at night. As a consequence of the practice of 24-hour flow and the larger number of field outlet pipes that are open at one time, the discharge through the pipes diminishes. The well defined daily pattern which characterized the old night storage use of the minors has been replaced by a much more irregular pattern, the levels rising and falling around mean levels well below FSL. Field surveys of sixteen fields outlets have shown the average discharge through the pipes to be between 40 to 55 l/s against the design discharge of 116 l/s for a head of 0.15 m. The water levels in the minor canals can generally not be maintained at FSL. Command over the number is consequently reduced and the land takes longer to irrigate.

The number of field outlet valves to be open at any one time has changed greatly since intensification. Although the number of outlets to be open was formerly under the control of the Ghaffirs, this is not now effective in practice. The openings of outlets depend now on the tenants' judgment of the requirements of their crops. Block inspectors today rarely interfere in the routine opening and closing of outlets.

The traditional angaya hod-by-hod irrigation method has gradually been superseded by the so-called open-plan method whereby the irrigation water is left to enter the field at different places and the hawasha is prepared in such a manner that the water will find its way over the whole field with minimum attendance. The tenant's imperative to reduce the time spent on field irrigation to economize on labor costs as far as possible is one of the main reasons for the adoption of the continuous-flow open-plan irrigation method. The crop intensification requires his attention for other crops - dura, groundnut and, later in the season and to a lesse extend, wheat - during the same season. However, the unattended open plan method is not used for all crops at all times. Many exceptions can be recognized especially at the young seedling stages.

The intensification and diversification of cultivation and the difficulties of communication between the block inspectors and the ADE's for nearly 10 years led also to the breakdown of the traditional method of indenting. Despite the fact that the Penman method has been available since 1970, the empirical method is still in use. The present practices of the block inspectors is to renew the indenting daily during the establishment of the crops from the beginning of the irrigation season in early June to the sart of rain in mid-July. During the rainy season, indent is renewed daily with a second indent in the evening called "rain-cut" indent in case of heavy rain. The block inspectors return to the daily indent after the rainy season around mid-October and adopt weekly indenting as soon as the wheat is established in the fields. From March to end of May water is released only to meet the requirements of water supply and irrigation for vegetables.

Actual monthly releases at Sennar dam for the period 1983-88 are given on Table 6 and compared with the calculation of water demand at Sennar based on Penman method. This table shows that the annual releases through the indenting system exceed the calculated water demand by only 9 percent in average, which is remarkable given the absence of communication during that period and the deterioration of the control facilities.

However a recent detailed investigations of the present performance of the system (References 10 to 13) revealed that the management information system is manipulated by both SGB and MOI staff. The indents calculated by the block inspectors exceeded the actual requirements by 44%. The releases authorized by MOI were only 85% of the indented quantity and they delivered only 78% of the authorized figure. The ultimate result was that the overall estimated crop requirements were correctly met although there were wide variations between individual canals.

Further investigation by HRS also revealed that there is little relationship between the observed values of gate openings and the values recorded by MOI in their books.

Efficiency

The conveyance and distribution efficiency of the network of unlined canals in the Gezira scheme estimated by MOI at 93% is one of the highest in the world. This high level is the result of (a) the impermeable clay soils, (b) the low level of escapage in the system, and (c) the important role of the minor canals acting as storage reservoirs.

Field efficiency, according to the GRS definition of crop water requirements which include field losses below the field outlet pipes is 100 percent in the conditions of the research station. Under this definition actual farm field efficiency would reflect the skill of the farmers to manage water on their fields as carefully as in a research station. However for purposes of comparison with other projects, estimate of field efficiency defined as the ratio of net crop requirements to releases at field outlet pipe should be made. GRS agronomists estimate the field losses at about 25 percent of the water requirements at the field outlet.

Accepting the above estimate of field efficiency, the overall efficiency is around 65-70%, lower than those of some other observers but still higher than in most large-scale irrigation projects in the world, not accounting for reuse of their drainage water.

Equity

The HRS study on the Hamza canal referred to above revealed that there is a high degree of equity of water distribution from top to tail of a minor canal, when it is cleared of silt and weed. The water delivery performance indicator[4] varies from 1.06 at the top to 0.96 at the tail. However this is not usually the case and claims of inequity caused by siltation and weed infestation are frequently being made.

Timeliness and Reliability

Since the openings of the field outlets are now dependent on the tenants' perception of their crop needs, in principle the water distribution should be timely. However, because of the increasing silting up of the canal system, especially of the minor canals, water delivery in some areas is neither timely nor reliable. Conditions have deteriorated so much in some areas that lands are

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4/ The water delivery performance indicator is defined as the ratio between irrigation water supplied and water required at field outlet. This indicator normally differs from the field efficiency which is the ratio of water supplied and crop requirements after deduction of effective rainfall.

taken out of production. The gap between the potential cotton serial area[5] and the area cultivated effectively during the year 1988 was about 120,000 fd.

A return to the traditional night storage system to improve equity and reliability of water deliver is sometimes urged but is should be remembered that the old code of practice was originated in years of low cropping intensity, and much lower wage rates for watermen. The present system is also more responsive to the crop water requirements at the different stages of the growing season and is perceived by the tenants as an economic labor method.

Equity and reliability of water distribution are expected to improve in the near future as a result of the efforts made by MOI for weed and silt clearance of major and minor canals.

MAINTENANCE ACTIVITIES

During the late 1970s, a serious backlog of weed clearance together with silt clearance built up and the canal system was severely clogged with weeds and silt. The infestation of canals with emerged and submerged weeds and the deposition of silt have become the most serious problem in the Gezira scheme, resulting in raising of water levels in the minors and reducing the transit capacity of canals. Considerable areas are still cut out from the rotation

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5/ The serial area is the total potential area for each course of the crop rotation, i.e. the total cultivable area of the scheme divided by the number of courses in the rotation. (See Chapter VI - Agricultural Production).

because of difficulty of water delivery, despite some recent progress in silt removal.

Prior to 1974, two Divisions of the Ministry of Irrigation, the Construction and Mechanical Divisions, were responsible for the maintenance of canals, drains and roads and construction of irrigation water. A review of the MOI operational activities in the early 1970s came to the conclusion that it was difficult to carry out these activities within the regulation of a Sudan Civil Service. In 1974, the Construction and Mechanical Divisions were therefore removed from MOI and established as two separate Branch Corporation:
i) Earthmoving Corporation (EMC) and ii) Irrigation Works Corporation (IWC). Both are semi-autonomous bodies empowered to work in the private sector and even outside Sudan. They are supposed to work as contractors to the MOI for maintenance work in the Gezira. In practice, the contractual relationship between MOI and EMC are still marked by their former association. There is also a tendency to recreate some of the activities which were given to EMC, through the MOI Electro-Mechanical Department.

Siltation of Canals and Drains

The irrigation water supplied to the Gezira carried with it silt, much of which is deposited in the irrigation canals. Other sources of siltation are wind-blown material and canal banks which are eroded by wind and rain. The minor canals are the most seriously affected by siltation due to the low velocity of the water in these canals as a result of the night storage system. A number of factors have contributed to the increased volume of silt sedimentation in the

Gezira scheme: (a) the increase of crop intensity in the Gezira; (b) the successive extension of Gezira up to its present stage of 2.1 million fd resulting in a three-fold increase of the total water release in the irrigation canal and the subsequent increase in silt released into the system; (c) the siltation of the dead storage of Sennar dam and consequently the possible scouring effect of the fine deposits by the flood flows passing through Sennar reservoir when water level is maintained at spillway level during flood season and possibly; (d) increased erosion in Ethiopian upper catchment after a drought period of several years.

Because of the lack of survey instruments and trained personnel, proper silt investigation and calculation of volumes excavated are not systematically undertaken. There are therefore great variation on the estimates of annual silt deposition from 4 to 10 million m^3 and over. Systematic measurement of silt entering into the system by the Hydraulic Research Station (HRS) in collaboration with Hydraulic Research Ltd., U.K., started in mid-1988.

Observations during the first year provide most interesting results:

i) of the nearly 6 million tonnes of sediment that entered the Gezira and Managhil main canals between July and November 1988, more than 95 percent consist of clay and silt particles;

ii) a third of this sediment settled in main canals, a third in minor canals and the other third passed to the fields;

iii) most of the sediment that settled in the major and minor canals did so in the first reach;

iv) about 60 percent of the sediment which entered the system did so during a period of five weeks in July/August, before MOI started to raise water level in Sennar reservoir; and

v) very little scouring of deposited sediment occurs in major and minor canals.

The HRS research report (Reference 13) concludes that "slope limitations make it impossible to design regime minor canals in the Gezira scheme. The sediment control options are limited to excluding sediment at the intake or trapping sediment in silting basins".

By far the greatest volume of maintenance on the drainage system is also that of silt clearance. Virtually all the minor drains are totally silted up so that they now take the form of a slightly depressed wide strip of uncultivated land between the lowest part of a number and the bank of the next minor.

The average rate of silt clearance from the canals has increased progressively from an average of 4.2 million m^3 per year during the period 1973-1977 to about 6.2 million m^3 in 1983 and is projected to reach about 11 million m^3 in 1990.

Clearance of canals and drains in the Gezira has been mainly carried out by draglines. However, since 1979, use of hydraulic excavators has been progressively expanded. EMC has acquired recently 32 hydraulic excavators and is in the process of purchasing 20 additional ones.

The present fleet of EMC machinery in the Gezira scheme used for silt removal in canals and drains includes 64 draglines, 31 hydraulic excavators, 19 bulldozers, 12 elevated motorgraders and 10 motorgraders. The draglines are now used mostly for the desilting of main and major drains, the hydraulic excavators for the desilting of minor canals, elevated motrograders for the excavation of minor drains and bulldozers and motorgraders for the dressing of canal banks.

