Nile Basin Initiative

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Pilot Study on Improving Water Use Efficiency and Productivity on the Rahad Irrigation Scheme - Sudan

FINAL REPORT

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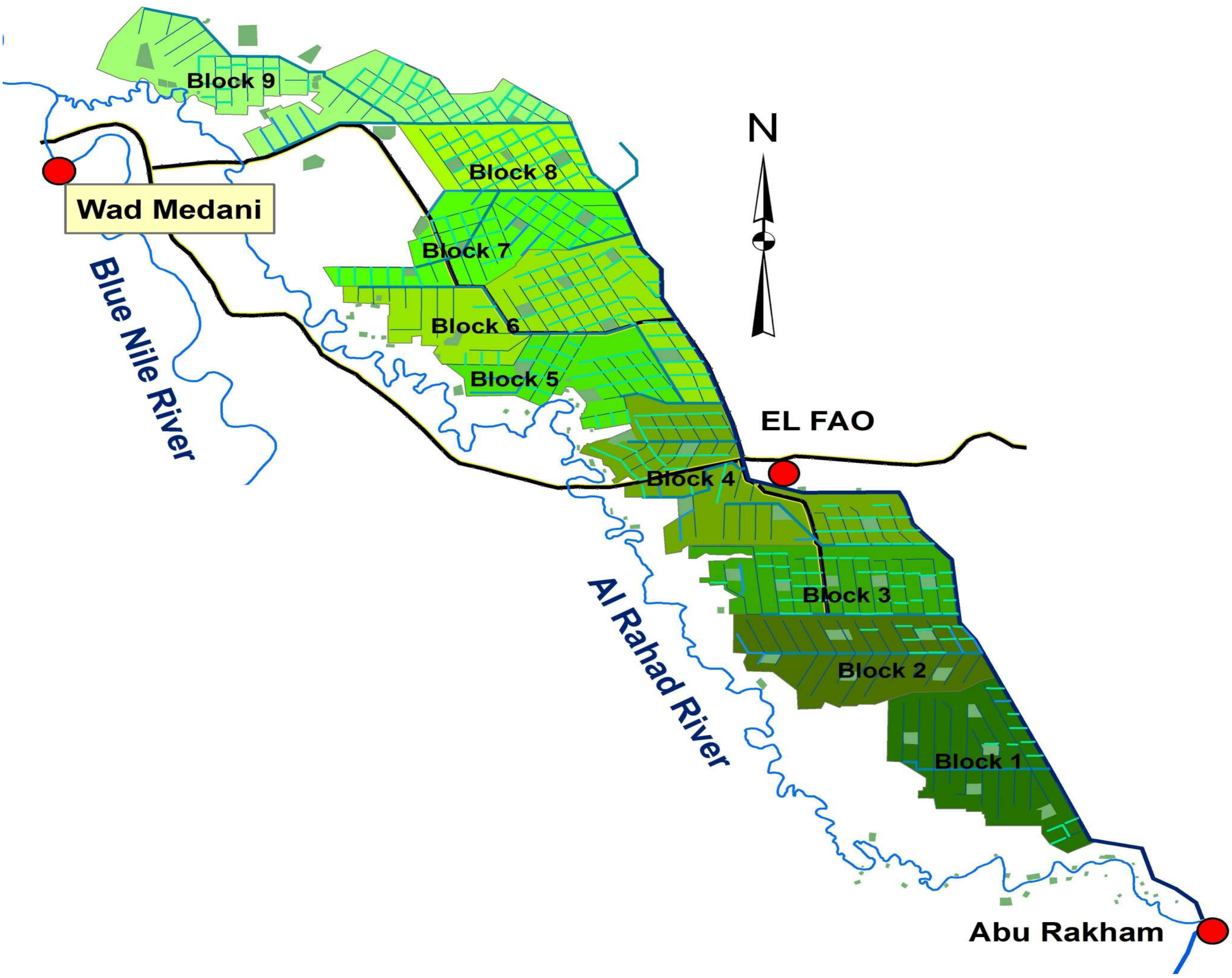

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EXECUTIVE SUMMARY

The Study Team was commissioned to carry out two tasks in this assignment. The first was to assess the performance of RIS using a range of indicators, both formal and informal, and compare the scheme's overall performance rating with that attributed by EWUAP's LSI Study. The second task was to prepare an Action Plan for remedial works, cost it and evaluate the expected benefits, and carry out a cost benefit analysis.

In respect of performance, RIS is a poor performer. While the LSI Study rated RIS as the second best performer in Sudan, with an overall average of 3.29, this team's conclusions, (an overall average of 2.23) are that it is poor performing beset with difficulties (see Table 3-25 Actual Values for RAHAD from the EWUAP LSI Study).

In respect of water and engineering indicators (see section 3.1):

- Adequacy (the satisfaction of crop demand) was rated poor (0.72), with a high variance
- Dependability (temporal variability and planning reliability) was rated poor (0.82) with a moderate variance
- Equity (spatial distribution) was rated consistently poor over the analysis period (0.7)

In respect of agronomic indicators (see section 3.2):

- In Actual EC (CWC) is about 5,800 m^3 per ha overall and the Crop Water Deficit is about 440 m^3 per ha using very crude calculations based on the HHS. These compute to indicators of 3.1 and 3.0 respectively, which compare favourably with the LSI study.
- .Comparing all the performance indicators from the LSI study with the pilot study, found that 4 indicators were agreeable, while 4 were not agreeable. Two indicators were not evaluated.

In respect of institutional indicators (see section 3,3):

- Government institutions: due to budget constraints and the dependency attitude of the farmers, functionality of the scheme deteriorated in the last 5 years; overall functionality of institutions is rated poor (4).
- Farmers Institutions: overall, performance of farmers' institutions in Rahad on MOM, O&M, and others is poor (4)
- Extension services: performance assessment is poor (4).

In respect of environmental and economic indicators (see section 3.4):

- the yield of main crop per scheme hectare (30 year average) was 1,005 kg/ha which is very low
- The Relative Water Cost indicator over the last years has increased to about 0.30: payment for water is the principle cost in tenant farmers' gross margins
- The O&M fraction is calculated as 0.53: this is a very poor value, and accounted for by RAC overhead salaries and administration
- The MOM funding indicator is the cost of MOM to the farmer as a ratio of net farm income: it has been calculated as 0.27 which is very high
- The scheme level Crop Area Ratio shows steady growth to about 0.8 in 1981, and improved to nearly 0.9 in the mid 1990s. Since 1995 the trend has been steadily downwards with marked dips in 1998 and 2003 which were flood years and caused widespread crop losses; now the CAR is about 0.6 which is very low
- Dependability is poor: a reduction in main delivery in August and September (due for example to late Rahad River flow or problems at Meina Pump Station) can reduce the planted to harvested area ratio significantly: and lead to financial losses of about SDG 0.015 per m^3 in crop inputs and unrealised yield

- The scheme first made a positive FIRR in 1993 and achieved quite good financial progress until 1996, when the net value of crop production declined until 1999. Since then slow but consistent increases in scheme return have been made and by 2007 the FIRR of the scheme was 2.7%. This is a very low return on the investment cost of US$ 400 million and does not include deferred maintenance, which is being made good by the on-going rehabilitation programme.

The Detailed Action Plan
Hydraulic Engineering

RIS was reached an all time low in its performance. An action plan has been prepared to reverse its fortunes, acknowledging the fact that Kanana Sugar Company has already taken over management of 50% of the command area, and is undertaking cultivation on behalf of tenants on a further 40,000 feddan. Further, rehabilitation funded by Islamic Bank and OPEC is in progress and will only begin to impact on production in the 2010/11 cropping season. The Study Team consider both of these activities part of the present situation. The "future with project" must analyse the impact of recommendations made by this study, assuming that with or without the recommendations made by this Study, Kanana Sugar will have water allocation to irrigate to maximum irrigation design on their share of the command area. However, without the recommendations made in this study, the Study Team envisages that the rehabilitation works presently being carried out will be effective for only five years, in which case the water share of tenant farmers will be eroded to nothing. These observations provide the justification for analysing the costs and benefits identified by this study exclusively on the operational area of tenant farmers: 130,000 feddan. However, it is acknowledged that Kenana Sugar may benefit from reductions in operational costs (in particular a reduction in the need for de-silting) as a result of the civil works proposed for the feeder and main canals.

The Study Team propose the following Action Plan. Starting at the top (South) of the project, at Maina Pump station the following action is planned:

The Meina Pump station has inadequate protection from siltation. The solution to this problem is to move the pump station to the river and reduce the deposition during flood flows. As this cannot happen, the river can be moved to the pump station, by opening the banks and allowing the river to flow directly past the pump intake, cleaning as it passes. A section of the Nile bank for 400 m upstream and 400 m downstream could be removed and a zone of gabion protection can be incorporated for 100 m either side. Once the protection is complete, the river could be opened using the cheapest form of soil removal, the dredger, allowing the river to clean away any deposited sediment. Pumping could then continue un-interrupted for year to come.

The Dinder siphon has proved to be a major bottle neck in the operation of the supply canal. The main reason for this is the operation of the pumps during the high sediment flows (July to September) which deposit large quantities of sediment in the canal. Poor operation of the siphon by opening too many barrels reduces the velocity and leads to deposition. For the siphon to be self cleaning (non-depositing) the velocity needs to maintained at a high level of about 3.0 m/s. The study looked at the possibility of turning the siphon into an aqueduct. The existing roof to the siphon barrels would be demolished at the entrance and exit of the siphon and a new floor cast for the aqueduct. There is sufficient capacity below the proposed aqueduct to pass the maximum Dinder flood. The structure will be built directly on top of the existing siphon, using the buried barrel as a foundation.

Sediment transport into RIS needs to be reduced from its current estimated level of 500,000 m^3 per year. Sediment concentrations in the Rahad River were plotted against river flows, canal flows and pumped flows and show that when the concentration is multiplied by the Rahad River flows there is a peak rate of sediment transport in July, which drops off sharply in August and September. These three months represent the greatest movement of sediment, and it is during these times that maximum effort is needed to reduce its importation. This study proposes to construct a large settling basin right beside the head works at Abu Rakham where some old low lying ox-bow depressions are found. A survey was made of these depressions which are very suitable for constructing this settling pond. The main method of settlement would be slow moving water. The design flow would be appropriate for the water requirements at that time of year when sediment is highest, in July. The effectiveness of the settlement will change from year to year as different concentrations are found, but this system can be improved by adding inclined tube clarifiers to increase deposition. The settlement ponds would only operate for three months of the year, July, August and September. The following three months would be used to clean the ponds using a floating dredger.

Canal automation should be introduced. Since the construction of the Gezira Scheme, Sudan has utilised centralised control of its irrigation using indenting or 'fixed-rate arranged scheduling. This all breaks down when there is little supply of water to control, and the main problem remains as zero flexibility. For this reason, the study recommends the installation of downstream control systems to change over from upstream central control to downstream user control. By this on-demand system, the farmer has complete control over time and amount of irrigation. Combined with this change should be a method of water charge based on water use, not on area irrigated. This will discourage wastage and allow the farmer much more freedom to irrigate at times suitable to his needs. Different crops can also be irrigated giving more freedom for farmers to grow crops with higher returns. With the strengthening of the WUA, farmers should be more inclined to police other water users who are wasting water. Central to this premise is that farmers have to be re-educated from "trained to wait" to "trained to take the initiative". The proposed structure for this downstream control is the Automatic Diaphragm Valve (ADV). The only place where the farmer controls his application is at the head of each abu-xx or d/abu-xx. By using 'Hydroflume' type delivery system, the only gate that needs to be controlled is the one in the 'Hydroflume' at the head of the level furrow. Thereafter all canal flows are automatic. With a proposed furrow irrigation set of 11.0 hours, the farmer can irrigate at night or day, and have a long time free to do other tasks.

On-farm irrigation improvements are essential. In Rahad, there is definitely a need for land smoothing. Most fields in RIS have underdone re-shaping due to the sediment importation and cultivation practises that have existed over the last 30 years. Fields have ended up as dish-shaped with high spots either side of the Abu-XX leading to local flooding. As well as land smoothing field drains must be constructed to improve irrigation efficiency and productivity. Kanana Sugar Company are expected to introduce some innovative approaches to on-farm irrigation but the Kanana Estate is very steep (up to 300 cm/km) relative to RIS at 20 to 40 cm/km. This makes the Kanana long furrow approach difficult to implement. The study put attention on the in-field efficiency of the furrow irrigation with the intention of identifying the most efficient system of irrigation these very flat soils. Two furrow design equations were evaluated in different conditions of slope and furrow length to determine and compare efficiencies. The results show that the very flat slopes give very poor irrigation efficiencies. Furrow irrigation on these flat slopes is going to be inefficient, no matter what length. With the very poor furrow efficiencies experienced at Rahad, the attraction of mechanical irrigation becomes large. With efficiencies of 90 to 95%, and high uniformity, drip and centre pivot irrigation are definitely worth consideration. Both centre pivot and linear move irrigation are already widely used in Sudan with good back up services. This study does not however consider the inclusion of these systems for small tenants at this time. The 'Hydroflume', (a plastic lay-flat pipe with screw gates for controlling flows) eliminates the use of siphons which are labour intensive and disliked by Rahad tenants. This study therefore recommends the adoption of combining at least two numbers into one new number and cleaning out one abu-xx. This would have to be combined with land smoothing of all abu-xx to remove all evidence of the dish-shaped fields and the construction of field drains. Minor drains need to be deepened by at least 1.0 m for at least half their length. New culverts will have to be installed at the exit to the collector drain. There is also other permanent loss of land from annual flooding. Deepening of the minor drains will require that all collector and main drains should also be deepened. This will benefit the whole project which sees annual local flooding in most of the fields.

Agriculture

All farmers interviewed during the FDGs showed high awareness about importance of water for high yields. Despite that, most of them, they do not actually apply this in their daily farming practice. The reasons for this are partly economic – the reliability of water supply and its cost being not least. The performance indicators show that RIS is in a down-spiral of performance, with poor technical performance and high costs - high O$M costs mostly due to silting of drains and canals and very high management costs as a legacy of RAD. Costs are high in relation to household incomes and tail enders go out of irrigation, the irrigated area contracts, overhead costs rise per unit area and more farmers go out of business.

Therefore an intensive training of farmers will be suggested to take place regarding the necessity to improve productivity. This will be done on two fronts. One will be concerned with new approaches to in-field irrigation; the second will be to train the farmers "not to wait". Farmers will be advised on a new approach to production

– higher input, higher yield and higher gross margins. More self help will be encouraged through the promotion of local water user organisations. Credit for incremental crop inputs will be made accessible.

The impact of this extension effort – and the proposed hydraulic engineering interventions - will be seen through farmers' consumption of water and the means of paying for it. RIS farmers find it difficult particularly difficult to meet this cost because of low productivity, which is several times lower than the productivity of irrigated crops should be. However, without the inclusion of a water charge that meets the sustainability of the project, the project should be closed down. It is this very aspect of lowering the water charge that starts the downward cycle of poverty because it goes hand in hand with the provision of water. If the administration cannot meet the needs of maintenance, as in the past, then there is a rapid spiral to un-sustainability. So what comes first, adequate maintenance paid by an outside source, or adequate production with sufficient income to pay the high water charge and support the level of maintenance required? In fact, both must be maintained at a high level from the start. Also the method of determining the charge should be changed to one if not by volumetric basis, at least one per irrigation basis. This is an essential component of changing the farmer's view of water. He must pay for what he uses, not by area. Payment by area leads to wastage on a large scale as there is no incentive for farmers at the head to use water efficiently. Only when farmers pay by usage will they respect water and its conservation. The proposed water charge is calculated by dividing the total annual maintenance budget by the total volume of water delivered, which equates to 0.0242 SDG/m^3. Using the standard daily rate of 33m3/fd/day and a 14 day cycle, each irrigation would deliver 462 m3, or an irrigation charge of SDG 11.18 /irrigation/feddan.

Institutional Strengthening

It is recommended to organize a WUO in the Rahad Scheme that will be under the umbrella of the FU but with a semi-autonomous status. The WUO will have its own Executive Committee parallel to that of the FU who will be mainly responsible for overseeing and monitoring irrigation water management, and operation and maintenance at the main system level in close coordination with the KIASCo Rahad Directorate ad Kenana Corporation management. Under the WUO Executive Committee will be the Block Committees who will be mainly responsible for overseeing and monitoring irrigation water management, operation and maintenance and water charge/fee collection covering the major canal system and then below will be the Sub-Block Committees mainly responsible for the MOM and O&M of each minor/sub-minor canal. Below the Sub- Block Committees will be the Farmers' Groups (existing now as Financing Groups) who will take care of the tertiary facilities and field channels. There is a very positive indication for expanding the existing FGs and integrating these into the Water Users Organization. The existing FGs can be expanded to represent one tertiary unit.

The WUO will have its own Executive Committee who will be mainly responsible for overseeing and monitoring irrigation water management, and operation and maintenance at the main system level in close coordination with the KIASCo management. Under the WUO Executive Committee will be the Block Committees who will be mainly responsible for overseeing and monitoring irrigation water management, operation and maintenance and water charge/fee collection covering the major canal system and then below will be the Sub-Block Committees mainly responsible for the MOM and O&M of each minor/sub-minor canal. Below the Sub- Block Committees will be the Farmers' Groups (existing now as Financing Groups) who will take care of the tertiary facilities and field channels.

The detailed action plans proposed in the study should be discussed and implemented through the medium of "water users' schools" (WUS). The concept of a water users' school is not a new one, it was adapted from the farmers' field school approach (FAO, 2001) and was implemented in Rahad Scheme sometime in early 1990. The fundamental approach is one of learning by doing aimed at developing skills amongst the farmers and other key stakeholders (staff from concerned agencies/ institutions), through an effective programme of transfer of knowledge, using adult learning techniques. It can be an effective tool in building a commitment on the part of the WUO to participate in irrigation management, in understanding the issues and ways to solve problems, and in ensuring that *the process of institutional development is embedded in the community rather than being externally driven*.

Financial Strengthening

A complete change from the use of held over seed to improved seed will be required. The quantity of fertiliser used is expected to double and therefore the application rate will increase nearly five times, because farm size has halved. The use of crop protection chemicals is virtually zero at present, and will have to be introduced. The quality of land preparation will have to improve, though the availability of existing equipment is expected to increase substantially, as the present private fleets at village level will serve only half the tenant farm area. This will improve timeliness, but the quality of land preparation will need upgrading.

It is recommended that capital to finance the revolving fund is raised through the profit share on tenants' land envisaged in the agreement between Kanana Sugar Company and GOS. The arrangement will be that profits after all expenses are paid will be shared between the Company and the tenant, with 50% to the Company, 40% to the tenant and 10% to be paid into a fund for RIS social services. Assuming that Kenana Sugar achieve crop gross margins per feddan for groundnuts, maize and sunflower at least as good as estimated for tenant farmers with project at full development, then the tenants' share will be SDG 46 million a year, SDG 360 per feddan and an average of SDG 3,200 per household. In other words, the payment is equivalent to a doubling of the average tenant's farm income.

The Study Team does not agree with the concept of profit share between Company and tenant. One economic argument is that an additional source of income raises the opportunity cost of the tenant farmer's time, encouraging him to reduce the effort on his own farm rather than increase it. This being so, we recommend that a portion of the tenants' "share" is allocated to establishing and servicing a revolving fund for input supply on credit. After the initial payment for working capital of SDG 15 million, management costs of the fund are only about 6% of the expected share to be paid by Kenana Sugar Company to tenants. This is a small price to pay for timely, pre-funded inputs and would be a substantial benefit to the RIS community as a whole.

Cost Benefit Analysis

The Total Capital Costs of the project is US$ 88.01 million (204.71 SDG).

The FIRR is satisfactory at 20.6%, with an NPV at 10% discount rate over 30 years of SDG 191.69 million. The BCR is a 1.63. MOM is only just affordable by project farmers but there is considerable latitude for increasing yields over those estimated in this study. The satisfactory FIRR is obtained not from dramatic improvements in present production, but by avoiding the scenario where declining water supply and even more rapidly declining share of water supply forces tenants out of the farming business. The sustainability of tenant farmer production in RIS is expected to be achieved by the engineering initiatives proposed by this study, which will safeguard post rehabilitation irrigation supply at about a peak delivery of about 6.57 MCM per day. Without the works proposed, peak deliveries are expected to decline rapidly to pre-rehabilitation levels of about 4 MCM/day in Year 6 of the project. With project, tenant farmers are also expected to use water more efficiently, by increased water control and improved field irrigation practices. A higher cropping intensity is expected on the tenant farm which halves in size and the use of inputs will also intensify, leading to productivity and financial gains per farm and per feddan.

Sudan has a comparative advantage in the production of oilseeds and good economic benefits are expected. However, the economic benefit from food grain (sorghum) production is very small to negative. Sorghum is not an appropriate crop for large scale farming on a large mechanised pump irrigation scheme; it must compete with much cheaper production from labour intensive rainfed production elsewhere. In particular at the present levels of yield, and even future with project yields are hardly predicted to be high. For this reason the economic valuation of the project is less attractive than the financial. The EIRR is 12%, but above the discount rate of 10%, so the ENPV is positive SDG 30.75 million. The BCR is 1. On economic grounds the project is therefore appropriate for selection for implementation

Table of Contents

LIST OF ACRONYMS

ADV	Automatic Diaphram Valve
ARC	Agricultural Research Corporation
BCM	Billion Cubic Metes
BCR	Benefit Cost Ratio
BI	Block Inspector
BPI	Biomass productivity Index
CAR	Cropped Area Ratio
CBA	Cost Benefit Analysis
CNSW	Circular Night Storage Weir
CP	Control Point
CRA	Cooperative Regional Assessment
CROPWAT	An FAO software program for irrigation design and monitoring
CWC	Crop water Consumption
CWD	Crop water Deficit
CWR	Crop Water Requirements
df	degrees of freedom
DTM	Digital Terrain Model
EIRR	Economic Internal Rate of Return
ENIDS	Eastern Nile Irrigation and Drainage Studies

ENSAP	Eastern Nile Subsidiary Action Program
ENTRO	Eastern Nile Technical Regional Office
ETo	Reference Crop Evapotranspiration
EWUAP	Efficient Water Use for Agricultural Production
F	F statistic
fd	feddan
FG	Financial Group
FGD	Focus Group Discussion
FIRR	Financial Internal Rate of Return
FOP	Field Outlet Pipe
FU	Farmers' Union
GDP	Gross Domestic Product
GIS	Geographical Information System
GOS	Government of Sudan
GRS	Gezira Research Station
ha	hectares
Hawash	Local name for Abu VI
HP	Horse Power
hr	hour
IWR	Irrigation Water Requirement
IWMI	International Water Management Institute
KIASCo	Kanana Integrated Agricultural Solutions Company
kcal	kilocalorie
km	Kilometer
KSC	Kanana Sugar Company
l/s/m	liters per second per meter
LP	Land productivity Index
LSI	Large Scale Irrigation
m	meter
m3	cubic meter
m3/s	Cubic meters per second
MCM	Million Cubic Meters
$MJ/m^2/day$	million joules per square meter per day
mkcal	million kilo calories
mm	millimeter
MoIWR	Ministry of Irrigation and Water Resources(Sudan)
MOI	Ministry of Irrigation
MOM	Management Operation and Maintenance
MWG	Movable Weir Gate
NBI	Nile Basin Initiative
No	Number
O&M	Operation and Maintenance
OER	Official Exchange rate
PA_{ac}	actual adequacy
PA_m	management adequacy
PA_s	structural adequacy
pH	measure of acidity/alkalinity
ppm	parts per million
Q_{ac}	supplied flow
Q_{cwr}	crop water requirement flow
Q_d	design flow
Q_i	indented flow
R2	R square value used in regression
RAC	Rahad Agricultural Corporation
RIS	Rahad Irrigation Scheme
RS	Remote Sensing
RSG	roller sluice gates
RWC	Relative Water Cost Indicator
SAP	Subsidiary Action Program

SCF	Standard Conversion Factor
SDG	Sudanese Guineas
sec	second
SER	Shadow Exchange Rate
SERF	Shadow Foreign Exchange Factor
SVP	Shared Vision Programme
t	t statistic
t/ha	tons per hectare
TLU	Tropical Livestock Unit
WDP	Water Delivery Performance
WHR	Well Head Regulator
WP	Water Productivity Index
WUA	Water User Association
WUE	Water use efficiency
WUO	Water User Organization
WUS	Water User School

APPENDIX A – CLIMATE DATA

APPENDIX B – ECONOMIC CONVERSION FACTORS

APPENDIX C – IRRIGATION DATA

APPENDIX D – INSTITUTIONAL ASPECTS

APPENDIX E – RAHAD IRRIGATION SCHEME HOUSEHOLD SURVEY

Table of Tables

Table of Figures

Table of References

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1 INTRODUCTION

1.1 Context of the Pilot Study

For the last decade, most countries in the Nile Basin had been classified as food insecure. All riparian countries have a limited capacity to absorb shocks such as drought and floods and high external prices. Production levels in all countries are lower than are needed to sustain their populations. Population growth is tending to outrun agricultural production, gains in which are based on crop area expansion rather than intensification though improved use of inputs. Water shortages remain in spite of efforts to recycle drainage water and reuse of treated wastewater. To meet these challenges, the Nile Basin Initiative (NBI) was established in 1999 by the ten Nile Riparian States[1] as a co-operative programme. A strategic action programme was developed to transform NBI's vision to action. This programme is being implemented through the Shared Vision Programme (SVP) and the Subsidiary Action Programme (SAP). As shown in Figure 1, two sub-basin Subsidiary Action Programmes (SAP) have been initiated, covering respectively the Eastern Nile and the Nile Equatorial Lakes regions. One is Eastern Nile Subsidiary Action Programme (ENSAP) formed by Egypt, Ethiopia and Sudan and the other one is Nile Equatorial Lakes Subsidiary Action Programme (NELSAP) formed by Burundi, Democratic Republic of Congo, Egypt, Kenya, Rwanda, Sudan, Tanzania and Uganda. Eastern Nile Irrigation and Drainage Study (ENIDS) is one of the eight ENSAP projects that aims at contributing to the enhancement of food security, reduction of rural poverty, and more efficient water use in the region, with all associated beneficial effects on the environment. ENIDS has two components; i) An Engineering Sub-study; and ii) A Cooperative Regional Assessment Sub-study The Cooperative Regional Assessment (CRA) is geared at enhancing the understanding of benefits and costs accruing to irrigation and drainage projects across the sub-basins countries. The CRA will propose guidelines for the selection of such projects having regional interest or implications and will develop a methodology to render explicit, using actual data, the incremental benefits of cooperation and the distribution of the costs and benefits of those projects.

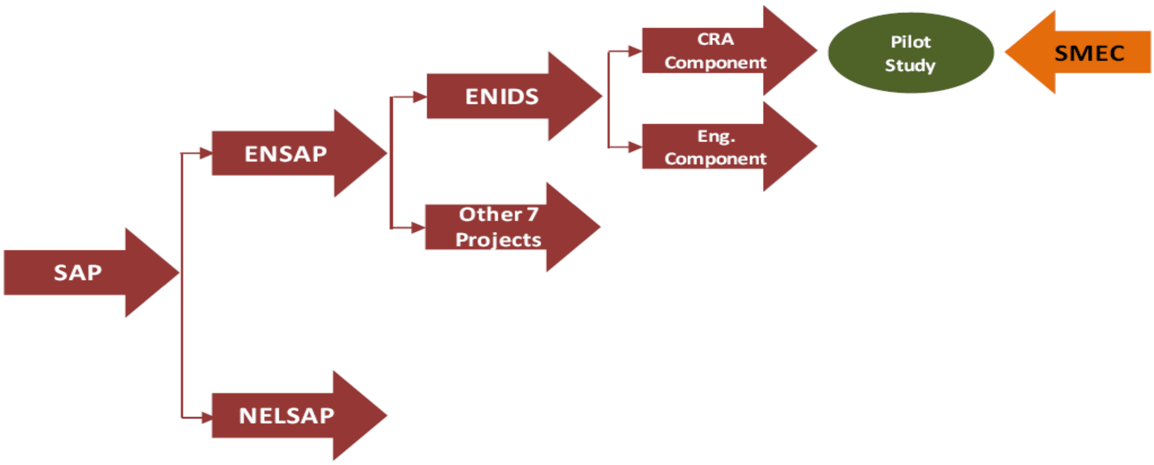

Figure 1-1 Context of the Pilot Study

This pilot study, for improving water use efficiency and productivity on selected irrigation schemes in Ethiopia and Sudan is the outcome of the CRA study.

One of the projects under the SVP is the Efficient Water Use for Agricultural Production (EWUAP) which studied Large Scale Irrigation (LSI) schemes in the Nile Basin. This study derived performance indicators based on remote sensing and evaluated them across large scale irrigation schemes in the basin. Unfortunately the project was unable to obtain much in the way of actual field data and had to rely on remote sensing technology to perform their analysis. The performance indicators derived need to be supplemented and compared with more conventional performance indicators based on detailed study at field level.

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[1] The ten Nile countries are Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Eritrea, Kenya, Rwanda, Sudan, Tanzania and Uganda. Eritrea currently holds an observer position.

1.2 Pilot Study Description

1.2.1 Background

Agriculture plays a major role in the lives and livelihoods of most households in the Nile Basin countries and contributes significantly to overall economic growth and Gross Domestic Product (GDP). Irrigation is considered an effective vehicle to boost rural development and provide jobs to disadvantaged people. There are now approximately 180 million people living in the Nile Basin, and food security is an issue of growing concern.

There is approximately 5 million ha of irrigated land in the Nile basin. The inflow of water from the many tributaries and main rivers of the Nile system (Kagera, White Nile, Sobat, Blue Nile, Atbara) is highly variable. Streamflow by default increases from the upperstream catchments to the central part of the basin. The longer term average discharge at the confluence of Khartoum is approximately 100 BCM/yr. Due to river abstractions, riparian vegetation water use, seepage losses and evaporation losses, the river looses water on its downstream course. The mean annual discharge of the main Nile measured at Dongola in Northern Sudan is 87 BCM (Conway, 2005). The longer term inflow into Lake Nasser is estimated to be 84 BCM/yr. An amount of 10 BCM/yr is evaporated from Lake Nasser and the remaining 74 BCM is shared among Egypt (55.5 BCM) and Sudan (18.5 BCM).

Policies of Egypt and Sudan combined massive irrigation investments (including the construction of the Aswan dam), promotion of Green Revolution technology packages (selected seeds, fertilizers and pesticides) and accompanying measures aiming at facilitating farmers' adoption of these technologies. In addition Egypt went through two successive agrarian reforms in 1952 and 1961 that expropriated the large estates in various ways and redistributed the land to smallholder farmers.

These policies were strongly sustained by the Nile Water Agreement that Egypt and Sudan signed on 8th November 1959. According to the Agreement, out of the average annual flow of the Nile at Aswan of 84 BCM, Egypt has an annual guarantee of 55.5 BCM and Sudan 18.5 BCM. The remaining 10 BCM are the estimated water losses through evaporation in the reservoir of the High Aswan dam. The 1959 Agreement made possible the immediate construction of the High Aswan Dam (1962-1970), the construction of the Roseires dam (1961 – 1966) on the Blue Nile in Sudan, the Managil extension of the Gezira irrigation scheme. The Construction of the Aswan dam also led to the construction of Khashm El Girba dam and the New Halfa irrigation scheme (180,000 ha) located on the upper Atbara River in Eastern Sudan where the inhabitants of the Sudanese Nubia were resettled after the inundation of their land. In Egypt, the completion of Aswan dam provided over-years storage and flood control, which supplied agriculture with steady and until recently plentiful irrigation water. Thus the High Aswan dam offered the possibility of irrigation expansion and substantial rise in the productivity of irrigated agriculture in Egypt and Sudan.

1.2.2 Constraints to Irrigation Productivity in Sudan

Sedimentation in the canals and hydraulic structures is claimed to be a major limitation in irrigation productivity. Consequences of the sedimentation problem are generally (1) decrease in conveyance capacity of canals, (2)"drowned" water control structures and (3) difficulties in supplying water to parts of the schemes (tail-end effect) and (4) reductions in cropped area. In short, sedimentation affects yields through decrease of reliability and equity of irrigation water supply. The origins of this problem lies in erosion of the Ethiopian highlands. This problem will be considered as part of one of the Tigrayan schemes. At least 70% of the maintenance budget is spent on sediment removal and this is not able to cope with the problem. For the Gezira scheme alone, the Ministry of Irrigation and Water Resources estimates the annual silt removal should be 16 MCM.

Outdated tenancy has long been identified as a constraint to productivity. The tenant size is too small to allow mechanised farming techniques but too large for improved labour technology. Tenants have to relay on share cropping to cope with labour financing. This leads to low yields and low productivity. Tenants are not allowed to sell or rent the tenant so there is no shift to invest in farming.

Lack of formal credit is also quoted as a major source of production limitation. The current situation is that because of financing problems, the Agricultural Corporations can no longer finance inputs and labour cash advances in a sufficient or timely manner. Fertilizers procured by the Agricultural Corporations often arrive too late for planting, or in insufficient amounts; farmers have to finance an increasing part of the labour costs. There is no accumulation of capital by farmers in Sudan public irrigation schemes. There has been a steady decrease in national income from cotton in the region and a low recovery on the O&M fee.

Lack of water in the cold season, from mid-October to mid-November, is considered a constraint. This is the most appropriate time to sow wheat or other winter crops, when cotton should receive its most critical watering and when groundnuts and sorghum are receiving their last irrigation before ripening.

The drainage system consists of open drains. Minor drains run parallel to minor canals. They discharge into the major or collector drains, which follow the lines of natural drainage until the nearest River. In some cases major drains terminate in large local depressions where water accumulates and then evaporate. In the heavy clay soils (vertisols or black cotton soils) the drainage systems can only evacuate excess rain water.

2 RAHAD IRRIGATION SCHEME

2.1 Background

After consultation with MOI, Rahad Irrigation scheme was chosen for study by the ENTRO pilot study. While the overall score obtained in the LSI study was second best in Sudan, with a score of 3.57, observations on the ground did not support this position. Throughout this study, data collected indicates the justification for selecting this scheme as a poor performing one. Late in 2009, the Ministry of Agriculture handed over the operation of Rahad Agriculture Corporation to Kenana Sugar Company which formed a new operating entity called Kenana Integrated Agriculture Solutions Company (KIASCo). Then in early 2010, the Ministry of Irrigation and Water Resources handed over the operation and maintenance of RIS also to KIASCo, giving them full responsibility for both the supply of water and control of all agricultural operations. This agreement enabled KIASCo to directly farm 50% of the land using direct labour and their own equipment. The remaining 50% of the land was for the tenant to do as he pleased. This agreement is in place for a 5 year period, after which either party can decide what to do next. This study then looked at both the operations of KIASCo, but mainly the future of the tenant under this new regime.

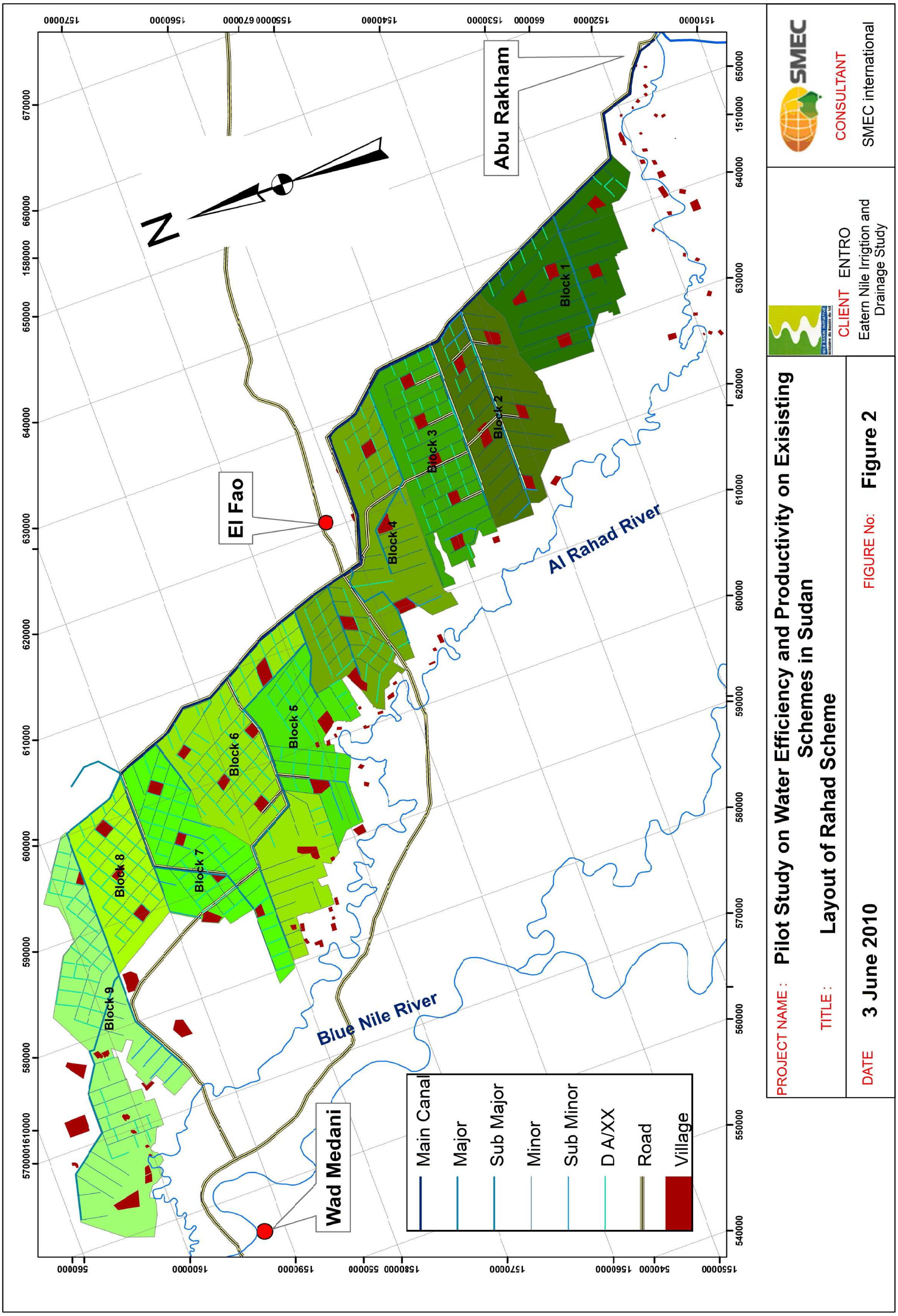
If the management and operation take-over by Kenanan Sugar Company did not happen, it is likely that scheme would collapse in the very near future. Basically every aspect of the project is inoperable or near inoperable and needs urgent attention. The findings of the LSI of placing Rahad at number 2 in productivity and Kenana at number 9 is inconceivable and the study will show just how poor the project has become.