Silt which is excavated from canals is dumped on the banks which are not usually dressed until access is required for further silt clearance and so do not provide good access for inspection and weed clearance operations. To some extent, this is unavoidable as bank dressing is not undertaken until the silt has dried out for about one year. Of the 95 draglines and hydraulic excavators, only 66 are in operable conditions. The average output of EMC machinery is low (about 7 to 10,000 m^3/month per machine), less than half the nominal output (20,000 m^3). This is partly due to the aging of EMC machinery, but also to the slackening in the field supervision of the performance of the earth-moving machines. EMC operators have no transportation and accommodation facilities and spend part of the official working time commuting from the nearest village.

With the newly-procured excavation equipment and with a modest improvement in the output of EMC machinery, it is expected that the silt backlog will be removed within about three years.

Weed Clearance

All canals of the system are infested with two main types of weed, namely, immersed weeds which grow on the bed and banks of the canal and submerged weeds which anchor with thick roots to the bed. Due to close control on the Blue Nile the water hyacinth is not present in the river and consequently there is no problem from this type of weed. However, weed growth is a serious problem in the system as the weeds reduce the discharge capacity of the canals and provide a habitat for mosquito larvae and snails which are vectors of malaria and schistosomiasis (bilharzia) respectively. Weed infestation has been aggravated in the last few years by a two fold increase in the number of weed species found in the Gezira canals.

During the period when there is a heavy silt load in the canals, the penetration of sunlight through the water is restricted and weed growth is inhibited. In January, the system starts drawing clearer water from storage at Sennar and there is then a rapid growth of weeds, particularly in the minor canals. Silt is subsequently deposited in the slow moving water around the weeds, provided a good environment for further weed growth and thus compounding the problems. The main weed growing season extends from January to around April/May. In earlier years, the main canal was closed down from mid-April until July and mainly domestic supplies only were obtained by pumping into the canal system from the Blue Nile. Consequently, most canals were closed and dried out during this period and much of the weed died. Weed clearance operations were concentrated in the time of maximum weed growth and there was less "carry-over" of infestation to the next irrigation season than there is today. After the Roseires Dam was completed in 1966, more water became available for the scheme and increased numbers of canals were kept open during the summer period. Changes in cropping calendars with intensification in the 1970s shortened the period of summer closure. Weed infestation is now a very serious problem which affects the delivery of water and is not easily dealt with.

The minor canals designed to store water overnight for daytime irrigation provide ideal conditions for the growth of both emergent and submerged plants. To function properly they require continuous action to keep them free of weeds and to reduce the deposits of silt. Clearance should be made two to three times on each minor canal. Hand-cutting using rakes and chains has been the traditional method of weed control in the Gezira scheme. This method presents a major health hazard from bilharzia to the laborers involved in the work. MOI is now finding it increasingly difficult to find sufficient laborers to carry out the work effectively. MOI, recognizing that the manual method cannot cope with the weed problem and is socially unacceptable is now anxious to introduce alternative systems of weed clearance. Biological and chemical methods of control are being researched. There is no doubt that the grass carp will eat the species found in the Gezira canals, but social factors may have to be overcome before biological control can be used successfully.

In 1979, MOI initiated a pilot project to experiment with the combined mechanical weed and silt control as an alternative to traditional methods. In 1982, a training project financed through a grant from the Netherlands, and with the technical assistance of a Dutch consultant, was set up in an area of 150,000 fd in Abu Usher to train MOI-EMC personnel with the new technique. The results obtained in this project using hydraulic excavators equipped with mowing and dredging buckets are impressive. There is no doubt that this method provides a better solution than the present methods used for silt clearance and weed control in minor canals. MOI has now decided to extend this method to three more units of 150,000 feddans each.

A combination of biological, chemical and mechanical control may provide the best results. Research program for biological and chemical control have been well prepared. However research activities on these two methods have not yet started because of lack of research equipment and other facilities.

Mechanical and Electrical Works

All major work on regulator gates and pumping stations including regular maintenance repairs and installation of replacement parts is carried out by the Mechanical and Electrical Department of the MOI. Due to the specialized nature of the work and the need to maintain workshops with specialist personnel, this Department is organized principally from the main MOI headquarters with mobile teams centered at workshops at Division headquarters for field work.

OPERATION AND MAINTENANCE BUDGETS

The annual MOI operation and maintenance budgets for the Gezira scheme is broken down in three main chapters.

1) Salaries and allowances of the staff involved in field operation plus a percentage of the salaries of the staff at the Medani Headquarters.

2) Operation and maintenance expenses including silt and weed clearance, repair of structures, expenses for Medani and El Gorashi Workshops, and Sennar dam, and administration expenditures.

3) Replacement of equipment machinery and major maintenance (replacement of Sennar dam gates), procurement of vehicles, and capital cost recovery.

The approved budget during the last three years has decreased from 77% to 51% of the proposed budget as of consequence of the economic situation in Sudan.

	1985/86	1986/87	1987/88
		(SP000)	
Proposed Budget	34,744	45,265	71,812
Approved Budget	36,694	32,029	39,533
Actual Expenditures (in current prices)	28,670	32,909	35,650
(in 1987/88 prices)	(50,459)	(45,086)	(35,650)

When expressed in 1988 prices, the actual expenditures has decreased by about 30 percent over a three-year period despite the need for increasing maintenance activities.

The O & M actual expenditures for the years 1985/86 to 1987/88 are shown on Table 7.

Salaries and personnel allowances represent only 10 percent of the total O & M expenditures which is very low compared to other countries. The main reason for this low percentage is that maintenance of civil works is executed under contracts by EMC and IWC and these expenses represent 65 percent of annual budgets. Expressed in US$, the average cost per hectare has decreased from US$12.0 to 9.69 between 1985/86 and 1987/88 (using official rate).

	1985/86	1986/87	1987/88
Actual Expenditures (US$1,000)	10,618	10,969	8,569
Cost per irrigable ha (US$/ha)	12.04	12.43	9.69
Cost per diverted volume (US$/1,000 m^3)	1.72	2.03	1.37

VI. AGRICULTURAL PRODUCTION

The total net cultivable area of the Gezira scheme is 212 million fd: 1.16 and 0.96 million fd in the main Gezira and Managhil extension respectively. The main crops on the Gezira are cotton, wheat, groundnut and sorghum, and, to a limited extent, vegetables.

Until 1985, these crops were grown on a four crop rotation including fallow in Gezira and a three-course rotation without fallow in Managhil.[6/] Available potential area was then 610,000 fd for each course (serial) of the rotation availing a total possible crop area of 1.83 million fd and an average cropping intensity of 86%.

Since 1980, SGB has been pressing for abolishing the three-course rotation and standardizing the whole scheme to a four-course rotation. The main disadvantages of the three-course rotation given to support the change were:

- lower actual cotton yields, depressed by about 15% to 25% depending on the year;
- shortage of available time for cotton land preparation which can only start after harvest and removal of sorghum and groundnut;
- cumulative water supply problems which are much more serious than similar problems experienced with the four-course rotation;

6/ In general, each number of 90 fd is planted with one crop: growing cotton is compulsory on one number and wheat on the second one. In the third one tenants cultivate groundnut or sorghum. In each number, 18 tenants cultivate a 5-fd hawasha.

- widespread serious infestations of noxious weeds which could not be arrested under the three-course rotational system;
- shortage of labor;
- no fallow area for livestock grazing[7/].

In 1985, SGB obtained the necessary approval to effect the changeover to a four-course rotation. To date, all Gezira and Managhil are under a four-course rotation. As a result of standardizing the scheme to a four-course rotational system:

- possible cropping intensity was reduced from 86% to 75%;
- fallow area increased by 236,000 fd to reach 530,000 fd annually;
- total annual area available for all crops was reduced to 1.59 million fd;
- area available for each serial to be cropped was reduced by 80,000 fd, i.e., a maximum possible serial area of 530,000 fd is now available.

Table 8 compares the actual cropping intensity with the possible authorized cropping intensities from 1978 to 1988. The average cropping intensity during the seven-year period 1978-1984 decreased steadily from 75% to 53%, when the attainable intensity was 86%. Since the generalization of the four-course rotation, it has remained at just below 60%. The gaps between the potential

7/ Livestock were originally prohibited on the scheme but are now tolerated. Feeding livestock in the scheme encourage unauthorized watering of the fallow area.

cultivated cotton area and the harvested area slightly decreases during the last four years showing the impact of the ongoing rehabilitation programme (Table 9).

Average yields obtained for cotton in Gezira between the 1969/70 and 1973/74 seasons was 1.63 ton/ha. Average yields declined to an average of 1.1 ton/ha between the 1974/75 and 1980/81 seasons. Since then the yield of ELS cotton has increased to an average of 1.37 ton/ha (Table 10). The average yield obtained for wheat (1.12 ton/ha) is also very low (Table 11). The improvement of cotton yield after 1981 is directly related to changes in the financial incentives caused by the abolition of the joint account (see Chapter VII, Recovery of Operation and Maintenance Costs).

There is a large gap between average yields on farmers' fields and yields obtained on the Gezira research station:

	Average Yields on Farm Field[8/]		Yields on Gezira Res. Sta.		Ratio
	kg/fd	T/ha	kg/fd	T/ha	%
Cotton	400	0.95	1,300	3.10	3.20
Wheat	360	0.85	1,500	3.57	4.20
Sorghum	500	1.20	2,000	4.75	3.95
Groundnut	600	1.43	2,200	5.24	3.65

Crop intensification and diversification have resulted in change in insect dynamics, disease prevalence, deterioration of soil fertility, competition for

8/ Average yields in 1982/83.

water and labor and a devastating attach of weeds. The Agricultural Research Corporation has undertaken a research program to stop the decline in crop yields and restore the levels of the late 1970s.