Construction of the project started in 1973 and the first phase was completed in 1977, with full production obtained in 1982. Rahad Irrigation Scheme (RIS) lies east of the Rahad River (also east of the Blue Nile at Wad Medani), between 13°-31' and 14°-25' North and 33°-31' and 34°-32' East. The project area is 130 km long with a maximum width of 25 km. It sits on a flat alluvial plain 400 m above sea level sloping from east to west and south to north. Slopes are generally less than 20cm per km in the south and about 40 cm per km in the north. The El Fao Mountains are the only outcrops in the area but a high spot is non-irrigable between major 6 and 7, beside village 40. The project layout is shown in Figure 2.

The gross project area is 300,000 fd (126,000 ha) with a net irrigable area of 270,000 fd (113,400 ha). There are two water sources, diversion of the Rahad River between July and September and pumped from Meina Station on the Blue Nile between October through June. At Meina are 11 pumps with a capacity of 9.55 m3/s (potential of 105 m3/s) deliver through an 81 km supply canal to the Abu Rakham Barrage on the Rahad River. The supply canal passes under the Dinder River through a three barrel siphon which gets blocked and has to be cleaned every two years.

The Abu Rakham Barrage will divert either river flow or pumped flow depending on availability. There are 6 roller sluice gates (RSG) of 4.0m wide controlling the main canal discharge. The main canal runs for 101 km ending in a four way divergence.

Figure 2 Project Map



2.2 Climate of Rahad

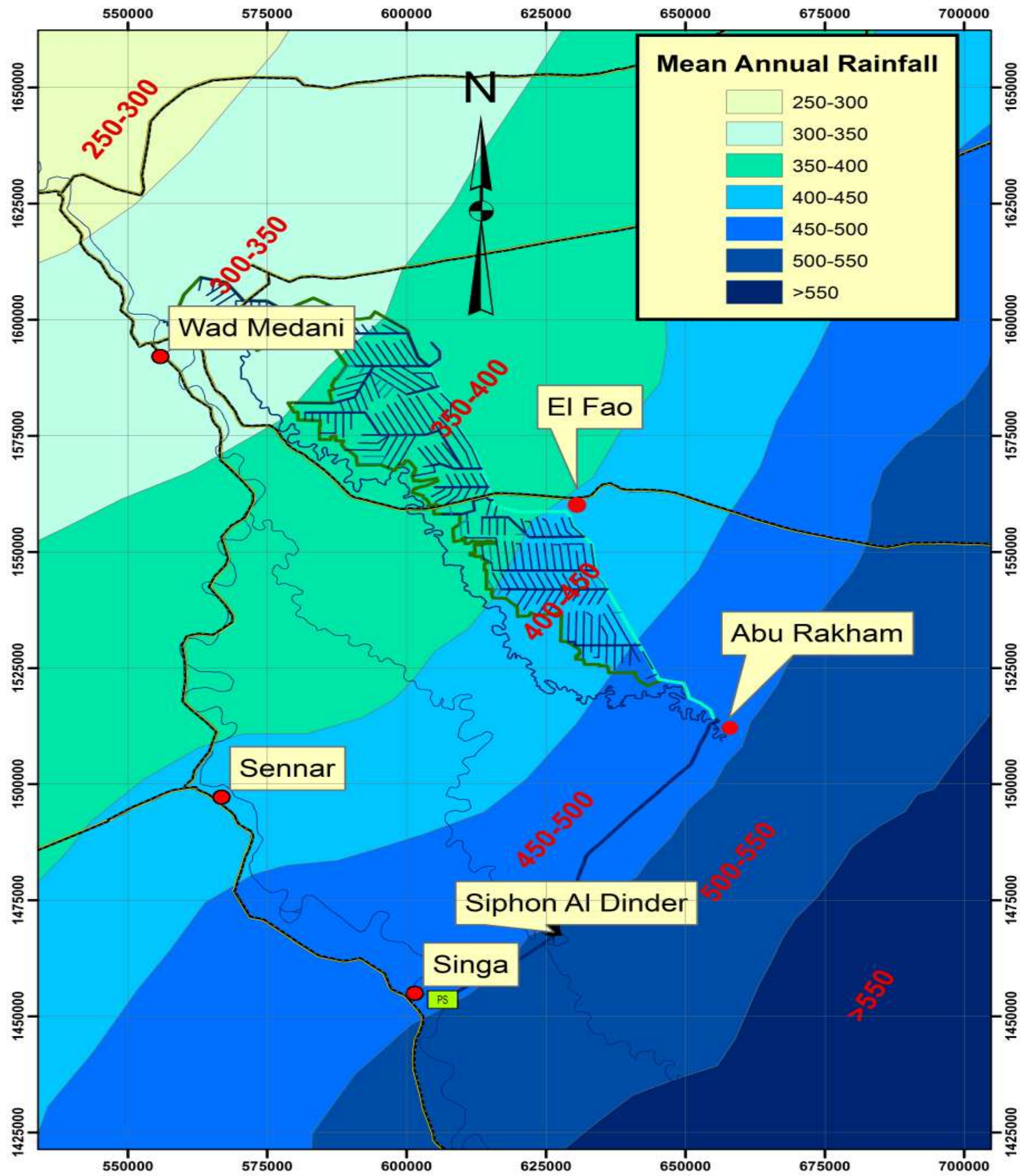
The project area has a semi-arid tropical climate with a humid rainy season from June to October followed by a dry rainless period from November to May[2]. Northerly winds predominate from November to March resulting in a relatively cool period. With the approach of the tropical continuity, unstable thundery conditions with variable, but mainly southerly, winds become predominant. Annual rainfall ranges from an average of 300 mm in the north to about 700 mm in the south, precipitation being mainly confined to the months of July and August, see Figure 4. Maximum temperatures vary between 30°C and 40°C, the highest occurring in May and a second peak in October. Minimum temperatures vary between 10°C in January and 25°C in June. Calculated ET_o ranges between 5.6 and 8.6 mm/day in the north and 4.0 to 6.9 mm/day in the south. Solar radiation is high throughout the year and mean daily hours of sunshine vary from about 7 in August to 10.5 throughout the dry season. See Table 2-1 for a Summary of Average Monthy Climate Data for Wad Medani. For the rainfall distribution, see Figure 2-1.

Table 2-1 Average Monthly Climate and ETo Data Wad Medini

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day	Rain mm	Eff rain mm
January	14	33.5	35	216	10.3	21.2	6.02	0	0
February	14.8	35	27	242	10.7	23.5	7.15	0	0
March	18.1	38.3	21	216	10.4	24.8	7.77	0	0
April	21	40.2	19	190	10.6	25.8	7.93	1	1
May	23.8	41.3	28	216	10.1	24.9	8.39	15	14.6
June	24.5	39.6	39	268	9.3	23.4	8.41	29	27.7
July	22.7	35.7	57	268	7.7	21	6.64	116	94.5
August	21.8	33.2	71	242	7.6	21	5.40	133	104.7
September	21.7	35.2	65	190	9.2	23	5.80	48	44.3
October	21.5	37.7	48	138	9.9	22.7	5.88	19	18.4
November	18	36.5	37	190	10.4	21.6	6.26	1	1
December	14.5	33.7	38	216	10.5	20.8	5.93	0	0
Average	19.7	36.7	40	216	9.7	22.8	6.8	362	306.2

[2] Roseires Pre-Investment Survey, Report No. 5, The Hawata Extension to the Rahad Project, Part IV, Agriculture, HTS October 1996

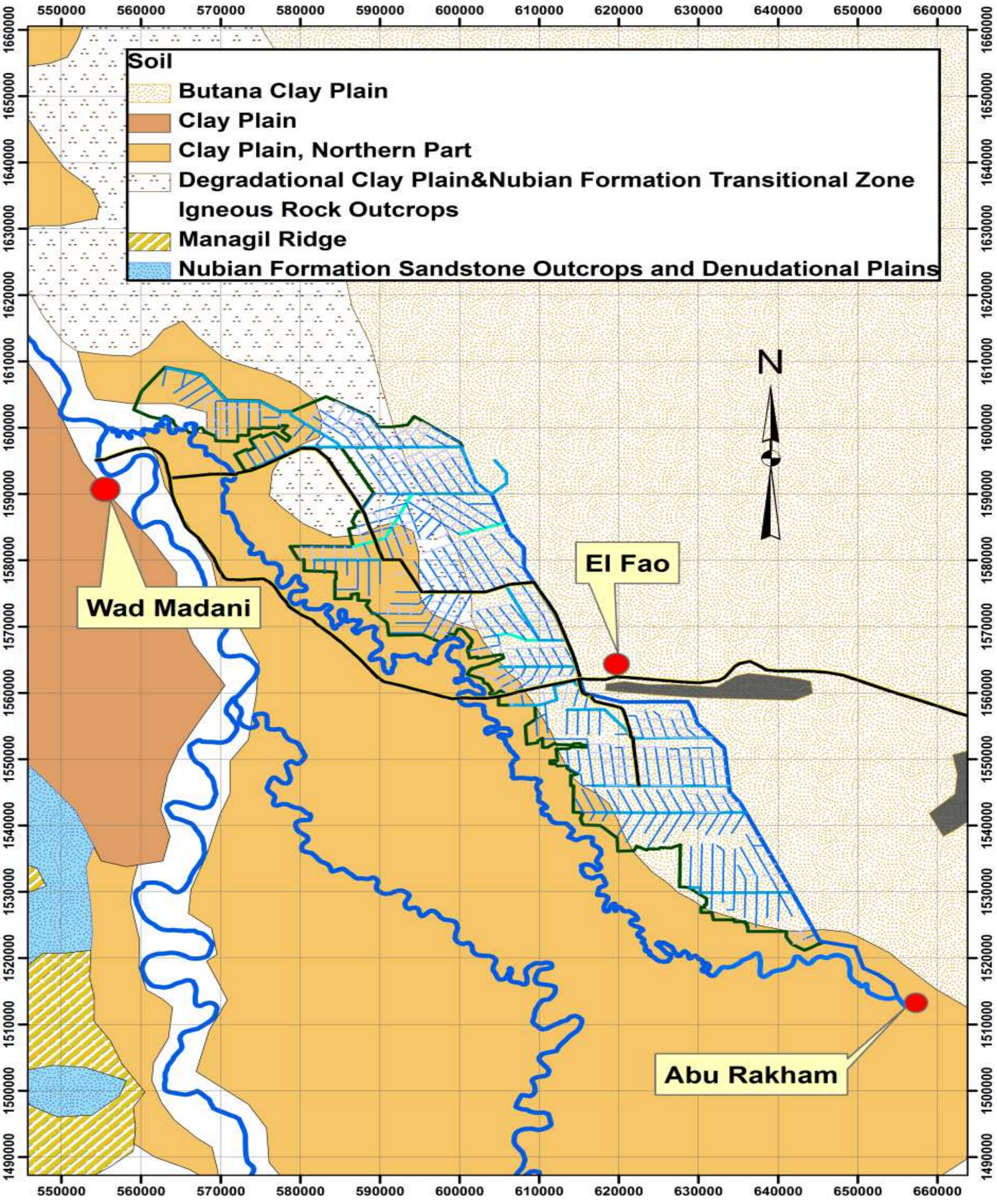
Figure 2-1 Mean Annual Rainfall



2.3 Soils of Rahad

The soils are classified as heavy cracking Vertisols with a clay content varying from 68% to 77%. The soils have low hydraulic conductivity, high water holding capacity, high water retention, very low nitrogen content (<300 ppm), phosphorous content 4-6 ppm and organic matter content of 0.5 %. Soils are non-saline, non-sodic, with a high exchangeable capacity, rich in potassium with a pH between 6.8 and 9.4. The soils are shown in Figure 2-2.

Figure 2-2 Soils Of Rahad



2.4 Supply to Rahad Irrigation Scheme

Before water for the scheme, it passes through four systems: Meina Pump Station, Supply Canal, Dinder Syphon and the Abu Rakham Head works. These are discussed below.

2.4.1 Meina Pump Station

This pump station is located just 5 km upstream of the town of Singah or 60 km from Sennar barrge. It has an intake channel of 150 m long and 100 m wide and a depth of 10.4m. The pump house has 11 pumps, each 9.55 m^3/s capacity with a TDH of 11.2 m and operational speed of 274 rpm.. Each pump has an a high tension motor of `930 HP. They were made in 1975 by Austrian company Andritz.

The intake channel design is extremely poor and fills completely with sediment every year, to a level at least of 3.5 m depth. This must be removed before any pumping can take place. Annual removal of this sediment is part of the maintenance system, but logistics gets the better of this procedure every year with a delay in supply of water causing late planting. Although a large costly dredger is available on site for the purpose of de-silting, it was not operational because the replacement engine was at Sennar and not installed. So an alternative de-silting method was employed to facilitate silt removal. This was by dragline excavator. However these machines are not large enough to reach the middle of the sediment material, leaving an island in the middle. The adjacent photo shows the pump station, the intake channel with the island of sediment. Also shown is the dredger which is non-functional.

Another aspect of the pump station is the operation of the pumps during the high sediment load months of July through September. This practise is done as it is the only method to keep some semblance of a channel open to the pumps during these months. If the pumps did not operate, the intake channel would completely silt over, blocking the pump intakes completely, rendering them in-operable, and considerable expense would be involved to clear the intake. This operation results in further problems downstream in the supply channel and siphon, as explained below.

The annual volume of sediment is estimated at 52,000 m^3. Using the large dredger which has an estimated capacity of 300 m^3/hr, the unit cost of removal is US$ 0.36/m^3. So although the annual cost of sediment removal could cost less than $20,000, this is not realistic as it assumes all equipment is in place and operational. Additionally, the operation of up to three pumps during the high sediment months to keep the channel open creates more problems downstream. The estimated sediment volume pumped by three pumps for three months with a concentration of 4,000 ppm will give 55,700 m^3 of sediment. Most of this sediment finds its way into the Dinder Siphon.

2.4.2 Supply Canal (Meina to Abu-Rakham Barrage)

The supply canal runs for 81 km to the Abu-Rakham barrage, located on the Rahad River. This canal is the main supply for the scheme, operating for months mainly October through July, depending on the spate flows in the Rahad River.

The characteristics of the supply canal are:

Design Discharge: 105 m^3/s
Bed Width: 40.0 m
Design Depth: 3.2 m
Design Velocity: 0.68 m/s
Design Slope: 6 cm/km

Adjacent photo shows dragline de-silting of supply canal.

There are a number of structures along its length, mainly 8 road bridges, but one siphon, one culvert one rail bridge and a regulator, as detailed below:

Supply Canal			
Chainage	**Structure**		
0.0	Maina Pump Station	1 Pump Station	
1.0	Road Bridge	8	Road Bridge
8.4	Road Bridge	1	Rail Bridge
21.2	Road Bridge	1	siphon
24.9	Dinder Siphon	1	Culvert
25.6	Road Bridge	1	regulator
31.1	Road Bridge	13 Structures	
32.6	Rail Bridge		
44.8	Road Bridge		
60.2	Road Bridge		
74.3	Road Bridge		
77.3	Culvert		
80.0	Regulator		

The canal starts with a bed level of 428.4 m and ends with a level of 427.54. There is a drop in bed level at the siphon of 0.88 m.

2.4.3 Dinder Siphon

At km 24.9 is the Dinder Siphon. This is a structure carrying the flow under the Dinder River. The siphon is 260 m long from inlet transition to outlet transition. There are three barrels, each 3.4x3.4 m square with a wall thickness varying from 0.7 to 0.8 m, depending on the location along the siphon. At the entrance to the siphon are three radial gates, 4.0 by 4.0 m. The problem with the gates is that the gear boxes are not serviceable, and cannot close.

The siphon is in good structural condition, but some aspects are in disrepair. The backfill around the structure is been subject to piping of the clay soils, creating huge holes around the structure. The stop logs on the downstream side are no longer serviceable.

The main problem with the siphon operation is two fold. Firstly, the operation of the Meina pumps during the high sediment months is putting a high level of sediment into the siphon and creating a blockage that needs cleaning every two years. Secondly, the operation of the siphon encourages the deposition of this high sediment load. In order for the siphon to be self-cleaning, a velocity of at least 3.0 m/s is required. This is possible if the barrels are opened and closed according to the number of pumps are operational. If less than four pumps are operational, only one barrel should be open. Two radial gates need to be closed. However, the gates cannot be opened or closed as they are not functional. If eight or less pumps are operational, then two barrels should be opened. And greater than eight pumps operational, then all three barrels should be open.

2.4.4 Abu-Rakham Barrage

This is the last structure on the supply chain for water at Rahad Scheme. It controls the spate flows on the river during the months of high flow, usually July to September. There are 9 Roller Sluice Gate (RSG) in the main river, with 6 RSG controlling the supply into the main canal. Most of these are operational with one gate into the main canal needs overhauling, and the rest needing regular maintenance. There is a need to seal a leak in the masonry columns in the river gates. The gates are 4.0 m wide. The operation of the gates have electrical motors, but these need maintenance and kept serviceable. The barrage is considered operational and as such does not constitute any hinderance to the efficient operation of the supply of water.

The only operational irony is that the design of the Meina pump station has to keep pumping to maintain an open channel and thus supplies a high volume of sediment into the supply canal and structures. During this time the Rahad River is supplying water to the scheme also high in sediment. At least one of these systems should be stopped to reduce the intake of sediment into the system. The most logical is to improve the design of the pump intake to stop sedimentation of the intake channel and allow the pumps to be shut down during the supply from the Rahad River. This would reduce the volume of sediment in the supply canal. Then measures could be considered downstream of the barrage to exclude the sediment during the high spate flows.

2.5 Irrigation System

The irrigation system for Rahad consists of main, major, minor and sub-minor canals with associated structures. These are itemised in Table 2-2 below. A description of the irrigation components is given after.

Table 2-2 Present Infrastructure

Rahad Infrastructure											
	Irrigation Canals		**Drainage Canals**		**Structures**			**Bridges**			
Location	**Number**	**Length (km)**	**Number**	**Length (km)**	**RSG**	**MWR**	**WHR**	**Heavy**	**Light**	**Crossing**	**Siphon**
Main	2	182	12	220	20	3	21	15	4	2	6
Major	7	214	162	952	16	9	233	19		2	1
Sub-Major	5										
Minor	162	820	1	14			524	41		4	
Sub-Minor	24		6	156							
D/Abu-xx	412	4280									
Abu-xx	2624								42		
drain								154	124		
Total	3236	5496	181	1342	36	12	778	229	170	8	7
RSG	Roller Sluice Gate			MWR=	Movable Weir Gate			WHR=	Well Head Regulator		

2.5.1 The canal system

The canal system in Rahad Scheme is composed of open earth canals. The net work is comprised of Major (7 in No), Sub-Major, Minor, Sub-Minor"Double ABU/XX" and Watercourse (Abu Ishreen ABU/XX) in descending order of magnitude of size. For most Tenant farmers the holding size is 22 feddans divided between two numbers (11 feddan in each number of 88 feddans and 8 farmers that share one watercourse—ABU/XX) although there were some specialist horticultural holdings of 5 feddans (2.1 ha). The Rahad scheme was designed to be totally mechanised from land preparation to harvest.

2.5.2 The control structures

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, the movable weir, well head regulator, circular night storage weir and field out let pipe. 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 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.

2.5.3 Water order (indenting)

Water order (indenting) in Rahad Scheme is empirical in nature. This empirical method estimates the requirements of all crops at 33 m^3/fed per day inclusive of field losses (at the head of the Abu XX). This is equivalent to 462 m^3/fed per fortnight (110 mm application depth). The quantity to be applied to a 88 fed "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.

The indent is a request for water passed at intervals from the Block Inspector of the Rahad Corporation 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 system head works who adjust their gates to give the discharge required. As the revised discharged becomes available all other regulators down streams are adjusted in turn

2.5.4 The field irrigation system

The field irrigation system is designed to serve standard units of 88 fd (Numbers) measuring 1,350 x 280 m and irrigated by water courses known as Abu Ishreen (Abu XX). This unit is divided into eight 11-fd plots (called Hawasha) watered by secondary water courses called Abu Sitta (Abu VI) taking off from water courses. The recommended on-farm irrigation methods according to the scheme Pilot Research Farm at Tamol are to employ long furrow system with 280 m length of run and 1.2 lit / sec inflow rates using 2 inch diameter siphon tube. The Tambul pilot farm, set up in May 1969, had shown that furrow irrigation was the best system of irrigation. The main advantage over the *angaya* (small basin) system used in Gezira was easier machine operation which should have reduced labour requirements and also there should have been more even application of water with potential savings in water use. The initial plan was for 280 m furrow irrigation system with 50 mm siphons taking water direct from *Abu XX* in batches of 30 in daylight hours. In the first year of the operation of the scheme there were 15,000 fed (6,300 ha) under furrow irrigation and 35,000 fed (14,700 ha) under the *angaya* system (basins operated in strict sequence). The expectations for the success of long furrow irrigation were so high that the target yield for cotton on Rahad was increased from 6 to 8 kantars of seed cotton/fed (2.0 to 2.7 t/ha). The land need to be levelled to 2 % slope and the land to be smoothed using automatic land plains annually. In addition, field drains are to be installed at tail of each number (area of 88 feddans). In practice[3] there were many difficulties with the use of long furrows which quickly led to their abandonment. Expensive land grading was required before successful long furrows could be prepared and there was a shortage of machinery. The operation of the siphons was also a problem. The water had to be cut off at the appropriate time to avoid ponding at the bottom of the fields. This was difficult and led to permanently wet conditions at the bottoms of fields causing problems of access. Also farmers were frustrated because it proved difficult to maintain a constant water level in the field channels so that siphons would lose their prime. If the farmers were not attentive, the water levels would then start to rise in the field channel and then overflow their banks. In fact, the old system was more acceptable to the farmers who could start water flowing into the field basin and then leave for a few hours until they expected sufficient water had been applied. Nevertheless, it should also be noted at this point that long furrows have been used much more successfully on plantations such as at the Kenana Sugar Project.

In the design of Rahad Scheme, it was assumed that there would be night storage system in the canals but some farmers preferred to irrigate at night. If they were using the *angaya* system they could leave the water running unattended into the basin overnight. Of course, this was one reason why it was then difficult to maintain the head in the field channels for furrow irrigation during daylight hours after the canals, which were intended to be full in the morning, had been drawn down because they had been supplying water all night.

As a solution to the problem, the project authority assumed to adopt the on-farm irrigation method used in the Gezira scheme. In the standard field layout of the Gezira Scheme, 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.

Figure 2-3 Detailed Arrangement of Abu-xx and field

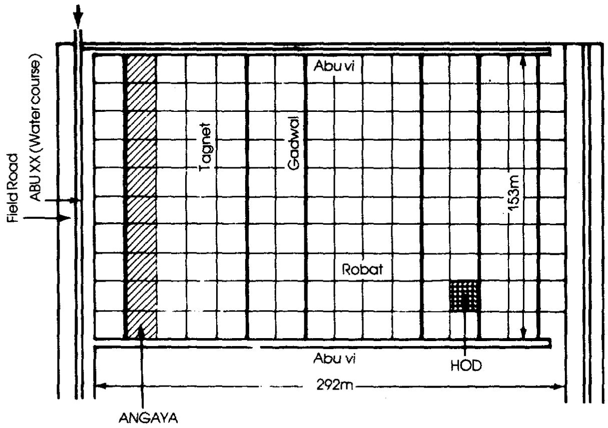
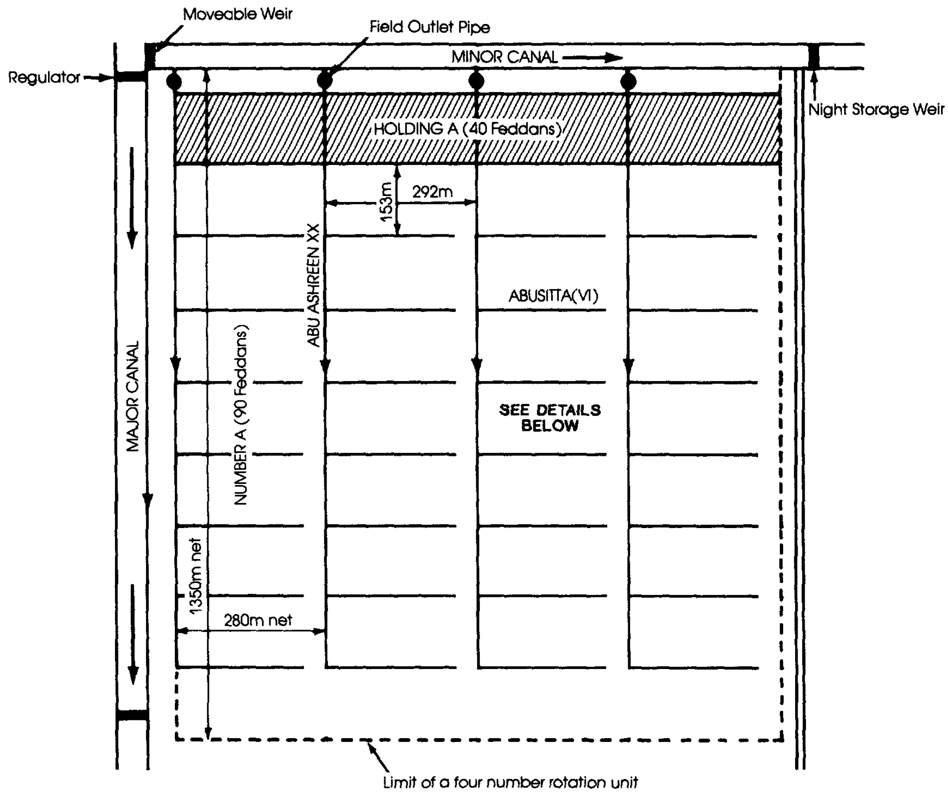


Figure 2-4 Detailed Arrangement of Minor and Abu-xx

3 Rahad Irrigation Project A Synopsis of Development, Sir M Macdonald and Partners, June 1984



In actual practice small and short basin (20 X 150 m) with furrows are used. The number of basins is reduced to only seven or some times the whole field is irrigated as one unit (open plain). Neither drain nor land levelling or smoothing are used. The tenants have adopted field methods which enabled them to keep pace with demands of free market and later to cope with the deterioration of water supply due to the poor maintenance. 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.

In Rahad, for each Block of about 30,000 fed there is the Block Inspector (BI) helped by 5 field inspectors, (one inspector / village = 5000 fed / inspector) . In each Minor Canal there is one Irrigation Controller (Khafir) riding a donkey to supervise irrigation + agric activities & cultural practices supported by one head farmer :"Samad" elected by farmers from each Rotation (Rotation is 2 adjacent land units (Nos) each of 88 fed . Hence, (one Head Farmer "Samad"/176 fed. The Samad is given nominal payment. There is one MOI Gate Keeper / structure to control Major or Main canal.

The Kafir takes the plan for the FOPs for the coming day from the field inspector and informs the Samad who in his turn contact the farmers.

The theoretical plan is to open half the number of FOPs in the Minor each week in practice they do not obey rules due to increase in cropping intensity.

The field inspector informs the BI every morning via a report on his indent or request of water (specially rain cut) .The BI collects all the indents and submits the Block order every week (on Monday) to ADE 9MOI engineer).

3 PERFORMANCE INDICATORS

3.1 Water and Engineering Indicators

3.1.1 Introduction

In the context of water delivery in Sudan system performance is reported to be related to degree of achievement of system objectives. The design objectives of irrigated schemes include (Taj el Din et al., 1984[4] , Shafique, 1993[5]):

1- No field irrigation at night is possible,
2- Disposal of water in excess of actual requirements was not possible after it had left the main canal,
3- Actual requirement of the cultivating agency had to be satisfied,
4- Measurement of water under varying conditions and levels was necessary,
5- The design and operation of the irrigation system is to deliver required quantities (indents) of water at farm level, adequate, reliable, and dependable manner,
6- The block inspector and his staff have to operate the regulators between the successive reaches in such a way that distribution to tenants from head to tail in the Minor Canal in as equitable as possible irrespective of their locations on the canal.

To monitor and evaluate the irrigation system by its objectives the data need to be obtained with respect to the variables for water control and management: indents, irrigation water demand, releases, and design requirements in terms of flows of water.

In line of system objectives and from review of literature the indicators for evaluating the hydraulic performance of canal system and at on-farm level includes:

1- Adequacy: refers to the degree of satisfaction of crop demand;
2- Dependability: express temporal variation of water delivery and the possibility of implementing successful plans;
3- Equity: reflects spatial distribution of water;
4- Efficiency: this is related to conservation of water resource and the negative impact of water ponding in clay soils;
5- Irrigation interval index: shows the status of adopted scheduling policy at farm level
6- Water use efficiency: this is related to level of production achieved compared to amount of water used.

These indicators are used to reflect system overall actual performance, operation efficiency of gates and structures, and standard of management of operating agencies (MOI, RAC and Farmers).

The syndrome of head-tail variations reported in large irrigation projects in Sudan (Faki et. al., 1984[6]) is also addressed in Rahad Scheme by evaluating the impact of farm location with respect to water source on crop yields (Ahmed M I, 1994)[7].

The hydraulic performance of water delivery system in Rahad Scheme was investigated by a series of academic studies made by students from University of Khartoum and Gezira and supported by IWMI

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[4] Taj El Din Sayed Tayeb Water Control Aspects of the Gezira Scheme.ICID Congress.C 38,R3
[5] Shafique M S Hydrulic and Agricultural Performance of Rahad Irrigaton Scheme. Sudan Field Operations – IWMI-The News of FOP of IWMI-Feb-Mar,1993.
[6] Faki H, El Bedawi A and Bailey C (1984) The effect of farm location on yields and farm income in the Gezira Scheme. Water distribution in Sudanese irrigated agriculture: Productivity and Equity Conference papers Editers: Fadl O A and Bailey C R. – 1984.
[7] Ahmed M I (1994) The Rahad crop yields location differences based on crop – cutting survey results a long selected Major Canals. The News of FOP of IIMI-Feb-Mar -1994

organization in 1993 – 1999. These studies covers performance of Major canals (major 2, 5 and 7), Minor canals (3 per each major at head, mid and tail locations along the Major), location of A/XX along Minor Canal at its head, mid and tail and locations of Hawashs (Abu VI) within each A/XX.

Recently, RS and GIS techniques were employed by Hamid (2006)[8] from Water Management and Irrigation Institute to assess the performance of water management in Rahad scheme. Another in line study was made from the same institute by Wagie Alla (2008)[9] to study water Management innovations for yield maximization in Rahad Scheme.

Evaluation of farmers attitudes and believes at on-farm level was investigated also by one scholar in relation to gender issue in irrigation in Rahad Scheme (Ali karar I L, 2001[10])

The data presented below are not supported by tedious explanation of approach or methodology as given in the respective studies, but only the results given for ease of information and comparison. Further reference to the quoted study will reveal the approach and methodology.

Water delivery efficiency (conveyance, distribution and field) has not been investigated due to the precision data required for these determinations which was not available in the time available for the study. Water Use Efficiency however has been investigated.

3.1.2 Study of Water Delivery System:

3.1.2.1 Msc. Studies on Major 5, 2 and 7:

These studies used Molden and Gates (1990)[11] formulas to assess system adequacy, dependability, and equity as follows:

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[8]El Awad El Hag Wagie Alla El Amein (2008) Water Management Innovations for Yield Maximization in Rahad Scheme Ph.D Thesis U of Gezira

[9] Hamid S. H (2006) A performance oriented management approach for large scale irrigation systems usin Rs and GIS Case study – Rahad Scheme Sudan.

[10]Ali karar I L, 2001. Perspective of farmer's attitudes and gender issue in irrigation water management. Msc. Thesis UK.

[11] Molden DJ, Gates TK (1990). Performance measures for evaluation of irrigation-water-delivery systems. Journal of Irrigation and Drainage Engineering, ASCE 116(6): 804-812.

Table 3-1 Matrix of Delivery System Performance Measures Relative to System Objective

Delivery System Objective	Actual	Structural Contribution	Management Contribution
Adequacy PA	$P_{AAC}= \frac{1}{T}\sum_{T=1}^{T=n}(\frac{1}{T}\sum_{R=1}^{R=n} Pac)$	$P_{AS}= \frac{1}{T}\sum_{T=1}^{T=n}(\frac{1}{T}\sum_{R=1}^{R=n} Pas)$	$P_{AM}= \frac{1}{T}\sum_{T=1}^{T=n}(\frac{1}{T}\sum_{R=1}^{R=n} Pam)$
Efficiency PF	$P_{FAC}= \frac{1}{T}\sum_{T=1}^{T=n}(\frac{1}{R}\sum_{R=1}^{R=n} PFac)$	$P_{FS}= \frac{1}{T}\sum_{T=1}^{T=n}(\frac{1}{T}\sum_{R=1}^{R=n} Pfs)$	$P_{FM}= \frac{1}{T}\sum_{T=1}^{T=n}(\frac{1}{T}\sum_{R=1}^{R=n} Pfm)$
Dependability PD	$P_{DAC}= \frac{1}{R}\sum_{R=1}^{R=n} CV_T (\frac{Qac}{Qcwt})$	$P_{ASC}= \frac{1}{T}\sum_{T=1}^{T=n} CV_T (\frac{Qd}{Qi})$	$P_{DM}= \frac{1}{T}\sum_{T=1}^{T=n} CV_T (\frac{Qac}{Qd})$
Equity PE	$P_{EAC}= \frac{1}{T}\sum_{T=1}^{T=n} CV_R (\frac{Qac}{Qcwt})$	$P_{ESC}= \frac{1}{T}\sum_{T=1}^{T=n} CV_R (\frac{Qd}{Qi})$	$P_{EM}= \frac{1}{T}\sum_{T=1}^{T=n} CV_R (\frac{Qac}{Qd})$

Notes: Pa = Qac / Qcwr if Qac ≤ Qcwr , otherwise = 1, Pas= Qd / Qi if Qd ≤ Qi , otherwise = 1, Pam = Qac / Qd if Qac ≤ Qdotherwise = 1, Pfac = Qac / Qcwr if Qac Q≤cwr , otherwise = 1, Pfs = Qi / Qd if Qi ≤ Qd , otherwise = 1, Pfm = Qd / Qac if Qd Q≤ac otherwise = 1, CVT = Temporal cofficient of variation over time period T, CVR = Spatial cofficient of variation over the region R.

As given in the table above twelve indicators (in terms of ratio) were used to express the quality of irrigation service and actual system performance indexes (Bos *et al.,* 1993). Their respective scale to judge their attainment is given in Table 3-2.

Table 3-2 Performance Standards for Indicators of Quality of Irrigation Service

Indicator	Scale		
	Good	Fair	Poor
Adequacy (PA)	0.90-1.0	0.80-0.89	< 0.80
Efficiency (PF)	0.85-1.0	0.70-0.84	<0.70
Dependability (PD)	0.00-0.10	0.11-0.20	>0.20
Equity (PE)	0.00-0.10	0.11-0.25	>0.25

Source: Molden and Gates (1990)

3.1.2.2 Study of Major 5 (Fadl H A M, 1993)[12]:

The study reveals that:

Mode of water delivery can be described as on-demand and request day and night irrigation and no night storage system are used.

- The number of operating field out let pipes (FOP) is more than (half number of pipes in a canal) that scheduled according to the design or indent.
- The structures at minor head are functioning well while the intermediate regulators are damaged and not working as design.
- As depicted in Table 3-3 the performance of operating agencies (MOI and Block Inspector of RAC) tend to operate the system within a safety limit margin when indenting or releasing water to farms . The indents are generally higher than crop water requirement. The actual supply exceeds crop water requirements in early season and get short in late season. Although the system is based on supplementary irrigation water is released to the field during rainy period.

Table 3-3 Performance of Operating Agencies for Irrigation Services as Major 5

indicator	Head		Mid		Tail	
	B I of RAC	MOI	B I of RAC	MOI	B I of RAC	MOI
Q_{ind}/Q_{des}	0.41	-	0.48	-	0.37	-
Q_{ind}/Q_{iwr}	1.20	-	1.50	-	1.02	-
Q_{ac}/Q_{des}	-	0.30	-	0.34	-	0.37
Q_{ac}/Q_{iwr}	-	1.06	-	0.90	-	1.02

- It is evident from analysis of the performance of Minor canal operation given in table 5 that:
    - Supply adequacy is in good and fair range,
    - Both equity and dependability show unsatisfactory levels except for the head of Minor 4.
    - The efficiency level attained is good except for structural component,
    - Within Minor operation adequacy is function of the sate of intermediate regulators (Circular Night Storage Weir CNSW),
    - Level of dependability was found unsatisfactory,
    - Efficiency indicates variable results between reaches,
    - The overall performance of Minor Canal operation indicates a good to fair level for head minors and poor level for tail minors.

12 Fadl H A M, 1993 Evaluating performance of Minor Canal operation –Case study Rahad Project Msc.Thesis UK.

Table 3-4 Variation of Performance Indicators Between Minors of Major 5

Indicator		Head Minor 84	Mid Minor 101	Tail Minor 107
Adequacy P_A				
	Actual Adequacy P_{Aac}	1.06	0.9	1.02
	Structural Adequacy P_{As}	2.5	1.7	2.9
	Management Adequacy P_{Am}	0.36	0.34	0.37
Efficiency P_F				
	Actual Efficiency P_{Fac}	1.00	1.20	1.00
	Structural Efficiency P_{Fs}	0.41	0.58	0.37
	Management Efficiency P_{Fm}	3.90	3.00	2.80
Equity P_E		0.54	1.10	0.77
DependabilityP_D		0.30	0.57	0.48

Table 3-5 Performance of Operation of Abu-xx within H, M, and T Minors of Major 5

Indicator	Minor 84			Minor 101			Minor 107		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
Adequacy P_A	0.78	1.10	1.70	4.40	0.80	0.61	1.40	0.75	1.90
Efficiency P_F	0.31	0.53	0.78	2.41	0.61	0.43	0.92	0.36	1.03
Dependability P_D	1.30	1.00	0.66	0.23	1.30	1.90	0.76	1.50	2.30

It is evident from the Table 3-4 that structural efficiency is low and head A / XXs are enjoining dependable supplies while those at the tails of the minor in general and those in ail of tail minors are suffering more.

The study concluded that: 1- There is urgent need to replace the type of water control structure by another one cable of equitable supply and resist unauthorised interferences. 2-Indenting system which is based on night storage system is impractical, rigid and its mechanism is not suitable, hence, other methods for water scheduling need to be introduced.

3.1.2.3 Study of Major 2 (Lado C. G. 1994)[13]:

An extensive set of field measurement were made to monitor Major No.2 (head Major in the project) water flows. Four control points (CP) and six Minor canals (MC) off takes were sampled to represent the Major Head, middle and tail conditions. Data monitoring program was initiated by calibrating ten hydraulic structures (Fig.1) using current meter and a dumpy level by following the procedure described by (Gideon, 1993). The

[13] Lado C. G. (1994) irrigation Major delivery system performance assessment – the case of Rahad Irrigation Project Msc. Thesis UK.

flow rate passing each structure was measured four times a day (with an interval of three hours) for a complete agricultural season. Water indents, cultivated area, sowing dates were taken from Block 2 Head Inspector (BI). Authorized water flow releases, 10-day discharges and design discharges were taken from Ministry of Irrigation Engineer (ADE) at kilo 36. Crop water requirements were calculated using Farbrother (1977) tables of indents. The study shows that:

Adequacy: based on the scale given in Table 3-2 it is evident from Table 3-6 that the actual adequacy (PA_{ac}) and the structural adequacy (PA_s) can be considered well while a poor management adequacy (PA_m) was indicated. According to (Francis et al., 1988) this can be attributed to the fact that the irrigation management agency always operates the canal system within safety limits to avoid water overflow and damage.

Table 3-6 Adequacy Performance According to Control Points (Seasonal)

Control Points / Indicator	CP_1	CP_2	CP_3	CP_4
$PA_{ac} = (Q_{ac}/Q_{cwr})$	1.00	1.00	0.89	0.86
$PA_m = (Q_{ac}/Qd)$	0.43	0.81	0.38	0.43
$PAs = (Q_d/Q_i)$	1.00	1.00	1.00	0.63
PA_{ac} = Actual adequacy, PA_m= management adequacy, PAs = Structural adequacy Q_{ac} = supplied flow, Q_{cwr} = crop water requirement flow, Q_d =design flow ,Q_i = indented flow				

Efficiency: as shown in Table 3-7 the efficiency indicator due to actual efficiancy PF_{ac} and management efficiency PF_m ranges between good and fair. However, the structural efficiency PF_s can be classified as poor. This may be due to the fact that indents tend to be far less than the design discharges (Giden, 1993)**.**

The poor structural efficiency can be attributed to the low level of reliability, resiliency and vulnerability of hydraulic structures. Damage assessment of existing structures of Gezira and Rahad irrigated schemes in Sudan was made as part of rehabilitation and modernization program reveled the need to urgently maintain the existing structures and replace some of them (roller sluice gates and field out let pipes) by installing more efficient ones such as hydro-mechanical gates (Francis and Elawad, 1986, Ahmed *et al.,* 1986).

Table 3-7 Efficiency Performance According to Control Points (Seasonal)

Control Points / Indicator	CP_1	CP_2	CP_3	CP_4
$PF_{ac} = (Q_{cw}r/Q_{ac})$	0.95	0.52	0.30	1.00
$PFm = (Qd/Q_{ac})$	1.00	1.00	1.00	1.00
PFs =(Qi/Qd)	0.62	0.52	0.50	1.00
PF_{ac} = Actual efficiency, PF_m= management efficiency, PF_s = Structural efficiency Q_{ac} = supplied flow, Q_{cwr} = crop water requirement flow, Q_d =design flow ,Q_i = indented flow				

Dependability: was found to be within the acceptable limits, see Table 3-8. However, dependability of water distribution along the Major canal tends to decrease slightly towards the tail end of the canal which agrees with the finding of (Elwad and Hamid, 1993) for Rahad main canal and for Gezira irrigation network (Mohamed, 1992).

Table 3-8 Dependability Performance According to Control Points (Seasonal)

Control Points / Indicator	CP_1	CP_2	CP_3	CP_4
$PD_{ac} = CVT(Q_{ac}/Q_{cwr})$	0.17	0.23	0.18	0.22
$PD_m = CVT(Q_{ac}/Q_d)$	0.08	0.07	0.08	0.11
$PD_s = CVT(Q_d/Q_i)$	0.18	0.23	0.22	0.26
PD_{ac} = Actual dependability, PD_m= management dependability, PD_s = Structural indicator Q_{ac} = supplied flow,Q_{cwr} = crop water requirement flow,Q_d =design flow ,Q_i = indented flow				

Equity: Table 3-9 shows good water distribution with respect to actual (PEac) and management (PEM) equity measures irrespective of location. However, equity due hydraulic structure (PES) can be marked as poor during early and late seasons, where in the mid season it is fair.

Elowad and Hamid (1993) reported that there are two periods of peak demand for water at early and late season. Early season water shortages arise from low rainfall and the need to sow all crops at short time period. The late season shortage is due to overlap of demand of all crops in the rotation for irrigation water after cession of rainfall. To meet variation in demand there is a need to use more in an up stream water level control made of operation flexible structures weirs as cross-regulator and to keep flow as steady as passable by sluice gates as off take structures (Burt, 1987). For the case of Rahad weirs rather than orifices are used as canals off take structures (Mohammed, 1992).Hence, low level of structural performance (PEs) is expected.

Table 3-9 Equity Performance According to Control; Points (Seasonal)

Control Points / Indicator	CP_1	CP_2	CP_3	CP_4
$PE_{ac} = CVR\ (Q_{cwr}/Q_{ac})$	0.25	0.51	0.21	0.17
$PE_m = CVR(Q_d/Q_{ac})$	0.06	0.14	0.06	0.06
$PEs = CVR\ (Q_i/Q_d)$	0.32	1.00	0.36	0.23
PE_{ac} = Actual Equity, PE_m= management Equity, PE_s = Structural Equity Q_{ac} = supplied flow, Q_{cwr} = crop water requirement flow, Q_d =design flow ,Q_i = indented flow				

3.1.2.4 Evaluation According to Minor Canal off Takes (Mc- Evaluation):

Adequacy: Table 3-10 indicates a good actual and structural adequacy irrespective of location or crop growth stage. However, management adequacy was poor in general. This may be due to lack of communication, late response time, and operation of hydraulic structures on basis of experience and quota rationing rather than on scientific rules (ELawad and Hamid, 1993).

Structural Efficiency: Although the selected structures were all functioning, the poor efficiency index is perhaps due to improper use, poor setting and manipulation of the gates by the gatekeeper.

Dependability: Seasonal dependability for head Major is generally fair in head reaches and poor in the mid and tail reaches. According to (Chember, 1988) this is a typical phenomenon in manually operated, upstream control, large irrigated schemes (Bos *et al.,* 1993).

Table 3-10 Evalaution of Performance According to Minor Canals

Indicator	Head Minor 84	Mid Minor 101	Tail Minor 107
Adequacy P_A			
(Q_{ac}/Q_{iwr})	1.00	1.00	1.00
(Q_{ac}/Q_d)	0.50	0.45	0.35
(Q_d/Q_{in})	1.00	1.00	1.00
Efficiency P_F			
(Q_{iwr}/Q_{ac})	0.79	0/65	0.83
(Q_d/Q_{ac})	1.00	1.00	1.00
(Q_i/Q_d)	0.56	0.62	0.64
Dependability P_D			
(Q_{ac}/Q_i)	0.20	0.21	0.21
(Q_{ac}/Q_d)	0.11	0.14	0.13
(Q_d/Q_i)	0.23	0.30	0.38

From the study it is emphasized that:

- BI tends to over estimate indent in order to insure adequate supply while MOI engineers operate canals by adjusting indent to insure canal safety. The philosophy adopted is to match supply and indent. However, indent was found to be more than crop demand.
- Gate keepers operate the system on basis of experience (They use number of threads on gate shaft to measure water flows).This results on poor management adequacy in control points. The study recommends to conduct specialized training for improving capacity building and also to conduct future research for water scheduling and for new indenting mechanism.
- The poor status of structural equity call for looking for alternative type of structure that can achieve fair water distribution between different canal reaches or off takes.

3.1.2.5 Study of Major 7 (Mahmoud M A, 1999)[14]:

Evaluation of irrigation performance in the tail of El Rahad Scheme was conducted in Major 7 which irrigate 17753 ha of cotton , wheat, sorghum and groundnut.

Table 3-11 shows adequacy and dependability indicators measured in a accordance with Molden and Gates (1990) procedure.

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[14] Mahmoud Mohammed Abd Elgalil , 1999 Evaluation of irrigation performance in the tail of El Rahad Scheme Msc Thesis U of Gezira

Table 3-11 Intra-seasonal Adequacy and Dependability Indicators of Major 7

Index	Period within the season			
	Early season	Mid Season	Late Season	The Whole Season
Adequacy	0.91	0.75	0.82	0.83
Dependability	0.23	0.14	0.2	0.28

The table indicates fair adequacy of supply and poor dependability with respect to seasonal performance which is expected phenomenon in large irrigation project. The within seasonal adequacy is fair to poor for mid and late season stages and poor for dependability in different stages of the season. Study of water delivery performance as given in Table 3-12shows values of 0.83, 0.75 and 0.85 for early, mid, and late stages of the season respectively. This shows that delivery is comparatively bad in mid season stage. The cause may be attributed to high demand for water when rain fall ceases and overlap of demand of various crops at one time.

Table 3-12 Water Delivery Performance Indicator (WDP) (indent/actual and indent./CWR) for Major 7

Indicator	WDP	(Indent / Actual)	(Indent / CWR)
Early	0.83	1.20	1.30
Mid	0.75	1.70	1.40
Late	0.85	1.30	1.30
Whole season	0.80	1.50	1.30

Comparison of water actually supplied to estimated demand (determined by CROPWAT – FAO program shows that about 82% of needed water is supplied to the crop (supply of 3699 m3/fed compared demand of to 4418 m3/fed). The ratios of indent to actual supply support the observed attitude that the BI based his indent on actual state of water levels rather than on crop water requirement.

Water use efficiency(WUE): As given in Table 3-13 WUE was found to be 0.19 kg/ m3 under condition of Major 7, While the standard value of 0.4 kg / m3 is reported by FAO (1979).This is attributed in Mahmoud study to lower values of WDP indicator during mid season stage.

Table 3-13 Average Volume of Water Used and Water Use Efficiency for Cotton

Season	Volume of water used m^3	WUE Kg/m^3
1993	3658	0.17
1994	3762	0.2
1995	3892	0.18
1996	3611	0.21
1997	3572	0.17
Average	3699	0.19

The study indicated that the yield of cotton crop in Major 7 (1.63 ton / ha) was found to be below the average yield of the project (1.83 ton / ha). The yield reduction is assumed to be related to the lower value of WDP (0.80) attained throughout the season.

Past On- farm Irrigation Studies:

Impact of farm location from water source (Ahmed M I, 1993)[15]: Farmers yield and income were collected by a series of crop cutting conducted on both sorghum and groundnut crops on assumption that tenancies located at head of canal system receive adequate water supply and thereby higher yields and income. The survey design is stratified multi-stage random sample. Data was collected from Major 2(Minor 6, 32, 25, 27,39and 31), and major 7 (Minor 3, 4, 6, 8, 12, and 17) and Numbers in each selected minor were grouped into head mid and tail groups. The tenancies within each selected number were then sub-divided into four equal groups according to sequence.

The study concluded that: Although yield per feddan in both crops showed a gradual decrease from head to tail in all type of canals, the location of minor canal ,ABU XX and the tenancy has no effect on crop yield. For farmer fields average yield per feddan showed a gradual decrease from 616 kg, in the first quarter to 463 kg in the last quarter for sorghum crop. Yield of Groundnut crop decreases from 1030 kg in the head sections to 786 kg at the tail section.

3.1.2.6 Study of irrigation performance at field level (Warrag A M, 1995)[16]:

The study examines: the probability of irrigating at night, impact of location of off take of ABU XX (Direct from Minor canal or from D/XX), adequacy, efficiency, dependability performance indicators for water management in ABU XX watercourse and Abu VI field channel.

Warrag (1995) studied performance of on-farm irrigation at block six in Minor 101 of Major 5.He selected ABU XX3,6,and16 to represent head, mid and tail locations. In each ABU XX he selected 9 Hawashas by randomly taking 3 at top, 3 at mid, and three at tail sections. No interference was exercised in the routine practice of the tenant farmers.

- Probability of irrigating at night: He observed that 67, 83, and 84% of the farmers irrigate their fields throughout the day and night. This result is higher than that (60%) reported by Fadl (1993).

- Adequacy, efficiency, and dependability at ABU XX Level: Table 3-14 gives the values adequacy, efficiency, and dependability measured at ABU XXs. According to the evaluation scale of Molden and Gate (1993) actual adequacy was good while management adequacy was poor for locations of the minor. Actual efficiency was poor, good and fair for head, mid, and tail ABU XXs along the minor respectively.

- Management efficiency was observed as good for all locations.

- Dependability (Actual and management): ranged from fair to poor at different locations of ABU XXs.

The low levels of actual efficiency of water distribution and its decrease in values down the length of the minor canal is attributed by the investigator to malfunctioning of the intermediate water control structure (CNSW) and better performance is observed with the directly fed ABU XXs. The case calls for using other type of control structure.

- Water delivery performance was found to be 0.96, 0.77, and 0.86 at head, mid, and tail locations of ABU XXs in the minor canal respectively. Along ABU XXs WDP was found to be

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15 Ahmed M I, 1993 The Rahad crop yields lcational differences based on crop-cutting survey results along selected Major Canals IWMI Workshop on Irrigation in Rahad Scheme. The News FOP-IWMI-Sudan
16 Warrag A M, 1995 An on-farm water management with reference to Rahad Project Msc. Thesis UK

0.86, 0.89, and 0.83 at head, mid, and tail locations respectively. The direct ABU XXs were found to be relatively of better WDP (0.96) compared to the indirect ones (0.88).

Table 3-14 Adequacy, Efficiency and Dependability Measured at Abu-xx Level

Indicator	Head ABU XX 3	Mid ABU XX 6	Tail ABU XX16
Adequacy PA			
(Q_{ac}/Q_{iwr})	0.97	0.86	0.94
(Q_{ac}/Q_{d})	0.63	0.45	0.49
Efficiency PF			
(Q_{iwr}/Q_{ac})	0.77	0.96	0.80
(Q_{d}/Q_{ac})	1.00	1.00	1.00
Dependability PD			
$CV_T(Q_{ac}/Q_{iwr})$	0.53	0.37	0.40
$CV_T(Q_{ac}/Q_{d})$	0.16	0.26	0.15

- Longer irrigation intervals were found to be applied in the study areas. It increased from head to tail locations along ABU XX and it is longer in the direct ABU XXs compared to the indirect ones.

- Higher application depths were applied in the study area irrespective to location or stage of crop growth. The indirectly fed ABU XXs showed relatively higher irrigation depth index (actual / target) compared to direct ABU XXs.

- Irrespective of location or seasonal stage of crop growth time of application was found to be higher than the recommended time of 7 days per cultivation unit of 88 feddan area (Number).However, to solve the problems of using longer irrigation intervals, longer irrigation time, and more water quantities per irrigation the researcher recommended to conduct a training program for improving the capabilities of farmers on scheduling of irrigation(when to irrigate, how much to apply and for how long).

3.1.2.7 Study of farmers attitudes and believes for irrigation at field level (Ali Karar I N, 2001)[17]:

The study main findings may be summarized in the followings:

- Labour cost of watering rise at the mid of the season due to competition of overlapping crops and dependency on pumped irrigation water after rain fall stops.

- Pre-watering is not practiced for all crops due to water shortage;

- Actual irrigation schedule do not match the recommended one and longer irrigation intervals are used;

[17] Ali Karar I N, 2001 Perspective of farmer's attitudes and gender issue in irrigation water management. Msc Thesis UK.

- In response to labour shortage farmers used larger irrigation basin compared to the orthodox Gezira Angaya basin. To compensate for lack of land levelling the length of field channel (Gadwal) is reduce to half and a second Abu VI is used to improve water distribution in the field.

- Farmers prefer to irrigate their fields during day time only but the majority irrigate their fields during day and night using the available low flows at all times of crop growth stages;

- Organization of water distribution within each number is made by mutual agreement between farmers and no specific rotation or sequence of priority of watering is practiced.

3.1.3 Evaluation of the Current Performance of Delivery and On-farm system:

3.1.3.1 Impact of farm location on Productivity of Cotton Crop:

Due to short of time and the un availability of irrigation water in the canal system at this time of season(time for land preparation) evaluation shall be based on secondary data collected from available reports and from rapid appraisal conducted during a field study tour for seven days inside the Rahad Scheme. During the field visits canals, structures, fields, and machinery were inspected. Direct discussions with Kenana people, MOI irrigation staff, and the former Rahad Corporation staff were made to spill out views and facts.

3.1.3.2 Diagnosis of Current Performance of Water Delivery System

Differences in crop yields between head tail areas of canal irrigation system are phenomena observed in many multi-farm large irrigation systems in the World. Variations in yields of cotton crop were attributed to many factors including: soil, climate, levels and management of inputs, and socio-economic factors. The exact role of each of these factors in affecting cotton productivity continues to be a matter of research and debate. However, it is widely agreed that adequacy, timeliness and reliability of irrigation water supplies are a critical ingredient in determining yields and therefore, farm income. In this study it is hypothesized that, other things being equal, yields from cotton farms tend to decline towards the tail ends of the irrigation system. An empirical approach is taken to test this hypothesis by collecting cotton crop yield data from head, mid and tail canals of various sizes in the project for all years of production in the scheme (the last 32 years). Hence, stratified multi-stage random samples were collected from Major 2 (Sub-Minor 5, 38, and Sub-Minor 7), Major 5 (Minor 84, 101, and 107) and major 7 (Minor 1, 8, and 19) and Numbers in each selected minor were grouped into head mid and tail groups .From each minor three ABU XXs were chosen from head mid and tail sections. From each section in ABU XX Three Hawashas from head mid and tail parts were selected.

Table 3-15 shows the over all variation of cotton yield due to location in the project. These results confirm the hypothesis of the head tail decrease in yield with respect to Majors, Minors and Hawashas. However, the same trend is followed for canals of Major 2, 5 and 7, see Table 3-15.

Table 3-15 Effects of Farm Locations on Cotton Productivity (kg/fd)

	Productivity Kant / fed			
Location	Major	Minor	A/XX	Hawasha
Head	2451	1373	946	1772
Mid	845	1328	1424	1286
Tail	557	1152	1484	795

Table 3-16 Variation of Cotton Yield by Location of Canal Type in Majors 2,5,7

Location	Major 2	Major 5	Major 6B
	Kg/fed	Kg/fed	Kg/fed
Hawasha (H)	3253	1495	568
Hawasha (M)	2607	668	583
Hawasha (T)	1493	372	520
A/ XX (H)	1576	732	529
A/ XX (M)	2963	740	569
A/ XX (T)	2814	1063	573
Minor Head	3026	513	580
Minor Mid	2816	511	657
Minor Tail	1511	1511	434

3.1.3.3 Evaluation of Performance at Head of the System

Monthly indent and supply inflow values were collected for all seasons since 1977 to date. As shown in Figure 3-1 supply markedly match indents. This confirms the policy adopted by MOI engineers is to satisfy indent. It is astonishing to note that high indent and supply values can be observed during the rainy months of July, August and September.

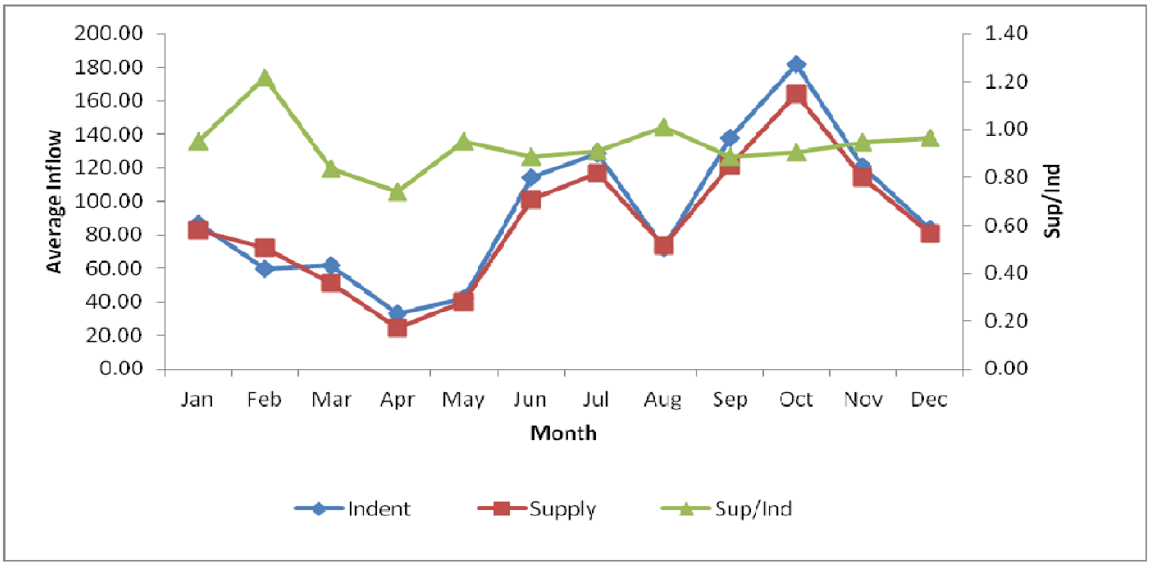

Figure 3-1 Project Average Monthly Indents and Supply Inflows (m^3/fed)

3.1.3.4 Evaluation of Performance at Major 2:

Indent and supply data is collected from MOI engineer responsible from operation of Major two. This data is analyzed following the procedure given by Molden and Gates (1993). The results are given Table 3-17, shows poor performance levels with respect to adequacy, dependability, and equity indicators with fair level for efficiency. Reason for such results may be explained by the problems frequently occurs in the head regulator of the Major (Hamad, 2006).It worth to note that no records is available for areas cultivated with each crop in this Major. Hence, it is difficult to analyze other performance indicators.

Table 3-17 Adequacy, Dependability, Equity and Efficiency of Supply for Canals of Major 2

Location	Sub-Minor 5	Minor 37	Sub-Minor 7	Major 2
Adequacy	(Q_{supp}/Q_{ind})	(Qs_{upp}/Q_{ind})	(Q_{supp}/Q_{ind})	(Q_{supp}/Q_{ind})
Average Ratio	0.69	0.77	0.75	0.92
Status	Poor	Poor	Poor	Good
Dependability	$C_{vt}(Q_{supp}/Q_{ind})$	$C_{vt}(Q_{supp}/Q_{ind})$	$C_{vt}(Q_{supp}/Q_{ind})$	$C_{vt}(Q_{supp}/Q_{ind})$
Average Ratio	1.93	0.69	0.00	0.05
Status	Poor	Poor	Good	Good
Equity	$= C_{vr}(Q_{supp}/Q_{ind})$			0.18
Status				Fair
efficiency	(Q_{sup}/Q_{ind})			0.82
Status				Fair

3.1.3.5 Evaluation of Performance at Major 5:

Due to availability of data for areas sown in each year it is decided to evaluate the actual performance with respect to irrigation water demand. The FAO CROPWAT program has been used to calculate Crop Water Requirements and Net Irrigation Requirements. The CropWat 4 for Windows program[18] first uses the Penman Monteith method to calculate Reference Crop Evapotranspiration (ETo). To account for the effect of crop characteristics on crop water requirements, crop coefficients (Kc) are used and relate to specific stages of growth. Four distinct stages of growth are generally used, an initial stage, crop development, mid season and late season. In selecting suitable lengths of growth stages and crop coefficients it is best to use local data if it is available. If local knowledge is not available, the FAO publications have a selection of lengths of growth stages and suggested crop coefficients for numerous crops grown in different climatic zones[19]. Detailed calculation procedure is given in the Appendices. Table 3-17shows the results of analyzing evaluation Parameters of Irrigation Performance for Major 5.The table indicate poor performance of all agencies responsible from water management. Both equity of water distribution and management of structures are poor. This result is confirmed by the poor performance of all canals in the Major for all types' of evaluation indicators Table 3-18.

In comparing the results given in Table 3-18 and Table 3-19, with those reported by Fadl (1993) it can be seen that the system is deteriorating at an alarming rate and requires urgent actions to both rehabilitate and modernize the whole irrigation process.

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[18] CropWat for Windows; User Guide, FAO 1998

[19] Crop Evapotranspiration – Guidelines for computing crop water requirements, Irrigation and Drainage Paper No 56, FAO, 1998 Tables 11, 12

Table 3-18 Evaluation Parameters of Irrigation Performance for Major 5

Indicator	Adequacy	Efficiency	Time Dependability PD	Equity
Actual	(Q_{sup}/Q_{iwr})	(Q_{iwr}/Q_{sup})	$CV_t(Q_{sup}//Q_{iwr})$	
	0.71	1.00	0.05	
Status	Poor	Good	Good	
Structural	(Q_{des}/Q_{ind})	(Q_{ind}/Q_{des})	$CV_t(Q_{des}/Q_{ind})$	
	1.00	0.26	4.27	
Status	Good	Poor	Poor	
Management	(Q_{sup}/Q_{des})	(Q_{des}/Q_{sup})	$CV_t(Q_{sup}/Q_{des})$	
	0.18	1.00	0.17	
Status	Poor	Good	Fair	
Agency Performance	(Q_{ind}/Q_{iwr})	(Q_{sup}/Q_{ind})		(Q_{supply}/Q_{ind})
	0.92	0.69		0.30
Status	Good	Poor		Poor

Table 3-19 Hydraulic Performance of Minor Canals in Major 5

Location	Minor 85	Minor 92	Minor 110	Major 5
Adequacy	(Q_{supp}/Q_{ind})	(Q_{supp}/Q_{ind})	(Q_{supp}/Q_{ind})	
Average Ratio	0.623	0.704	0.772	
Status	Poor	Poor	Poor	
Dependability	$Cv_t(Q_{supp}/Q_{ind})$	$Cv_t(Q_{supp}/Q_{ind})$	$Cv_t(Q_{supp}/Q_{ind})$	
Average Ratio	1.625	0.06	0.133	
Status	poor	Good	Fair	
Equity	$= Cv_r(Q_{supp}/Q_{ind})$			0.3
Status				Poor

3.1.3.6 Evaluation of Performance at Major 7:

Following the procedure given for Major five hydraulic performances of Major 7 and its associated Minor and ABU XXs is summarized in Table **3-20** and **Table 3-21**. The results in general are in agreement with that given by Mahmoud in 1999.

Table 3-20 Evaluation Parameters of Irrigation Performance for Major 7

Indicator	Adequacy	Efficiency	Time Dependability PD
Structural	(Q_{des}/Q_{ind})	(Q_{ind}/Q_{des})	$CV_t(Q_{des}/Q_{ind})$
	1.00	0.62	0.43
Status	Good	Poor	Poor
Management	(Q_{sup}/Q_{des})	(Q_{des}/Q_{sup})	$CV_t(Q_{sup}/Q_{des})$
	0.64	1.00	0.55
Status	Poor	Good	Poor
Agency Performance	(Q_{ind}/Q_{iwr})	(Q_{sup}/Q_{ind})	$CV_t(Q_{sup}/Q_{ind})$
	0.92	0.69	0.12
Status	Good	Poor	Fair

Table 3-21 Hydraulic Performance of Minor Canals in Major 7

Location	Minor 1	Minor 8	Minor 19	Major 7
Adequacy	(Q_{supp}/Q_{ind})	(Q_{supp}/Q_{ind})	(Q_{supp}/Q_{ind})	
Average Ratio	1.03	1.00	1.00	
Status	Poor	Good	Good	
Dependability	$C_{vt}(Q_{supp}/Q_{ind})$	$C_{vt}(Q_{supp}/Q_{ind})$	$C_{vt}(Q_{supp}/Q_{ind})$	
Average Ratio	0.113	0.57	0.20	
Status		Poor	Poor	
Equity	$= C_{vr}(Qsupp/Q_{ind})$			0.13
Status				Fair

3.1.4 Lessons learned

From the analysis of project performance by various investigators and through different span of time it is evident that the following areas need to be considered in order to help the project to achieve its objectives:

- Replace the existing type of structure and mode of water delivery from rotational irrigation to continuous and down stream control system (*this is because of poor tail performance*).
- Water charge system based either on actual number of irrigation received or volumetric basis (*to reduce wastage by head users and create an environment of responsibility for water use*).
- Introduce proper land levelling program and routine seasonal land smoothing as cultural practice (*because in-field performance is poor*).
- Create an incentive system base on monitoring in-seasonal system performance for personnel working on water management (*because government agencies do not have performance incentives as private enterprise does*).

- Initiate capacity building program to train farmers, share croppers and personnel working on water management on irrigation scheduling, system maintenance and operation (*because farmers have been "trained to wait" and need to be "trained to take the initiative"*).
- Develop operation and maintenance manuals (*for pre-seasonal planning, in-seasonal operation, procedure for sediment clearance and operation of hydraulic structures, to improve performance of O&M*).
- Create a system for flow measurements and record keeping.
- Operating rules at times of low flows (water shortage), and when rain fall stops (end of September – early October) (*to reduce wastage of water*).
- Erect a meteorological station inside the research farm (*to improve meteorological data for scheduling)*
- Improve communication system
- Set clear criteria for irrigation scheduling (when to irrigate, and when to stop irrigation, *to reduce wastage*)
- Clearly define factions and roles of WUA.
- Create a monitoring and evaluation unit inside the project (*so managers can determine areas that need improvement or are working satisfactory).*

The review of existing scheme identified a number of potential issues and constraints, these are:

- **Irrigation methods:** there has been no serious update of the assessment of potential irrigation methods for schemes in the project area since the 1970s. While the current method of basin/furrow irrigation is well understood by tenant farmers there is a need to identify alternative surface and pressure methods better suited to alternative farming systems (such as larger farming units) and crops. There is also the possibility that soils within the project areas will have differing soil water characteristics therefore the need to adapt irrigation methods and management regimes accordingly.

- **Irrigation efficiencies:** estimates of field irrigation efficiency for Rahad scheme are based on earlier work at the Gezira Research Station (GRS). These showed that field losses due to deep drainage and runoff are extremely low. These assumptions need to be reassessed as to their applicability for different types of irrigation methods that may be used.

- **Canal efficiencies:** estimates of canal irrigation efficiencies (90%) are based on those determined for the Gezira scheme in the 1970s. These are based on the assumption that the only significant losses are from canals surface water evaporation. The applicability of this approach needs to be reassessed based on soil drainage characteristics, canal design and likely operational losses.

- **System design capacities:** the determination of system capacities in previous studies and scheme design has been based on criteria of peak daily demand as assessed at Rahad Scheme and extrapolated from field to main canals based on assumptions of cropping intensities. Whilst the approach is sound, it has lead to lower than assumed cropping intensities resulting in an over estimation of canal capacities. There is a need to build into the approach realistic assessments of most probable crop intensities and crop rotations to ensure that systems are not inadvertently over-designed. It is thus, essential to estimate the probability of fields that likely to irrigate at one time.

- **Day-Night Irrigation:** the original concept of a 12 hour irrigation day, the basis of the original Gezira design in the 1920s and 30s, appears to be outdated. The reality appears to be that due to limitations on labour and in some cases increased cropping intensities that irrigation duration is approaching 24 hours. Actually night storage system is not adopted, and damage of intermediate circular night storage weirs confirm this, see Photo of damaged WHR, page 11, Appendix C.

- **Pre and Post Irrigation:** whilst pre and post irrigation was recommended in the past, the practice evidently has now largely been dropped. This may be due to changes in cultivation practices and timing of sowings.

- **System control:** on existing schemes system control is, by default, moving from a strictly upstream control to some form of demand or downstream control with 24 hour irrigation and a more erratic scheduling of water. This is due in part to the poor performance and problems (financial and organisational) with scheme management as well as crop changes. The approach to the new projects should recognise this reality and be based on automating system operation and providing water on an on-demand basis down to the field outlet level (ABU XX).

- **Maintenance:** the requirement for, and cost of, on-going maintenance is perhaps the biggest challenge for irrigation schemes in the project area. Seasonal planning and operation of the project needs to take into consideration the likely sediment loads and the practicalities of financing and managing of on-going de-silting and weeding works.

- **Scheme management:** in previous studies there appears to have been too little attention paid to institutional issues, such as organisational structure, stakeholder participation, and long term O&M sustainability. As highlighted by the current problems in large scale public irrigation schemes such as Rahad, this is a major issue for both on-farm and scheme performance. The highly centralised organisation and planning approach has a number of obvious constraints. Project modernization should take into consideration the likely organisational structure in selection of canal types and control methods. This structure should allow for self control of independent operational entities which could reinvest income in maintenance of infrastructure without interacting with a central management scheme.

3.2 Crop Productivity Indicators

3.2.1 Deterioration in Yields

Agricultural production in Rahad is characterised by low production. Deterioration of crop yields was attributed to a variety of reasons, the main of which include:

- late land preparation (lack of adequate machinery, 16% operable)
- improper land preparation
- late seed delivery
- bad seed quality
- late sowing
- labour shortage
- weeds
- pest and diseases
- lack of extension services
- farm location (tail problems, shortage of water)
- insufficient credit
- no fertilizers application
- water logging (heavy rains and over irrigation).

- administrative hindrances

The Rahad scheme was designed for fully mechanized crop production and this has never been achieved. The main reason behind this is the lack of sufficient funds required for machinery procurement and timely maintenance. Recently, for the last three years, involvement of the private sector in executing mechanized cultural operations has progressively increased.

Signs of soil salinity were observed by the study, although in small areas at villages 18 and 40. The reason for that could be attributed to excessive water application.

The following figures show the changes of yields in the period of 1977 to 2008 seasons for cotton, groundnut and sorghum crops in t/ha. There is a general downward trend for cotton yields, but a slight increase in yields for sorghum and groundnuts.

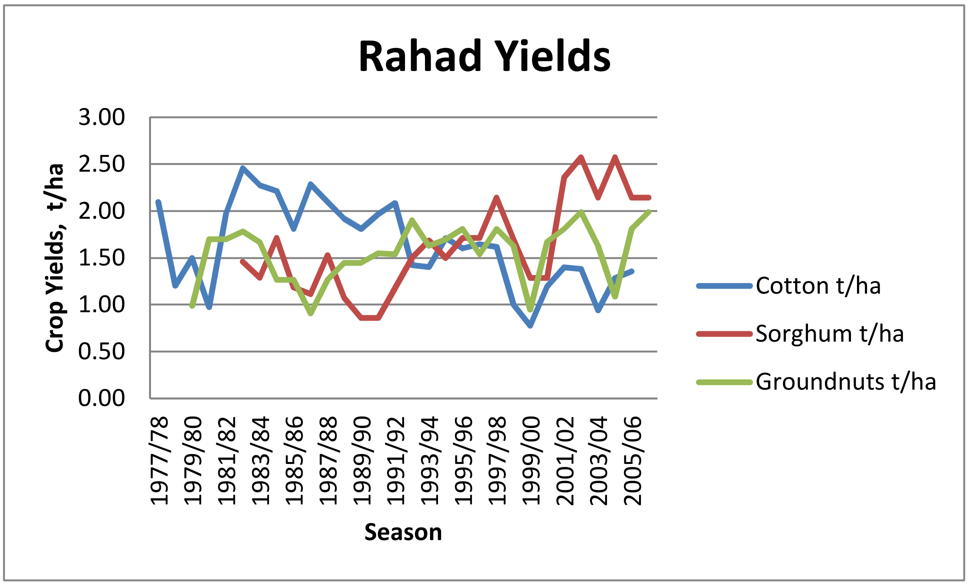


Figure 3-2 Seasonal Variability of Seed Cotton, Groudnut and Sorghum Yields

3.2.1.1 Changes in actual versus potential yields

Figure 3.2 clearly shows that since the second cropping season, the actual seed cotton yields had never reached the projected yield limits. This indicates that the performance of cotton productivity was low. This was attributed mainly to incomplete cultural practices and some cases to low seed quality.

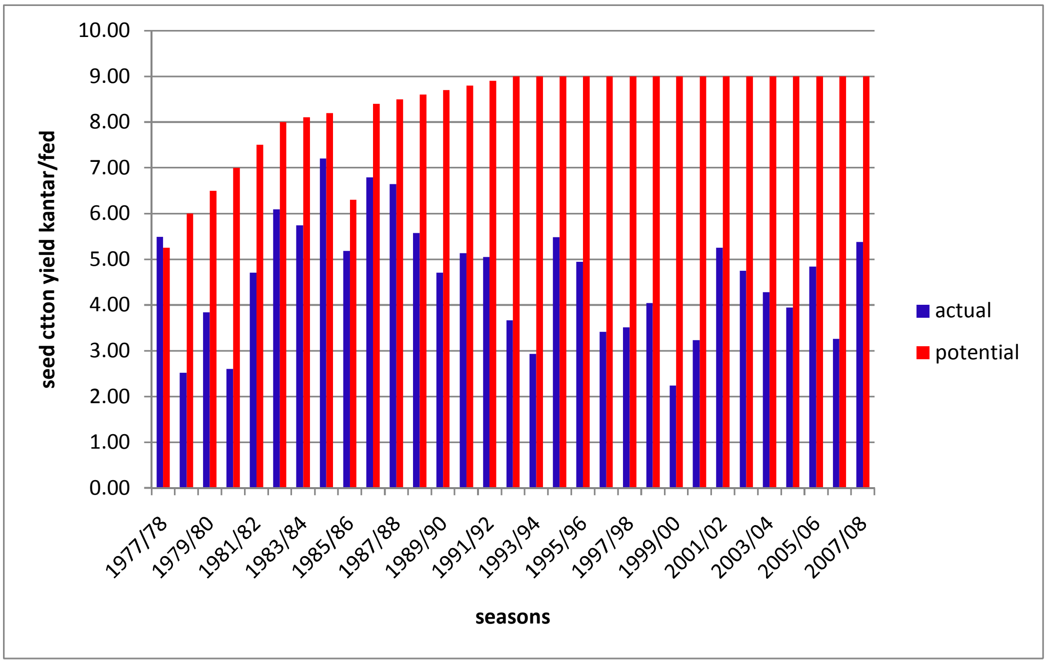


Figure 3-3 The Gap Between Projected and Actual Cotton Yields

For groundnut, as Figure 3.6 shows, the actual productivity was lower than the projected since the first cropping season in 1977/78. In the earlier seasons productivity was low because of delayed land preparation, weeds and floods. During the last seasons, 2001/02 – 2008/09, groundnut suffered from the infestation of the white grub.