VII. RECOVERY OF OPERATION AND MAINTENANCE COSTS

The Joint Account system was in use in most irrigation schemes in the Sudan until 1980. Under this system the expenditures incurred by the Agricultural Corporations such as Sudan Gezira Board were deducted from the total revenue received from cotton sale. The net revenues from cotton were then distributed between the government, the corporation, and the tenants in agreed proportions. The tenants' share was then divided by the total scheme production of seed cotton to arrive at a price per kantar of seed cotton payable to each tenant. Under this system cotton bears the burden of other crops in the rotation resulting in a disinterest of the tenants which grow cotton because they must, and a sharp decline in cotton productivity in the mid 1970s. In 1980 the Joint Account system was abolished and replaced by the individual account system. The tenants are charged for each input for each industrial crop and they get the net revenue based on their productivity. In 1981 the new method to be used in settling land and water charges was established to recover administration and operating costs of both SGB and MOI and their capital replacements and new investment costs. These costs amounted to about LS28.4 million in 1981-82.

Because the main crop is cotton which is most demanding for both tenants and management, the total number of feddans under irrigation were converted to the number of feddans equivalent which could be irrigated by applying the total volume of water available. The other crops are weighted according to the quantity of water required in relationship to cotton. The number of irrigations for cotton, wheat, groundnuts, sorghum and vegetables was fixed at 16-10-8-4 and 14 respectively. Since 1981/82 no new calculation of land and water charges were based on this method. The rates were determined each year by increasing the rates established in 1981/82 by a certain percentage for each crop as indicated below:

Land and Water Taxes (LS/fd)

Crops	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89
Cotton	28.50	28.50	38.00	50.00	65.00	80.00	101.00	130.00
Wheat	14.00	14.00	23.75	31.00	40.00	49.00	62.00	95.00
Groundnut	18.00	18.00	19.00	25.00	32.50	40.00	50.00	55.00
Sorghum	3.50	7.00	19.00	25.00	32.50	40.00	50.00	55.00
Vegetables	25.00	25.00	33.25	44.00	57.00	70.00	90.00	130.00

The land and water charges for each crop for the three years 1985/86 to 187/88 and the amount collected are given in Table 12, showing a collection rate of 70% to 80%, as summarized below:

Year	Recoverable Charges	Collected	Collection Rate %
	------------000'Ls	------------	
1985/86	60,214	42,352	70.3
1986/87	68,525	55,595	81.1
1987/88	85,497	64,205	75.1

The comparison between the actual administrative and operating costs of SGB and MOI and the land and water charges recoverable based on rates settled yearly show that the corrected factors applied to the 1981/82 rates since the first application of the new method do not take full account of the inflation and increases in SGB/MOI expenditures:

Year	Actual Expenditures MOI	SGB	Total	Recoverable Charges	%
	-----	-----	-----	000'Ls -----	-----
1985/86	28,670	40,963	69,633	60,214	86.5
1986/87	32,909	52,476	85,385	68,525	80.2
1987/88	35,650	21,909	107,559	85,497	79.5

Cotton has the highest collection rate (90%) followed by wheat (75% to 80%) and the other 3 crops groundnuts, dura and vegetables (49% to 68%).

Collection Rate by Crop

	1985/86	1986/87	1987/88
Cotton	88.0	93.0	90.0
Wheat	74.0	25.0	80.0
Vegetables, Dura and Groundnuts	49.01	68.3	54.1

The reason for the higher collection rate for cotton and to some extent for wheat is that SGB has a firm hand on cotton returns, and partly on wheat returns while the tenants sell the other crops independently.

SGB collects both land and water charges. However no payment has been made by SGB to government account during the last year for MOI expenditures.

An example of calculation of water rates, if dissociated from land taxes, based on the new method established in 1981 is given in Table 13. Table 14 show the actual cultivated areas, the water rates and the amount recoverable from each crop by MOI. For the year 1987/88, the water rates would have varied from a maximum of LS46.07 per feddan of cotton (US$27.61/ha at official rate) to a minimum of LS11.52 per feddan of sorghum (US$6.90/ha).

VIII. IMPROVEMENT OF SYSTEM PERFORMANCE

In the late 1970s, the government of Sudan was very much concerned about the general decline of the irrigated agriculture subsector, particularly in the Gezira scheme. Following a visit by a joint FAO/World Bank mission in 1979, it was agreed to initiate a rehabilitation program as a first phase for a period of 4 to 5 years to be followed by a modernization phase. The rehabilitation project initiated in 1984 concentrates on the restoration of the irrigation water supply in order to reach the highest possible production level using proven technology. The modernization phase would involve the upgrading of technology in agricultural production and irrigation practices. The irrigation component of the rehabilitation project included:

(a) repair of canal regulators and movable weirs and replacement of obsolete gates;

(b) replacement of the 29,000 FOP gates by vertical sliding gates;

(c) silt and weed clearance of canals and drains;

(d) excavation of new drains;

(e) rehabilitation of irrigation and drainage pumping stations;

(f) installation of a new telecommunications network system; and

(g) repair and maintenance of sluice gates at Sennar dam.

Installation of the new telecommunications system was completed in 1987 and greatly improves the information transfer about the delivery of water. The program of silt clearance is well under way and is expected to be completed within 3 years. Implementation of the other irrigation components is just starting.

Desilting of existing drains and execution of new drains totalling 6000 km is extremely slow because of number of constraints found along the drainage lines. The implementation of a complete and proper drainage system is crucial to the future development of Gezira scheme.

Advanced technological changes introduced by this project are limited to the modern telecommunications system. Some mechanical features of the control structures will be improved, but the basic concept of operation of the Gezira scheme is unchanged.

Further research would have to be carried out before the implementation of the modernization process. Areas which would have to be addressed include:

(a) night storage versus continuous irrigation;

(b) design of field outlet gates; and

(c) crop water requirements and irrigation practices aiming at the reduction of the number of waterings, saving of water and increase in crop production, reduction of risk of waterlogging (see section on improvement of farm management practices);

Night Storage Versus Continuous Irrigation

The issue of night storage versus continuous irrigation is clearly the most complex one to be resolved in Gezira. Several aspects have to be taken into consideration: (a) silt and weed clearance; (b) operation of the main system; (c) labor requirements for irrigation with different methods of field water application; and (d) flexibility in water delivery.

It has been suggested to replace the night storage system by continuous 24-hour irrigation and to narrow the minor canals. The advantages advocated to support this approach are: (a) flow velocities would be increased, causing reduction in the volumes of silt now trapped in the minor canals; (b) the area requiring weed clearance would be reduced; (c) the quantity of excavation of future canals would be reduced. It also argued that, since continuous flow irrigation is already widely practiced in Gezira, the changes in the rules of irrigation should not be a critical social issue. This controversial issue of night storage versus continuous irrigation is the subject of a long-time debate. It implies the elimination of a key feature of the design of the irrigation system in Sudan. Only the downstream effects of this change, i.e., on field water applications and social and economic consequences on maintenance costs have been considered so far. A fundamental aspect seems to have been overlooked: the night storage concept plays a major role in the operation of the Gezira scheme. The inevitable deviations between demand and supply of water are stored or withdrawn from the minor canals. The minor canals are the main reason for the successful operation of the Gezira despite the absence of staff gauges, the inaccuracy of adjustments of gate regulators and movable weirs. Night storage played an essential role in the operation after the failure of the communication system in the late 1970s. Elimination of the buffer volume will require a much stricter control of the system, possibly the replacement of all the movable weirs, highly sensitive to upstream variations of levels in the major canals, by orifice type gates, construction of escapes at end of each minor and more generally a profound modernization of the control equipment and operation procedures. Without implementation of a part or all of these measures, there is a serious risk that water distribution will become inequitable and wasteful.

A final answer to this issue of changing the original design of the minor canals is given by the silt monitoring study carried out since 1988. The conclusion is that shift from night storage to continuous irrigation by narrowing the canals will not solve the problem of siltation in the minor canals; it may only transfer the silt to another location in the minor canals.

An answer to the issue itself of continuous versus night storage irrigation may be found in a future modernization of the operation of the main branch and major canals. The present indenting system - either based on rules of thumb or on crop requirements - could be substituted by a dynamic regulation system based on monitoring of water levels in the minor canals or by a combination of the two methods.

Field Outlet Gates

The field outlet gates used in the past, and the new sliding gates adopted by MOI, are sensitive to variations of level in the minor canals. The design of the new gate will deter unauthorized resetting and tampering -- an MOI concern. However the openings and closings of the new gates are time consuming and require the intervention of the SGB ghaffirs. It is recommended to test the reaction of the users in one or two subdivisions before deciding on the installation of the new gates at the 29,000 field outlet pipes of the scheme.

Improvement of Farm Management Practices

The causes of low agricultural production in the Gezira are several. We will limit the discussion to the water-related aspects. The clay soils in the Gezira plain show a tendency to waterlogging which reduce oxygen for crop growth and nutrient uptake. Poor irrigation management, excessively wet seasons, and poor irrigation and drainage layout can contribute to waterlogging and therefore reduce yields on Gezira clay soils. Two of the main crops, cotton and groundnuts, are badly affected when the soil become waterlogged, especially while the plants are very young. Water management and other practices must aim at: i) sufficiently high plants when the rains start; ii) reduce time of irrigation waterings and drainage. We will examine four aspects of irrigation management which play a critical role in attaining these objectives: a) time of sowing; b) method of water application; c) length of irrigation; d) pre-irrigation.

a) Time of Sowing

The traditionally recommended period of sowing for the four main crops cultivated in Gezira have been as follows:

Sowing Dates

ELS Cotton	25/07 - 10/08
MS Cotton	15/07 - 31/07
Sorghum	15/06 - 30/06
Groundnut	01/06 - 15/06
Wheat	01/11 - 30/11

In practice crops are often sown later because of a shortage of equipment with which to prepare the land and shortage of Nile water for pre-irrigation and first irrigation. Early establishment of crops would reduce risk of interruptions and harmful delays of operation due to rains. According to some research carried out in Tambul pilot farm on the right bank of Blue Nile on similar soils, best results are obtained when sowing of cotton takes place in late June - early July. A one-week delay result in a yield decline of 0.5 kantar/fd.

Effect of Time of Sowing on Yield

	Variety ELS ACALA 4-42	Variety MS Barac 67B
	-----------kantar/fd-----------	
June 25	9.2	-
July 6-8	7.9	8.5
July 21-23	6.9	8.1
August 13	5.5	-
September 11	-	6.9

"Cotton sown later than mid-July could only be thinned in September owing to heavy rainfall in August. Cotton planted earlier than mid-June begins to open late September. This carries a risk of rain damage in late September-early October. Cotton planted in late July ripens in the cool period starting late November. Cool nights hinder cellulose formation. Then while fly begins to appear and the resulting honeydew is a threat to the marketability of cotton." (Reference 15)

b. Method of Water Application

The traditional method of field water application by basins (by angaya or by hod) promotes waterlogging. The network of cross-bunds of the angaya system prevents the removal of water which may stand for days. Furthermore there is no field drain at the lower end of the numbers so the tenants have no other option than to evacuate drained water if possible on the adjacent number if fallow.

Unlike the angaya system, the furrow system is field self-draining. (Assuming there is possibility of evacuation). The furrow method was tested in the early 1970s in the Tambul pilot farm. Experiments have demonstrated the feasibility of the method in the clay soils of Gezira. Several systems to control the stream of each furrow, by syphon or by short pipe were tried.

A main disadvantage of the syphon system is the extra head required in the Abu XX and consequently the minor canals. This needs higher bunds resulting in higher construction costs.

The already very low head available at the FOP is a serious obstacle to the generalization of use of syphons which may require a remodelling of the minor structures and night storage weirs. The other alternative is to convey water from the Abu XX through pipes, about one for each feddan. With this system no extra-high bunds are required but the maintenance of the Abu XX could not be done mechanically by a ditcher.

The adoption of the furrow method by the farmers will depend on their perception of the additional labor required for watering the crops and the expected yield increases.

c. Length of Irrigation Periods

The necessary length of irrigation periods were also subject to investigation in the early 1970. The total period of irrigation of ELS cotton is about 26 weeks or even more. It is known that late irrigation in February carries a risk of honeydew contamination and of build-up of insect pests. It also reduces the time for land preparation for the following groundnut. Trials on MS cotton conducted in early 1970s, in Tambul pilot farm indicate that an irrigation period of 18 weeks is advisable followed by a late irrigation. Recent trials of GRS confirmed that irrigation of MS cotton should be stopped in the second fortnight of December, any further irrigation has little effect on yield.

d. Pre-irrigation

Pre-irrigation has been a standard practice in the Gezira scheme for many years. This pre-watering starts in early March and normally takes about two months. However because of lack of water and also of disinterest on the part of the farmers, only a part of the cotton area is treated. Pre-irrigation is a most profitable operation if it is performed on time so cotton crop establishment (including sowing, initial hand-weeding and cotton thinning) can be finished as early as possible to prevent harmful delay during the rainy season.

Measurements indicate that there is usually a compact layer between 40 and 80 centimeters below the surface. Deep plowing and ripping are important to break the compact layer and to increase the water intake and the depth of wetting, which are important for the root penetration and crop response.

GEZIRA IRRIGATION SCHEME IN SUDAN

METEOROLOGICAL DATA FOR WAD MEDANI

	Period	J	F	M	A	M	J	J	A	S	O	N	D	Yearly
Rainfall, average (mm)	1941-75	-	-	-	1	15	27	110	131	52	17	-	-	354
Rainfall, average (mm)	1971-80	-	-	-	3	13	27	94	96	57	8	1	-	299
Absolute max. daily rainfall (mm)	1941-60	-	-	6	11	48	37	118	71	72	42	7	-	
Temperature (degree C)														
mean max.	1941-75	33.4	35.1	38.3	40.8	41.4	39.6	35.8	33.4	35.2	37.8	36.5	33.6	36.7
mean min.	1941-75	14.0	15.2	18.3	21.2	24.0	24.7	22.8	22	21.8	21.6	18	14.5	19.9
average, (max. + min.)/2	1941-75	23.7	25.1	28.3	31.0	32.7	32.1	29.3	29.3	28.5	29.7	27.2	24.1	28.3
abosulte max.	1941-70	40.7	43.5	44.6	46.1	46.2	45.3	43.6	43.6	40.7	41.2	40.7	39.6	-
absolute min.	1941-70	5.2	3.3	7.3	12.0	15.6	16.7	18.5	18.5	17	13.8	8.7	4.8	-
Relative humidity mean (%)														
06.00 GMT*	1941-70	38.0	29.0	22.0	18.0	30.0	48.0	68.0	79	72	52	37	40	44
12.00 GMT	1941-70	18.0	13.0	10.0	9.0	15.0	23.0	39.0	51.0	42.0	27.0	19.0	19.0	24.0
18.00GMT	1941-70	30.0	22.0	16.0	15.0	23.0	35.0	55.0	69.0	62.0	45.0	34.0	33.0	37.0
Wind speed, mean (m/s)	1941-70	3.6	4.0	3.6	3.1	3.6	4.5	4.5	4.0	3.1	2.2	3.1	4.0	3.6
Evaporation, Eo (Penman) (mm)	1957-68	177.0	189.0	247.0	256.0	280.0	282.0	244.0	206.0	206.0	204.0	180.0	171.0	2632.0

Source: Agro-climatological study in the Ara Countries 91976), except for evaporation data which were supplied by the Gezira Research Station (GRS)
*GMT = Greenwich Mean Time

Table 2

GEZIRA IRRIGATION SCHEME IN SUDAN

Crop Water Requirements by Penman Method
Crop Factor

Period	Cotton ELS	Cotton MS	Groundnuts Ashford	Groundnuts Barberton	Wheat	Dura
May 1	-	-	-	-	-	-
May 2	-	-	-	-	-	-
May 3	-	-	-	800*	-	-
June 1	-	-	800*	0.50	-	-
June 2	-	-	0.50	0.55	-	-
June 3	-	-	0.53	0.65	-	-
July 1	-	-	0.59	0.78	-	800*
July 2	-	-	0.68	0.95	-	0.50
July 3	600*	600*	0.78	1.01	-	0.55
Aug 1	0.50	0.50	0.91	1.11	-	0.70
Aug 2	0.50	0.50	1.01	1.03	-	0.94
Aug 3	0.53	0.57	1.09	0.93	-	1.10
Sept 1	0.58	0.67	1.10	0.80	-	1.14
Sept 2	0.65	0.85	1.07	0.70	-	1.08
Sept 3	0.81	0.99	1.03	-	-	0.93
Oct 1	1.01	1.12	0.89	-	-	0.80
Oct 2	1.10	1.20	0.80	-	-	0.70
Oct 3	1.13	1.20	-	-	400*	-
Nov 1	1.17	1.21	-	-	0.50	-
Nov 2	1.20	1.21	-	-	0.66	-
Nov 3	1.18	1.11	-	-	0.87	-
Dec 1	1.16	0.92	-	-	1.07	-
Dec 2	1.15	0.75	-	-	1.15	-
Dec 3	1.11	0.68	-	-	1.18	-
Jan 1	1.00	-	-	-	1.11	-
Jan 2	0.95	-	-	-	0.95	-
Jan 3	0.86	-	-	-	0.76	-
Feb 1	0.77	-	-	-	0.60	-
Feb 2	0.68	-	-	-	0.50	-
Feb 3	0.68	-	-	-	-	-
Mar 1	-	-	-	-	-	-
Mar 2	-	-	-	-	-	-
Mar 3	-	-	-	-	-	-
Apr 1	-	-	-	-	-	-
Apr 2	-	-	-	-	-	-
Apr 3	-	-	-	-	-	-

* Pre-irrigation in mm.

Table 3

GEZIRA IRRIGATION SCHEME IN SUDAN

Monthly Crop Water Requirement
(M3/Feddan)

	Cotton ELS	Cotton MS	Wheat	Groundnut	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

Source: Gezira Rahabilitation Project, Staff Appraisal Report.

Notes: 1. Crop requirements are at field outlet pipe taking into account the staggered planting dates and requirements for initial irrigation.
2. Crop requirements are calculated using the crop factor based on GRS field measurements (GRS 1979), and the Penman Eo at Wad Medani.