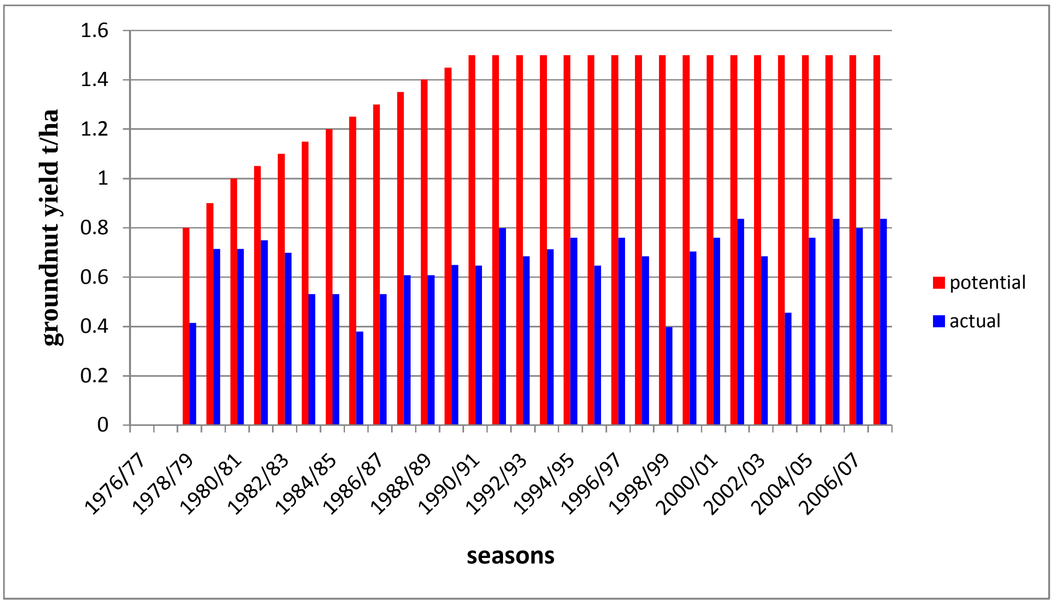


Figure 3-4 The Gap Between Potential and Actual Groundnut Yields

3.2.2 Cropping pattern at RIS

Since the beginning of the RIS, cropping season 1977/78, the common farmer holding was determined to be 22 fed (9.2 ha) divided between four, what so known as, Numbers (command area of Abu xx). In some areas were only 11 fed (4.6 ha). The Number command area was 88 fed (36 ha) and farm unit of 5.5 fed. This was different from what was initially proposed for land division in the feasibility study of RIS which was supposed to be exactly similar to that of the Gezira scheme. Areas were also allocated for horticultural production and forest tree plantations.

The cropping pattern at Rahad has ended up as medium staple cotton, groundnut and sorghum as main crops with some crops left for the farmer choice.

Cropping patterns in the RIS passed through major amendments that were made according to changing situations with the initially planned rotation being groundnut – cotton – groundnut – cotton – fallow – sorghum and free choice. The RIS practically started with a two-course rotation with only cotton and groundnut crops and then sorghum was introduced as a staple food crop, later, wheat was added in the rotation but for only a few seasons.

The last crop rotation decided by the RIS administration was supposed to be a non-fallow rotation with cotton, groundnut and sorghum as summer crops and wheat as a winter crop. This rotation continued for nine years and then was disrupted by the withdrawal of wheat which failed to produce economically in 1990/91 and consequently rejected by farmers. Instead, sunflower and maize were introduced. Cotton also was eliminated from the rotation since 2007/08 and only a small area was grown for seed production. Cotton was abandoned mainly because of the delays of payments, lack of cash credit and the decreased subsidy that was provided by the government. Sorghum area usually exceeds its targeted area as farmers believe that it is more profitable compared to other crops.

Crops to be grown in areas allotted for horticultural production are left merely for the farmer's choice and no rotation is followed and no intervention from the scheme administration.

3.2.3 Comparison of Performance with the EWUAP LSI Study

3.2.3.1 Crop Water Consumption and Crop Water Deficit

Crop water consumption and deficit indicators were estimated from CROPWAT8 using the crop area estimates from the Household Survey and RIS statistics. The values of ETo and rainfall for RIS are known. Planting dates and the numbers and intervals of irrigation applications are based on Household Survey recall data. The application depth was assumed to be about 40 mm. This information was manipulated to obtain gross irrigation applications by crop to resemble those estimated for different crops in the Household Survey. The values of EC_{crop} and EC_{actual} estimated by CROPWAT for the main crops in RIS are shown in Table 3-22.

Actual EC (CWC) is about 5,800 m^3 per ha overall and the Crop Water Deficit is about 440 m^3 per ha. These are very crude estimates based on the HHS, but can be compared to the EWUAP-LSI values. Based on their scale for arid regions, this gives a CWC figure of 3.06 and CWD of 3.0. The EWUAP-LSI study calculates indices for these two parameters for RIS, estimating CWC = 2.58 and CWD = 2.86. The crude estimate of CWC and CWD therefore give comparable estimated of performance to the LSI values.

Summer rainfall contributes 41% to the water supply for groundnuts and 46% for sorghum. According to the data entered into CROPWAT8 the yield depression of these crops is negligible. Nevertheless, the information that goes into the CROPWAT model represents favourable conditions. Unexpected shortages in the main canal in August and September and/or less than anticipated rainfall can lead to yield depression and even total area losses.

There is virtually no rainfall in winter and yield depression of winter crops is severe. Winter cropping comprises only a small proportion of the cropping pattern so the high CWD on these crops do not affect scheme level CWD very much.

The dependence of RIS on summer rainfall is much higher than expected. But the scheme deficit is only 41 MCM compared with gross irrigation supply of 397 MCM, only 10% shortfall. The main problem is timing of supply to coincide with CWR.

Table 3-22 CWC and CWD Estimates 2009 Season

	EC_{crop} mm	EC_{actual} mm	Rainfall mm	Gross Irrigation mm	ha	EC_{crop} MCM	EC_{actual} MCM	Rainfall MCM	Gross Irrigation MCM	CWC m^3 per ha	CWD MCM	CWD m^3 per ha	% of cropped area	Yield depression (CROPWAT) %	% rainfall contribution
Groundnut	764	723	329	481	31,224	238.5	225.7	102.7	150.2	7,230	12.8	409	34%	3%	41%
Sorghum	538	534	331	393	47,242	254.0	252.3	156.1	185.7	5,340	1.7	37	51%	0%	46%
Sunflower	621	394	0	337	8,126	50.5	32.0	0.0	27.4	3,940	18.5	2,271	9%	34%	0%
Vegetables	496	411	0	500	5,676	28.2	23.3	0.0	28.4	4,110	4.8	850	6%	16%	0%
Cotton	939	592	317	550	919	8.6	5.4	2.9	5.1	5,920	3.2	3,472	1%	31%	37%
Total					93,186	579.8	538.8	261.8	396.7	5,782	41.0	440			40%

EC_{crop} Maximum Crop Transpiration
EC_{actual} Actual Crop Transpiration = CWC
CWC Crop Water Consumption
CWD Crop Water Deficit = EC_{crop} - CWC

3.2.3.2 Crop water consumption and water deficient indicators:

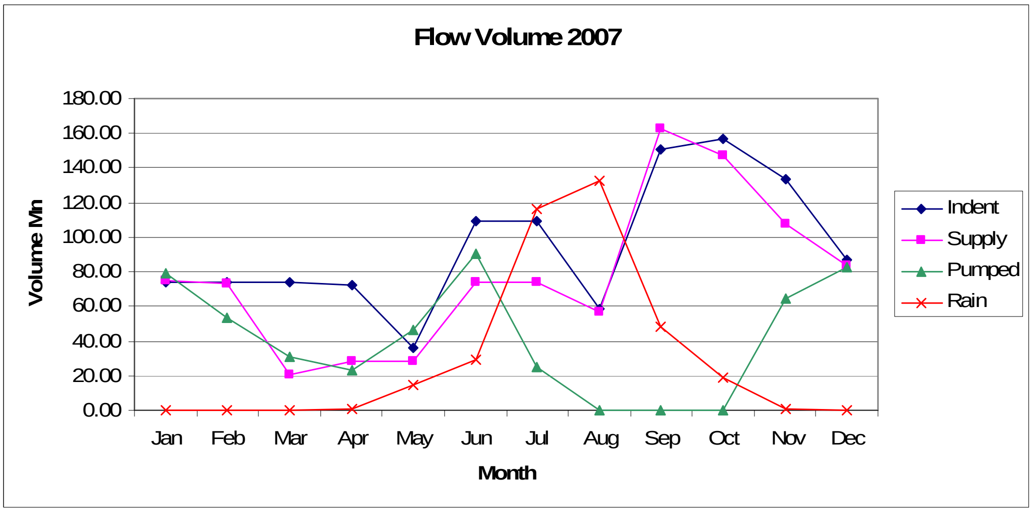
An alternative view of the EWUAP-LSI indicators is made using actual indented values and actual canal flows. Major 5 is taken to represent the overall conditions of Rahad Scheme. This is based on the fact that Major 5 is located in the centre of the project. In addition, all crop and water flow data needed is available for seasons 2002 to 2009.

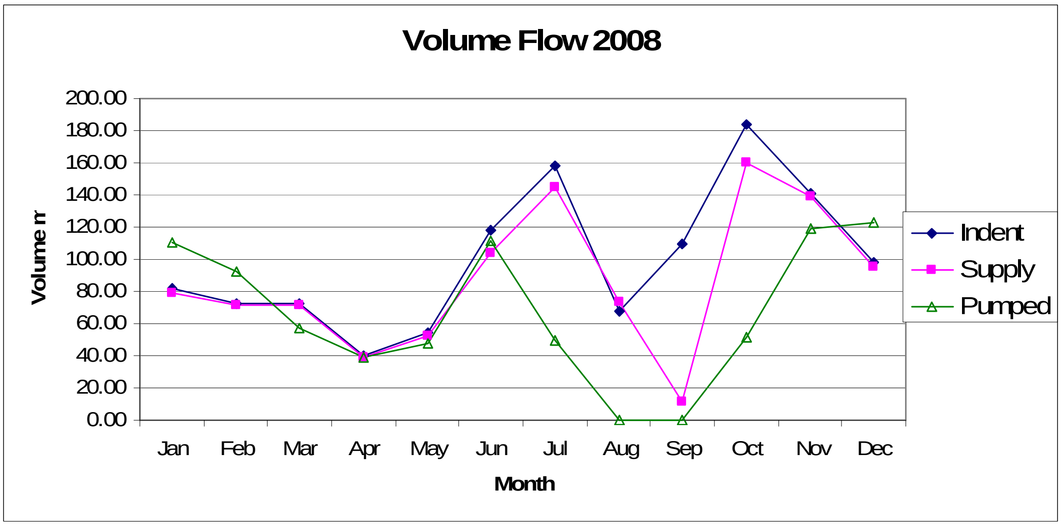
Using the scheme of evaluation adopted in EWUAP study it can be deduced from Table 3-23 that:

- Actual supply (cwc) is fair compared to crop water requirement and is good compared to indent indicating that overall supply is adequate. This result is in agreement with that given by EWUAP (2009), Hamad (2006) and Fadl (1993). As given in Figure 3-5 supply fairly match indent. This picture is not always true according to Hamad (2006) who stated that overall conditions mask the variation between locations and between months of the seasons. This may be the explanation for water losses currently evident from the results of water deficient indicator (cwd) of Table 3-23. Deep percolation water losses in clay soil are reported by many investigators to be minimal. The presence of high water losses is attributed by Wagialla (2009) to be due to the tendency of farmers to pond water in furrows as sign of satisfactory irrigation.

Table 3-23 Estimate of the Loss As Expressed

Year	Crop water deficit(IWR-Supply) cwd=m^3/ha/year		crop water consumption=cwc	
			Indent	Supply
	Indent Supply	Actual Supply	m^3/ha/year	
2004	13456	37756	4.08	2.77
2005	-598	22902	4.26	0.00
2006	249	24679	4.21	2.86
2007	-24434	-1745	5.38	3.75
2008	34655	58780	3.43	2.32
2009	-13432	9004	4.60	3.18
averge	1649	25229	4.33	2.48
Existing Status	Good	Poor	best	Fair
EWUAP -Evaluation	Good	Good	Fair	Fair





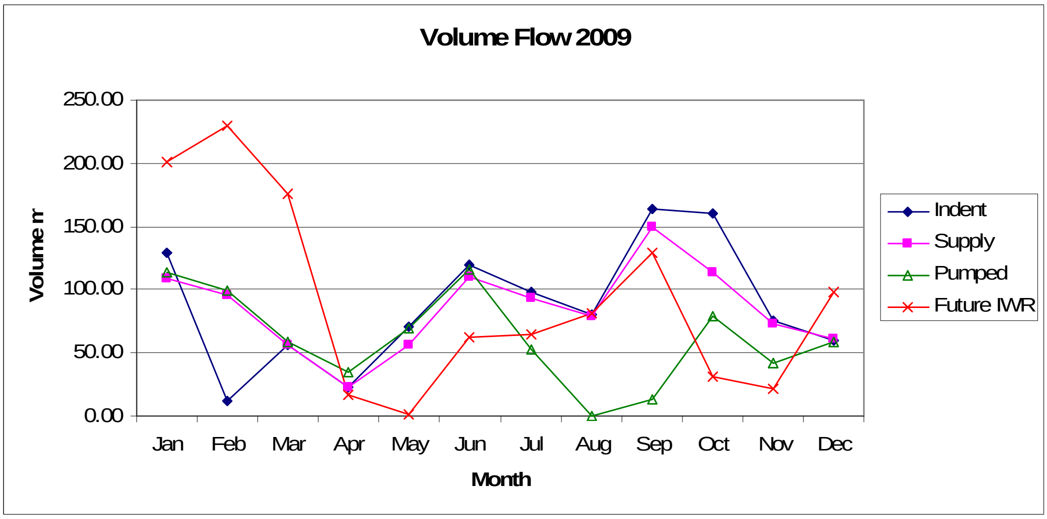


Figure 3-5 Variation of Irrigation Water Indent, Overall Supply, Pump Supply and Rainfall, 2007-2009

Adequacy, Dependability (Reliability), and Equity indicators: Table 3-24 comparison of current status of these indicators with those reported by the study of EWUAP-LSI (2009). The optimistic values estimated by EWUAP (2009) study differ from actual status. The evaluations made by Fadl in 1993, based on field measurements, indicated the temporal and spatial variation of these indicators. These results are in line with that given by Hamad (2006).

Table 3-24 Comparison of Overall Adequacy, Dependability (Reliability) and Equity Indicators

Year	Adequacy ad=Tac/Tpot	Dependability(Reliability) rel=1-CVt(Tac/Tpot)	Equity un=1-CVR(Tac/Tpot)
2004	0.58	0.85	0.70
2005	0.70	0.82	0.70
2006	0.68	0.83	0.70
2007	1.03	0.73	0.70
2008	0.46	0.88	0.70
2009	0.85	0.78	0.70
average	0.72	0.82	0.70
Existing Status	Fair	Fair	Poor
EWUAP -Evaluation	good	good	best

3.2.3.3 Actual Values from the EWUAP LSI Study compared to ENTRO Study

The EWUAP LSI study does not give all the values for the 10 performance indicators presented in the report. However, all ten values have been obtained and are presented for comparison. The determination of the performance value was used to obtain the value for direct comparison, and are presented below in Table 3-25. These values were obtained from the consultants that performed the evaluation, and are somewhat different to the results presented in the LSI report. Three indicators, CWC, CWD and AD are shown higher in the report than given by the consultant. Even using the higher values of these indicators, the average overall from the consultant for Rahad is only 3.29, but LSI report is 3.59.

Table 3-25 Actual Values for RAHAD from the EWUAP LSI Study

Remote Sensing Value		Abbreviation	LSI Report Value	LSI Report Average	Pilot Study Value	Pilot Study Agreement
Landproductivity_s1.img	lp_s1	bio	3.13			
Landproductivity_s2.img	lp_s2		3.73	3.43	1.0	X
Totalwaterproductivity_s1.img	wp_s1	bwp	2.45			
Totalwaterproductivity_s2.img	wp_s2		3.04	2.74	1.0	X
Waterconsumption_s1.img	wc_s1	cwc	3.08			
Waterconsumption_s2.img	wc_s2		2.09	2.83	3.1	ok
Cropwaterdeficit_s1.img	wd_s1	cwd	3.11			
Cropwaterdeficit_s2.img	wd_s2		2.60	3.51	3.0	ok
Beneficialfraction_s1.img	bf_s1	bf	3.75			
Beneficialfraction_s2.img	bf_s2		4.03	3.89		
Adequacy_s1.img	ad_s1	ad	3.85			
Adequacy_s2.img	ad_s2		4.38	4.55	5.0	ok
Uniformity		un	4.00	4.00	1.0	X
Relative_water_supply.img	wsup		3.17			
Reliability.img	relia	rel	3.38	3.38	4.0	ok
Sustainability_land_longterm.img	sus_l	spot	3.13			
Sustainability_land_shortterm.img	sus_s		4.04	3.58	1.0	X
Water_sustainability.img	wsust	amsre	1.00	1.00	1.0	
		Overal Average Ranking		3.29	2.23	

Only four indicators were confirmed, while four were not confirmed. Two indicators were not evaluated. This table shows that the indicators presented by the EWUAP-LSI (2009) study are an over-estimation (3.29) while this study gives an average value of 2.23. Rahad is therefore poor performing scheme.

3.3 Institutional Indicators

3.3.1 Performance indicators

Performance indicators for institutional aspects of the Rahad Irrigation Scheme are focused on institutions involved in the management and operation and maintenance of the irrigation scheme and in the provision of extension services to the farmers benefited by the irrigation scheme.

In line with the objectives of the pilot study on improving Water Use Efficiency, the performance indicators used in the study of the Rahad Irrigation Scheme are presented in the following table. It shows the performance indicators with the corresponding variables studied, methodology for data gathering and performance assessment.

Variables

a. Mandate/Functions

b. Organization, System and Procedures for MOM, O&M, and extension services

c. Fee Collection (components, amount and efficiency)

Perception on efficiency of the organization, system and procedures

Methodology for Data Gathering

a. Household Survey

b. Direct on-site observation

c. Conduct semi-structured interviews with key informants e.g. relevant officials and staff at Wad Medani, El Fau locality and Rahad Directorate levels

Conduct Focus Group Discussions with sample farmers in 6 villages

Table 3-26 Institutional Performance Indicators

No.	Performance Indicators	Preliminary Performance Assessment
1.	Functionality of Government & Private Institutions e.g. MoIWR, and Rahad Agricultural Corporation (RAC)	a. Pumping station and the main system up to the major canals are managed and operated fully by the MoIWR. RAC on the other hand is responsible for the minor down to the Abu XX. Water distribution is both the function of MoIWR and RAC b. Fee collection is being handled fully by RAC. Information from FGDs and interviewed showed that collection efficiency was almost 100% because RAC had installed mechanisms to ensure farmers pay in full and on time c. Farmers are very dependent on RAC and MoIWR on almost everything and they lack initiative to perform O&M responsibilities. Due to budget constraints and dependency attitude of the farmers, functionality of the scheme had been deteriorating in the last 5 years resulting to water shortage and lower crop yield. Overall functionality of institutions is poor (4).
2.	Functionality of Farmers' Institutions e.g. Farmers' Union (FU) and Financing Groups (FGs)	a. The FU had been collecting SDG 3/cropped feddan from the farmers for its operational costs but 90% of the farmers in the FGDs conducted expressed dissatisfaction on the performance of its duties and responsibilities b. The FU does not provide guidance to farmers on irrigation management and marketing assistance based on farmers' perception c. Only in one of the 6 villages covered by the visit that FGs performed well. The FGs in Village 37 were able to repay back their loan from the Bank in full. They were in control of the whole process from the opening of their bank account up to the payment of their loan. The head of the FGs directly dealt with the Bank without the guidance and supervision from neither RAC nor the FU. d. 90% of the farmers who attended the FGDs are still interested to reactivate their FGs but mainly for the purpose of maintenance and water distribution and no longer for borrowing money from the Bank. e. There is no water users' organization responsible for MOM and O&M. d. Overall, performance of farmers' institutions in Rahad on MOM, O&M, and others is poor (4)
3	Adequacy and effectiveness of Extension Services	a. RAC had been mainly responsible in providing extension services and training to the farmers since the establishment of the Rahad Scheme b. Nature and content of the extension and training had been directed mainly towards cotton production specifically on land preparation and sowing date but Irrigation was never discussed as a topic in the extension and training subject matter c. Visits and off farm meetings were the principle forms of contact, with courses and demonstrations less important. Farmers do not have access to manuals and leaflets. The frequency of an individual receiving extension and training information through contacts was 8 times per annum per sampled households., and 40 times per annum amongst those who actually received the contacts.

		f. According to those present in the FGD, the extension services and training they have received so far is adequate. No extension visits were made on irrigation nor animal production. 31% did not know what the extension visit was about. Performance assessment is poor (4).

3.3.2 Key Institutional Issues

1. **Tenancy Administration**. Based on a study conducted earlier, 55% of sample respondents said that other persons operate their tenancy on their behalf (11% lease/rent, 15% sharecropper, and 29% Wakil). Although leasing was not formally allowed, 13.6% of the sample respondents practice this.[20]This is high especially among female farmers having tenancy rights. Some of the major reasons cited by the study for tenancy administration by other persons are as follows: income from farming is low so they need to look for other means of livelihood; lack of labour; and not enough capital to operate tenancy. This situation has direct implication on farmers' participation and assumption of responsibility in MOM, O&M and fee collection.
2. **Water Users' Organization**. There is no separate farmers'/water users' organization that is responsible in addressing irrigation and maintenance related issues and in coordinating with MoIWR and RAC on the scheme's functionality. The Farmers' Union, who is a strong and powerful association in the area, has stifled efforts in the past to organize a separate Water Users' Association (WUA) to handle MOM and O&M aspects of the Rahad Scheme. There seems to be apprehension on the part of the FU officers that their influence and authority may diminish through time with the establishment of a WUA. The FU as it is now will not be an appropriate organization to handle the MOM and O&M aspects of the Rahad Scheme due to its mandate and other functions. It is also preoccupied with facilitating provision and implementation of socio-economic, health and other social services in the area by various government agencies.
3. **Strong Dependency Attitude of Rahad Farmers on Government and Private Institutions**. It was observed that farmers were waiting for Kenana Corporation or MoIWR to tell them what to do before taking any action on the remaining 50% part of their land. During the Consultant's visit in the area (until 1st week of May), farmers have not started land preparation yet. During the FGDs, one of the questions raised was, "Where will they now get financial support for their agricultural operations e.g. for land preparation, seeds, fertilizers, etc.?" It is apparent that there had been no effort to develop capacity of farmers to be more self-reliant from the time they were allocated their parcels of land to use and develop until the present time. RAC staff, based on information from the former staff involved in the study, have mainly dictated to farmers what they should do and not really involved them in the decision making process on important issues affecting them. Instead, RAC and MoIWR addressed all their farming needs and solved their problems. Farmers were not given any responsibility for MOM and O&M except to pay a small amount of water charge—SDG 47/feddan.
4. **Farmers generally lacked knowledge on proper irrigation water management.** This can be attributed to the absence of irrigation topic in the extension services provided by RAC staff. It is not known whether or not also MoIWR Staff at Rahad Directorate did not impart this knowledge to RAC or farmers. Kenana Staff at the Block Level will maintain the type of extension services and training

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[20] Perspective of Farmer's Attitudes and Gender Issue in Irrigation Water Management, a Thesis submitted by Ilham Nasr Alla Ali Karar, 1981.

being provided to the Rahad farmers. During the project visit of the Consultant, 3 Kenana Staff (formerly RAC employees) were interviewed. Though their designation had been changed, their work remains basically the same.

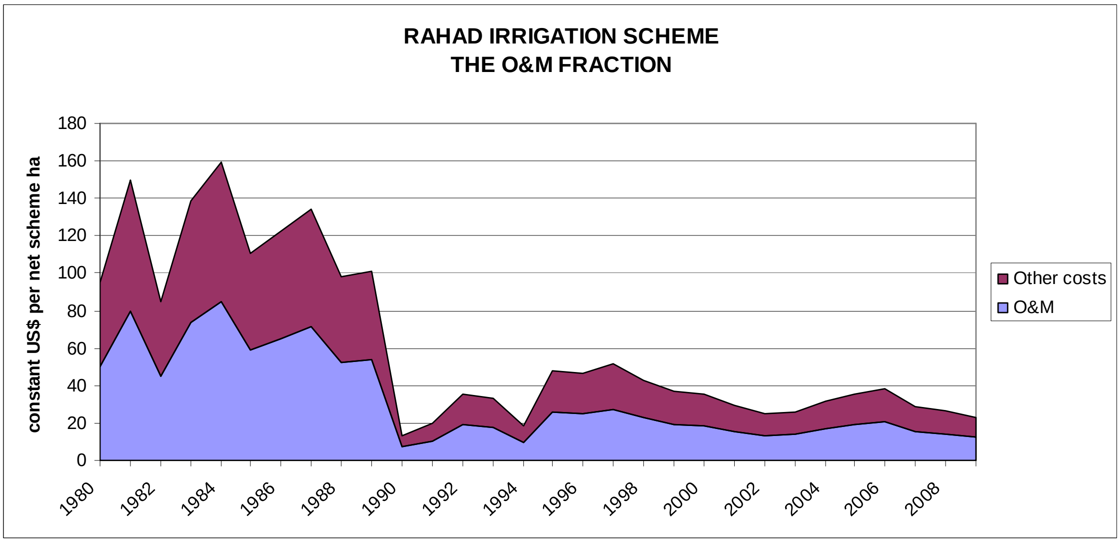
3.4 Economic and Environmental Indicators

The Land Productivity index is best envisaged as the yield of main crop per scheme hectare. A 30 year average of 1,005 kg/ha was calculated which is very low. The trend of the index is strongly upwards to 1981 when it reached 1,200 kg/ha, followed by a long period of stability to 1995 when the index began to fall to reach present levels of about 600 kg/ha. The index mirrors the historical trend of cropping intensity. Yield trends (kg/crop area) show a rather different pattern, see below Figure 3-8. The Water Productivity index is also very low, an average of 0.19 kg per m^3 over the last 28 years.

The Relative Water Cost indicator is the cost of irrigation as a ratio to the other costs of crop production. It has been calculated as an average of 0.14 over a 30 year time series using official RIS data. The standard deviation of this index is very low (0.03). However, the data was found to be misleading, and this calculation was rejected in favour of Household Survey (2009/10) and FAO (1999) production cost data. The revised indicator was found to be 0.29. Payment for water is the principle cost in tenant farmers' gross margins.

The O&M fraction is the ratio of the cost of O&M to total MOM cost. Calculated to be 0.53 this is a poor value, and accounted for by this percentage of the water charge being ear-marked for RAC salaries and administration. The problem is RAC has borne huge overhead costs in research, extension, input supply and marketing. There is a strong discontinuity in MOM paid from water charges received from 1990, when wheat was introduced and the cotton area halved. Since then, MOM revenues have never recovered, remaining below constant 2009 US$ 40 per ha ever since.

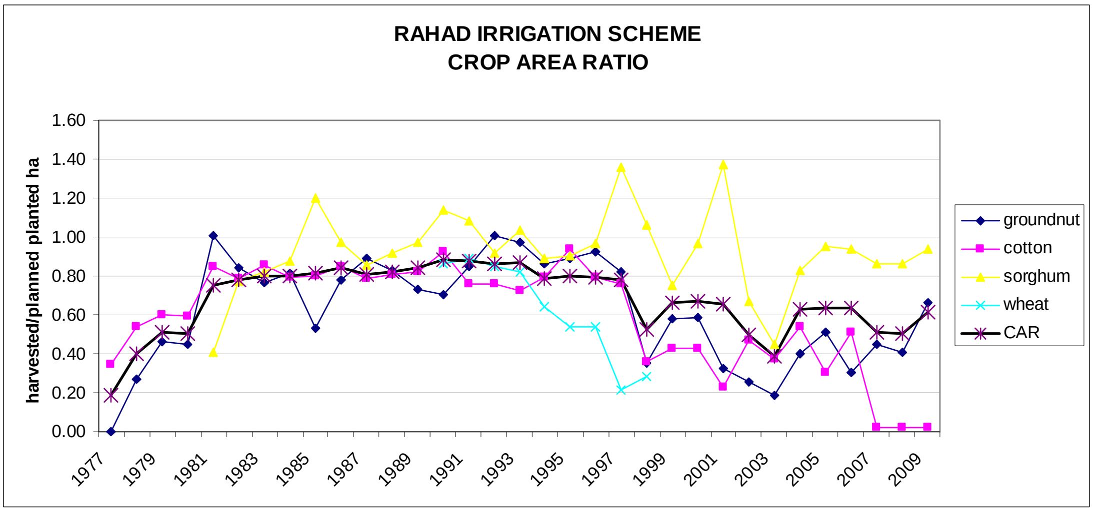
Figure 3-6 MOM Revenue: constant 2009 US$ per ha. 1980 - 2009



The present MOM funding indicator is the cost of MOM to the farmer as a ratio of net farm income. By comparing the Administration and Water Charge with farm incomes estimated in the Household Survey, it has been calculated as 0.27. This implies that the average farm must allocate 27% of its net annual income to irrigation charges for the next year. This is a very high proportion and one which tenant farmers find extremely difficult to manage. The sustainable MOM funding indicator was calculated using future with project farm budgets (farm size halves and the cropping pattern changes slightly with the introduction of winter maize) and estimated as only 0.11. This would be much more attractive to farmers, providing they can make the necessary small increases in productivity. It should be possible to maintain net farm incomes even though farm size halves.

The Cropped Area ratio is the ratio of the present gross cropped area to the designed net irrigable area of 132,405 ha. The irrigation of this area has never been realised because of water supply difficulties, but the CAR requires planned against achieved crop areas, so the larger command area is used as the benchmark. The agronomic planning of RIS was originally done in 1977 at scheme design, modified in 1981/82, again in 1990/91 with the introduction of wheat, and finally in 1999/2000 when wheat was finally excluded from the cropping pattern. Different rotations have been advised for the northern section and the central and southern sections on the basis of agronomic recommendations. The actual harvested areas for the period 1977-2009 are known from the RIS Statistical Bulletin. However, some crops are not enumerated, including sunflower and "other crops". An estimate of the areas of these in 2009//10 are available from the Household Survey, and these areas have been incorporated into the official statistics. A CAR can be calculated for each crop and each year, and a scheme level CAR can be calculated simply by summing planned and actual crop areas. The results are shown in Figure 3-7.

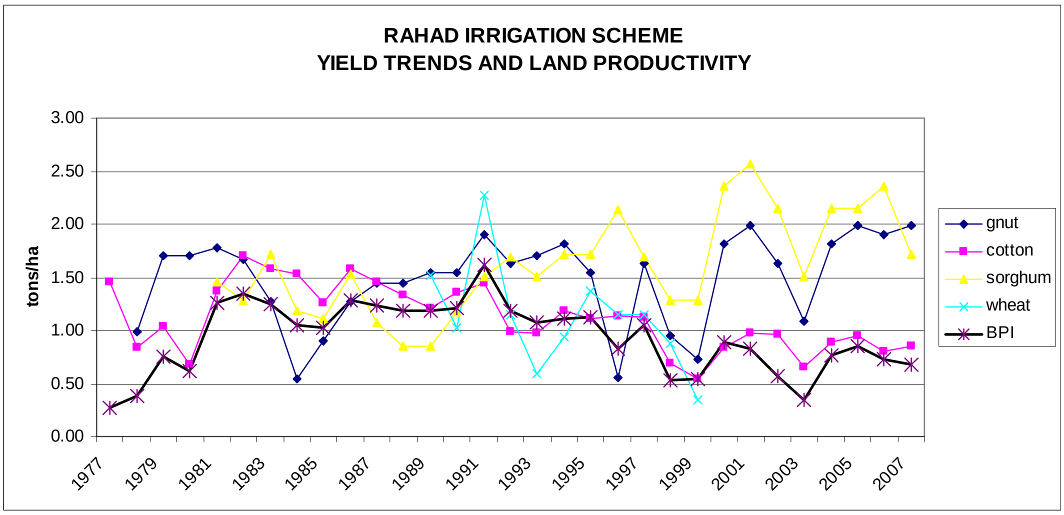
Figure 3-7 RIS Crop Area Ratio



The scheme level CAR shows steady growth to about 0.8 in 1981, and improved to nearly 0.9 in the mid 1990s. Since 1995 the trend has been steadily downwards with marked dips in 1998 and 2003 which were flood years and caused widespread crop losses. Now the CAR is about 0.6. The only crop to exceed the planned area has been sorghum, in 1985, 1989 -1991, 1997 and 2001. Occasionally groundnut harvested areas have approached planned areas, but there has been a long decline since 1991. The cotton area has been in decline since 1995.

The data also exists to calculate the yield of main crop per hectare, by summing known production by crop and dividing by scheme irrigated area (111,300 ha). This is a part of the scheme Biomass Productivity Index (BPI), expressed in kg/scheme ha/per annum, but does not include the weight of crop residues. The result is shown in Figure 3-8, which also shows the conventionally calculated yields of the main crops, in tons per harvested hectare. The graph shows that while scheme crop productivity per unit area is declining, the yields per unit area harvested of sorghum and groundnut are actually increasing, but are also becoming more variable. Cotton yields are in long term decline, caused by reduced input applications and shortage of irrigation water.

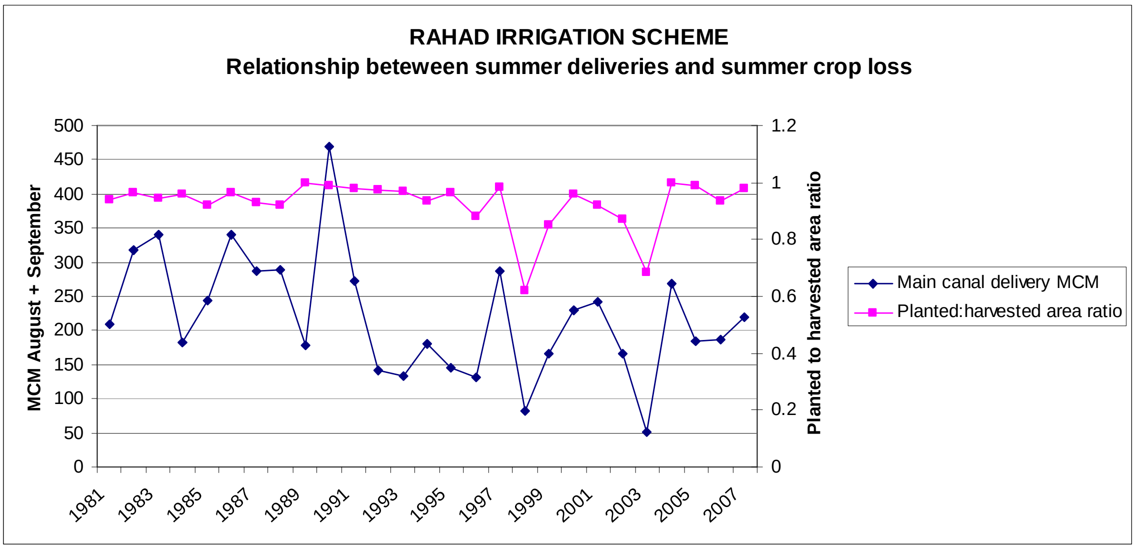
Figure 3-8 RIS Yield Trends and Land Productivity



The total annual biomass production was an average of about 1,700 kg per ha per annum over the last 30 years. Biomass production per unit of water was calculated using volumes available in the main canal in the last 28 years, an average of 1,078 MCM, then the biomass production was only 0.11 kg per m^3, a very low index.

Scheduling irrigation delivery for CWR is important in RIS. Comparing irrigation applications (based on recall data) showed the critical constraint to volume applied was main canal delivery in August and September, a critical period in the growth of the important summer crops sorghum and groundnuts. There was a very good correlation between main canal delivery in this period and the planted : harvested ratio, as shown in Figure 3-9.

Figure 3-9 Summer Main Canal Deliveries and Summer Crop Loss



A simple regression gives a strong positive correlation (R2 =0.30, df = 26, F=10.86, significant at 99%). The coefficient of the independent variable is 0.00054 (t = 3.3, significant at 0.3%), suggesting that over the time series, a 1% reduction in main delivery in August and September can reduce the planted to harvested area ratio by 0.054%. The cost implications are that a 1% reduction in the average main canal delivery in August to September of 220 MCM (about 2.2 MCM) causes a fall in the planted to harvested ratio and an absolute loss of about 50 feddan. The loss in inputs and crop over the area (weighted for the constituent crops) is about

SDG 30,000, which is a loss of about SDG 0.015 per m^3. In addition one would have to consider the cost of yield depression on a wider, unknown area which is not lost, and would eventually be harvested.

Economic performance indicators include ex post financial and economic analysis, but it is often difficult to mobilise the data. Such an analysis was carried out for RIS in current US$. Construction took place in the period 1974-1976 at a cost of US$ 400 million. The land and water charge revenue is known for the period, by multiplying crop area by its unit area charge rate. The pumping cost, which was almost completely subsidised up to 2009, was calculated by deflating the 2009 unit cost of pumping (US$ 0.0036 per m^3), multiplying by the annual volume pumped and added to investment and MOM costs.

The net value of crop production was estimated by crop for the period using data from the RIS Statistical Abstract. There are questions about the accuracy of crop production costs from this source, but the gross value of production calculated from this data should be fairly accurate.

A financial net benefit stream was then calculated. The scheme first made a positive FIRR in 1993 and achieved quite good financial progress until 1996, when the net value of crop production declined until 1999. Since then, and despite perceptions of negative performance, slow but consistent increases in scheme return have been made. By 2007 the FIRR of the scheme was 2.7%, which is no doubt well below the expected return after 30 years when the scheme was constructed, but possibly better than popular perception of its performance. Nevertheless the scheme carried a large bill for deferred maintenance in 2007, which resulted in the necessity for a further US$ 20 million investment in equipment and de-silting in 2009 – 2010. The impact of this investment on FIRR has not been calculated.

A summary of the environmental and economic irrigation performance indicators discussed above is given in Table 3-27.

Table 3-27 RIS Environmental and Economic Performance Indicators

Indicator	Indicator formula	Key Parameters				Indicator value	Unit	Desription	Rating
		Scheme area, ha	Average cropping intensity	Average annual crop production, tons	Water application, m3 pa				
Water Productivity	$WP = \frac{Y_c(kg)}{V_a(m^3)}$	111,300	80%	111,860	690,903	0.11	kg/m3	Production per unit volume of water	very poor
Land Productivity	$LP = \frac{Y_c}{A_a}$	111,300	1	111,860	690,903	1,005	kg/ha	Production per unit area of land	very poor
Indicator	**Indicator formula**	**Key Parameters**				**Indicator value**	**Unit**	**Desription**	**Rating**
		Total Scheme Production Cost US$	**Scheme MOM and field irrigation charge, US$**						
Relative Water Cost	$RWC = \frac{C_w}{C_{tc}}$	7,285,480	2,100,503			0.29	ratio	Ratio of cost of water to cost of other factors of production	good
Indicator	**Indicator formula**	**Key Parameters**				**Indicator value**	**Unit**	**Desription**	**Rating**
		Scheme MOM US$/scheme ha	**Scheme Management US$/scheme ha**	**Scheme O&M US$/scheme ha**					
O&M Fraction	$O\&M = \frac{C_{o\&m}}{I_S}$	23	11	12		0.53	ratio	Ratio of cost of O&M to cost of MOM	too high
Indicator	**Indicator formula**	**Key Parameters**				**Indicator value**	**Unit**	**Desription**	**Rating**
		Total Net Income of 261 sampled farms, US$ pa	**Net irrigable area of sampled farms, ha**	**MOM Requirement, US$**					
Present MOM Funding Ratio	$MOM\_FR = \frac{I_a}{I_S}$	288,766	1,996	79,280		0.27	ratio	Ratio of cost of MOM to Annual Household Income	too high
Indicator	**Indicator formula**	**Key Parameters**				**Indicator value**	**Unit**	**Desription**	**Rating**
		Total Net Income,US$ pa per HH	**Net irrigable area, ha per HH**	**MOM Requirement, SDG**					
Sustainable MOM Funding Ratio	$MOM\_FR = \frac{I_a}{I_S}$	1,220	3.76	622		0.28	ratio	Ratio of cost of sustanable MOM to with project Annual Household Income	too high
Indicator	**Indicator formula**	**Key Parameters**				**Indicator value**	**Unit**	**Desription**	**Rating**
		Gross cropped ha	**Designed net irrigable ha**						
Cropped Area Ratio	$CAR = \frac{A_a}{A_I}$	89,983	132,405			0.68	ratio	Ratio of gross cropped area to designed net irrigable area	poor
Indicator		**Key Parameters**				**Indicator value**	**Unit**	**Desription**	**Rating**
		Main crop tons	**Residues tons**	**Net scheme area, ha**	**Water application, MCM**				
Biomass Production per unit area		104,107	87,570	126,000	997	1,722	kg/ha	kg of bimass per unit area	poor
Biomass Production per unit of water		104,107	87,570	126,000	997	0.19	kg/m^3	kg of bimass per unit of water	poor
Indicator		**Key Parameters**				**Indicator value**	**Unit**	**Desription**	**Rating**
		NPV scheme construction, US$ m @10%	**NPV paid MOM, US$ m @10%**	**NPV pumping cost, US$ m @10%**	**NPV Value of crop production, US$ m @ 10%**				
Financial Internal Rate of Return		332	126	23	369	2.67%	FIRR	Ex post Financial Cost:Benefit Analysis	very poor

4 DETAILED ACTION PLAN

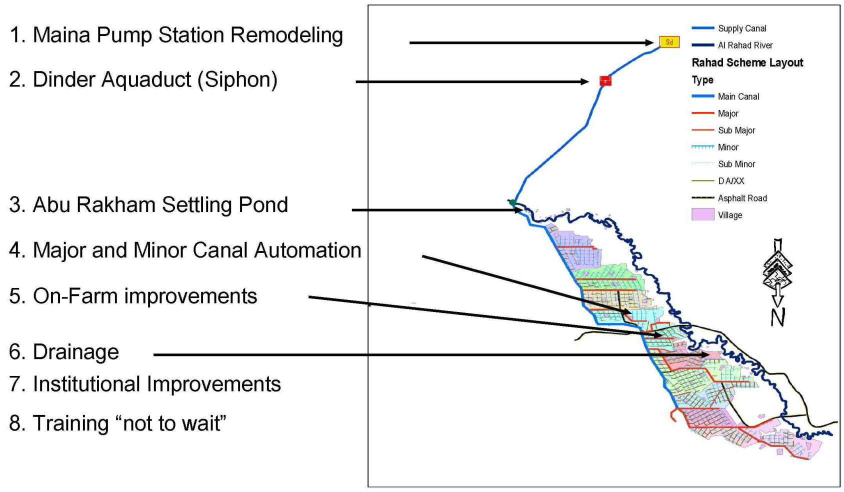
4.1 Introduction

The first major limitation was the sedimentation problem, similar to Gezira. The scheme canals are presently being desilted under a rehabilitation program, but further attention to this problem is needed. Then water availability has tended to limit production. This is due to the fact that out of 11 pumps at Meina, only two are presently working, so water supply is important. Part of this limitation is the sedimentation of the pump station intake channel of 100 m from the Nile River, which has to be cleaned on an annual basis otherwise there would be no water. The Dinder Siphon is also a limitation to the supply, which has to be cleaned every two years. Control of the water to farmers fields has been a concern as gate keepers are no longer present beside the regulator gates, as their houses have fallen down. In the farmers fields productivity is very low due to late cultivation operations, poor seed, no fertilizer, poor agricultural practises etc., and also water-logging of fields. So in-field practises need urgent attention. Then availability of credit and farm inputs is severely lacking. Both government institutional bodies, MOI and RAC have little incentive to maintain services as salaries are low, conditions are poor, housing in delapdeted state resulting in poor services in supply of inputs (water, supervision, instruction etc.). In fact, in every direction the study looked there was a problem.

An incipient situation in the project which needs to be addressed is that of the tenant who have been “trained to wait”. Tenants wait for everything. Over the years they have gained little incentive to get up and do things for themselves, but have to wait on the RAC to provide everything. With the introduction of a private entity, Kenana Sugar Company, things will be different for the supply of inputs, but for the tenant’s 50% remaining land, he has to make his own arrangements. When the team looked around the scheme, there was however many examples of individuals who were not waiting for RAC or KSC to provide inputs but were farming on their own accord, thus increasing the project productivity. There were Okra farmers along the main canal, using little water during the off period. This shows that not all farmers are waiting, and these individuals should be held up as an example of what to do, which is not to wait. However, during the visit, KSC, in a show of authority, closed down these motivated people and squashed incentives. This is hardly helping to improve productivity on this already very poor scheme. Farmers need to be re-trained “not to wait”.

In order to make a quick assessment, the study embarked on data collection. A Rapid Rural Appraisal was made in the form of House Hold Survey of three blocks, 2, 5 and 8. House holds were selected at random and questionnaires completed. Data on water deliveries were obtained from MOI in Wad Madeni as well as design, drawings and any M.Sc or PH.D. conducted on Rahad. This data has been analysed and the result is the following detailed action plan.

Starting at the top (South) of the project, at Maina Pump station the following action is planned:



4.2 Hydraulic Engineering

Key components of the system are identified as limiting production and major changes to the system are identified.

4.2.1 Meina Pump Station Re-Modelling

4.2.1.1 Options for Operation

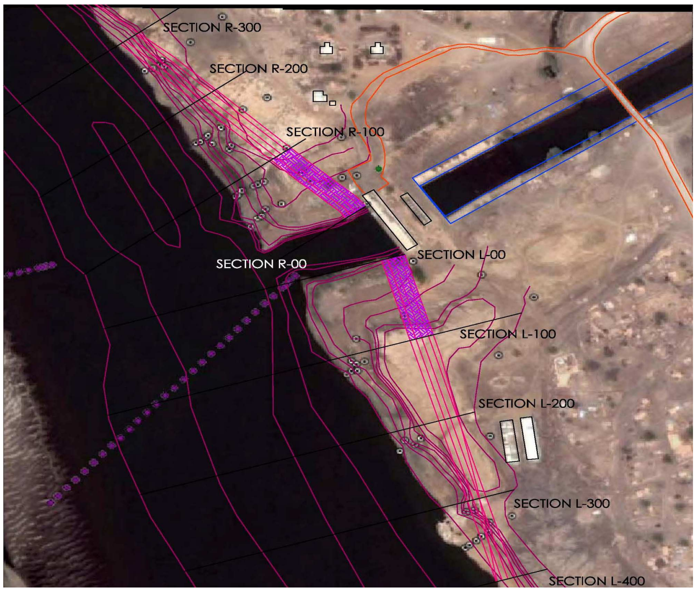
A. Maintenance System

Use the existing methods of maintenance but have the dredger available for continuous de-silting. While this is the cheapest solution, it has proved to be unreliable and in the end, far more costly in water and timeliness lost because it is not implemented effectively. It also leads to other problems, because pumps have to operate right through the high sediment flows to keep the channel open. This sediment could be returned back to the river through a by-pass channel, but it still means the dredger must be operational too keep the channel clear. This method is not recommended. This is discussed in more detail in 2.4.1

B. Intake Re-modelling

By remodelling the station intake, it is possible that all the problems best the operation can be removed and allow the station to operate unhindered on an annual basis. Option B has been included in this action plan.

Inspection of the Meina Pump station found the dredger parked and two draglines cleaning sediment from the intake to allow pumping to take place. This is an annual occurrence which is costly and often delays the supply and quantity of water to the project. The solution to this problem is to move the pump station to the river and reduce the deposition during flood flows. As this cannot happen, the river can be moved to the pump station, by opening the banks and allowing the river to flow directly past the pump intake, cleaning as it passes. This would not take much work as the intake channel is only 100 m. A section of the Nile bank for 400 m upstream and 400 m downstream could be removed and incorporating a zone of gabion protection for 100 m either side. While it is anticipated that some deposition may occur, this will be removed by the higher velocities on the east bank as this section is on a left hand bend. The maximum depth of scouring that could be encountered would be in the region of 2.0 m which would not affect the integrity of the pump house.



The plan shows how the situation looks. The gabion protection would be built on dry land before opening out to the river. The site would need de-watering to install the gabions below Nile water levels. Once the protection is complete, the river could be opened using the cheapest form of soil removal, the dredger, allowing the river to clean away any deposited sediment. Pumping could then continue un-interrupted for years to come.

Detailed surveys were made of the embankments upstream (left) and downstream (right) of the pump station.

Previous bathometric surveys of the Nile River were obtained from HRS, Wad Medani. These were combined to create a contour model of the existing situation at Meina. Cross sections were made of this model, as given in Figure C1. The Nile bed level adjacent to the pump station is 416 m. This is the level at which a 6.0 m long gabion mattress will be placed. Any scouring below this level will be protected by the gabions which will move and take up the new level. In this manner the bank will be protected from scour below 416 m elevation. A berm will be placed at elevation 422 m for ease of construction and bank stability. A second berm will be a elevation 427 m. The proposed method of construction will be to excavate the gabion section to below 416 m elevation and to use de-watering pumps to allow placement of gabions and rock fill in dry conditions. After the gabion structure passes low water level, about 419.5 m the de-watering is no longer needed. A filter blanket, of either filter fabric or graded sand will be placed behind the gabion mattress until elevation 427 m. Once gabion mattresses have been competed, then the removal or remaining material on the river side can be removed using the floating dredger at a much cheaper rate. Once both sides of the pump entrance have been removed, the river will have un-restricted access to the pump station.

It is anticipated that allowing the river to pass close to the pump station will not allow sediment to deposit in front of the pumps. If however there appears to be either further deposition in front of the station or scouring, then a gabion deflection wall can be constructed to deflect any problems created. This has been done in a river extraction project in Peru, see photo adjacent.

The total cost of the Meina Pump Station Re-modelling is given in the Table 5-3 Meina pump Station Costs.

4.2.2 Dinder Aquaduct (Siphon Replacement)

4.2.2.1 Options for Operation

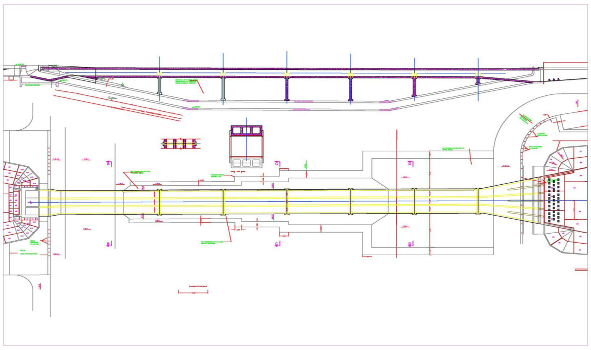
A. Maintenance System

If Option A for the pump station is chosen, then the correct operation of the siphon is essential. This can only be achieved by two changes: repair and make operational the radial gates at the entrance to the siphon barrels, and then closing the barrels depending on the number of pumps running. This operation will increase the velocity within the barrels and reduce the deposition inside the barrels. While this is on the face of it the best option, it still relies on the management operating the gates correctly which is a high expectation considering past performance. Also, the annual cost of cleaning the siphons is $169,000, this is part of this option.

B. Replace siphon with aquaduct bridge.

Replacing the siphon with an aquaduct is an expensive option and will take 30 years to pay for it. However, it does have two major advantages; it provides the community with a bridge where there is none on the Dinder for many miles, and is give the project an unhindered operation of the supply canal without any management required. Despite these high costs, this option has been included in the action plan as it represents an great improvement in the supply of water.

The Dinder siphon has proved to be a major bottle neck in the operation of the supply canal. The main reason for this is the operation of the pumps during the high sediment flows (July to September) which deposit large quantities of sediment in the canal. Poor operation of the siphon by opening too many barrels reduces the velocity and leads to deposition. For the siphon to be self cleaning (non-depositing) the velocity needs to maintained at a high level of about 3.0 m/s. However, for some time the gates have not been maintained and are not operational. Deposition in the siphon can be reduced by correct operational procedures. This cannot be done all the time, but if four pumps are operating, then only one barrel should be open, the other two closed to ensure high velocities in the one barrel. If five pumps are operating, then another barrel is opened, and so forth. With a low number of pumps operating and at least two barrels open, the velocities in the barrels is much lower than optimal, and silt deposition occurs, causing the siphon to be shut down every two years for cleaning. If the Meina pump intake canal siltation is solved by opening up the entrance to the river, then the pumps could be shut down during high sediment flows. Then once pumps are operational, the number of barrels open must be relative to the number of pumps operational, reducing the potential of deposition.



Unhindered operation of the siphon assumes management will be effective in maintaining the above scenario. However, this has not been the case in the past for many reasons. So the study looked at the possibility of turning the siphon into an aquaduct by utilising the existing structure as the foundation for the piers. This would remove any possibility of sedimentation disrupting the supply of water and also provide an extremely useful bridge for the local community.

A survey was made of the river to determine the maximum flood levels, and it was found that the highest level of flood (elevation 422.2 m amsl) would be 3.54 m below the sofit of the aquaduct (425.75 masl). This provides adequate safety margin against flooding. The barrel was also designed to span 28 m, with 5 piers in the river. Finite element analysis was made on the barrel span to determine its safety in span and barrel dimensions.

The accompanying photo below shows the Dinder River looking upstream. The downstream barrel of the siphon is exposed, as per design as this section is on the bend of the river. The river is remarkably stable and the siphon has survived very well. Converting this into an aquaduct would allow a bridge to be constructed on top and give access to the local community during heavy rains.

A drawing was obtained of the as-built siphon at Dinder. The river cross section was surveyed to determine the present land levels and also the maximum flood level. This confirmed that there is sufficient capacity below the proposed aquaduct to pass the maximum floods. The existing roof to the siphon barrels would be demolished at the entrance and exit of the siphon and a new floor cast for the aquaduct. The present barrel design of three sections of 3.4 m square with 0.83 m thick walls was used in the design. Finite element analysis was made of the span section to determine its suitability for carrying the water and one truck load. The design section was found quite adequate. The structure will be built directly on top of the existing siphon, using the buried barrel as a foundation. The detail of this design is given in Figure C3. The cost estimate is summerised in Table 5-2 Summary of Total Project Costs, with details in Table 5-3.

4.2.3 De-silting Basin at Head works

4.2.3.1 Options for Operation

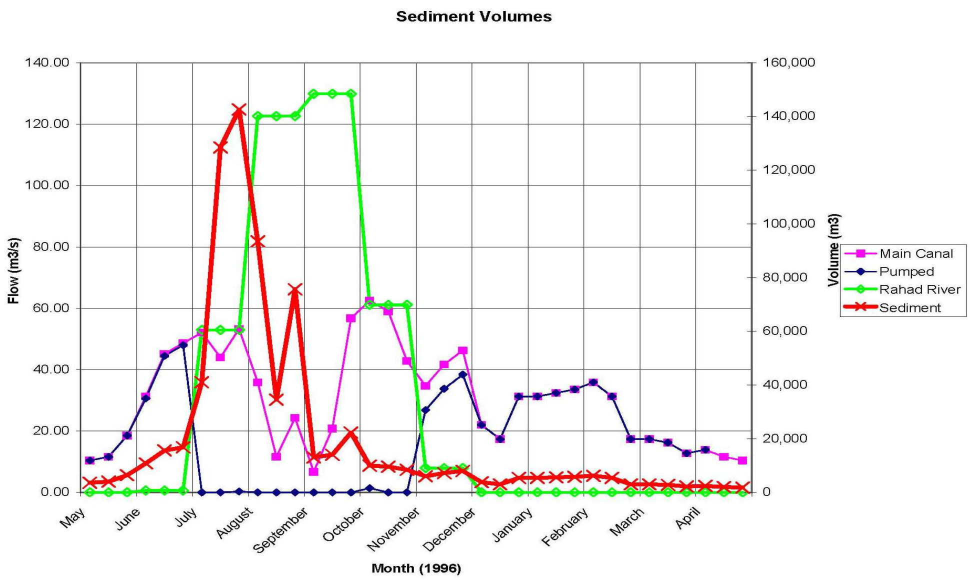
A. De-silting Canals Maintenance System

The present system is rehabilitation of the canal system by de-silting with excavators distributed throughout the project. This presents a logistical problem, high costs, and is not done on an annual basis. If the canal de-silting is done on an annual basis, there would be slight improvement.

B. De-silting Basin At Head Works

Building a settling basin at the head works is proposed as it would concentrate the de-silting operation to one location. Also the use of a floating dredger is the cheapest method of moving sediment. The main attraction of the basin is that it would allow the canal system to be converted to downstream control, an integral part of this action plan. This option is included in the action plan.

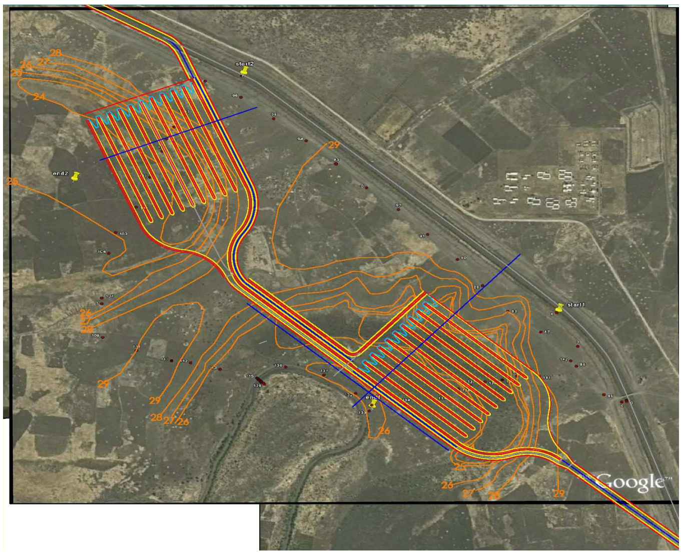
Despite the huge sediment problem in Rahad, the study of its source has not been exhaustive. The Gezira scheme has been studied to exhaustion, but in Rahad, only the canals have been studied, not the source. So there was only one period when sediment samples were taken for the Rahad River, in 1996. The concentrations during this period have been plotted against river flows, canals flows and pumped flows, see below. When the concentration is multiplied by the Rahad River flows, it presents a startling picture, that shows there is a peak rate of sediment transport in July, which drops off sharply in August and September. These three months represent the greatest movement of sediment, and it is during these times that maximum effort is needed to reduce the importation of sediment. The annual sediment transport into Rahad scheme is estimated in the order of 500,000 m^3 per year.



This study proposes to construct a large settling basin right beside the head works at Abu Rakham where some old low lying ox-bow depressions are found. A survey was made of these depressions which are very suitable for constructing this settling pond. The study team consulted the Khartoum city water works for their experience of sediment removal from Nile flood water. It was found that they use a flocculant to coagulate the fine sediment and cause rapid deposition during cleaning. This method has been utilised in large drip projects in Peru irrigating sugar cane in sand dunes from a heavily sediment laden canal. Primary settlement is achieved by short reaches of slow flow allowing the bed load to deposit first, followed by secondary settlement in long wide ponds of very slow flowing water. A flocculant is introduced before the primary settlement to ensure good mixing. The starting turbidity is over 2,000 ppm and the exit turbidity is reduced to 6ppm, suitable for drip irrigation.

However, surface irrigation does not want such clean water as weed growth would be excessive, creating another problem. Additionally, the use of flocculants, which are toxic, need to be removed completely before the water is allowed to reach the public. For this reason, toxic flocculants are not considered. There are natural flocculants used in the area by locals for cleaning their drinking water. These should be investigated for possible future use to increase to effectiveness of the settlement pond.

After consultation with water quality experts at the water works, the following design was agreed upon. The main method of settlement would be slow moving water. The pond should be 700 m long with a 50 m top surface width. The main flow would be split into two ponds, each with 10 sub-ponds. The design flow would be appropriate for the water requirements at that time of year when sediment is highest, in July. This corresponds to a discharge of 74 m^3/s. The approach velocity in the channel would be 23 mm/s slightly increasing to 27mm/s in the main settling reach. At the end of each pond is a level duck-bill weir 150 m long with a flow of 25 l/s/m length. The approach velocity beside the weir would be 8 mm/s. The effectiveness of the settlement will change from year to year as different concentrations are found, but this system can be improved by adding inclined tube clarifiers to increase deposition.



The settlement ponds would only operate for three months of the year, July, August and September. The following three months would be used to clean the ponds using a floating dredger. A small dredger with a 450 HP engine could achieve an output of 200 m^3/h of sediment flushing. At 20 hours per day and an expected settlement efficiency of 60% (equal to 300,000 m^3), the required time to clean the sediment would be 2.5 months (75 days). The sediment could be flushed back into the Rahad River or preferably turned into high quality bricks and exported from the project. This would avoid the build up of material from the settlement ponds. The remaining 6 months of the year, January to June, the ponds should be used for fish production, turning this project into a income earner, rather than a consumer of finance. Ponds of this size could be expected to yield over 145 ton of fish in 6 months.

The layout of the two ponds is shown in the adjacent photo. Protection dykes would be built along the Rahad River to sufficient height to stop overtopping by floods. A drain would be constructed between the ponds and the main canal with a culvert outlet into the Rahad River.

A reconnaissance survey was made of the ox-bow depressions to determine their suitability for holding two de-silting ponds right beside Abu Rakham head works. The elevation was found to be 423.5 m which is very similar to the canal bed elevation of 423.3 m. The upper part of the ox-box is at elevation 425.0 m which is below the anticipated bank level of the pond. This makes the area suitable for the large pond construction.

For details of the proposed layout, see Figure C4. The major part of the work would be earthmoving, diverting the main canal into the ponds and the construction of the ponds. Over 2.0 Mm^3 of excavation is required, but less than half this, 0.8 Mm^3 is compacted fill for a protection dyke and the internal bunds for the settling ponds. Another major component is the level retaining wall for regulating the flow at the end of each pond. The control of the incoming water would be achieved by a gated regulator with a bifucator weir to split the flow in two equal parts. A bridge over this regulator is required to allow local traffic to pass. A drainage culvert below the double canal after pond 1 is needed for internal drainage between the ponds and the main canal. Lastly, another bridge is required at the end of the exit canal, before joining the main canal, at chainage 5+079. The cost of the settling pond is given in Table 5-5 Summary of De-silting Basin Costs.

4.2.4 Canal Automation

4.2.4.1 Options for Operation

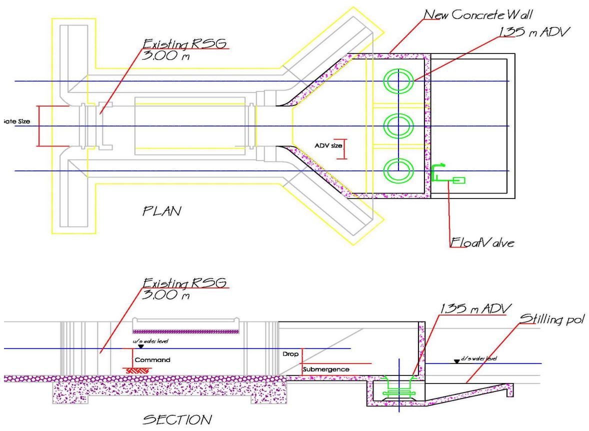
A. Roller Gate Manual Operate System

The system is designed as a top-down rigid system with complete control of discharges. This required effective collection of field water requirements (by indenting), a good communication to send this data to the managers, and gate operators to then supply the water. All aspects of this system are presently breaking down. Communication systems are hardly working, and the gate operators are not present, while the inflexible system wastes much water. Also it leads to un-equitable distribution of water (head and tail).

B. Canal Automation

This option proposes downstream control as the future modernisation system. A modified arranged schedule demand would be used together with downstream control to give more control to the farmers and WUA in managing their water. This would give more equitable distribution of water than the present system, but it does require farmer participation and effective re-training "not to wait". This option is included in the action plan.

Since the construction of the Gezira Scheme, Sudan has utilised centralised control of its irrigation using indenting or 'fixed-rate arranged scheduling. There is zero flexibility other than the date of delivery. For indenting to succeed, it needs a fully controlled canal, good communications and accurate records of water deliveries. This is fine when communications are good but before the advent of cell phones, communication was poor. Accurate records are maintained by gate keepers, but the keepers are often absent after records are taken. This all breaks down when there is little supply of water to control, and the main problem remains as zero flexibility. For this reason, the study recommends the installation of downstream control systems to change over from upstream central control to downstream user control. By this on-demand system, the farmer has complete control over time and amount of irrigation. Combined with this change should be a method of water charge based on water use, not on area irrigated. This will discourage wastage and allow the farmer much more freedom to irrigate at times suitable to his needs. Different crops can also be irrigated giving more freedom for farmers to grow crops with higher returns. With the strengthening of the WUA, farmers should be more inclined to police other water users who are wasting water. The on-demand system will not be a free for all take as one needs system, but some form of modified on-demand system. The proposed system is a semi-demand arranged schedule rotational system which the WUA would control. Farmers would be given a day during the week which he can apply his water in any amount, but only on these days. The WUA would monitor and control these rotations.



Central to this premise is that farmers have to be re-educated from "trained to wait" to "trained to take the initiative". This will require a lot on effort on behalf of the extension services and a special program is needed during the transition.

The first part of downstream control is level top canals. All of the minor canals are night storage canals, so are by virtue level top canals and therefore need no adjustment to bank levels. However, most well head regulators, used in control of minor canals have exposed steel pipes immediately around the structures with embankments needing re-instatement. Apart from this, the minor canals can be readily changed over to downstream control. The proposed valves to be used require a head drop of at least 0.2 m to operate and close effectively. In canals where this drop is not available, the regulator should be removed and the canal reach moved to the next regulator. There is usually sufficient clay material from de-silting to allow an increase in water level of 0.2 m in these situations. In the major canals, the level top is taken as the immediate water level from the upstream regulator. A case study was made on Major 2 canal. In each regulator there is sufficient bank top freeboard to accommodate level top canal operation.

The proposed structure for this downstream control is the Automatic Diaphragm Valve (ADV), see photo below. The valve is opened and closed using an adjustable float to set downstream level. The valve proposed will be completely drowned and unless vandals are prepared to dive they should be vandal proof. The most common type of downstream control gate is the AVIO type gate which is expensive and very subject to hunting due to its design. The ADV is not subject to hunting as it operates in a different mode and the response time to opening and closing can be adjusted.

The command area of Major 2 (block 2) was used as the sample for design of canal automation. The canal profile and design was obtained from MOI, Wad Medani and reviewed for possible change over to downstream control. There is sufficient head at each drop in the canal to control the automatic diaphragm valves. All minor WHR and d/abu-xx would regulators would be changed over to ADV. The only place where the farmer controls his application is at the head of each abu-xx or d/abu-xx. By using 'Hydroflume' type delivery system, the only gate that needs to be controlled is the one in the 'Hydroflume' at the head of the level furrow. Thereafter all canal flows are automatic. With a proposed furrow irrigation set of 11.0 hours, the farmer can irrigate at night or day, and have a long time free to do other tasks.

Costs are given in Table 5-6 Costs of ADV for Major and Minor Canals and Table 5-7 Summary of Automation Costs.

4.3 On-Farm Irrigation Improvement

With the advent of KIASCo take over, many changes are taking place in the field. Kenana have good success with long furrow and are planning to introduce this system to Rahad. At first glance, this is appropriate technology to try at Rahad, by there has been a history of failure with long furrow in Rahad. The original designers M. MacDonald's identified the area as a potential long furrow area and initiated trials for its implementation. However, this was not successful because the tenants did not accept the use of siphons for irrigation as it took too much labour. Also the fields were not land levelled or smoothed, and long furrow was abandoned. In Rahad, there is definitely a need for land smoothing and this has been identified all studies on the scheme and adjacent schemes (Rahad II). The M. MacDonald's study of 1978 identified a minimum of 10% of the area should be land smoothed, and the rest land planned. Unfortunately little or no land smoothing has been undertaken in the project's life. KIASCo are planning on converting many fields into long furrow and presently engaging in land smoothing using a motor grader. While the use of a motor grader is a great improvement on no land smoothing, it falls well short of the necessary land smoothing machine, practised in Kenana Sugar Company (KSC), as shown in the accompanying photo. The land plan in the photo has a length of 22 m as opposed to the grader of only 10 m. Production rates with a 160 HP tractor are 50 fd per 10 hour day.

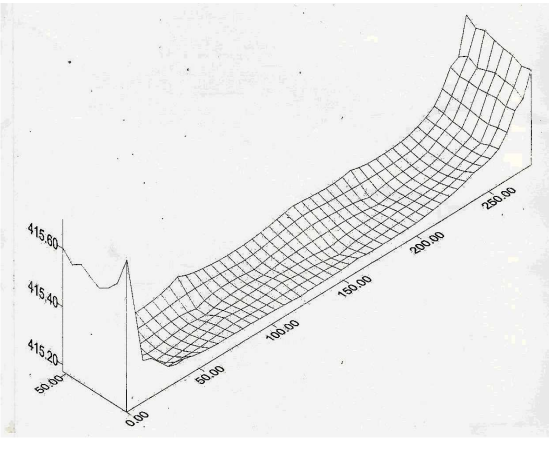
A trip was made to investigate the use of long furrow in KSC to gain experience from a successful good-performing scheme. What KSC practise is very interesting and worthy of mention. There is a big difference between KSC and Rahad in the slopes found. KSC is very steep (up to 300 cm/km) relative to Rahad at 20 to 40 cm/km. This steep slope enables the scheme to irrigate furrow lengths of 500 m (C-system) on steep slopes of 300 cm/km and up to 1,500 m on slopes of 166 cm/km. Stream flows are also high, about 5 l/s, and the furrow size is very large: 90 cm wide by 10 cm deep, see photo. On the steep slopes, check dams are required to reduce velocity and increase contact time and improve distribution efficiency. Inspection intervals are included in the cane field 200 m from the field end to enable supervisors and irrigators to monitor irrigation. The latest improvement KSC have installed is 'Hydroflume', a plastic lay-flat pipe with screw gates for controlling flows. By using this system they have eliminated the use of siphons which are labour intensive and disliked by Rahad tenants. The main advantages of the 'Hydroflume' are :

- 30% reduction in labour requirement due to saving in handling and control.
- Eliminates the need for machinery to flatten and rebuild field canals each season.
- Even discharges at every outlet and a uniform water advance.
- Reduced losses from delivery system due to seepage and evaporation.
- Adds more land, approximately 12 m to each field.
- Easily removed to enable machinery easy assess to field without climbing over the field canal.
- Improved efficiency and ability to meet CWR, up from 70% to over 85%.

The visit to KSC showed just what is possible given incentives and capital to implement desired improvements.

Further to the issue of land planning and smoothing, most fields in Rahad have underdone re-shaping due to the sediment importation and cultivation practises that have existed over the years. Fields have ended up as dish-shaped as identified by El Awad El Hag Wagie Alla El Amein (unpublished Ph. D. thesis) with high spots either side of the Abu-XX, see digital terrain model of field below. The reasons for this can be summerised as:

- Cultivation in same direction, without ploughing the headlands in 90° direction, the local word is shalabi,
- Lifting cultivation equipment onto headland, depositing soil at each end,
- Erosion of land beside abu-xx due to steeper slope and depositing at tail,
- Lack of any land smoothing operations to eliminate the accumulation of the above effects.
- Deposition of sediment at the end of the



land,

- Lack of any field drainage ditch to remove drainage water.

As can be seen from the above DTM, there will be local flooding as excess irrigation water cannot be removed. The HHS showed that there is this local flooding in the order of 2.5%. Therefore field drains must be constructed to improve irrigation efficiency and productivity.

The study put attention on the in-field efficiency of the furrow irrigation with the intention of identifying the most efficient system of irrigation these very flat soils. Two furrow design equations were evaluated in different conditions of slope and furrow length to determine and compare efficiencies, from Jensen and Clemmens. Below is the results of this desk exercise:

Results of Furrow irrigation Efficiency
Intake Family: 0.1, Furrow spacing 1.5 m, 'n' = 0.04

		Jensen		Clemmens	
Slope	Length	Discharge	Efficiency	Discharge	Efficiency
	m	l/s	%	l/s	%
0.00016	280	1.05	27.8%	1.24	20.7%
0.00016	600	2.6	20.5%	1.24	32.5%
0.00016	1000	4.8	16.1%	1.24	40.6%
0.0006	280	0.5	53.8%	2.40	12.6%
0.0006	600	1.3	39.7%	2.40	22.1%
0.0006	1000	2.6	31.3%	2.40	30.1%

Results of Level Furrow irrigation Efficiency
Intake Family: 0.1, Furrow spacing 1.5 m, 'n' = 0.04

		Jensen	
Slope	Length	Discharge	Efficiency
	m	l/s	%
0.0004	280	2.05	99.0%
0.00027	600	6.00	98.1%
0.00019	1000	9.00	94.5%
using a 11.0 hour design intake time			
0.00018	600	1.82	93.5%

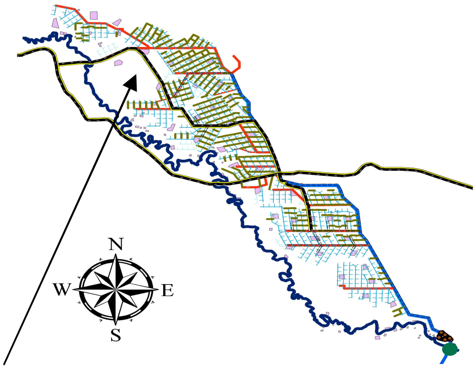
The results show that the very flat slopes give very poor irrigation efficiencies, and only by increasing the slope does the efficiency increase. But obtaining a steeper slope of 0.0006 (60 cm/km) from 16 cm/km would require 550 m^3 of cut and fill to be moved, just to obtain an efficiency of about 35%. This study also shows that any furrow irrigation on these flat slopes is going to be in-efficient, no matter what length. An alternative method was identified, being level impoundment furrow (basin type). Putting our parameters into the Jensen equations give a better result, and shows that the idea combination of level furrow length, discharge and design intake time is 600m length with a flow of 1.8 l/s and a time of 11.0 hours. This would give the farmer a lot of time to set the irrigation and engage in other activities while irrigating. It also allows for night irrigation as the set time is 11 hours. See Figure C2 for an example of the Jensen calculations.

This study therefore recommends the adoption of combining at least two numbers into one new number and cleaning out one abu-xx. This would have to be combined with land smoothing of all abu-xx to remove all evidence of the dish-shaped fields and the construction of field drains. Also included in the recommendations is the use of ‘Hydroflume’ for efficient delivery of water. The size for the double number would have to 24” as the 18” is too small to deliver the required amount of water. See Figure C10 and C11 for the layout of the field with this arrangement. Costs are given in Table 5-8 Summary of On-farm Improvement Costs.

4.3.1 Mechanical Irrigation - Linear Move and Centre Pivot Irrigation

With the very poor furrow efficiencies experienced at Rahad, the attraction of mechanical irrigation becomes large. With efficiencies of 90 to 95%, and high uniformity, drip and centre pivot irrigation are definitely worth consideration. Both centre pivot and linear move irrigation are already widely used in Sudan with good back up services. However there are a number of issues to be considered with this technology. Firstly, centre pivot has high application rates at the ends of the machine and with the very low infiltration rate of the heavy black clays, this is a very important consideration. With linear-move machines, this is much less of an issue as the application rate is uniform across the machine. Secondly the heavy black clays have a very low bearing capacity and wheel tracks will become a major problem with these mechanical machines. If these two issues can be solved adequately, then mechanical irrigation can be given consideration in Rahad. Centre pivot irrigation is being used in Zambia on black clay soils so this is not new. This study does not however consider the inclusion of these systems for small tenants at this time.

However, KIASCo are considering these machines for future use and this is commended although attention needs to be paid to the above mentioned issues. This study also recommends that KIASCo consider utilising areas presently not under command of the gravity system, such as the high ground between blocks 7 and 9, as shown in the diagram. In this manner the necessary experience can be gained without affecting the tenants land.

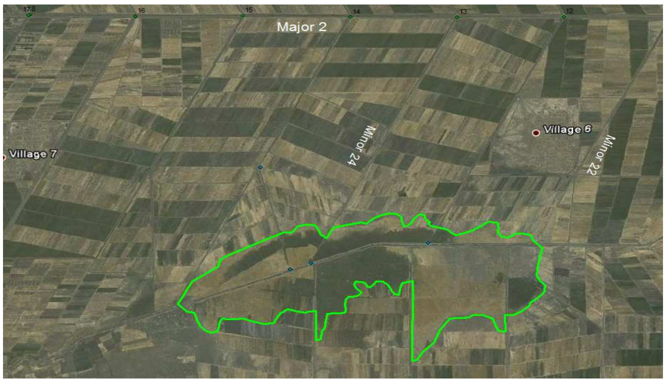


High Ground Potential for Centre Pivot

4.4 Drainage

Flooding is often a problem to productivity in Rahad and the HHS gives a percentage of 2.5% lost in local flooding. Most of this is caused by the lack of field drains.

Additional to the field drainage problem is the depth of the minor drains. In many flat locations the minor drain is just not deep enough, see photo?? beside. This shows the minor culvert only about 0.5 m below field level, which is much too low for this situation. Farmers have resorted to digging a drain around the structure just to get some water off the field, and even this is insufficient. The fields above the drain is permanently waterlogged. This means that all minor drains need to be deepened by at least 1.0 m for at least half their length. New culverts will have to be installed at the exit to the collector drain.



There is also other permanent loss of land from annual flooding, as clearly seen on google earth image. This is collector drain No. 2, between blocks 1 and 2. The area has been out of production for many years and is an area of 725 ha. The cause of this problem could not be ascertained during the study, but deepening of this drain is required.

Deepening of the minor drains will require that all collector and main drains should also be deepened. This will benefit the whole project which sees annual local flooding in most of the fields.

Costs are given in Table 5-9 Summary of Drainage Costs.

4.5 Agriculture

All farmers interviewed during the FDGs showed high awareness about importance of water for high yields. Despite that, most of them, they do not actually apply this in their daily farming practice. Therefore an intensive training of farmers will be suggested to take place regarding the necessity of time and duration of irrigation, application of optimum quantities and drainage of excessive water. New methods of irrigation are to be introduced like, level basin furrow or hydro-flume systems. But the overall emphasis on the new extension training will be to train the farmers "not to wait". The new downstream canal operation will allow water users to irrigate on-demand, and not wait for someone to provide a service.