Table 4

GEZIRA IRRIGARION SCHEME IN SUDAN
Water Demand at Sennar Dam
(Million M3)

	1983/84	1984/85	1985/86	1986/87	1987/88
Annual Rainfall (mm)	168.0	51.0	279.0	231.0	187.0
Crop Requirements					
ELS Cotton	1,845.6	1,838.7	2,002.7	1,748.9	1,267.3
MS Cotton	631.5	499.4	102.0	362.1	606.1
Wheat	713.2	0.0	650.6	482.6	677.0
Groudnut	560.5	873.4	420.7	619.8	654.7
Dura	1,511.3	1,545.4	2,129.2	1,648.2	1,435.8
Vegetable	394.5	282.6	332.1	399.4	451.5
Green Belt & Domestic	292.0	292.0	292.0	292.0	292.0
Total Field Requirements	5,948.6	5,331.5	5,597.0	5,553.0	5,384.4
Effective Rainfall	494.0	150.0	820.2	679.0	550.0
Net Requirement	5,454.6	5,181.5	4,777.0	4,874.0	4,834.4
Total At Sennar	6,061.0	5,757.0	5,308.0	5,415.0	5,372.0

Table 5

GEZIRA IRRIGATION SCHEME IN SUDAN

INTENSIFICATION OF IRRIGATION

IN THE MAIN GEZIRA DURING THE 1960'S

	Cotton	Wheat	Total	Cropping Intensity(%)	Seed Cotton yield kg/ha
	--------000 feddan----------				
1960-61	246	5	461	47	903
1961-62	240	10	439	45	2236
1962-63	240	14	466	47	1455
1963-64	248	21	464	47	610
1964-65	251	75	514	51	1263
1965-66	250	75	541	54	1138
1966-67	283	88	619	55	1485
1967-68	290	98	668	58	1435
1968-69	294	122	696	59	1788
1969-70	296	127	746	63	1775
1970-71	305	129	751	62	1775

1) including cotton, wheat, groundnut sorghum and vegetables.

Table 6

GEZIRA IRRIGATION SCHEME IN SUDAN
Monthly Water Releases from Sennar Dam
(Million M3)

Month	1983/84	1984/85	1985/86	1986/87	1987/88
June	623.3	668.0	183.5	202.6	199.6
July	731.2	910.1	589.4	521.2	609.4
August	810.5	919.5	767.7	691.3	509.9
September	973.5	949.1	571.0	544.0	685.5
October	910.1	566.2	756.7	890.2	867.1
November	755.4	471.2	858.2	748.0	880.6
December	642.2	641.8	701.9	582.6	924.4
January	544.2	529.5	515.0	508.2	562.6
February	377.2	337.7	461.0	392.9	511.2
March	79.1	85.9	381.3	187.0	309.5
April	62.3	114.3	86.2	44.1	58.5
May	302.5	299.7	85.0	71.0	98.0
Total	6,313.5	6,448.0	6,156.9	5,383.1	6,216.3
Water Demand	6,061.0	5,757.0	5,308.0	5,415.0	5,372.0
Ratio Releases/ Requirements	1.04	1.12	1.16	0.99	1.16

Table 7

GEZIRA IRRIGATION SCHEME IN SUDAN

ACTUAL OPERATION AND MAINTENACE EXPENDITURES OF MINISTRY OF IRRIGATION FOR THE GEZIRA SCHEME

	1985/86	1986/87	1987/88	1985/86	1986/87	1987/88
	----------Current LS-------------			--------1988 Constant LS--------		
Chapter I (salaries & allowances)	2,700,000	3,780,000	3,780,000	4,752,000	5,178,000	3,780,000
Chapter II						
Operation & Maintenance (Civil)	17,498,000	19,919,349	23,446,375	30,796,480	27,289,508	23,446,375
Operation & Maint.(Mechanical)	1,991,500	2,604,789	1,818,360	3,504,160	3,568,560	1,818,360
Administration	875,000	1,000,000	1,000,000	1,540,000	1,370,000	1,000,000
Chapter III						
Betterment of irrigation means	825,000	825,000	825,000	1,452,000	1,130,000	825,000
Removal Sennar dam gates	148,500	148,500	148,500	261,360	203,445	148,500
Roseries Dam recovery	858,000	858,000	858,000	1,510,080	1,175,460	858,000
Managil Scheme Recovery	3,774,000	3,774,000	3,774,000	6,642,240	5,170,380	3,774,000
	28,670,000	32,909,638	35,650,235	50,459,200	45,086,204	35,650,235

Note

	1985/86	1986/87	1987/88
Inflation:	1.76	1.37	1.00
Exchange Rate:	2.70	3.00	4.17

Table 8

GEZIRA IRRIGATION SCHEME IN SUDAN

CROPPING INTENSITY IN

GEZIRA SCHEME 1978/79-87/88

SEASON	CROPPING INTENSITY %	
	POSSIBLE	ACTUAL
78/79	86	75
79/80	86	71
80/81	86	65
81/82	86	63
82/83	86	54
83/84	86	63
84/85	86	53
85/86	82*	64
86/87	79	58
87/88	75	58
88/89	75	60**

Note: * Start of change from 3 to 4- course rotation.

** Provisional.

Table 9

GEZIRA IRRIGATION SCHEME IN SUDAN
Harvested Cotton Areas in Gezira Scheme
(fd)

	ELS Cotton (1)	MS/LS Cotton (2)	Total (3)	Cotton Serial (4)	Gap (4)-(3)
1980/81	437,127	84,933	522,060	610,000	87,940
1981/82	382,146	56,460	438,606	610,000	171,394
1982/83	376,742	109,864	486,606	610,000	123,394
1983/84	347,706	154,154	510,575	610,000	99,425
1984/85	362,677	127,530	490,207	610,000	119,793
1985/86	390,110	25,569	415,879	610,000	194,121
1986/87	331,405	88,008	419,458	580,000	160,542
1987/88	238,524	156,545	385,069	530,000	144,931
1988/89	223,281	181,224	404,505	530,000	125,495

Table 10

GEZIRA IRRIGATION SCHEME IN SUDAN

ELS COTTON YIELDS (SEED COTTON)

IN GEZIRA SCHEME SINCE 1978/79

SEASON	YIELDS		
	PROJECTED	ACTUAL	
	Ton/Fd	Ton/Fd	Ton/ha
78/79	-	0.41	0.97
79/80	-	0.35	0.83
80/81	-	0.30	0.71
81/82	-	0.54	1.28
82/83	-	0.61	1.43
83/84	-	0.60	1.42
84/85	-	0.62	1.47
85/86	0.50	0.48	1.14
86/87	0.50	0.67	1.59
87/88	0.54	0.55	1.31
Average 10 years	1.21		
Period 1981/82-1987/88	1.37		

Table 11

GEZIRA IRRIGATION SCHEME IN SUDAN

AVERAGE WHEAT YIELDS IN GEZIRA SCHEME SINCE 1978/79

SEASON	PROJECTED	ACTUAL	
		Ton/fed.	Ton/ha.
78/79	-	0.25	0.59
79/80	-	0.48	1.14
80/81	-	0.23	0.54
81/82	-	0.40	0.95
82/83	-	0.60	1.42
83/84	-	0.39	0.92
84/85	-	0.00*	-
85/86	0.36	0.40	0.95
86/87	0.36	0.53	1.26
87/88	0.39	0.52	1.23

Note: 1984/85 excluded

GEZIRA IRRIGATION SCHEME IN SUDAN

LAND AND WATER CHARGES

CROP	1985/86		1986/87		1987/88	
	CHARGED	RECOVERED	CHARGED	RECOVERED	CHARGED	RECOVERED
GROUDNUTS	3,281,120	1,608,304	6,042,000	4,126,630	7,978,100	4,319,106
DURRA	18,809,472	9,219,826	17,920,200	12,239,333	19,514,750	10,564,706
VEGETABLES	1,712,850	839,586	2,529,520	1,727,639	3,676,410	1,990,299
COTTON	26,722,761	23,516,030	33,205,784	30,881,379	38,692,973	34,823,676
WHEAT	9,688,040	7,169,149	8,827,889	6,620,916	15,634,912	12,507,929
TOTALS	60,214,243	42,352,895	68,525,393	55,595,897	85,497,145	64,205,716
RECOVERY rate (%)		70.34%		81.13%		75.10%

Table 13

GEZIRA IRRIGATION SCHEME IN SUDAN

Example of Water Rate Calculation
Based on Number of Irrigation

(1987/88)

No. of Irrigations	Actual Areas	Conversion Factor	Cotton Areas Equivalent (fed)	
Cotton	16	384,000	16/16	384,000
Wheat	10	300,000	10/16	187,500
Groundnut	8	159,000	8/16	79,000
Sorghum	4	397,000	4/16	99,250
Vegetables	14	27,000	14/16	23,625
Total				773,875

Water rate per feddan of cotton equivalent:

$$\frac{\text{Total expenditure}}{\text{Cotton area equivalent}} = \frac{35,650,235}{773,875} = \text{LS } 46.07$$

Cost of one irrigation:

$$\frac{\text{SP } 46.07}{16} = \text{LS } 2.88$$

Water Rates

	(LS/Fd)			(US$/Ha) (equivalent)
Cotton	2.88 x 16	=	46.07	27.61
Wheat	2.88 x 10	=	28.80	17.26
Groundnut	2.88 x 8	=	23.04	13.81
Sorghum	2.88 x 4	=	11.52	6.90
Vegetables	2.88 x 14	=	40.32	24.17