4.5.1 Future Cropping Pattern

The future of Rahad will be direct farming of 50% of the land, some 130,000 fd (54.600 ha), with KIASCo performing all operations. This study has therefore focused its attention on the remaining 130,000 fd left to the tenant.

The existing cropping pattern is underutilizing the land resource at RIS due to canals siltation and lack of funds for production inputs. The proposal is to allow the tenant to increase their production of vegetable, maximising returns and increasing productivity. Initially the intensity will be 50% of the remaining 130,000 fd will be cropped, 65,000 fd. The summer crops will be sorghum 30,000 fd (23%) planted in June, and groundnuts 28,250 fd (22%)., planted in June. The winter crops will be sunflower 30,000 fd (23%) and maize 28,250 fd (22%), both planted in end of October.

Table 4-1 Proposed Future Cropping Pattern

Month	Dry season					Rainy season					Dry season		'000 fd
Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Sorghum													30
Groundnut													28.25
Sunflower													30
Maize													28.25
Vegetable													13.5
Fodders													
Forests / fruit treess													1.3

Solid cell color = Duration of crop in the field   Red color= Duration of irrigation

This cropping pattern represents an intensity of just over 100%, and with KIASCo also intending to utilise 100% intensity, the scheme overall intensity will be 100%.

With 50% of the area in fallow at any one time, it is possible to envisage this fallow reducing as more crops are grown. Thus the intensity could possibly reach 200% in the future, although this is not considered part of the action plan, at this time.

Other crops that could be considered for the rotation in future are soya bean and chick pea. The first can be produced for export where there is a big demand and the second can be produced for in-country consumption and both are legumes. Other crops that are to be considered for production at RIS include sugar beet as an agro-industrial crop and this will encourage the establishment of small scale industry at RIS and for value to be added to agricultural products. Research should be started at an early stage on sugar beet production to outline the technical package and to plan for the purchase of appropriate machinery for production and sugar processing. A feasibility study has already been conducted by Abd Elkarim A. A, in 2003 for growing 50,000 feddans at block 10, but this study needs updating especially with respect to varieties and economic analyses.

Animal production has been mentioned in previous studies as an important component of RIS. Animal production includes both animal health and improvement of local breeds in addition to forage crops production. Improvements made in this respect is possible through financial support in form of material supplies to the veterinary units in the vicinity of RIS, import of improved types of livestock, artificial insemination and improved extension services. These are included in the financial costs.

Horticultural production at RIS is increasingly gaining more attention and awareness of farmers. Interviewed farmers reported that okra, eggplant and sweet potato are the most profitable crops and that marketing is no longer a constraint as vegetable traders used to come from remote areas. This warrants the proposal of utilizing the whole area allotted for horticultural production (about 13,500 fed).

It is legally required that 5% of the irrigable area is to be allocated for forest trees but the actual area was reported to be far less than that 1,300 fd. In addition, the allocated areas are either high land, crossed by rills and gullies or subject to floods. The total area supposed to be under forestry ranges between 1,300 – 1,440 feddans according to various reports.

Some farmers do practice limited pest control for vegetable production but never for sorghum or groundnut and it was perceived that most farmers are aware of the importance of pest control but they lack either funds or the knowledge about chemicals to be used, so they asked for the advice.

Other cultural operations that need improvement but they are out of farmer control include: early land preparation and sowing date, furrow width, seed rate and control of weeds and other pests and diseases (if to be mechanized) and this applies for both field and vegetable crops. Farmers need to be put in a position of being able to control these aspects, but only after intensive re-training “not to wait”.

4.5.2 Access to external factors

It was evident that extension services represented the weakest point in the implementation of RIS bearing in mind that the majority of the farmers are basically of nomadic background. There was a complete absence of plans for extension network and technology transfer and also complete absence of the research-extension-monitoring and evaluation (moneval) cycle. The top-down approach seemed to be dominantly practiced and no extension agents were appointed at village level, no contact farmers and not even extension assistant staff to field inspectors were appointed.

Extension services provided in the past were all parts of sporadic programs financed by agents other than RIS. In some years a technical committee was established (ARC represented) to conduct monthly field visits and to identify production problems and to provide extension advice but it became inactive for a long time. All most all farmers interviewed claimed that they had never received handouts, brochures or field leaflets regarding crop production practices but some of them attended meetings with the technical committee. An estimated 5% said that they were visited in the field once by the field inspector during cotton growing season only.

Improvements are suggested to cover the following areas: training sessions on various production packages preferably by crops, production of brochures leaflets and posters, meetings, field visits, on farm demonstrations and organizational issues. Most of all, farmers need to be trained “not to wait”.

Access to agricultural production inputs is of great concern at RIS. Apart from cotton, farmers get their seed inputs from either retained stocks or from the local market. Chemical and fertilizer inputs are obtained mainly from the local market and also the technical advice about the doses and application methods, thus yields came down and problems grew up with regard to stem borers and the white grub on sorghum and groundnut, respectively.

The establishment of a fully authorized company to trade on all agricultural production inputs is advised. An initial operational capital can be allocated for seed production and then develop to a large scale enterprise. This is dealt with in more detail in the financial action plan as a type of revolving fund for farmers with access to credit.

4.5.3 Future Crop Water Requirements

With the above proposed cropping pattern, the crop water requirements have been determined using FAO CROPWAT 8.0 and climate data from Wad Medani, as shown in Table 2-1. The daily main canal flows have been computed using an efficiency of 82%. The project was originally designed using 100% efficiency as it was anticipated that conveyance losses would be negligible. However, the studies of on-farm irrigation efficiencies indicate that this is far from the cast and a much lower efficiency should be used. The theoretical level impounded furrow gives an efficiency of 92,9% but the proposed on-farm level furrow will reduce this efficiency to the level of 82%. The IWR are shown in Table 4-2 .

In order to determine if the proposed cropping pattern combined with that proposed by KIASCo could be supplied by the canal system, an IWR was also computed for KIASCo pattern, shown in Table 4-3. The critical month in this scenario is February. During this month the "with project" IWR is 2.62 Mm^3/day and that for KIASCo is 5.58 Mm^3/day. The total number of pumps that can supply this amount is 10 pumps. However, the present maintenance program being supervised by KIASCo is for 8 pumps to be operational, but with future funding in place, it is anticipated that the remaining two pumps will be operational.

It is appreciated that Rahad is completely dependent on the operation of these pumps and as soon as one pump is down, the whole productivity deteriorates.

Table 4-2 CROPWAT8 With Project Tenant Cropping Pattern and Irrigation Requirement

With Project Cropping Pattern

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Planted Area ('000fd)
1. SORGHUM (Grain)	0	0	0	0	0	30.7	37	64.9	114.9	36	0	0	283.5	30.0
2. Groudnut	0	0	0	0	0	48	40.7	86.2	150.4	63	0	0	388.3	28.3
3. Forest	101.4	106.9	128.9	126.8	122.7	97.7	10.3	0	43	76.4	97.3	99.7	1011.1	1.3
4. Sunflower	213.2	223.8	92.8	0	0	0	0	0	0	0	45.5	116.3	691.6	30.0
5. MAIZE (Grain)	226.6	210.9	57.1	0	0	0	0	0	0	0	39.2	136.8	670.6	28.3
6. Small Vegetables	196.8	80.8	0	0	0	0	0	0	0	0	91.1	165.6	534.3	13.5
														131.3
Net scheme irr.req.														
in mm/day	4.1	3.9	1.1	0	0	0.6	0.6	1.1	2	0.7	1.1	2.6		
in mm/month	127.5	110.3	35.2	1.3	1.2	18.6	17.6	33.9	60	22.9	32.8	81		
in l/s/ha	0.48	0.46	0.13	0	0	0.07	0.07	0.13	0.23	0.09	0.13	0.3		
Irrigated area (% of total area)	60	60	46	1	1	46	46	45	46	46	60	60		
Irr.req. for actual area (l/s/h)	0.79	0.76	0.29	0.49	0.46	0.16	0.14	0.28	0.5	0.19	0.21	0.5		
at Efficiency of %	82%	82%	82%	82%	82%	82%	82%	82%	82%	82%	82%	82%		
Gross Irr.req. for area (l/s/h)	0.963	0.927	0.354	0.598	0.561	0.195	0.171	0.341	0.610	0.232	0.256	0.610		
Mm^3/ha/day	83.24	80.08	30.56	51.63	48.47	16.86	14.75	29.50	52.68	20.02	22.13	52.68		
Gross irrigated area fd	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000		
Gross irrigated area ha	54,600	54,600	54,600	54,600	54,600	54,600	54,600	54,600	54,600	54,600	54,600	54,600		
Total Vol. Mm^3/day	2.73	2.62	0.77	0.03	0.03	0.42	0.37	0.72	1.32	0.50	0.72	1.73		

Table 4-3 CROPWAT8 With Project Kanana Sugar Cropping Pattern and irrigation Requirement

Kenana (KIASCo) Cropping Pattern

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		Planted Area ('000fd)
1. Groudnut	0	0	0	0	0	75.1	79.9	89.6	135.5	23	0	0		130.0
2. MAIZE (Grain)	184.6	239.3	210.9	12.4	0	0	0	0	0	0	0	65.5		65.0
3. Sunflower	161.4	228.8	242.2	33.9	0	0	0	0	0	0	0	67.5		65.0
														260.0
Net scheme irr.req.														
in mm/day	5.6	8.4	7.3	0.8	0	2.5	2.6	2.9	4.5	0.7	0	2.1		
in mm/month	173	234.1	226.5	23.1	0	75.1	79.9	89.6	135.5	23	0	66.5		
in l/s/h	0.65	0.97	0.85	0.09	0	0.29	0.3	0.33	0.52	0.09	0	0.25		
Irrigated area (% of total area)	100	100	100	100	0	100	100	100	100	100	0	100		
Irr.req. for actual area (l/s/h)	0.65	0.97	0.85	0.09	0	0.29	0.3	0.33	0.52	0.09	0	0.25		
at Efficiency of %	82%	82%	82%	82%	82%	82%	82%	82%	82%	82%	82%	82%		
Gross Irr.req. for area (l/s/h)	0.793	1.183	1.037	0.110	0.000	0.354	0.366	0.402	0.634	0.110	0.000	0.305		
Mm^3/ha/day	68.49	102.20	89.56	9.48	0.00	30.56	31.61	34.77	54.79	9.48	0.00	26.34		
irrigated area fd	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000		
Gross irrigated area ha	54,600	54,600	54,600	54,600	54,600	54,600	54,600	54,600	54,600	54,600	54,600	54,600		
Total Vol. Mm^3/day	3.74	5.58	4.89	0.52	0.00	1.67	1.73	1.90	2.99	0.52	0.00	1.44		
	6.47	8.20	5.66	0.55	0.03	2.09	2.10	2.62	4.31	1.02	0.72	3.16		

Total Vol. Mm3/day, KIASCo + With Project 8.20 Mm^3/day No. of Pumps: 10 Capacity of Pumps: 8.2512 Mm^3/day

4.5.4 Water Charge

Water charge is always an issue with farmers already having to pay for many aspects of production and some find it difficult to meet this additional cost. However, without the inclusion of a water charge that meets the sustainability of the project, the project should be closed down. It is this very aspect of lowering the water charge that starts the downward cycle of poverty because it goes hand in hand with the provision of water. If the administration cannot meet the needs of maintenance, as in the past, then there is a rapid spiral to un-sustainability. So what comes first, adequate maintenance paid by an outside source, or adequate production with sufficient income to pay the high water charge and support the level of maintenance required. In fact, both must be maintained at a high level from the start. Also the method of determining the charge should be changed to one if not by volumetric basis, at least one per irrigation basis.

It is proposed that measurement of water delivered should be at each abu-xx or d/abu-xx. This proposal has not been included in the costs at this time as investigations are continuing into the appropriate methods of measurement. The study proposes to change the system of water charging from one by crop area to one for each irrigation, ultimately changing to one of actual water used. This is an essential component of changing the farmers view of water. He must pay for what he uses, not by area. Payment by area leads to wastage on a large scale as there is no incentive for farmers at the head to use water efficiently. Only when farmers pay by usage will they respect water and its conservation. A change over to a volumetric payment cannot happen quickly, and an interim stage by paying per irrigation is the first step in this direction. Instead of converting the water charge to feddans on an annual basis, the charge should remain by the irrigation. The block inspectors will record each time water is requested and delivered to each farmer or group of farmers on one abu-xx.

The proposed water charge is calculated by dividing the total annual maintenance budget by the total volume of water delivered, which equates to 0.0242 SDG/m^3. Using the standard daily rate of 33m3/fd/day and a 14 day cycle, each irrigation would deliver 462 m3, or an irrigation charge of 11.18 SDG/irrigation/fd. The detailed calculations to obtain this amount are given below.

Total Volume Pumped With Project + KIASCo

Annual Volume		1112.7 Mm^3
Pump capacity		9.55 m^3/s
Pump Head		11.2 m
Pump Power		1,312 kW
Volume per Hour		34,380 m^3
Total Hours pumped		32,365 hours
Power comsumed per year		42,449,505 kWH
Cost	0.22 SDG/kWH	9,338,891 SDG

Electricity Cost US$	2.357	3,962,194 US$
Annual Pump maintenance		1,500,000 US$
De-silting ponds		330,000 US$
Abu Racham costs		200,000 US$
Main, major, minor de-silting		392,000 US$
Drain de-silting		1,372,000 US$
Structure RSG		103,000 US$
Structure WHR, and MWG		1,068,000 US$
Overheads Budget		2,500,000 US$
Total MOM Budget		11,427,194 US$
Unit Cost of Water		0.0103 US$/$m^3$
		0.0242 SDG/m^3

Cost per irrigation 11.18 SDG/irrigation/fd

Irrigation Volume 462 m³/fd (based on 33m³ per fd/day for 14 day cycle)
Efficiency = 82%

	Net IWR mm/year	Gross IRR	Volume/ha	Volume/fd	Number of irrigations	SDG/ fd
1. Sorghum (Grain)	283.5	345.7	3,457	1,452	4	44.7
2. Groudnut	388.3	473.5	4,735	1,989	5	55.9
3. Forest	1011.1	1233.0	12,330	5,179	12	134.2
4. Sunflower	691.6	843.4	8,434	3,542	8	89.5
5. Maize (Grain)	670.6	817.8	8,178	3,435	8	89.5
6. Small Vegetables	534.3	651.6	6,516	2,737	6	67.1

Proposed Future Cropping Pattern and Water Recovery

Annual Charge Future	Area fd	# of Irrigations	Amount
1. Sorghum (Grain)	30,000	4	1,341,975
2. Groundnut	28,250	5	1,579,616
3. Forest	1,300	12	174,457
4. Sunflower	30,000	8	2,683,949
5. Maize (Grain)	28,250	8	2,527,386
6. Small Vegetables	13,500	6	905,833
KIASCo			
1. Sorghum (Grain)	65,000	4	2,907,612
2. Groudnut	130,000	5	7,269,029
4. Sunflower	65,000	8	5,815,224
5. Maize (Grain)	65,000	8	5,815,224
	Total Water Charge	SDG	28,112,692
		US$	11,927,319

Using the rate of SDG 11.18 /irrigation/fd and the anticipated cropping pattern, the maintenance budget would be covered by the water charge.

4.6 Institutional Strengthening

4.6.1 Establishment of a Water Users' Organization

Establishment of a water users' organization for Rahad Scheme can be done in 2 stages:

Stage 1: **Organize WUO under the Umbrella of the Farmers' Union**

It is recommended to organize a WUO in the Rahad Scheme that will be under the umbrella of the FU but with a semi-autonomous status. The WUO will have its own Executive Committee parallel to that of the FU who will be mainly responsible for overseeing and monitoring irrigation water management, and operation and maintenance at the main system level in close coordination with the KIASCo Rahad Directorate ad Kenana Corporation management. Under the WUO Executive Committee will be the Block Committees who will be mainly responsible for overseeing and monitoring irrigation water management, operation and maintenance and water charge/fee collection covering the major canal system and then below will be the Sub-Block Committees mainly responsible for the MOM and O&M of each minor/sub-minor canal. Below the Sub- Block Committees will be the Farmers' Groups (existing now as Financing Groups) who will take care of the tertiary facilities and field channels. There is a very positive indication for expanding the existing FGs and integrating these into the Water Users Organization. The existing FGs can be expanded to represent one tertiary unit. Figure 55 shows the proposed Organizational Set-Up for the Farmers Union and WUO for Rahad Scheme.

This option will motivate the Farmers' Union to support the WUO establishment and realize in the process the importance of having a separate farmers' organization to address irrigation management issues. This will be initiated as soon as possible and in the meantime, KIASCo should take the initiative in recommending a policy to formalize WUOs and establish registration arrangement to make them legal entities.

Stage 2: **Formally Establish an Independent WUO with Legal Status**

This process should be initiated once a policy for formalizing WUO is established. It is further recommended that the field staff who will initiate the process of establishing the WUO must undergo extensive training in Community Organizing before they are deployed to undertake their responsibility.

There are 2 options in selecting the field staff who will be directly involved in WUO establishment and strengthening process. The first option is to evaluate the present extension staff now working for KIASCo and retain the ones with the potential of becoming effective community organizers and then hire new ones to replace those with no potential. The 2nd option is for the KIASCo to be responsible for the institutional development work in the Rahad Scheme and include the costs in its O&M budget. In this case, recruitment, training and supervision of the field staff/community organizers will be the responsibility of the KIASCo Rahad Directorate Office. The basic qualifications, duties and responsibilities of the community organizers as well as the suggested steps and process in establishing and strengthening of WUO are discussed in detail in the appendices of this report.

4.6.1.1 Tenancy Administration

There should really be genuine incentive to farmers to administer their own tenancy right. Improving water use efficiency in Rahad scheme is a must to help motivate the farmers to operate their own farm. Female farmers should be encouraged to participate in decision making processes and be made members of the WUO. Involvement of female members in the household in farming activities will help alleviate scarcity of labour though this will depend on the tribal cultural practices.

Moreover, the tenancy allotment policy has to be further examined in the light of the situation in Rahad and accordingly change or revise this.

4.6.1.2 Management of O&M (MOM), Operation and Maintenance and Fee Collection

As mentioned in section 3.1.6.1, the WUO will have its own Executive Committee who will be mainly responsible for overseeing and monitoring irrigation water management, and operation and maintenance at the main system level in close coordination with the KIASCo management. Under the WUO Executive Committee will be the Block Committees who will be mainly responsible for overseeing and monitoring irrigation water management, operation and maintenance and water charge/fee collection covering the major canal system and then below will be the Sub-Block Committees mainly responsible for the MOM and O&M of each minor/sub-minor canal. Below the Sub- Block Committees will be the Farmers' Groups (existing now as Financing Groups) who will take care of the tertiary facilities and field channels. Figure 4-3 presents the proposed organization for MOM and O&M for Rahad Scheme.

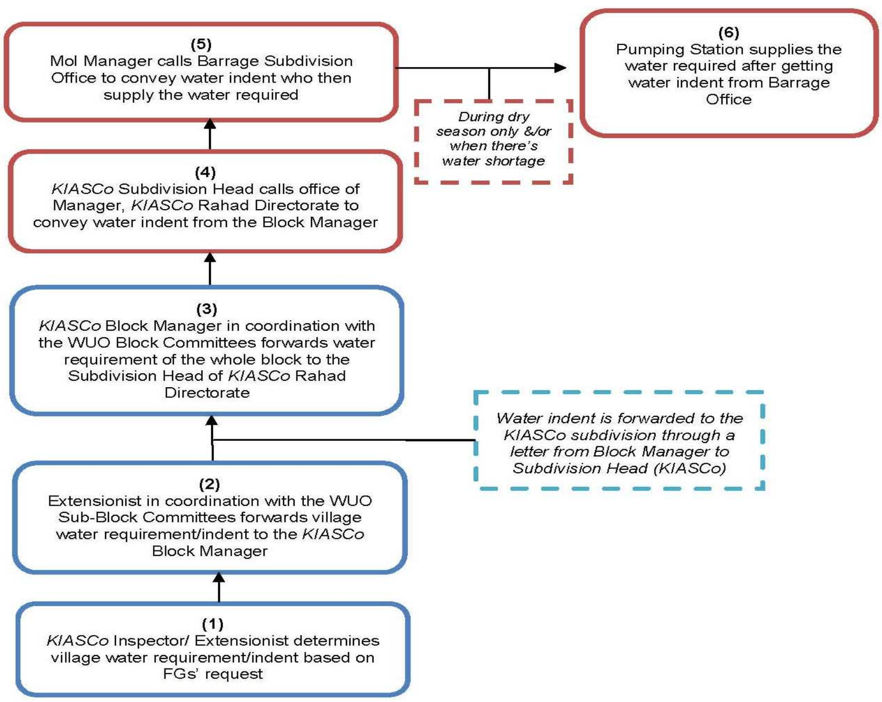
With regard to water indenting and water distribution, it is proposed that the same procedure be maintained however, the procedure should now integrate and involve the proposed WUO committees. Figure 1 presents the flow of water indent requests.

Water indenting and water distribution mode should be discussed and agreed upon with the farmers through their WUO. Moreover, there should be proper training and dissemination of the system and procedures to the concerned KIASCo Staff who will be directly involved in its implementation.

On fee collection, there should definitely be an increase in the water charge to be collected from the farmers to somehow reduce the burden of the government. Based on a study conducted for the period (1990 to 1996/97), on the average, the budget approved by MoIWR was only 76% of the budget requested by the Rahad Directorate Irrigation Office[21]. This scenario is still true now and the water charge being collected does not help. Hence, the functionality of the scheme has steadily deteriorated that it now needs major rehabilitation. Calculation of water charge shall be based on the overall O&M and institutional development costs of the improved/rehabilitated Rahad scheme. The basis and rationale for the new water charge should be presented and discussed with the FU/WUO association before it is finalized. The FU/WUO officials should in turn present and discuss this in a General Assembly Meeting for its ratification.

In addition to increasing fee collection, there should also be efforts to motivate the WUO to assume more O&M responsibility. Gradually, MoIWR should initiate management transfer of the minor system to the WUO after undertaking institutional strengthening activities.

Figure 4-1 Flow of Water Indenting in RIS



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[21] Perspective of Farmer's Attitudes and Gender Issue in Irrigation Water Management, *Op cit.*

Figure 4-2 Proposed Organisational Set-up of Rahad Farmers Unions and WUO

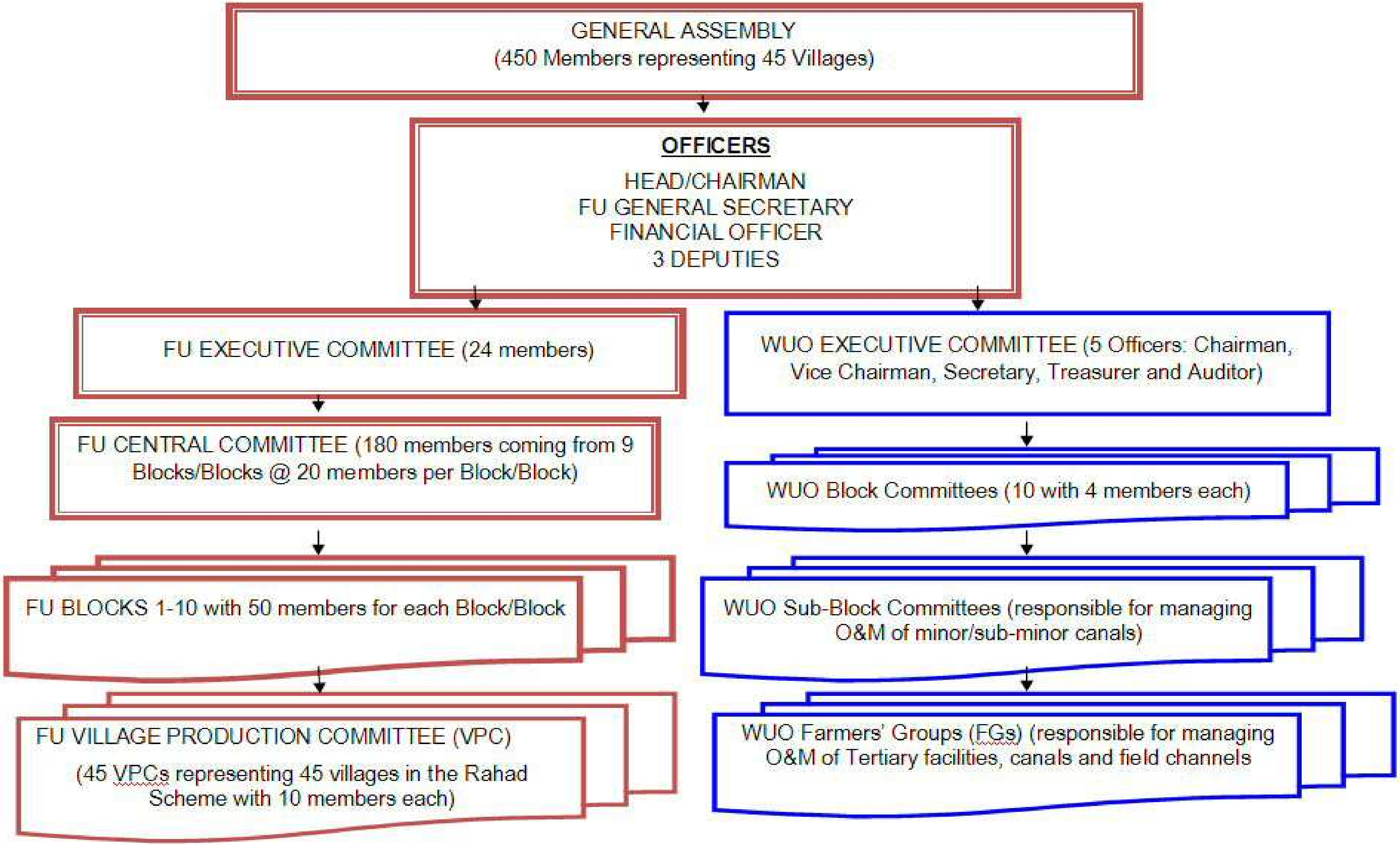
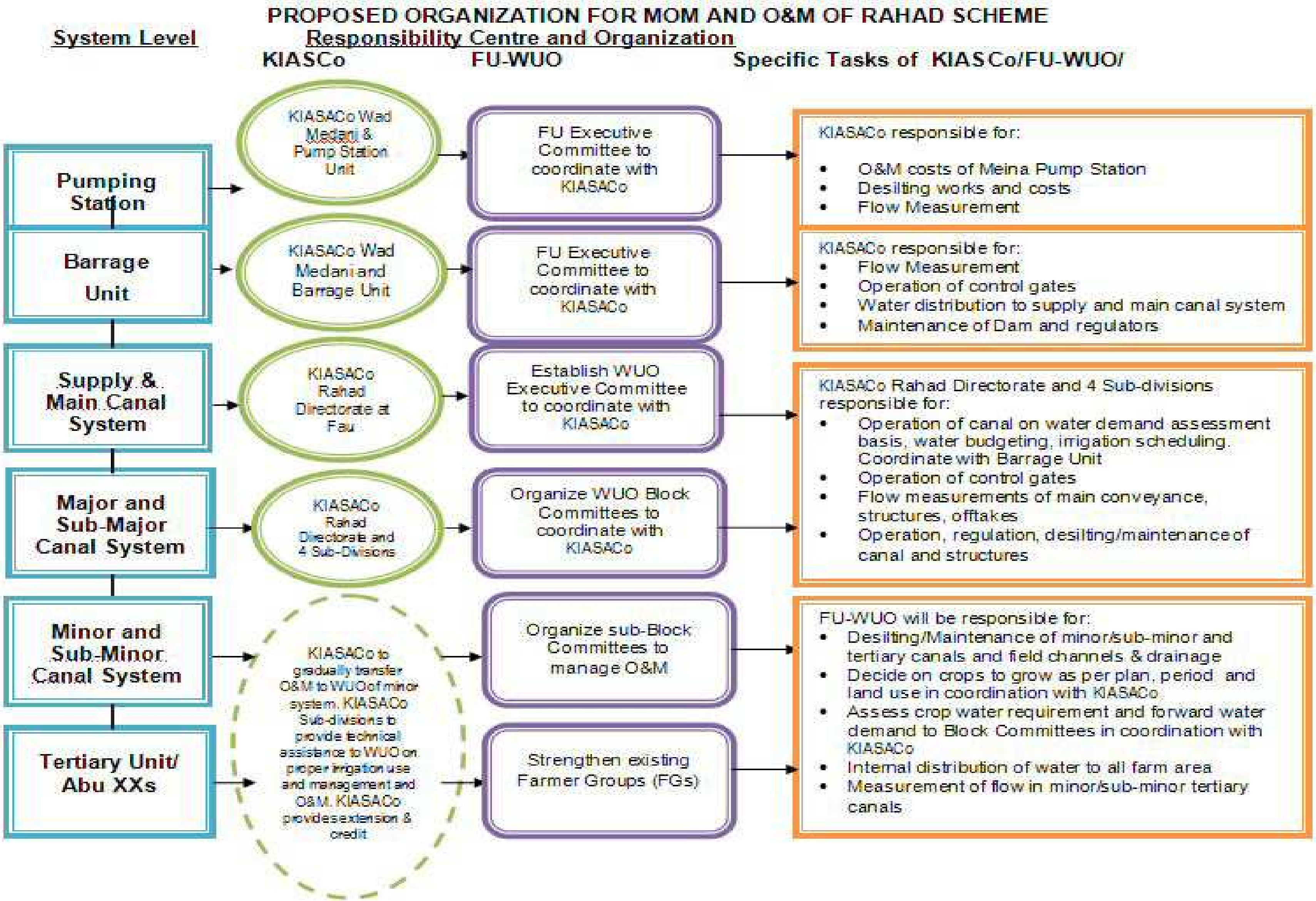


Figure 4-3 Proposed Organisation for MOM and O&M for RIS



4.6.1.3 Water User School

Establish "Water Users School (WUS)" or site-level workshops to be participated in by key staff from MoIWR Rahad Directorate, Kenana Corporation, FU and WUO officials and selected members.

The detailed action plans proposed in the study should be discussed and implemented through the medium of "water users' schools" (WUS). The concept of a water users' school is not a new one, it was adapted from the farmers' field school approach (FAO, 2001) and was implemented in Rahad Scheme sometime in early 1990. The fundamental approach is one of learning by doing aimed at developing skills amongst the farmers and other key stakeholders (staff from concerned agencies/ institutions), through an effective programme of transfer of knowledge, using adult learning techniques. It can be an effective tool in building a commitment on the part of the WUO to participate in irrigation management, in understanding the issues and ways to solve problems, and in ensuring that *the process of institutional development is embedded in the community rather than being externally driven*. Transferring management responsibilities should be accompanied by a careful review of the infrastructure with the WUO and concerned agency/institutions including the proposed design for system improvement/ rehabilitation and proposed action plan for crop production and cropping pattern, water distribution, O&M, fee collection and others. The outcome of this process will be joint action plan agreed upon by both the Rahad WUO Association and concerned agencies/institutions that specifies who will do what, where, when, how and resources needed.

4.6.1.4 Capacity Building

Capacity Building Programme for MoIWR Staff and Kenana Extension Staff. O&M Planning and Budgeting, Irrigation Water Management and Irrigation Management Transfer, Community Organizing and Organizational Development and how to run/facilitate WUS programme with the WUO will be the main subject matters of this capacity building programme.

One of the important objectives of this program is to equip the concerned staff with basic skill and knowledge in developing the capacity of the WUO to make it strong, functional and effective. It also aims to develop in them the appropriate attitude in working with the farmers/water users.

4.6.1.5 Coordination Meetings

Implement Regular Coordination Meetings at MoIWR Rahad Directorate Level for Review and Planning. This is proposed in order that progress on WUO-MoIWR-Kenana joint action plan implementation and outcome of the WUS/on site-workshops can be reviewed and accordingly monthly or quarterly work plan of the staff will be formulated to facilitate and sustain the progress. This coordination meeting can be done on a monthly or quarterly basis involving the following: a) head of MoIWR Rahad Directorate as the chairperson; b) key extension staff of Kenena Corporation; and c) representatives from FU/WUO Executive Committees.

4.7 Financial Strengthening

The quantities of incremental inputs required to achieve the productivity levels attainable with project are specified in Table 4-4. A complete change from the use of held over seed to improved seed will be required. The quantity of fertiliser used is expected to double and therefore the application rate will increase nearly five times, because farm size has halved. The use of crop protection chemicals is virtually zero at present, and will have to be introduced. The quality of land preparation will have to improve, though the availability of existing equipment is expected to increase substantially, as the present private fleets at village level will serve only half the tenant farm area. This will improve timeliness, but the quality of land preparation will need upgrading.

Table 4-4 RIS With Project Incremental Use of Inputs

	Units	Present use	Unit cost, SDG	Incremental quantity	Incremental value SDG	Incremental value SDG
Retained seed	kg	2,471,426	1	0	0	0
Improved seed	kg	0	3	1,211,870	3,635,610	1,563,098
Fertiliser	bags	48,735	70	94,485	6,613,918	2,843,595
Pesticides	litres	0	60	78,600	4,716,000	2,027,602
Herbicides	litres	0	60	78,600	4,716,000	2,027,602
Land preparation	ha	212,177	30	129,720	3,891,600	1,673,159
Total cost					23,573,128	10,135,056
Cost per feddan					181	78

Table 4-4 shows incremental input requirements at full development, in project year 11, and this will build up from the present as the cropping pattern changes. Credit financing through a revolving fund is recommended, administered if possible through the Agricultural Bank which has long experience in this type of programme.

It is also recommended that capital to finance the revolving fund is raised through the profit share on tenants' land envisaged in the agreement between Kanana Sugar Company and GOS. The arrangement will be that profits after all expenses are paid will be shared between the Company and the tenant, with 50% to the Company, 40% to the tenant and 10% to be paid into a fund for RIS social services. Assuming that Kenana Sugar achieve crop gross margins per feddan for groundnuts, maize and sunflower at least as good as estimated for tenant farmers with project at full development, then the tenants' share will be SDG 46 million a year, SDG 360 per feddan and an average of SDG 3,200 per household. In other words, the payment is equivalent to a doubling of the average tenant's farm income.

The Study Team does not agree with the concept of profit share between Company and tenant. One economic argument is that an additional source of income raises the opportunity cost of the tenant farmer's time, encouraging him to reduce the effort on his own farm rather than increase it. This being so, we recommend that a portion of the tenants' "share" is allocated to establishing and servicing a revolving fund for input supply on credit.

4.8 Implementation Schedule

The implementation schedule has been phased over a tem year program. The construction of the Meina pump station is over two years, the Dinder aquaduct over three years as well as the Abu0Rakham settling ponds. The automation and on-farm improvements will take five years with drainage improvements taking three years. The WUA Training and support will be over five years and both the extension and credit support taking ten years. These are shown in Table 4-5.

Table 4-5 Project Implementation Schedule

		Year										
Item	Program	1	2	3	4	5	6	7	8	9	10	Total Cost US$ mil
1	Meina Pump Station	■	■									2.79
2	Dinder Aquaduct	■	■	■								4.92
3	Abu-Rakham Settling Ponds	■	■	■								23.64
4	Canal Automation	■	■	■	■	■						12.90
5	On-Farm Improvement	■	■	■	■	■						17.20
6	Drainage	■	■	■								4.89
7	WUA Training and Support	■	■	■	■	■						1.96
8	Extension Programme	■	■	■	■	■	■	■	■	■	■	4.61
9	Credit Support	■	■	■	■	■	■	■	■	■	■	15.10
												88.01
Note: Additional Costs are: pumping costs for tenants and other MOM costs or tenants, valued at US$ 18.09 mil. and 28.3 mil respectively												

4.9 Relationship of Kenana Integrated Agricultural Solutions Co. and Tenant

KIASCo has been given a 5 year contract agreement to manage both the agricultural section and the irrigation management. This gives them a free hand to invest and manage as they determine will serve their economic ends. KIASCo therefore will control 50% of the land, namely 130,000 fd will be farmed directly. Some tenants have offered their half for KIASCo to farm for the first year to the extent of 40,000 fd.

This leaves the tenant with 11fd of their 22 fd to farm as they please. This has many implications for the farmer. It effectively reduced their farm by half allowing them to better control a smaller area. However it places a new responsibility on their shoulders not experienced before, namely to determine what they please with the land. The tenants will need a lot of re-training from the past "trained to wait" to now be "trained to take the initiative". When KIASCo achieve a working capital and can pay the tenant a share of the profit, this study recommends that half of this profit (25% of the total) be held as a working capital to finance inputs for the tenants. This is vital for two reasons. It will give the tenant a vital supply of credit, to be paid back, to enable them to purchase inputs that have been extremely limited in the past. Secondly, this study does not recommend that the tenant be rewarded just for holding the tenant right, but that he be encouraged to invest his labour to reap the benefits of increased capital being made available by the investment of KIASCo.

Another aspect of this KIASCo – tenant relationship is what will happen after KIASCo departs after the 5 years agreement. This will depend on the economic condition left behind. The tenant should have received much training and extension in the 5 years of the agreement putting the tenant in a more technical position able to make decisions on their own. The 50% of the tenancy used by KIASCo will return to the tenant, but this decision can be reviewed upon the success of the tenant using their half, 11 fd. In many ways, the reduction of the tenancy during this period should be used as a trial for the tenant to make much more effective use of their land. All possible efforts should be made to implement the recommendations of this study in training the tenant and boosting the extension services and in providing a revolving credit fund.