Table 14

GEZIRA IRRIGATION SCHEME IN SUDAN

Water Rates
Based on
Actually Cultivated Areas

Year	Actual Area Cultivated	Actual Calculated Area	Recoverable Amount	%	Water Rates
(1985/86)	(Fed)	LS/fed	(LS)		(US$/Ha)
Cotton	401,000	37.05	14,857,000	51.80	34.30
Wheat	240,000	23.20	5,568,000	19.50	21.48
Groundnut	103,000	18.50	1,905,000	6.60	17.12
Sorghum	580,000	9.28	5,370,000	18.70	8.59
Vegetables	30,000	32.48	970,000	3.40	30.07
Total	1,354,000		28,670,000	100.00	
(1986/87)					
Cotton	415,000	44.21	18,347,600	55.70	36.84
Wheat	180,000	27.63	4,973,400	15.10	23.02
Groundnut	149,000	22.11	3,294,390	10.00	18.42
Sorghum	443,000	11.05	4,897,630	14.90	9.21
Vegetables	36,135	38.65	1,396,618	4.30	32.21
Total	1,223,135		32,909,638	100.00	
(1987/88)					
Cotton	384,000	46.07	17,690,850	49.60	27.61
Wheat	300,000	28.80	8,639,000	24.30	17.26
Groundnut	159,000	23.04	3,662,330	10.30	13.81
Sorghum	397,000	11.52	4,572,415	12.80	6.90
Vegetables	27,000	40.32	1,085,640	3.00	24.17
Total	1,267,000		35,650,235	100.00	

GEZIRA IRIGATION SCHEME IN SUDAN
MAIN FEATURES OF GEZIRA SCHEME

Location

Country	Sudan
Geographic Coordinates	14 degrees North

Climate

Classification	warm, arid, continental
Average Annual Rainfall	160 mm (North) to 472 mm (South)
Average Annual Temperature	28.3^{o}C
Average Annual Pan Evaporation	2,632 mm

Water Supply

Source	Blue Nile
Type	Annual Regulation
Average Annual Flow	50,000 Mm^3

Water Quality

Classification	C1-S1 (higher flow) to C2-S1 (lower river flow)

Storage Dams

Number	Two
Total Storage Capacity	3.930 Mm^3 (design) reduced to 2.880 Mm^3 by siltation

Purpose	Irrigation/Energy/Flood Control

Conveyance System

Total Length	261 Km
Type	Earth Canals
Maximum Discharge Capacity	186 + 168 m^3/s
Flow Control	Upstream - Manual

Distribution Network

	Length Km	Capacity m^3/s
11 Branch Canals	651	25-120
107 Major Canals	107	1.5-15
1,498 Minor Canals	8,119	0.5-1.5
29,000 Water Courses	40,000	0.116
350,000 Field Channels	100,000	0.05

Irrigation Area

Surface Irrigation	882,000 ha

Soils vertisoils

Main Crops cotton, wheat, sorghum, groundnuts

Land Tenure

Land ownership	tenants (100%)
Average farm size	8.6 ha

O & M Service Public Administration

<u>Water Users' Group</u>	Tenants Union	
<u>Design Operational Procedures</u>		
System of Water Allocation and Distribution	indenting	
Conveyance and Distribution Efficiency	90%	
Field Efficiency	100%	crop water requirements inclusive of field losses
Overall Efficiency	90%	
Average Peak Demand at Headworks	0.4 l/s/ha	
Specific Design Flow at "Number"	3 l/s/ha	116 l/s for 37.8ha (90f)
Concept of Operation	upstream	
Water Measurement System	Flow control	
Water Measurement Device	Moveable weir	Head of minor
Rate of Flow to Water Course	116 l/s	
<u>Project Description</u>		
Storage Dam	Roseires	
Diversion Dam	Sennar	
Operating Wells (No.)	0	
Pumping Stations	14	

Conveyance Network (m/ha)	0.29 m/ha	two main canals combined capacity 345 m^2/s - 261 km
(lined)	0	
(unlined)	100%	
Distribution Network (m/ha)	11.8 + 45 m/ha	branch, major and minor canals: 10,422 km; water courses:40,000km
	-	
(lined)		
	100%	
(unlined)		
	37.8 ha	
Area served by Farm Turnout	7.3	
Drainage Canals (m/ha)	Yes	
Linkage between Irrigation and Farm Layout		

Present Status

Dams	Sennar: gates need urgent repair Roseires: good
Pumping Stations	Rehabilitation underway
Conveyance System	good
Distribution Canals	silt and weed clearance required
Farm Turnouts	100% of gates have been moved away
Earth Irrigation Canals of Farm Network	Fair
Hydromechanical Equipment	Poor

Drainage Canals	100% silted
Need for Rehabilitation	High
Need for Improvement	High

<u>Actual Project Performances</u>

Water Allocation/ Distribution System	Indent by SGB combined with management of FOP gates taken over by farmers
Conveyance/Distribution Efficiency	93%
Field Efficiency	75%
Overall Efficiency	70%
Average Annual Water Demand at Headworks	7,030 m^3/ha
Average Peak Water Demand at Headworks	0.4 l/s/ha
Flexibility in Water Distribution	High
Equity in Water Distribution	High (when canals are clean) to very poor
Reliability in Water Distribution	High (when canals are clean) to very poor
Timeliness in Water Distribution	High (when canals are clean) to very poor
	No measurement at FOP gate

Water Management System			
Negative Environmental Impact			
o Waterlogging	No		
o Salinization	Fringe Areas		
o Siltation	Very high		
Rate of Flow delivered to users	40 to 60 l/s in practice		

<u>Operation and Maintenance</u>

O & M Staff (No.) excluding EMC and IWC	6,820 (MOI: 4,900; SGB:1,920)		MOI: Gezira Directorate:3,210
Net Irrigation Area per O & M Staff	120		Mechanial Electrial Dept. 1,387 1/
Net Irrigation Area per Ditchrider (SGB ghaffir)	1,200 fd (504 ha)		Administration: 288 1/ 1/ prorated
Farm Turnouts per Ditchrider (SGB ghaffir)	13		
Farmers per Ditchrider	60		
Operation	Questionable		
Maintenance	Insufficient		
O & M Total Expenditure (1987/88)	<u>Official rate</u> 8,569,000 US$	<u>Commercial rate</u> 2,946,000 US$	

Expenditures on O & M
(including energy)

	1986/87	1987/88
o per irrigable area (ha)	9.69 US$	3.34 US$
o per net irrigated area (ha)	16.7 US$	5.75 US$
o per diverted volume (1,000 m^3)	1.37 US$	0.47 US$
o per delivered volume at farm turnouts (1,000 m^3)	1.47 US$	0.50 US$

Land and Water Charges	1986/87	1987/88	1986/87	1987/88
	----------Ls/fd---------		US$/ha (at commercial rate)	
Cotton	101	130	19.9	25.6
Wheat	62	95	12.2	18.7
Groundnut	50	55	9.8	10.8
Sorghum	50	55	9.8	10.8
Vegetables	90	130	17.7	25.6
Recoverable rate (%)	80.2	79.5		
Collection rate (%)	81.1	75.1		
Recovery rate (%)	65.0	59.7		

Water User's Groups — Tenants' Union

Agricultural Production
(Average)

Cropping Intensity (%) — 62%

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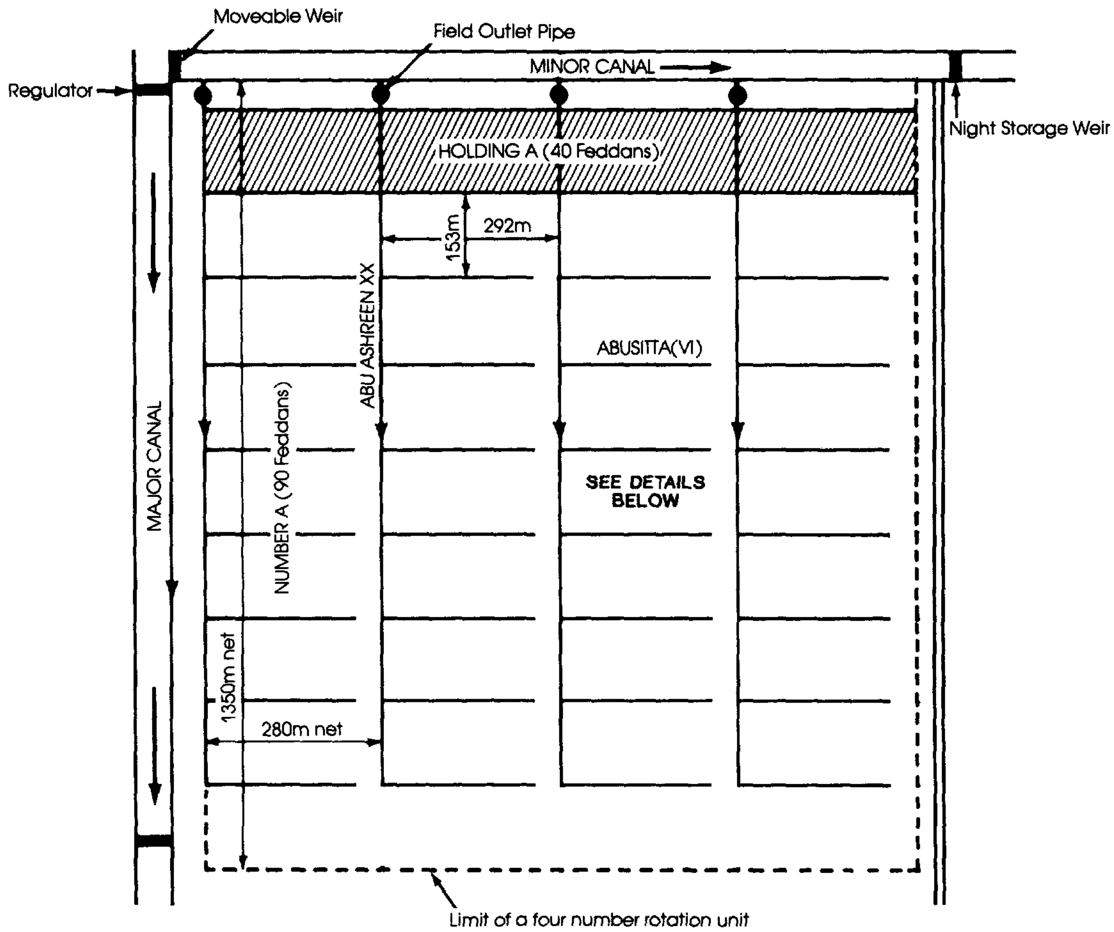
FIGURE 1