5 BUDGET- FINANCIAL COSTS

5.1 Costs, Quantities and Unit Rates

Table 5-1 Unit Rates used in the Financial Costs

Item	Description	Unit	Unit Cost (US$)		
			L/C	F/C	Total
1	Removal of Rip Rap	m^2	0.26	5.07	5.33
2	Backfill from Borow Pit	m^3	0.70	13.46	14.16
3	Excavate around structure	m^3	0.33	6.27	6.60
4	Common Excavation Haul Max. 500 m	m^3	0.26	5.12	5.38
5	Plain Excavation, no haul	m^3	0.09	1.87	1.96
6	Excavation by Dredger	m^3	0.01	0.37	0.38
7	Site Clearing with Dozer	ha	9.00	171.00	180.00
			-	-	-
8	Compaction, embankment fill, from canal excavation		0.34	6.56	6.90
9	Compaction, embankment fill, less than 500 m		0.38	7.32	7.70
			-	-	-
10	Formwork (included in concrete costs)	m^2	-	-	-
11	Plain Concrete C19	m^3	7.60	144.54	152.14
12	Plain Concrete C20	m^3	12.13	230.58	242.71
13	Plain Concrete C25	m^3	13.65	259.49	273.14
			-	-	-
14	Reinforced Concrete C 25	m^3	22.01	418.37	440.38
15	Reinforced Concrete C 35	m^3	26.95	512.19	539.14
16	Reinforcement	ton	80.40	1,527.65	1,608.05
			-	-	-
17	Demolish Concrete	m^3	3.11	59.21	62.32
			-	-	-
18	Gabion Matress	m^3	8.31	157.89	166.20
19	Dumped Riprap	m^3	5.34	101.50	106.84
20	Stone Pitching	m^3	8.01	152.25	160.26
21	Filter Type 3	m^3	1.15	21.99	23.14
			-	-	-
22	Cross regulator, 80 m^3/s	No.	240,408	4,567,752	4,808,160
23	Culvert, 2x2m barrel	No.	24,041	456,775	480,816
24	Bridge, Main Canal	No.	115,752	2,199,288	2,315,040
			-	-	-
25	Filter type 3	m^3	1.15	21.99	23.14
26	HydroFlume 18"	fd	3.84	72.96	76.80
27	HydroFlume 24"	fd	2.65	50.35	53.00
28	Land Smoothing/planning	ha	3.90	74.10	78.00
29	Laser Land Levelling	ha	12.80	243.20	256.00
30	Field Drains	ha	0.05	1.12	1.18
31	700 mm ADV, Supply, install, commission for Major	No.	770	14,630	15,400
32	600 mm ADV, Supply, install, commission for Major	No.	640	12,160	12,800
33	500 mm ADV, Supply, install, commission for Major	No.	618	11,733	12,350
34	450 mm ADV, Supply, install, commission for Major	No.	571	10,849	11,420
35	350 mm ADV, Supply, install, commission for Major	No.	493	9,358	9,850
36	300 mm ADV, Supply, install, commission for Major	No.	418	7,933	8,350
37	500 mm ADV, Supply, install, commission for Minor	No.	791	15,022	15,812
38	450 mm ADV, Supply, install, commission for Minor	No.	730	13,875	14,605
39	350 mm ADV, Supply, install, commission for Minor	No.	627	11,908	12,535
40	300 mm ADV, Supply, install, commission for Minor	No.	518	9,833	10,350

These unit rates have been based on current market prices for those available from suppliers and for others based on Lahmeyer unit rates and updated to today's prevailing conversion factors.

Table 5-2 Summary of Total Project Costs

Item	Description	Unit	Quantity	Unit Cost (US$)			Amount
				L/C	F/C	Total	
1	Meina Pump Station						2,789,045
2	Dinder Aquaduct (Siphon Replacement)						4,919,900
3	Settling Pond						23,637,991
4	Canal Automation						12,898,876
5	On-Farm Improvements						17,198,682
6	Drainage						4,891,829
7	Credit Support						15,098,772
8	Extension Programme						4,612,266
9	Insititutional Strengthening						1,964,577
	Project Grand Total						**88,011,937**

5.1.1 Meina Pump Station

Dredger costs are taken from the existing machine available on site used every year to clear the entrance. The provision of stone and placement in gabions represent the largest part of this cost. Below, in Table 5-3 is the details of the cost of re-modelling the pump station.

Table 5-3 Meina pump Station Costs.

Item	Description	Unit	Quantity	Unit Cost (US$)			Amount
				L/C	F/C	Total	
1	Site Clearance	Ha	12	9.00	171.00	180.00	2,160
2	Dewatering	Sum	1			50,000.00	50,000
3	Excavation for the gabions .	m^3	263,450	0.09	1.87	1.96	516,362
4	Excavation by Dredger	m^3	337,400	0.01	0.37	0.38	128,212
5	Filling with () filter 0.20 m layer thick	m^3	2,450	1.15	21.99	23.14	56,693
6	Supply and fix in posstion (3m X 1m X 1m) gabions filled massonary ranged between (100 - 200) mm.& according to the Engineer insturction.	m^3	12,248	8.31	157.89	166.20	2,035,618
	Total						**2,789,045**

5.1.2 Dinder Aquaduct (replacement of siphon)

The cleaning of the siphon takes place every two years at a cost of $169,000. This will be saved once it is replaced by an aquaduct. The main benefit of the aquaduct will be smooth operation of the supply canal, plus the provision of a bridge across the Dinder River. This will both serve the local community and the management especially during repairs that are often required during the rain periods. The total estimated cost of the new aquaduct is given in Table 5-4 below.

Table 5-4 Summary of Dinder Aquaduct Costs

Item	Description	Unit	Quantity	Unit Cost (US$)			Amount
				L/C	F/C	Total	
1	Coffer dams during construction	Sum	1			50,000.00	50,000
2	Demolish barrel roof	m^3	257.1	3.11	59.21	62.32	16,022
3	Reinforced Concrete C35	m^3	9003	26.95	512.19	539.14	4,853,877
	Total						**4,919,900**

5.1.3 De-Silting Basin at Abu Rakham

The de-silting ponds represent the greatest cost in the action plan but will deliver the greatest savings and improvement in the operation of the scheme. Since construction in 1977, the scheme has suffered from the transport of sediment into the canal system which eventually suffocates the system. By removing the majority of this sediment at the source and putting it either back into the river of converting it to bricks, the system will be able operate on a sustainable basis. The removal of sediment by floating dredger is the cheapest method by far, so huge savings are anticipated with this component of the action plan. The costs are summarised below in Table 5-5. Detailed annual dredging costs are given in Appendix C, section 3.2, at $0.88/m^3.

Table 5-5 Summary of De-silting Basin Costs

Item	**Description**	**Unit**	**Quantity**	**Unit Cost (US$)**			**Amount**
				L/C	**F/C**	**Total**	
1	Site Clearance	Ha	200	9.00	171.00	180.00	36,000
2	Wall Reinforcement (drawing attach)	m^3	12,338	22.01	418.37	440.38	5,433,408
3	Excavate and transport not more than 500m	m^3	2,023,271	0.09	1.87	1.96	3,965,611
	Compaction, embankment fill, less thar	m^3	857,007	0.38	7.32	7.70	6,598,955
3	Barrage-regulator, 80 m^3/s (with bridge)	No.	1	240408	4567752	4,808,160	4,808,160
4	Culvert	No.	1	24041	456775.2	480,816	480,816
5	Bridge	No.	1	115752	2199288	2,315,040	2,315,040
	Total						**23,637,991**

5.1.4 Automatic Diaphragm Valves

The traditional approach to downstream control is to use AVIO gates. These are high-tech precision gates and are subject to interference by placing weights on the balance. Also if not designed properly, they will hunt across the reach, causing transient waves and overtopping. This study proposes another type of control, an automatic diaphragm valve. For the main canal, this valve would be installed completely underwater making them virtually tamper proof. They are also not subject to hunting. Lastly, these valves could easily be manufactured in Sudan as they are not high-tech precision devices. The details of ADV in the major canal is shown in Figure C6 and that for the minor canal in Figure C7. The costs of canal regulation has been divided into the cost of modification of the structure, plus the cost of the ADV valves, for each type, major and minor canals, see Table 5-6. These costs are then carried forward to the total cost of the canal automation, see Table 5-7.

Table 5-6 Costs of ADV for Major and Minor Canals

Major 2 ADV Regulator

Item	Description	Unit	Quantity	Unit Cost (US$)			Amount
				L/C	F/C	Total	
1	Removal of Rip Rap	sum	1			1,000.00	1,000
2	Reinstatement of broken riprap	sum	1			1,000.00	1,000
3	Excavate around structure	m^3	208	0.33	6.27	6.60	1,373
4	Concrete C 25	m^3	139	22.01	418.37	440.38	61,213
	Total						64,586

ADV control Valves

5	1,350 mm ADV, Supply, install, commission,	No.	7			22,950	160,650
6	1,200 mm ADV, Supply, install, commission,	No.	8			21,900	175,200
							335,850

7	700 mm ADV, Supply, install, commission,	No.	2			15,400	30,800
8	600 mm ADV, Supply, install, commission,	No.	17			12,800	217,600
9	500 mm ADV, Supply, install, commission,	No.	3			12,350	37,050
10	450 mm ADV, Supply, install, commission,	No.	7			11,420	79,940
11	350 mm ADV, Supply, install, commission,	No.	4			9,850	39,400
12	300 mm ADV, Supply, install, commission,	No.	1			8,350	8,350
			34				413,140

Bill of Quantities

Minor 2 ADV Regulator

Item	Description	Unit	Quantity	Unit Cost (US$)			Amount
				L/C	F/C	Total	
1	Excavate around structure	m^3	32	0.33	6.27	6.60	211.20
2	Fill to reinstate earthworks	m^3	276	0.34	6.56	6.90	1,904.40
3	Supply and Place Rip Rap	m^2	42	8.01	152.25	160.26	6,730.92
4	Plain Concrete C19	m^3	2.2	7.60	144.54	152.14	334.71
5	Concrete C 25	m^3	12.6	22.01	418.37	440.38	5,548.79
							14,730.02

ADV control Valves

6	500 mm ADV, Supply, install, commission,	No.	3	790.63	15,022	15,813	47,438
7	450 mm ADV, Supply, install, commission,		19	730.25	13,875	14,605	277,495
8	350 mm ADV, Supply, install, commission,		14	626.75	11,908	12,535	175,490
9	300 mm ADV, Supply, install, commission,		19	517.50	9,833	10,350	196,650
			55				697,073

5.1.5 Automation Costs

The cost of adding the ADV has been done by designing all structures on Major 2 and sample minors, and then applying to the whole scheme on a unit area basis. The cost for all structures on Major 2 is US$ 1.637 million and on the minors US$ 1.507 million. The total of US$ 3.144 over the command area of 31,692 fd gives a unit cost of US$ 99.22/fd. Applying this over the whole project of 260,000fd gives a scheme cost of US$ 25.797 million.

For the longitudinal profile of Major 2 is given in Figure C5

Table 5-7 Summary of Automation Costs

Item	Description	Unit	Quantity	Unit Cost (US$)			Amount
				L/C	F/C	Total	
	MINOR CANAL						
1	Structure for Minor ADV	No.	55			14,730.02	810,150.88
2	ADV valves, supply, delivery and installation	No.					697,072.50
	MAJOR CANAL						
3	Abu-XX, and Minor ADV on Major offtake	No.	34			14,730.02	500,820.54
4	ADV valves, supply, delivery and installation	No.					413,140.00
5	Major Structure for ADV	No.	6			64585.62	387,513.72
6	ADV valves, supply, delivery and installation	No.					335,850.00
	Total automation of Major 2						3,144,547.64
	Area	fd	31,692			Unit rate: $/fd	99.22
		ha	13,310			Unit rate: $/ha	236.25
	Total Rahad area	fd	260,000				25,797,753
	Total Project Area	fd	130,000				12,898,876

5.2 On-Farm Irrigation Improvement

The on-farm improvements would be applied over 50% of the total area, representing the farmers half of the project. As this study is not considering the KIASCo half in any of the cost benefit analysis, this figure is for farmers only. Land with flat slopes of less that 20 cm/km would only have land smoothing performed and are assumed to cover only blocks 1 to 4. Blocks 5 to 9 are generally steeper with slopes greater than 40 cm/km and would require laser land levelling to bring them flatter and increase their efficiency by using level furrow irrigation.

Included in the cost of on-farm improvements are the following items: land smoothing or land levelling, field drains and hydroflume. Omission of any of these items will render this programme useless and negate these improvements. The use of hydroflume can be replaced by using traditional abu-IV, but this will not lead to the full benefits as gained by using the hydroflume.

Table 5-8 Summary of On-farm Improvement Costs

Fields <20 cm/km				
Unit Cost/ha	205.37	$/ha	203.30	SDG/fd
Farmers area	51,133	ha	121,745	fd
Blocks 1-4	10,501,165	$	24,751,247	fd
Fields >40 cm/km				
Unit Cost/ha	383.37	$/ha	379.51	SDG/fd
Farmers area	62,332	ha	148,409	fd
Blocks 5-9	23,896,198	$	56,323,339	SDG
Rahad Area	113,465	ha	270,154	fd
	34,397,363	$	81,074,586	SDG
Total Project	17,198,681.70	$	40,537,293	SDG

5.3 Drainage

Drainage is an area that has been neglected for many years until many fields cannot be cropped due to water logging. As mentioned already in the problems of fields with a dish shape, internal drainage will be part of the on-farm solution. This cost is provided for in that section. The outfalls of many minor drains is inadequate in many places and it is proposed to deepen all minor drains for the last part before they discharge into collector drains. This deepening should be at least 1.0 m, but deepening the minors requires that all downstream drains also be deepened until the outfall in the Rahad River. This requires some 1,289 km of drain maintenance to be carried out. Of this portion, 50% will be accounted for in this "with project" cost. Details of these costs are given below in Table 59.

Table 5-9 Summary of Drainage Costs

Drains							
1	Minor Drains, 50% increase depth by 1.0 m			km	km		
	Area of excavation	1.5	m^2	820	410	615,000	m^3
2	Major Drains, 75% increase depth by 1.125 m						
	Area of excavation	3.4	m^2	952	714	2,427,600	m^3
3	Main Drains,						
	Area of excavation	11.81	m^2	220	165	1,949,063	m^3
Total Drain quantities						4,991,663	m^3

Item	Description	Unit	Quantity	Unit Cost (US$)			Amount
				L/C	F/C	Total	US$
A	Plain Excavation, no haul	m^3	4,991,663	0.09	1.87	1.96	9,783,659
	Farmers contribution = 50% for With-Project						**4,891,829**

5.4 Financial Strengthening

The outline of a revolving fund for credit for inputs is shown Table 5-10. Build up of credit supply follows the expected growth of crop area, which is a function of increased on-farm cropping intensity. Fund management is modelled at 20% of input value (which is passed on to the loanee) and the loan term is 12 months. Late payments are modelled at 10% and bad debts at 5%. "Fund in at year end" = cost of inputs to be purchased + management cost – repayments by year end. "Fund in" covers the growth in credit demand, fund shortfalls resulting from late payment and losses due to bad debts. The fund is closed in Year 12.

Only the costs of fund administration and bad debts are passed to the cost benefit analysis. The resource cost of the inputs is already covered in the gross margins. Any interest incurred is a transfer payment and therefore not included in the economic analysis, though fund management costs are included.

After the initial payment for working capital of SDG 15 million, management costs of the fund are only about 6% of the expected share to be paid by Kenana Sugar Company to tenants. This is a small price to pay for timely, pre-funded inputs and would be a substantial benefit to the RIS community as a whole.

Table 5-10 Outline of Revolving Credit Fund for Input Supply, SDG million

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Irrigated feddan		*68,240*	*74,388*	*80,536*	*86,684*	*92,832*	*98,980*	*105,128*	*111,276*	*117,424*	*123,572*	*129,720*	
Value of Incremental Inputs													
Seeds		1.91	2.08	2.26	2.43	2.60	2.77	2.95	3.12	3.29	3.46	3.64	
Fertiliser		3.48	3.79	4.11	4.42	4.73	5.05	5.36	5.67	5.99	6.30	6.61	
Chemicals		4.96	5.41	5.86	6.30	6.75	7.20	7.64	8.09	8.54	8.98	9.43	
Land preparation		2.05	2.23	2.42	2.60	2.78	2.97	3.15	3.34	3.52	3.71	3.89	
Total		12.40	13.52	14.64	15.75	16.87	17.99	19.10	20.22	21.34	22.46	23.57	
Fund management		14.88	16.22	17.56	18.90	20.24	21.58	22.93	24.27	25.61	26.95	28.29	0
Scheduled repayment			14.88	16.22	17.56	18.90	20.24	21.58	22.93	24.27	25.61	26.95	30.98
Less late payments			1.49	1.62	1.76	1.89	2.02	2.16	2.29	2.43	2.56	2.69	0.00
Less bad debts				0.81	0.88	0.95	1.01	1.08	1.15	1.21	1.28	1.35	1.55
Repayment by year end			13.39	15.28	16.55	17.82	19.10	20.37	21.64	22.92	24.19	25.47	32.13
Fund in at year end	14.88	0.00	2.83	2.29	2.35	2.42	2.49	2.55	2.62	2.69	2.76	2.82	-32.13
Costs of managing the fund SDG		2.48	2.70	3.74	4.03	4.32	4.61	4.90	5.19	5.48	5.77	6.06	1.55
Costs of Revolving Credit Fund US$	6.40	0.00	1.22	0.98	1.01	1.04	1.07	1.10	1.13	1.16			
Total 10 Year Cost US$										15.10			

Table 5-11 Agriculture Extension Cost Summary

Extension Programme								Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total
	unit	number	unit US$	unit SDG	Cap[ital	Annual												
Salaries																		
Field extension worker	46	number	430	1,000		552,000		184,000	276,000	552,000	579,600	608,580	639,009	670,959	704,507	739,733	776,719	5,731,108
Supervisors	9	number	645	1,500		162,000		54,000	81,000	162,000	170,100	178,605	187,535	196,912	206,758	217,095	227,950	1,681,956
Senior Extension Officer	1	number	860	2,000		24,000		24,000	24,000	24,000	25,200	26,460	27,783	29,172	30,631	32,162	33,770	277,179
Administarive staff/Guardmen	9	number	155	360		38,880		12,960	19,440	38,880	40,824	42,865	45,008	47,259	49,622	52,103	54,708	403,669
Allowances; field staff	46	number	86	200		9,200		3,067	3,067	3,067								9,200
Allowances, supervisors	9	number	107	250		2,250		750	750	750								2,250
Allowances, SEO	1	number	150	350		350		350										350
Vehicles		number																
Cars	1	number	17,198		40,000			40,000	0	0	0	40,000	0	0	0	0	0	80,000
Motorbikes	9	number	1,720	4,000	36,000			36,000	0	0	0	36,000	0	0	0	0	0	72,000
Bicycles	46	number	129	300	13,800			13,800	0	0	0	13,800	0	0	0	0	0	27,600
Operational cost of transpost	40%							30,400	30,400	30,400	30,400	30,400	30,400	30,400	30,400	30,400	30,400	304,000
Offices and Stores																		
Main stores	9	number	107	250	2,250			750	750	750								2,250
Sub stores	46	number	43	100	4,600			1,533	1,533	1,533								4,600
Office (at Fao using RAC buildings)	1	number	860	2,000		2000		2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	20,000
Building maintennace	10%							428	857	1285	1285	1285	1285	1285	1285	1285	1285	11,565
In service training																		
Field extension worker	46	number		500		23,000				23,000	23,000	23,000	23,000	23,000	23,000	23,000	23,000	184,000
Supervisors	9	number		1,000		9,000				9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	72,000
Senior Extension Officer (seminars & wo	1	number		2,000		2,000				2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	16,000
Extension equipment	1	sets	120,641	280,600	280,600			280,600					280,600					561,200
Farmer allowances	30,000	per annum	1	1		33,000		11,000	16,500	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	291,500
Contingencies	10%							69,564	45,630	88,367	91,641	104,700	128,062	104,499	109,220	114,178	119,383	975,243
Total SDG								765,202	501,926	972,032	1,008,050	1,151,695	1,408,683	1,149,486	1,201,423	1,255,956	1,313,216	10,727,669
Total US$								328,992	215,799	417,916	433,402	495,161	605,651	494,211	516,541	539,987	564,606	4,612,266

5.4.1 Institutional Strengthening

The estimated costs required for the programme described are shown in Table 5-12.

Table 5-12 Costs of Institutional Strengthening

	unit	number	unit US$	unit SDG	Capital	Annual		Year 1	Year 2	Year 3	Year 4	Year 5
Staff												
Community Organisers	10	number	645	1,500		180,000		180,000	180,000	180,000	180,000	180,000
Senior WUO Specialist	1	number	860	2,000		24,000		24,000	24,000	24,000	24,000	24,000
Office Manager	1	number	645	1,500		18,000		18,000	18,000	18,000	18,000	18,000
Support staff	2	number	215	500		12,000		12,000	12,000	12,000	12,000	12,000
Allowances												
Housing allowance	10	number	86	200		2,000		2,000	0	2,000	0	2,000
Per diems												
Community organisers	10	number	21	50		60,000		60,000	60,000	60,000	60,000	60,000
MoIWR staff	7	number	21	50		42,000		42,000	42,000	42,000	42,000	42,000
Site Visits and Coordination Meetings	20	number	21	50		12,000		12,000	12,000	12,000	12,000	12,000
Extension workers	460	number	21	50		23,000		23,000	23,000	23,000	23,000	23,000
Vehicles												
Cars	1	number	17,198		40,000			40,000	0	0	0	0
Motorbikes	10	number	1,720	4,000	40,000			40,000	0	0	0	0
Bicycles	0	number	129	300	0			0	0	0	0	0
Operational cost of transpost	40%							32,000	32,000	32,000	32,000	32,000
Offices and Stores												
Office (at Fao using RAC buildings)	1	number	860	2,000		2,000		2,000	2,000	2,000	2,000	2,000
Building maintennace	10%							200	400	600	600	600
Training												
Community Organisers	10	days	430	1,000		10,000		10,000	10,000	10,000	10,000	10,000
Extension workers												
Irrigation practices	5	days	215	500		115,000		115,000	115,000	115,000	115,000	115,000
O&M procedures	3	days	215	500		69,000		69,000	69,000	69,000	69,000	69,000
Financing and record keeping	2	days	215	500		46,000		46,000	46,000	46,000	46,000	46,000
Workshops						82,000		82,000	82,000	82,000	82,000	82,000
Capacity Building												
O&M training	125	people days				10,000		10,000	10,000	10,000	10,000	10,000
Water Management	125	people days				10,000		10,000	10,000	10,000	10,000	10,000
Community orgnisation	30	people days				22,000		22,000	22,000	22,000	22,000	22,000
Resource persons fees						8,000		8,000	8,000	8,000	8,000	8,000
Physical contingencies	15%							128,880	116,610	116,940	116,640	116,940
Total SDG								988,080	894,010	896,540	894,240	896,540
Total US$								424,816	384,372	385,459	384,471	385,459
											Grand Total US$	1,964,577

5.4.2 Cost Summary

A summary of project costs and the assumed phasing is given in Table 5-13. The costs of Meina Pump Station, Dinder Aqueduct and the Settling Ponds is the total cost for each cost item. This is because they are fixed costs and therefore indivisible, and because they would not be implemented without the project. That is, KSC would be able to access sufficient irrigation water for its proposed activities using the existing infrastructure. In S 7.3 the impact of this assumption is considered on the project economic indicators.

Canal automation, on-farm improvements and drainage are variable costs dependent on the project area, the total cost estimated for RIS has been proportioned between tenants and KSC according to their share of the net irrigable area, see Table 5-7 and Table 5-8 and Table 5-9.

The extension programme, credit support and training budgets have been worked out specifically for the tenant farmers, as have pumping and MOM costs.

Table 5-13 Summary of With Project Cost

	US$ million	Year										
Table		1	2	3	4	5	6	7	8	9	10	Total
5-3	Meina Pump Station	0.28	2.51									2.79
5-4	Dinder Aqueduct	0.49	2.21	2.21								4.92
5-5	Settling Pond	2.36	10.64	10.64								23.64
5-7	Canal Automation	1.29	2.58	2.58	3.22	3.22						12.90
5-8	On-farm improvements	1.72	3.44	3.44	4.30	4.30						17.20
5-9	Drainage	0.49	0.98	0.98	1.22	1.22						4.89
5-10	Credit Support	6.40		1.22	0.98	1.01	1.04	1.07	1.10	1.13	1.16	15.10
5-11	Extension Programme	0.33	0.22	0.42	0.43	0.50	0.61	0.49	0.52	0.54	0.56	4.61
5-12	Insititutional Strengthening	0.42	0.38	0.39	0.38	0.39						1.96
	Total	13.79	22.96	21.87	10.55	10.64	1.65	1.56	1.61	1.67	1.72	88.01

Pumping costs and MOM costs for tenants are taken from CBA Table 6-12

6 COST BENEFIT ANALYSIS

6.1 Scope of the Cost Benefit Analysis

The following observations assist in defining the project:

- "The present" refers to the last complete cropping season 2009/10 which was the subject of analysis of the Household Survey; "the present" cannot include the operations of Kanana Sugar since the company's involvement with RIS had only been agreed in February 2010 and the company did not begin planting until 14th May 2010
- "The present" also cannot include the on-going rehabilitation works funded by Islamic Bank and OPEC which began in 2009 and will only begin to impact on production in the 2010/11 cropping season
- The "future without project" must take account of the impact on tenant farmers of the operations of Kanana Sugar (a project in itself and the subject of feasibility studies undertaken by the company) and the rehabilitation programme; Year 1 of the future is 2010/11
- The "future with project" must analyse the impact of recommendations made by this study; these recommendations have little to say about the production activities of Kanana but are mainly concerned with re-design of the Meina Pump Station and the Dinder Aqueduct, the design of a settlement pond to control sediment, automation of canals which will give downstream control of supply to tenant farmers, and on-farm irrigation improvements also directed to tenant farmers.
- The team recommendations also include a comprehensive agricultural extension programme directed to improving the productivity of tenants' farms and a community mobilisation programme to promote better water management and greater self-determination in farming activities amongst tenants.

These observations provide the justification for analysing the costs and benefits identified by this study exclusively on the operational area of tenant farmers: 130,000 feddan. However, it is acknowledged that Kenana Sugar may benefit from reductions in operational costs (in particular a reduction in the need for de-silting) as a result of the civil works proposed for the feeder and main canals.

RIS was designed to provide 8.6 MCM per day to irrigate 260,000 feddans, a delivery of 33 m^3 per feddan per day. This design was never realised due mainly to aggressive sedimentation and difficulties with the operation of Meina Pump Station: 6.4 MCM was the best delivery achieved in the past.

The Present Situation:

Over time, system delivery declined to only 4.0 MCM per day in 2008/09, which is sufficient for the irrigation of 121,200 feddan at 33 m^3 per feddan per day. However, the results of the Household Survey show that tenant farmers did better than that, achieving about 197,000 net feddan, but at the cost of very low productivity per unit area. The achieved area implies a delivery of about 20.3 m^3 per feddan per day. The areas and yields achieved by tenants suggests that about 80% of delivery was to the head and middle of the system, and the remaining 20% to the tail. This defines the "present" situation, shown in the first section of Table 6-1.

The Future without Project Situation:

Rehabilitation works are expected to restore the system to as good as or slightly better than its maximum achieved delivery of 6.4 MCM, which is sufficient for the irrigation of 195,000 feddan at the design application. At the same time, Kenana Sugar will take over the operation of 50% of the net irrigable area of 260,000 feddan (as according to the agreement with GOS), plus about 40,000 feddans on behalf of tenant farmers to grow sorghum. It is assumed – an important assumption – that Kenana will irrigate to full design capacity of 33 m^3 per feddan per day and they will be successful in cropping 90% of their land allocation. Tenant farmers will have at their disposal the balance of water and land. In respect of water they will have 1.38 MCM per day peak delivery, which they will use to irrigate 68,250 feddan of the 90,000 feddan which remain for their own operations – assuming a similar use of water as in the present. This defines Year 1 (2010/11) of the future without project situation.

Without the remedial works proposed by this study for Meina Pump Station, Diner Aqueduct and sediment control, it is estimated that maximum deliveries will return to present levels in five years after the completion of the rehabilitation programme. The maximum delivery available will then be 4 MCM per day, and it is assumed that Kanana Sugar will continue to irrigate according to design, at 33 m3 per feddan. The company prioritises water for its own operations. There is sufficient to continue to irrigate 90% of its allocation of 130,000 feddan. However, there is now insufficient to continue with its operations for tenants, and that area will decline from 40,000 feddan in 2010/11 to only 4,200 feddan. Tenant farmers themselves will go out of the irrigation business. They may leave the scheme, become casual labourers for Kanana Sugar or return to rainfed cropping - if they manage to retain their leases. This defines Year 5 (2014/15) of the future without project situation.

The Future with Project Situation:

With the remedial works proposed by this study, the peak delivery of 6.56 MCM achieved after the rehabilitation programme is sustainable over time. Kenana Sugar operations will continue according to the company's understanding with the government. Their cropping pattern in ten years time cannot be predicted, Kenana Sugar is a commercial company and would not make a firm prediction itself. The important thing is that the Company uses its land and water allocation according to the agreement with GOS. However, by Year 10 (2020/21), after the intensive social mobilisation and agricultural extension programmes proposed, tenant farmers will achieve the "with project" cropping pattern described in the next section, totalling 129,720 gross feddan from 130,000 net feddan, i.e. a cropping intensity of about 100%. Kanana Sugar's operations on behalf of tenants will gradually phase out and cease.

As shown in Table 6-1, the peak delivery to tenants can only be 20.88 m^3 per feddan, after Kenana Sugar has taken its allocation, which is similar to what tenants receive now (20.29 m^3 per feddan). However, this study proposes improvements in canal automation and in-field irrigation which will make the use of the allocation sufficiently efficient to achieve the expected productivity increases described in the next section.

The key implication of this discussion is that benefits from the study team's recommendation can be derived from the tenant farmer area of the scheme, 130,000 feddans. We assume Kanana Sugar will take its benefits whether or not these recommendations are implemented, as its land and water allocation is comparatively secure. What is at stake now is the future existence of tenant farming in RIS. Tenant farmers now have little security for either land or water. Land leases were only for 30 years when RIS was established. Kenana Sugar is now manager of the main canal.

Having established the scope of the Cost Benefit Analysis, it is now possible to describe the financial implications, proceeding through a financial analysis of the present situation, the future without project situation and the future with project situation. The incremental benefits expected as a result of the project can then be defined.

Table 6-1 Land and Water Allocations: Present, Future Without Project and Future With Project

Present	FLOW VOLUME						IRRIGATION AREA			
	Head and Middle		Tail		Total		Head and Middle	Tail	Total	
	Peak Delivery, m^3/fd/day	Peak MCM/day	Peak Delivery, m^3/fd/day	Peak MCM/day	Peak Delivery, m^3/fd day	Peak MCM/day	Net irrigated feddan	Net irrigated feddan	Net irrigated feddan	Net Irrigable feddan
Tenant farmers	23.76	3.20	12.80	0.80	20.29	4.00	134,658	62,479	197,137	260,000

Future Without Project Year 1	FLOW VOLUME						IRRIGATION AREA			
	Head and Middle		Tail		Total		Head and Middle	Tail	Total	
	Peak Delivery, m^3/fd day	Peak MCM/day	Peak Delivery, m^3/fd day	Peak MCM/day	Peak Delivery, m^3/fd day	Peak MCM/day	Net irrigated feddan	Net irrigated feddan	Net irrigated feddan	Net Irrigable feddan
Tenant farmers	23.76	1.11	12.80	0.28	20.29	1.38	46,613	21,627	68,240	90,000
Kenana operations	33.00	2.59	33.00	1.27	33.00	3.86	78,390	38,610	117,000	130,000
Kenana operations for tenants	33.00	0.88	33.00	0.44	33.00	1.32	26,800	13,200	40,000	40,000
Total		4.58		1.99		6.57				

Future Without Project Year 5	FLOW VOLUME						IRRIGATION AREA			
	Head and Middle		Tail		Total		Head and Middle	Tail	Total	
	Peak Delivery, m^3/fd day	Peak MCM/day	Peak Delivery, m^3/fd day	Peak MCM/day	Peak Delivery, m^3/fd day	Peak MCM/day	Net irrigated feddan	Net irrigated feddan	Net irrigated feddan	Net Irrigable feddan
Tenant farmers										
Kenana operations	33.00	2.59	33.00	1.27	33.00	3.86	78,390	38,610	117,000	130,000
Kenana operations for tenants	33.00	0.09	33.00	0.05	33.00	0.14	2,822	1,390	4,212	4,212
Total		2.68		1.32		4.00				

Future With Project Year 10	FLOW VOLUME						IRRIGATION AREA			
	Head and Middle		Tail		Total		Head and Middle	Tail	Total	
	Peak Delivery, m^3/fd day	Peak MCM/day	Peak Delivery, m^3/fd day	Peak MCM/day	Peak Delivery, m^3/fd day	Peak MCM/day	Net irrigated feddan	Net irrigated feddan	Net irrigated feddan	Net Irrigable feddan
Tenant farmers	20.88	1.12	20.88	0.55	20.88	2.71	53,551	26,310	129,720	130,000
Kenana operations	33.00	2.59	33.00	1.27	33.00	3.86	78,390	38,610	117,000	130,000
Kenana operations for tenants	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0
Total		3.71		1.82		6.57				

6.2 Present Situation

6.2.1 Farm Size and Land Use

Farm size is easy to estimate in the Rahad Irrigation Scheme because of the tenancy system, where farmers are allocated a defined land area. Taking the head and middle tail together, mean tenancy size is 17.91 feddan and the tail tenancy size is 19.24 feddan. In 2009/10 season the cropped area comprised 112,480 feddan of sorghum, 74,340 feddan groundnut, 19,350 feddan sunflower , 2,190 feddan cotton and 13,510 feddan of "other crops". The mean number of TLU per owning household was 5.5. The total number of tenant farmers owning livestock in the RIS is expected to be about 8,000, with about 44,000 TLU, of which 36,000 TLU will be cattle, or 51,500 head. 60% will be dairy cattle, 31,000, leaving 20,000 beef animals. Model farms for the head and middle and the tail were prepared with this information.

6.2.2 Enterprise Gross Margins

Present and future without project crop and livestock gross margins are summarised in Table 6-2. Similar calculations were made for tail end production. Yields, input applications and prices are based on the data collected in the Household Survey. There may be some modifications based on data collected by other team members and information from other sources. Note that family labour is not costed in the financial gross margins. It is however costed in the economic analysis using a shadow price for labour.

Table 6-2 Crop Gross Margins, Present Without Project, Financial SDG: Head and Middle

	Labour SDG									
	Total	Family	Hired	Land prep SDG	Other inputs SDG	Total costs SDG	SDG/kg	Gross return SDG	Net return SDG	Return SDG/family labour day
Sorghum	50		50	20	86	156	0.76	419	263	15
Groundnut	53		53	25	124	202	2.40	355	153	7
Sunflower	20		20	20	72	124	2.65	171	47	4
Cotton	150		150	50	171	371	2.00	632	261	16
Other crops	80		80	20	177	177	0.68	643	366	12

6.2.3 Farm Budget

The land use model and enterprise gross margins provide a basis for a simplified tenant farm present farm budget for the head and middle and tail which can be used in the cost benefit analysis. The budget shown in Table 6-3 is in financial prices. They are easily converted to economic prices using project specific conversion factors. Similar calculations were performed for a tail end farm budget.

Table 6-3 Present Tenant Farm Financial Farm Budget, SDG: Head and Middle

Average Farm Size= 17.91 net feddan

Enterprise/activity	Area summer (%)	Area winter (%)	Area summer (fed)	Area winter (fed)	Gross margin per fed.	Financial Gross Margin
Sorghum	42.3%		7.6		263	1,991
Maize						
Groundnut	26.6%		4.8		153	731
Sunflower		9.4%		1.7	47	79
Cotton		0.9%		0.2	261	41
Other crops		5.6%		1.0	366	368
Net Crop Returns						3,210
Livestock	No.Units				GM/unit	Fin.GM
Dairy Cows (1 cow unit)	2.18				171	372
Beef Cattle (1 bullock unit)	1.40				131	184
Net Livestock Returns						556
Less Fixed Costs:						
Farm tools and other expenses [1/]	1.00				500	500
Irrigation equipment	0.00					0
sub-total						500
Net Farm Household Returns (excluding maintenance)						3,980
Maintenance Fees [2/]						714
Net Farm Household Returns less maintenance						3,265
Maintenance Fees %						21.9%

The cropping intensity is 69% in the summer and 16% in the winter in the head and middle, and 70% in the summer and 5% in the winter in the tail. Crop gross margins are much lower in the tail than the head and middle of the system. Returns from livestock are only about 7% of net farm income in the head and middle and 10% in the tail. Farm returns are very low, SDG 180 per farm feddan in the head and middle, and SDG 24 per feddan in the tail. Tail enders are barely breaking even. 65% of households interviewed in the tail had negative household income, while only 45% of farmers interviewed in the head and middle were in the same condition.

The administration and water charge has been included in the crop gross margins and added to the net farm income. Clearly it is very high in comparison to net income from crops and livestock, particularly in the tail where irrigation services are poorer than in the head and middle. All the classic symptoms of a shrinking irrigation area are visible – high water charge because of high costs and small irrigation area, and de-motivated farmers at the tail abandoning irrigation because it is too expensive, thus increasing unit area administration and water charges for the head and middle.

The net farm incomes in the budgets are slightly higher than reported in the Household Survey (average of about SDG 1,200). This is mostly because the budgets include the value of production retained for family consumption. About 20% by weight is retained in the head and middle, and 30% in the tail. Also respondents tend to understate sales prices and therefore income.

The tenant farm model farm labour requirement is shown in Table 6-4. The compilation is useful because it can be used to ensure that labour requirements calculated at scheme level approximately match the labour availability claimed in the Household Survey.

Table 6-4 Present Tenant Farm Labour Requirement: Head and Middle

Enterprise/activity	Family days/fed	Hired days/fed	Family days	Hired days
Sorghum	18	10	136	76
Maize				
Groundnut	21	11	98	50
Sunflower	14	7	23	11
Cotton	16	30	2	5
Other crops	31	16	31	16
Crop labour requirement			290	158
Livestock				
Dairy Cows (1 cow unit)			70	
Beef Cattle (1 bullock unit)			7	
Stock labour requirement			77	0
Farm labour requirement			367	158
Maintenance Labour			0	0
Total labour requirement			367	158

The total labour requirement estimated for both crop and livestock in the RIS is 7.0 million labour days per year, 5.9 million on crops and 1.1 million on livestock. The sample respondents said they committed about 70,000 days to cultivation per year and 5,100 days to livestock. Extending these estimates to the scheme suggests 3.8 million labour days on crops and 0.3 million days on livestock. The stated availability of tenant farmers for crop cultivation can then be subtracted from the total, leaving about 2.1 million days for casual labour. If each casual labourer's family puts in 300 days per annum on tenant farms, then that suggests a total of 7,000 casual labourers' families at work in the scheme. If their family size is roughly the same as tenants', this represents 56,000 additional people on the scheme and a total scheme population of 173,600 – a considerable reduction on the 300,000 estimated in the late 1990s (FAO 2000). But the reduction is not surprising; the cropping intensity was over 90% then, whereas now it is about 77%. Cotton, a big consumer of field labour is now only grown on tiny areas.

The time spent on livestock is mis-matched between respondents' data and the livestock model enterprises. No adjustments are made, because it is believed that the time allocation was under reported by respondents. Dairy work is usually done by women, and the respondents were nearly all men.