SUDAN
GEZIRA IRRIGATION SCHEDULE
Typical Field Layout



ORIGINAL DETAILED FIELD LAYOUT OF A 10 FEDDAN HAWASHA

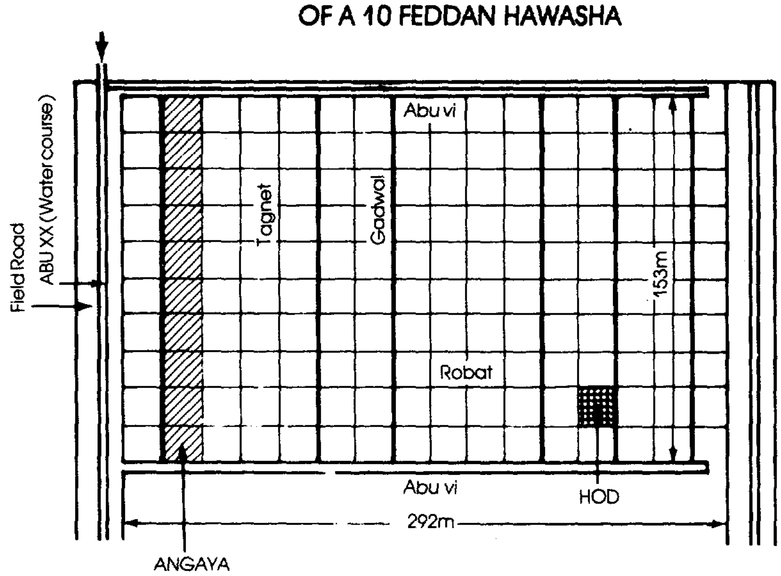


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FIGURE 2

EVAPORATION AND RAINFALL AT WAD MEDANI

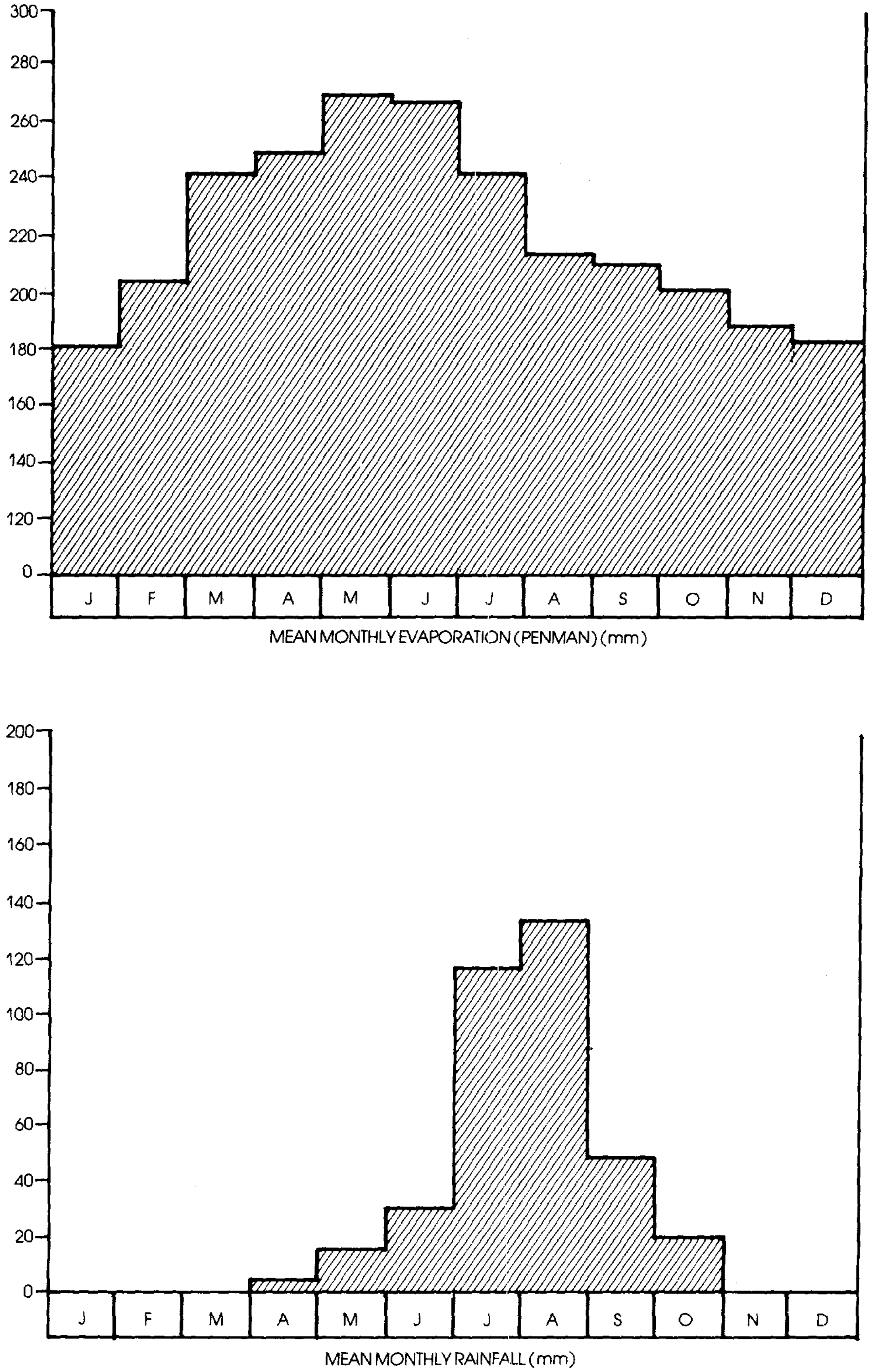

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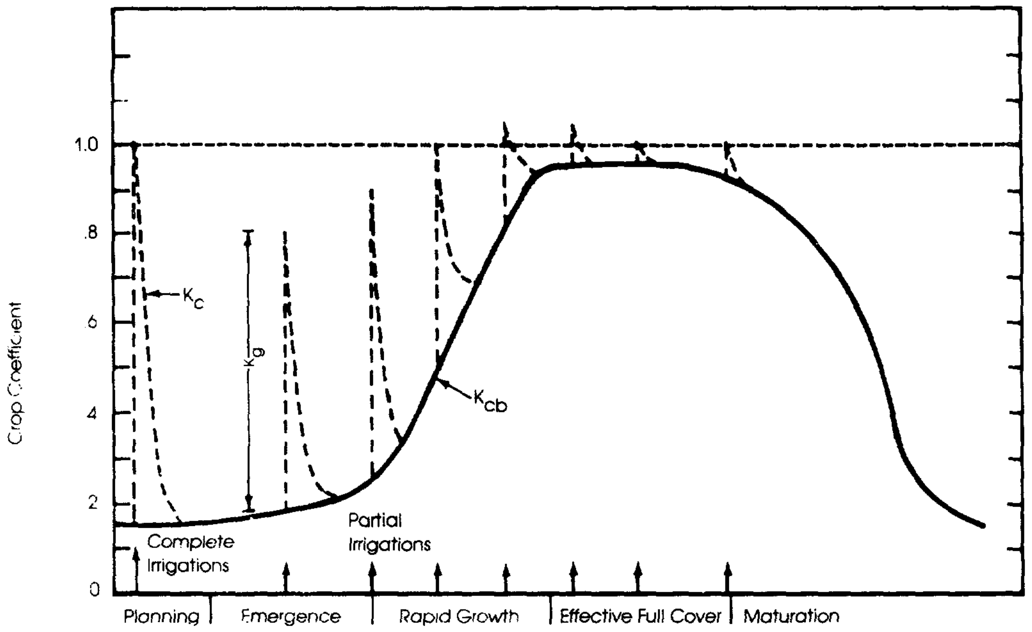
FIGURE 3

EFFECT OF PROLONGED SOIL WETNESS ON CROP COEFFICIENT



ET crop coefficient curve (K_{cb}) with adjustment for increased evaporation due to surface soil wetness (K) to determine the over-all crop coefficient (K_c).

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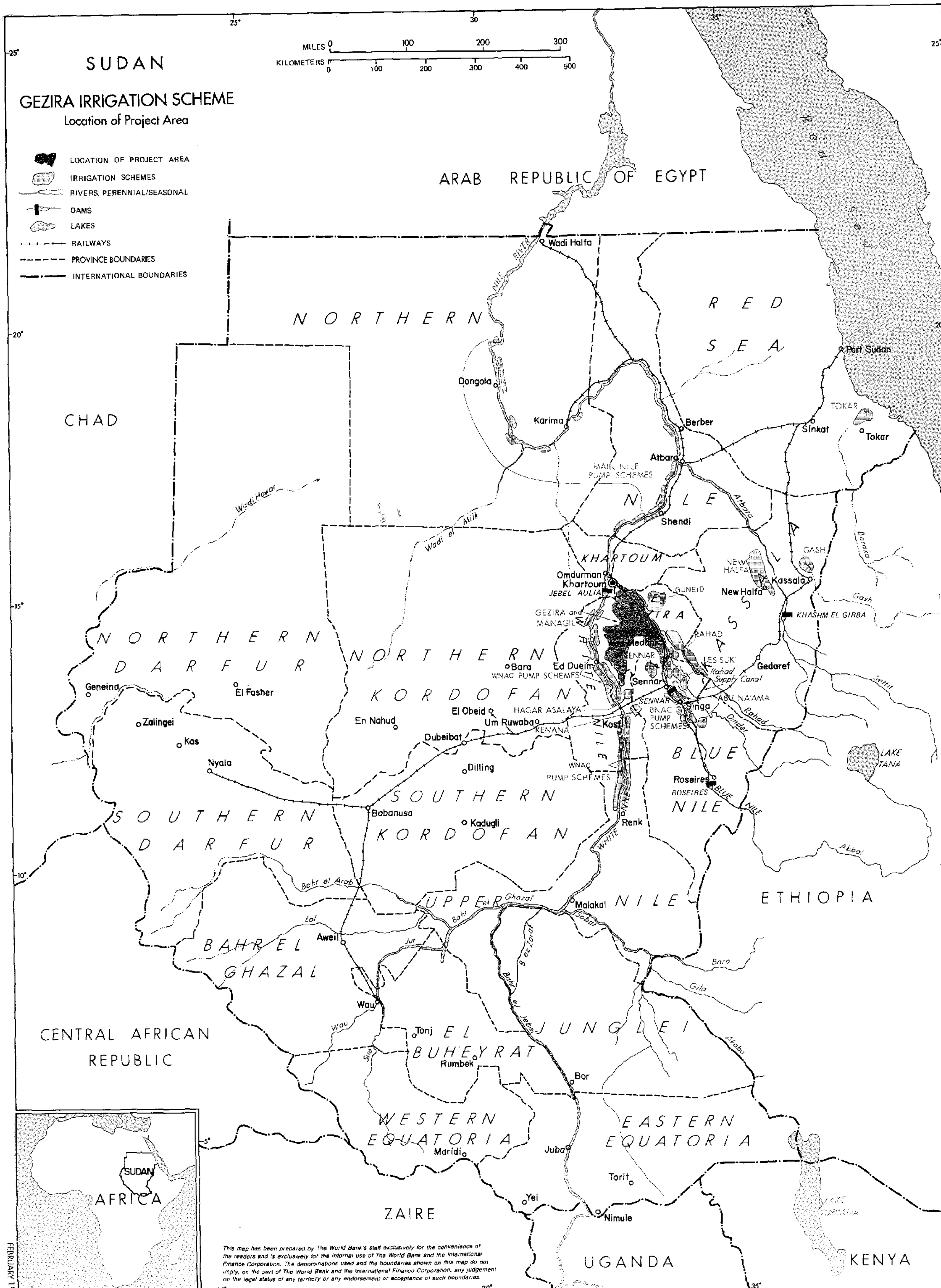

SUDAN
GEZIRA IRRIGATION SCHEME
Location of Project Area
LOCATION OF PROJECT AREA
IRRIGATION SCHEMES
RIVERS, PERENNIAL/SEASONAL
DAMS
LAKES
RAILWAYS
PROVINCE BOUNDARIES
INTERNATIONAL BOUNDARIES
MILES 0 100 200 300
KILOMETERS 0 100 200 300 400 500
ARAB REPUBLIC OF EGYPT
CHAD
CENTRAL AFRICAN REPUBLIC
ZAIRE
UGANDA
KENYA
ETHIOPIA
NORTHERN
RED SEA
NILE
KHARTOUM
KASSALA
NORTHERN DARFUR
SOUTHERN DARFUR
NORTHERN KORDOFAN
SOUTHERN KORDOFAN
BLUE NILE
UPPER NILE
BAHR EL GHAZAL
EL BUHEYRAT
JUNGLEI
WESTERN EQUATORIA
EASTERN EQUATORIA
Wadi Halfa
Dongola
Karima
Berber
Atbara
Shendi
Port Sudan
Sinkat
Tokar
TOKAR
MAIN NILE PUMP SCHEMES
Omdurman
Khartoum
JEBEL AULIA
GUNEID
GEZIRA and MANAGIL
NEW HALFA
New Halfa
Kassala
GASH
KHASHM EL GIRBA
RAHAD
LES SUK
Rahad Supply Canal
Gedaref
Sennar
SENNAR
ABU NA'AMA
Singa
BNAC PUMP SCHEMES
Ed Dueim
Bara
WNAC PUMP SCHEMES
El Obeid
HAGAR ASALAYA
Um Ruwaba
KENANA
Kosti
En Nahud
Dubeibat
Dilling
WNAC PUMP SCHEMES
Roseires
ROSEIRES
LAKE TANA
Renk
Babanusa
Kadugli
El Fasher
Geneina
Zalingei
Kas
Nyala
Malakal
Aweil
Wau
Tonj
Rumbek
Bor
Juba
Maridi
Torit
Yei
Nimule
Wadi Howar
Wadi el Milk
NILE RIVER
Atbara
Baraka
Gash
Setit
Rahad
Dinder
BLUE NILE
WHITE NILE
Abbai
Bahr el Arab
Bahr el Ghazal
Lol
Jur
Sobat
Bahr ez Zeraf
Bahr el Jebel
Baro
Gila
Akobo
Wau
Sue
Red Sea
LAKE TURKANA
SUDAN
AFRICA
25° 30° 35°
25° 20° 15° 10° 5°
FEBRUARY 1990
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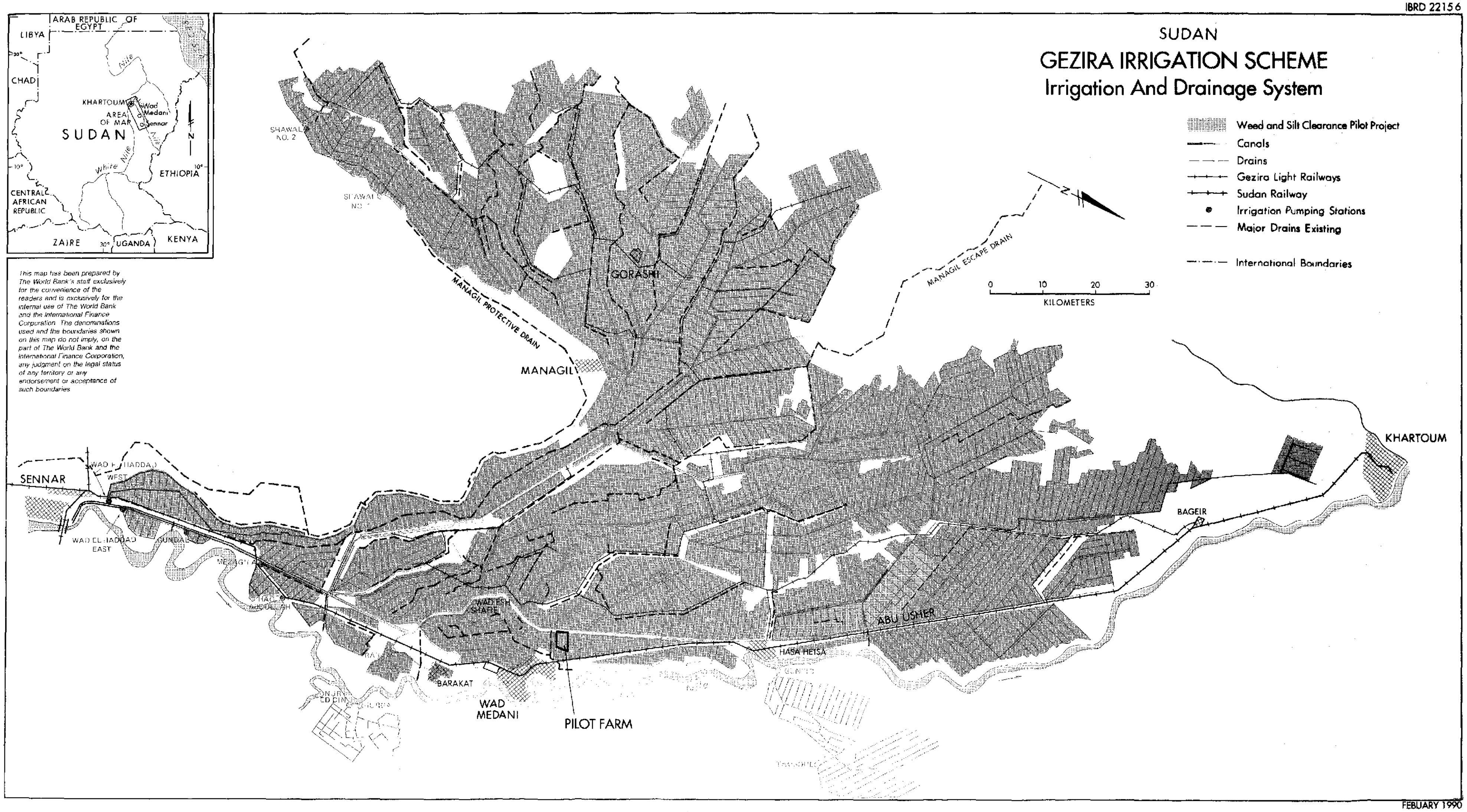

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Irrigation And Drainage System
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Canals
Drains
Gezira Light Railways
Sudan Railway
Irrigation Pumping Stations
Major Drains Existing
International Boundaries
0
10
20
30
KILOMETERS
ARAB REPUBLIC OF EGYPT
LIBYA
CHAD
KHARTOUM
AREA OF MAP
Wad Medani
Sennar
SUDAN
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