It is a useful calculation to estimate the food energy budget of the household. Since the production by crop and livestock enterprise and the amount retained for family consumption is known it is straightforward to compile, as shown in Table 6-5 (for the tail only, the worst case). The unit energy equivalent by commodity is obtained from the FAOStat website. Tenant farms in the RIS retain for consumption about 20% of crop production by weight in the head and middle, and about 30% in the tail. This is a high proportion for a scheme intended for the production of export crops. The stated retained production only meets 50% of household food energy needs in the head and middle, and only 33% in the tail. Bearing in mind there is a limit to the amount of groundnuts and sunflower that can be included in the diet it is surprising that respondents claimed that so high a proportion of "other crops" was sold. But even if all were retained, it would not have much impact on the food energy balance.

The data available do suggest that the food energy balance at household level is unfavourable. Families clearly depend on a cash income to buy in the order of half the food energy it needs, and the farm is providing a very low income. Further, the farm is providing an undiversified diet, unappealing in itself, and risky in the event of crop failure.

The model farm food energy budget is only an indication of food security status of the scheme population, which varies by household (depending on farm size, productivity and number of household members) and individuals (depending on dietary entitlement).

Table 6-5 Food Energy Budget, Tenant Farmer Model Farm, Tail

Commodity	Production, tons	mkcals per ton	mkcals	Home consumption, tons	mkcals
Sorghum	1.42	2.55	3.61	0.64	1.63
Maize					
Groundnut	0.57	0.39	0.22	0.04	0.02
Sunflower	0.08	0.39	0.03	0.00	0.00
Cotton	0.02	0.00	0.00	0.00	0.00
Other crops	0.45	0.77	0.35	0.04	0.03
Crop mkcal production			4.22		1.68
Livestock					
Milk	0.17	0.62	0.10	0.10	0.06
Beef	0.22	2.36	0.52	0.11	0.26
Livestock mkcal production			0.62		0.32
mkcal production			4.84		2.00
Total requirement per household, mkcals			6.08		6.08
Farm Food energy balance, mkcals			-1.25		-4.09

6.3 The Future With Project Situation

6.3.1 Farm Size and Cropping Pattern

Tenant farms will halve in size from the present, according to the agreement between GOS and Kanana Sugar, which will take over management of 50% of the scheme's 260,000 net irrigable feddan. Tenant farmers will receive an income from this, but this will be an "off-farm" income which may be a useful source of financing for farm operations, either discretionary, or placed in a revolving fund with the Agricultural Bank to finance land preparation and inputs. Farms in the head and middle will be on average 9 feddan and farms in the tail 9.6 feddan. The cropping pattern will also change. The predicted future with project scheme cropping pattern on tenant farms will be:

- Of 130,000 feddan, 13,500 feddan will be allocated to horticultural crops – this is the same as the present area, reported in the Household Survey as 13,514 feddan of "other crops" which are mainly winter vegetables
- Of the balance, 50% will be in summer crops: that is 30,000 feddan of sorghum and 28,250 feddan of groundnuts; and 50% will be in winter crops: 30,000 feddan of sunflower and 28,250 feddan of maize
- The cropping intensity will therefore be around 100%, compared to about 85% at present.

The advantage of the cropping pattern is that it avoids the problem of following on summer crops with winter crops which has always been difficult on the black cotton soils of the area. A good rotation is achieved with a leguminous break crop every four years, Scheme food security will improve, with two grain crops, one summer and one winter which will reduce risk. There will be economic benefits to reducing the area of sorghum – the sorghum price is so high that it would be cheaper to import it.

6.3.2 Enterprise Gross Margins

With project, there will be increases in productivity, reflected in improved enterprise gross margins per unit area and per unit of livestock summarised in Table 6-6. Moderate increases in yields are expected, plus concomitant expenditure on fertiliser and plant protection chemicals. A formal water charge is introduced to cover sustainable MOM. Increases in labour requirements have also been modelled, especially for harvesting and processing. It is assumed that head and tail differences in farm budgets disappear.

Table 6-6 Crop Gross Margins, Future With Project, Financial SDG

	Labour SDG									
	Total	Family	Hired	Land prep SDG	Other inputs SDG	Total costs SDG	SDG/kg	Gross return SDG	Net return SDG	Return SDG/family labour day
Sorghum	68	0	68	30	150	247	0.76	726	479	17
Maize	75	0	75	30	388	493	0.94	1,169	675	21
Groundnut	63	0	63	30	255	347	2.40	731	384	14
Sunflower	40	0	40	40	332	412	2.65	598	186	12
Cotton	150	0	150	50	300	500	2.00	661	161	10
Other crops	113	0	113	50	457	457	0.68	1,682	1,063	22

6.3.3 Farm Budget

The expected future with project model farm budget is shown in Table 6-7. Farm budgets will be similar between the head and tail, though tail end farms are slightly larger.

Table 6-7 Future With Project Smallholder Farm Budget, Financial SDG

Average Farm Size=	**8.96**	**net feddan**				
Enterprise/activity	Area summer (%)	Area winter (%)	Area summer (fed)	Area winter (fed)	Gross margin per fed.	Financial Gross Margin
Sorghum	23.1%	0.0%	2.1		479	990
Maize	0.0%	21.7%		1.9	675	1,314
Groundnut	21.7%	0.0%	1.9		384	747
Sunflower	0.0%	23.0%		2.1	186	382
Cotton	0.0%	0.0%	0.0		161	0
Other crops	0.0%	10.4%		0.9	1,063	988
Net Crop Returns						4,422
Livestock	No.Units				GM/unit	Fin.GM
Dairy Cows (1 cow unit)	2.18				232	505
Beef Cattle (1 bullock unit)	1.40				131	184
Net Livestock Returns						689
Less Fixed Costs:						
Farm tools and other expenses [1/]	1.00				500	500
Irrigation equipment	0.00					0
sub-total						500
Net Farm Household Returns (excluding maintenance)						5,233
Maintenance Fees [2/]						622
Net Farm Household Returns less maintenance						4,611
Maintenance Fees %						13.49%
1/ Farm tools, building repairs and miscellaneous expenses						
2/ Fees and labour to recover costs of maintaining irrigation and other infrastructure.						

Crop returns rise from SDG 182 per farm feddan in the head and middle to SDG 515 per farm feddan. Returns per cultivated feddan rise from SDG 211 to SDG 494. The household farm return with project is absolutely greater than the without project situation, rising from SDG 3,210 to SDG 4,422, a 38% increase, even though farm size has halved. The situation for the tail enders improves dramatically, household farm income is projected to increase from about SDG 400 per annum now to SDG 4,457 with project.

6.4 Incremental Benefit Analysis

6.4.1 Without Project Production and Benefits

The future without project value of production is based on the present situation, the scheme area of 260,000 net feddan, of which 212,180 gross feddans on 197,133 net feddans are cultivated by tenant farmers with a peak delivery of 4 MCM per day. In Year 1 of the project, 2010/11 the tenant farm area will decrease to 90,000 feddan, and farmers are expected to cultivate only 68,240 net feddan. Of the remainder, 130,000 feddan will be under the control of KSC, and the company will cultivate sorghum on behalf of tenant farmers on a further 40,000 feddan.

This analysis is not concerned with the details of KSC's activities on 130,000 feddan. It is assumed that they will irrigate using the full peak design allowance of 33m^3 per feddan on this area, and the 40,000 feddan they are operating on behalf of tenant farmers (sorghum production) will also get the peak allocation. The irrigation system will be rehabilitated (with Islamic Bank and OPEC funding), so the system peak delivery will be 6.57 MCM per day. Tenant farmers will get the water that KSC do not use, which is expected to be a peak delivery of 20.29 m^3/feddan/day. Please see Table 6-1. Because their allocation is the same as the present, it is assumed the tenants can irrigate an area *pro rata* on the present cultivated area and available land, and cultivate 68,240 feddan. It is assumed their cropping pattern will be more or less the same as at present.

Without the project as proposed by this study, it is estimated that the irrigation system will return to a maximum delivery of 4 MCM per day in five years. Table 6-1 shows that the likely result: KSC continues to irrigate 170,000 feddan at full design capacity, plus a much smaller area of sorghum, 4,200 feddans for tenant farmers. That exhausts irrigation supply, and tenants will probably return to rainfed farming on their remaining tenancy, if they still have land rights. They may also become casual workers for KSC.

The future annual scheme land use on the tenant farm area without project is shown in Table 6-8. It is straightforward to multiply areas by the without project gross margins shown in Table 6-2, Table 6-3 and Table 6-4 to calculate a without project benefit stream.

It is important to bear in mind the without project scenario when considering the results of the cost benefit analysis. The project is not dependent on achieving dramatic yield increases over and above the present situation, its foundation rests on avoiding 130,000 feddan going out of productive irrigation.

6.4.2 With Project Production and Benefits

The calculation of the future with project value of production assumes that the engineering measures proposed will ensure that the post-rehabilitation maximum delivery of 6.54 MCM is sustained over at least 10 years. The division of land between KSC and tenant farmers stands as 130,000 feddans each. However, the productivity of tenant farms will increase such that they no longer wish to contract KSC to grow food crops. Within 10 years this operation will cease. As in the without project situation, water is allocated under the assumption that KSC irrigates to the peak delivery of 33 m^3 per day. Tenant farmers will use all the residual, 20.88 m^3/day, which is similar to their present allocation. But the change in cropping pattern and reduction in farm size results in the cultivation by tenant farmers of only 129,720 net feddan compared to their present 197,140 net feddan. This means that the irrigation allocation per unit area increases from 1,640 m^3 per feddan now (347 MCM/ 212,177 gross feddan), to 2,870 m^3 per feddan in the future with project (373 MCM/129,720 gross feddan). Improvements in productivity will be gained from this, as shown in the with project gross margins. The gross margins per unit area and enterprise are used to calculate a with project benefit stream.

Table 6-8 Estimate of Without Project Tenant Farm Land Use, Feddan

		Head and Middle									Tail								
Calendar Year	Project Year	Sorghum grown by tenants	Sorghum grown by Kenana	Maize	Groundnuts	Sunflower	Cotton	Other crops	Dairy cows	Beef cattle	Sorghum grown by tenants	Sorghum grown by Kenana	Maize	Groundnuts	Sunflower	Cotton	Other crops	Dairy cows	Beef cattle
2009/10	Present	73,715		0	46,391	16,298	1,517	9,774	21,203	13,616	33,451		0	26,647	1,361	378	2,646	9,723	6,244
2010/11	Year 1	25,517	26,800	0	16,058	5,642	525	3,383	21,203	13,616	11,579	13,200	0	9,224	471	131	916	9,723	6,244
2011/12	Year 2	20,413	22,004	0	12,847	4,513	420	2,707			9,263	10,838	0	7,379	377	105	733	9,723	6,244
2012/13	Year 3	15,310	17,209	0	9,635	3,385	315	2,030			6,947	8,476	0	5,534	283	79	550	9,723	6,244
2013/14	Year 4	10,207	12,413	0	6,423	2,257	210	1,353			4,632	6,114	0	3,690	188	52	366	9,723	6,244
2014/15	Year 5	5,103	7,618	0	3,212	1,128	105	677			2,316	3,752	0	1,845	94	26	183	9,723	6,244
2015/16	Year 6	0	2,822	0	0	0	0	0	21,203	13,616	0	1,390	0	0	0	0	0	9,723	6,244
2016/17	Year 7	0	2,822	0	0	0	0	0	21,203	13,616	0	1,390	0	0	0	0	0	9,723	6,244
2017/18	Year 8	0	2,822	0	0	0	0	0	21,203	13,616	0	1,390	0	0	0	0	0	9,723	6,244
2018/19	Year 9	0	2,822	0	0	0	0	0	21,203	13,616	0	1,390	0	0	0	0	0	9,723	6,244

Table 6-9 Estimate of With Project Tenant Farm Land Use, Feddan

		Head and Middle									Tail								
Calendar Year	Project Year	Sorghum grown by tenants	Sorghum grown by Kenana	Maize	Groundnuts	Sunflower	Cotton	Other crops	Dairy cows	Beef cattle	Sorghum grown by tenants	Sorghum grown by Kenana	Maize	Groundnuts	Sunflower	Cotton	Other crops	Dairy cows	Beef cattle
2009/10	Present	73,715	0	0	46,391	16,298	1,517	9,774	21,203	13,616	33,451	0	0	26,647	1,361	378	2,646	9,723	6,244
2010/11	Year 1	25,517	26,800	0	16,058	5,642	525	3,383	21,203	13,616	11,579	13,200	0	9,224	471	131	916	9,723	6,244
2011/12	Year 2	24,840	23,450	2,366	16,417	7,436	459	4,091	21,203	13,616	11,369	11,550	1,154	9,225	1,650	114	1,358	9,723	6,679
2012/13	Year 3	24,163	20,100	4,732	16,776	9,231	394	4,799	21,203	13,616	11,159	9,900	2,308	9,226	2,828	98	1,801	9,723	7,114
2013/14	Year 4	23,485	16,750	7,098	17,134	11,026	328	5,506	21,203	13,616	10,949	8,250	3,462	9,227	4,007	82	2,243	9,723	7,549
2014/15	Year 5	22,808	13,400	9,464	17,493	12,821	263	6,214	21,203	13,616	10,740	6,600	4,616	9,228	5,186	65	2,685	9,723	7,984
2015/16	Year 6	22,131	10,050	11,830	17,852	14,616	197	6,922	21,203	13,616	10,530	4,950	5,770	9,229	6,364	49	3,128	9,723	8,418
2016/17	Year 7	21,454	6,700	14,196	18,211	16,410	131	7,630	21,203	13,616	10,320	3,300	6,924	9,230	7,543	33	3,570	9,723	8,853
2017/18	Year 8	20,777	3,350	16,562	18,569	18,205	66	8,337	21,203	13,616	10,110	1,650	8,078	9,231	8,721	16	4,013	9,723	9,288
2018/19	Year 9	20,100	0	18,928	18,928	20,000	0	9,045	21,203	13,616	9,900		9,232	9,232	9,900	0	4,455	9,723	9,723

6.5 Engineering Costs

The civil works are calculated to US$ 66.34 million in current 2010 prices, as shown in Table 5-13Table 5-2 composed of:

Meina Pump Station US$ 2.79 m

Dinder Aqueduct US$ 4.92 m

Settling Pond US$ 23.64 m

Canal Automation US$ 12.90 m

On farm improvements US$ 17.20 m

Drainage US$ 4.89 m

Note that the full costs of the pump station, aqueduct and settling pond have been attributed to the proposed project, which is directed to RIS tenant farmers. This means that farmers bear the full investment cost of these items. This is justified because the costs are fixed costs (they do not vary with the scheme irrigated area) and are therefore indivisible, and it is assumed they would not need to be carried out in the without project scenario, because KSC would be able to access their design water allocation without this investment.

Construction has been assumed to be phased over two years for the Meina Pump Station, three years for the Dinder Aqueduct and Settling Pond and five years for canal automation and on-farm improvements.

Sustainable MOM was estimated to be SDG 17.60 million per annum for RIS of 260,000 feddan. In 2009 the Administration and Water charge raised SDG 10 million. The proportion of MOM costs attributed to tenant farmers and KSC was calculated proportionally to the use of water. In Year 1, the volume used by tenants will be a peak delivery of 1.38 MCM per day on their own tenancy plus 1.32 MCM per day peak delivery on land irrigated by KSC on their behalf. It is assumed they will pay for the production costs on this land in some way. This will amount to about 41% of the water delivered to the main canal. In Year 10, adoption of the recommended with project cropping pattern with the assumed allocation of a peak delivery of 2.71 MCM per day implies the use of about 33% of the water delivered to the main canal.

Without project, tenants will be ceasing to irrigate their own farms in about Year 5, but they will still be paying for irrigation on the (by then) small sorghum growing operation that Kanana carries out on their behalf. The water required for this operation is expected to be no more than 3% of water delivered to the main canal.

Pumping costs have been attributed in a similar way. The cost of pumping was determined to be SDG 0.0084 per m^3. The volume pumped in 2009 was 1,021 MCM and irrigated 197,140 net feddan of tenant farmers. The volume pumped in 2010, after rehabilitation, is expected to be 1,347 MCM. KSC will require 740 MCM to irrigate their land allocation at full design capacity. They will require a *pro rata* amount to irrigate a further 40,000 feddan on behalf of tenants, 253 MCM. The balance, 353 MCM will be used by tenants to irrigate 68,240 net feddan. In the future without project, the volume pumped will be reduced to 767 MCM, all of which will be used by KSC on 130,000 feddan and a small area of food grain crops for tenants. With project, the volume pumped will be 1,113 MCM, sufficient for 740 MCM for KSC to irrigate 130,000 feddan at full design capacity, and 373 MCM for tenant farmers, which is sufficient to irrigate 129,720 feddan using the tenant farm with project cropping pattern. The projected use is sufficient to calculate pumping costs and allocate them between users.

6.6 Costs of Project Support

The adoption of the with project cropping pattern depends on the adoption of improved agricultural practices and stronger water management by farmers. To promote these, the following initiatives have been designed:

- community mobilisation (cost estimated at SDG 870,000 pa), scheduled for five years starting in Year 1 of the project and described in detail in the Main Report and Annex material
- agricultural extension support (cost estimated at SDG 82 per scheme feddan over 10 years) scheduled for ten years starting in Year 1 of the project and described in detail in the Main Report and Annex material
- credit for planting material, land preparation, fertiliser and pesticide, with an average management cost of SDG 4 million per anum.

The details of these initiatives are described in section 3.

6.7 The Water Charge

The fixing of a charge for water is the pivot between costs and benefits on which the project hinges. It must be fixed so that it allows sustainable MOM, and be affordable to irrigators. The water charge was calculated as follows:

- The gross cropped area of each irrigated crop without and with project was calculated (see Table 6-8 and Table 6-9)
- The present application was estimated from Household Survey recall data and the future required application was calculated with CROPWAT8 using 82% efficiency (calculations described in Main Report and supporting Annex material)
- The water requirement by crop was calculated from the future with project application and the gross cropped area
- The sustainable MOM cost per m^3 for RIS was obtained by dividing the total volume of water required with project (1,112.7 MCM) by pumping costs with project (SDG 9.34 million) plus the estimated with project maintenance budget (SDG 17.60 million). The calculations are described in Main Report and supporting Annex material.
- A cost per irrigation was calculated assuming $462m^3$ per application and the number of irrigations required per crop was calculated using CROPWAT8. The annual charge per irrigated crop feddan was then easily calculated, SDG 11.18.

The resulting division of land, water and payments for water at full project development are shown in Table 6-10. The water charge by crop was inserted into crop gross margins as a variable cost, shown in Table 6-6.

Table 6-10 Land and Water Use and Water Charge With Project

	Units	Tenants	Kanana	Total
Total use of water	MCM	380.62	780.78	1,161.40
Payment for water	SDG m	9.21	18.90	28.12
Share of irrigated land	gross feddan	131,300	260,000	391,300
Share of command area	net feddan	130,000	130,000	260,000

6.8 Cost Benefit Analysis

6.8.1 Financial Analysis

The CBA in 2010 financial SDG is given in Table 6-13 (cost stream) and Table 6-14 (benefit stream). The results for both the financial and economic analysis are summarised in Table 6-11.

Table 6-11 RIS Project Indicators

	Financial	Economic	Units
Internal Rate of Return	20.6%	12.0%	
Net Present Value	191.69	30.76	SDG million
NPV Benefit Stream	409.85	234.83	SDG million
NPV Cost Stream	251.58	235.42	SDG million
Benefit : Cost Ratio	1.63	1.00	

The FIRR is satisfactory at nearly 21%, with an NPV at 10% discount rate over 30 years of SDG 192 million. The BCR is 1.63. MOM is only just affordable by project farmers (13.5% of household farm income, see Table 6-7) but there is considerable latitude for increasing yields over the life of the project. Incremental inputs required are certainly affordable; these will be provided through a credit programme described in section 6.6).

The satisfactory FIRR is obtained not from dramatic improvements in present production, but by avoiding the scenario where declining water supply and even more rapidly declining share of water supply forces tenants out of the farming business. The sustainability of tenant farmer production in RIS is expected to be achieved by the engineering initiatives proposed by this study, which will safeguard post rehabilitation irrigation supply at about a peak delivery of about 6.57 MCM per day. Without the works proposed, peak deliveries are expected to decline rapidly to pre-rehabilitation levels of about 4 MCM/day in Year 6 of the project.

Tenant farmers are also expected to use water more efficiently, by increased water control and improved field irrigation practices. A higher cropping intensity is expected on the tenant farm which halves in size and the use of inputs will also intensify, leading to productivity and financial gains per farm and per feddan.

Note that the calculation behind Table 6-11 assumes that the full costs of Meiner Pump Station, Dinder Aqueduct and the Sedimentation Basins are loaded on tenant farmers. This is correct project economics: these are fixed costs and therefore indivisible and would not be carried out without the project on the assumption that KSC can access sufficient irrigation water for their needs using the existing infrastructure. However, it is straight- forward to proportion these costs equally between tenants and KSC to obtain a cosmetically more satisfactory set of project indicators, as shown in Table 6-12. Nevertheless, the differences are small, and congruent with the relative insensitivity of the project indicators to capital costs, as discussed in section 6.8.3.

Table 6-12 RIS Project Indicators Assuming Division of Fixed Infrastructure Costs

	Financial	Economic	Units
Internal Rate of Return	24.6%	14.3%	
Net Present Value	221.00	57.54	SDG million
NPV Benefit Stream	409.85	234.83	SDG million
NPV Cost Stream	222.27	208.64	SDG million
Benefit : Cost Ratio	1.84	1.13	

Table 6-13 CBA Rahad Irrigation Scheme Cost Stream in Financial 2010 SDG

COST BENEFIT ANALYSIS: RAHID IRRIGATION SCHEMEMODERNISATION PROJECT
Financial Prices SDG million
Cost Stream

		WITH PROJECT COSTS												WITHOUT PROJECT COSTS			
		CAPITAL COSTS									OPERATIONAL COSTS						
Calendar year	Project year	Pump station	Dinder syphon	Settlement Pond	Canal Automation	On farm improvements	Drainage	Extension Programme	Credit Support	Institute Strengthening	Pumping costs for tenants	Other MOM costs for tenants	Total with project costs	Pumping costs for tenants	Other MOM costs for tenants	Total without project costs	INCREMENTAL COST
2010	Year 1	0.65	1.14	5.50	3.00	4.00	1.14	0.77	14.88	0.99	5.09	7.25	44.40	5.09	7.25	12.34	32.06
2011	Year 2	5.84	5.15	24.74	6.00	8.00	2.28	0.50	0.00	0.89	4.90	7.10	65.40	4.12	5.59	9.71	55.69
2012	Year 3		5.15	24.74	6.00	8.00	2.28	0.97	2.83	0.90	4.70	6.95	62.51	3.14	3.93	7.07	55.44
2013	Year 4				7.50	10.00	2.84	1.01	2.29	0.89	4.50	6.80	35.84	2.17	2.27	4.44	31.40
2014	Year 5				7.50	10.00	2.84	1.15	2.35	0.90	4.31	6.66	35.71	1.20	0.61	1.81	33.90
2015	Year 6							1.41	2.42		4.11	6.51	14.45	0.22	0.61	0.84	13.61
2016	Year 7							1.15	2.49		3.91	6.36	13.91	0.22	0.61	0.84	13.07
2017	Year 8							1.20	2.55		3.72	6.21	13.68	0.22	0.61	0.84	12.85
2018	Year 9							1.26	2.62		3.52	6.06	13.46	0.22	0.61	0.84	12.62
2019	Year 10							1.31	2.69		3.32	5.91	13.24	0.22	0.61	0.84	12.40
2020	Year 11								2.76		3.13	5.77	11.65	0.22	0.61	0.84	10.81
2021	Year 12								2.82		3.13	5.77	11.72	0.22	0.61	0.84	10.88
2022	Year 13								0.00		3.13	5.77	8.89	0.22	0.61	0.84	8.06
2023	Year 14										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2024	Year 15										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2025	Year 16										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2026	Year 17										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2027	Year 18										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2028	Year 19										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2029	Year 20										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2030	Year 21										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2031	Year 22										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2032	Year 23										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2033	Year 24										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2034	Year 25										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2035	Year 26										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2036	Year 27										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2037	Year 28										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2038	Year 29										3.13	5.77	8.89	0.22	0.61	0.84	8.06
2039	Year 30										3.13	5.77	8.89	0.22	0.61	0.84	8.06
First 10	SDG	6.49	11.44	54.98	30.00	40.00	11.38	10.73	35.12	4.57	42.08	65.81	312.60				
year	US$	2.79	4.92	23.64	12.90	17.20	4.89	4.61	15.10	1.96	18.09	28.30	134.40				
										88.01							

Table 6-14 CBA Rahad Irrigation Scheme Benefit Stream in Financial 2010 SDG million

COST BENEFIT ANALYSIS: RAHID IRRIGATION SCHEMEMODERNISATION PROJECT

Financial Prices SDG million

Benefit Stream

Calendar year	Project year	Without project benefit		Benefit build up		With project benefit		INCREMENTAL BENEFIT			NET BENFIT STREAM
		Head & Middle	Tail	Head & Middle	Tail	Head & Middle	Tail	Head & Middle	Tail	Scheme	
2010	Year 1	34.36	11.09			34.36	11.09	0.00	0.00	0.00	-32.06
2011	Year 2	23.46	9.51			23.46	9.51	0.00	0.00	0.00	-55.69
2012	Year 3	17.97	7.94	25%		29.28	7.94	11.31	0.00	11.31	-44.13
2013	Year 4	12.47	6.36	25%		35.05	6.36	22.58	0.00	22.58	-8.82
2014	Year 5	6.98	4.79	25%	25%	39.66	9.78	32.68	5.00	37.68	3.78
2015	Year 6	6.89	3.21	25%	25%	43.40	12.54	36.52	9.33	45.84	32.23
2016	Year 7	6.89	3.21		25%	46.73	14.79	39.84	11.58	51.42	38.35
2017	Year 8	6.89	3.21		25%	52.37	16.67	45.48	13.46	58.94	46.09
2018	Year 9	6.89	3.21			53.50	20.04	46.61	16.83	63.44	50.82
2019	Year 10	6.89	3.21			54.63	20.80	47.74	17.59	65.33	52.92
2020	Year 11	6.89	3.21			55.76	21.55	48.87	18.34	67.21	56.40
2021	Year 12	6.89	3.21			55.76	22.31	48.87	19.10	67.96	57.08
2022	Year 13	6.89	3.21			55.76	23.06	48.87	19.85	68.72	60.66
2023	Year 14	6.89	3.21			55.76	23.82	48.87	20.61	69.47	61.42
2024	Year 15	6.89	3.21			55.76	24.57	48.87	21.36	70.23	62.17
2025	Year 16	6.89	3.21			55.76	25.33	48.87	22.12	70.98	62.92
2026	Year 17	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68
2027	Year 18	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68
2028	Year 19	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68
2029	Year 20	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68
2030	Year 21	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68
2031	Year 22	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68
2032	Year 23	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68
2033	Year 24	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68
2034	Year 25	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68
2035	Year 26	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68
2036	Year 27	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68
2037	Year 28	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68
2038	Year 29	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68
2039	Year 30	6.89	3.21			55.76	26.08	48.87	22.87	71.74	63.68

6.8.2 Economic Analysis

The economic objective of the Rahad Irrigation and Drainage Project is to maximize GDP by allocating project resources in the project area to achieve:

- import substitution through production and processing of oilseed crops; siunflower and groundnut
- food grain (sorghum) production, though Sudan has no comparative advantage in the production of this commodity
- increasing the production of non-traded agricultural and livestock products
- increasing economically "intangible" benefits of reduced land degradation (flooding and sedimentation).

Sudan has a comparative advantage in the production of oilseeds and good economic benefits are expected, reflected in the economic price conversions described below. However, the economic benefit from food grain (sorghum) production is very small to negative. Sorghum is not an appropriate crop for large scale farming on a large mechanised irrigation scheme; it must compete with much cheaper production from labour intensive rainfed production elsewhere. But increased production of non-traded agricultural goods will add to farm income and improve household food security. The increased value of environmental goods achieved by the project will be important, and will be valued by a reduction in costs of de-silting and scheme management. The method of economic analysis chosen – i.e. increasing the CIF/FOB value of traded goods by the Shadow Exchange Rate (SER) and using unadjusted prices for non-traded goods – reflects the expected benefits.

The calculation based on the OER in 2009 gives SER = SDG 2.55 to the US$, SERF = 1.09 and SCF = 0.91. There has been a dramatic change in these parameters in the last decade as IMF structural adjustment policies have been adopted. Calculations presented in the Appendix show the progressive change in the period 2006-2009.

The Standard Conversion Factor (SCF) and specific conversion factors for construction, crop inputs, main commodities and labour have been calculated based on border prices and import or export parity as appropriate. The calculations are also given in the Appendix to this Annex, and a summary of the conversion factors used are given Table 6-15.

Table 6-15 Conversion Factors Used in the Economic CBA

Commodity/input	unit	Financial SDG	Economic SDG	CF
Sorghum	per 90 kg bag	68.4	42.49	0.62
Groundnut	per 38 kg bag	34.10	31.19	0.91
Sunflower	per 38 kg bag	34.10	40.52	1.19
Cotton	per 315 lb bag	160.00	173.16	1.08
Maize	per 90 kg bag	80	46.57	0.58
Vegetables (other crops)	per 90 kg bag	61.60	61.60	1.00
Milk	litre	1.1	1.10	1.00
Meat	kg liveweight	3.775	3.78	1.00
Family labour	per day	5	4.15	0.83
Unskilled labour	per day	5	4.15	0.83
Skilled labour	per day	25	25.00	1.00
Urea	50 kg bag	62.00	51.92	0.84
Crop protection chemicals	litre bottle	60	54.83	0.91
Local seed	various	1,600	1,600	1.00
Improved seed	various	2,000	1,828	0.91
local construction materials				1.00
imported machinery and materials				0.86
unskilled labour				0.83
skilled labour				1.00
Imported vehicles				0.75
Fuel and lubricants				0.80
Electricity	kWhr	0.22	0.19	0.85

Normally, economic analysis returns more attractive project indicators than financial analysis. This is because taxes and transfer payments are removed and labour is valued at its opportunity cost so investment and production costs tend to fall, while commodity prices tend to maintain their value. In the case of RIS the economic valuation of the project is less attractive than the financial. This is because of the choice of cropping pattern that includes a large proportion of low value grains grown at very low yields. The choice is inappropriate given that RIS is a pump scheme (11 metre pumping head) with an 80 km conveyor canal, which makes irrigation comparatively expensive. Another problem is the cost of labour in northern Sudan, which is moderately high, and the opportunity cost of labour is also high as the economy grows rapidly. Unfortunately there was very little guidance available on the shadow wage rate to choose.

The results of the economic analysis are shown in Table 6-13 and Table 6-14. They are also summarised in Table 6-11 above. The EIRR is 12%, above the discount rate of 10%, and the ENPV is thus positive SDG 30.76 million. The BCR is 1. On economic grounds the project would be appropriate for selection for implementation, though the analysis should be reviewed by an economic planning department with access to accurate economic conversion factors.

Table 6-16 CBA Rahad Irrigation Scheme Cost Stream in Economic 2010 SDG million

COST BENEFIT ANALYSIS: RAHID IRRIGATION SCHEMEMODERNISATION PROJECT
Economic Prices SDG million
Cost Stream

		WITH PROJECT COSTS											WITHOUT PROJECT COSTS			INCREMENTAL COST
Calendar year	Project year	Pump station	Dinder syphon	Settlement Pond	Canal Automation	On farm improvements	Pumping costs for tenants	Other MOM costs for tenants	Extension Programme	Credit Support	WUO Training and Support	Total with project costs	Pumping costs for tenants	Other MOM costs for tenants	Total without project costs	
2010	Year 1	0.59	1.05	5.02	2.74	4.70	4.33	7.25	0.70	14.88	0.90	42.17	4.33	7.25	11.58	30.58
2011	Year 2	5.34	4.71	22.61	5.48	9.39	4.17	7.10	0.49	0.00	0.83	60.11	3.50	5.59	9.09	51.02
2012	Year 3		4.71	22.61	5.48	9.39	4.00	6.95	0.95	2.83	0.83	57.76	2.68	3.93	6.61	51.15
2013	Year 4				6.85	11.74	3.83	6.80	0.99	2.29	0.83	33.33	1.85	2.27	4.12	29.22
2014	Year 5				6.85	11.74	3.66	6.66	1.11	2.35	0.83	33.21	1.02	0.61	1.63	31.58
2015	Year 6				0.00	0.00	3.50	6.51	1.36	2.42		13.79	0.19	0.61	0.80	12.98
2016	Year 7						3.33	6.36	1.13	2.49		13.30	0.19	0.61	0.80	12.50
2017	Year 8						3.16	6.21	1.18	2.55		13.11	0.19	0.61	0.80	12.31
2018	Year 9						3.00	6.06	1.24	2.62		12.91	0.19	0.61	0.80	12.11
2019	Year 10						2.83	5.91	1.29	2.69		12.72	0.19	0.61	0.80	11.92
2020	Year 11						2.66	5.77		2.76		11.18	0.19	0.61	0.80	10.38
2021	Year 12						2.66	5.77		2.82		11.25	0.19	0.61	0.80	10.45
2022	Year 13						2.66	5.77		0.00		8.43	0.19	0.61	0.80	7.63
2023	Year 14						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2024	Year 15						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2025	Year 16						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2026	Year 17						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2027	Year 18						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2028	Year 19						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2029	Year 20						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2030	Year 21						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2031	Year 22						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2032	Year 23						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2033	Year 24						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2034	Year 25						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2035	Year 26						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2036	Year 27						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2037	Year 28						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2038	Year 29						2.66	5.77				8.43	0.19	0.61	0.80	7.63
2039	Year 30						2.66	5.77				8.43	0.19	0.61	0.80	7.63

Table 6-17 CBA Rahad Irrigation Scheme Benefit Stream in Economic 2010 SDG million

COST BENEFIT ANALYSIS: RAHID IRRIGATION SCHEMEMODERNISATION PROJECT
Economic Prices SDG million
Benefit Stream

Calendar year	Project year	Without project benefit		Benefit build up		With project benefit		INCREMENTAL BENEFIT			NET BENFIT STREAM
		Head & Middle	Tail	Head & Middle	Tail	Head & Middle	Tail	Head & Middle	Tail	Scheme	
2010	Year 1	16.12	2.96			16.12	2.96	0.00	0.00	0.00	-30.58
2011	Year 2	11.15	2.62			11.15	2.62	0.00	0.00	0.00	-51.02
2012	Year 3	8.48	2.29	25%		13.81	2.29	5.34	0.00	5.34	-45.81
2013	Year 4	5.81	1.95	25%		17.48	1.95	11.67	0.00	11.67	-17.55
2014	Year 5	3.14	1.62	25%	25%	20.56	3.76	17.42	2.14	19.56	-12.02
2015	Year 6	2.78	1.29	25%	25%	23.20	5.33	20.42	4.05	24.47	11.48
2016	Year 7	2.78	1.29		25%	21.82	6.72	19.04	5.43	24.47	11.97
2017	Year 8	2.78	1.29		25%	28.46	7.97	25.69	6.68	32.37	20.06
2018	Year 9	2.78	1.29			29.79	9.19	27.02	7.91	34.93	22.81
2019	Year 10	2.78	1.29			31.12	10.04	28.35	8.75	37.10	25.18
2020	Year 11	2.78	1.29			32.45	10.88	29.68	9.59	39.27	28.89
2021	Year 12	2.78	1.29			32.45	11.72	29.68	10.43	40.11	29.66
2022	Year 13	2.78	1.29			32.45	12.56	29.68	11.27	40.95	33.32
2023	Year 14	2.78	1.29			32.45	13.40	29.68	12.12	41.79	34.17
2024	Year 15	2.78	1.29			32.45	14.24	29.68	12.96	42.63	35.01
2025	Year 16	2.78	1.29			32.45	15.08	29.68	13.80	43.47	35.85
2026	Year 17	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69
2027	Year 18	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69
2028	Year 19	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69
2029	Year 20	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69
2030	Year 21	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69
2031	Year 22	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69
2032	Year 23	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69
2033	Year 24	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69
2034	Year 25	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69
2035	Year 26	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69
2036	Year 27	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69
2037	Year 28	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69
2038	Year 29	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69
2039	Year 30	2.78	1.29			32.45	15.92	29.68	14.64	44.32	36.69

6.8.3 Sensitivity Analysis

Sensitivity analysis has been carried out in economic prices for the following scenarios:

- Changes in capital costs of the main cost items
- Failure to develop the full tenant command area as anticipated
- Changes in the cost of MOM
- Changes in the prices of agricultural labour, crop inputs, crop prices and crop yields.

For efficiency in presentation, sensitivities are calculated as two variable Data Tables. Examining first the relationship between total capital cost and MOM cost, it is evident that a +20% increase in MOM cost would lower EIRR to 11.4%, though the project economic return would still not be below the assumed discount rate. A similar increase in the capital costs of a similar amount would lower EIRR to 10.5%, so we may conclude that scheme economic performance is more sensitive to increases in investment costs than MOM. Clearly this is because MOM cost increases are discounted more heavily.

Table 6-18 Sensitivity of EIRR to Changes in Capital and MOM Costs

Change in MOM cost	Change in Capital Cost				
	-20%	-10%	0%	+10%	+20%
-20%	14.4%	13.4%	12.5%	11.7%	11.0%
-10%	14.1%	13.1%	12.2%	11.5%	10.8%
0%	13.8%	12.8%	12.0%	11.2%	10.5%
+10%	13.5%	12.5%	11.7%	11.0%	10.3%
+20%	13.2%	12.3%	11.4%	10.7%	10.1%

Note: the 0% change is 12%, the EIRR of the project without sensitivity changes

In respect of sensitivity to the individual cost items, the tables are not reproduced, since changes in price of none of them in isolation have a substantial impact on the economic performance. Investment costs for the settling pond do have the greatest impact however, and a +20% increase in this cost item would lower EIRR to 11.4%. Changes in estimated costs can always happen as a result of exchange rate changes or cost over-runs or delays in implementation. However, it would appear that the proposed project is reasonably resilient to such changes.

This is equally true for the important costs of extension, institutional and farm-budgetary (input supply) support. Even a +20% increase in institutional costs lowers the EIRR to 11.8% - a negligible difference from the 12% expected. Bearing in mind tenants' technical ability and institutional organisation no effort should be spared to organise and resource these aspects for maximum effectiveness.

Changes in the economics of crop production can have a serious impact on the EIRR, particularly since the cropping pattern is not very diversified and there is a large proportion of low value crops. If crop prices fell to -20% of the assumed values, then the EIRR would be reduced to below 5%. The cost of crop inputs does not have such a strong impact on economic performance, it can be seen that a +20% increase would reduce the EIRR to only 10.3%.

Table 6-19 Sensitivity of EIRR to Changes in Crop Price and Cost of Crop Inputs

Change in cost of crop inputs	Change in Crop Price				
	-20%	-10%	0%	+10%	+20%
-20%	7.1%	10.5%	13.5%	16.2%	18.7%
-10%	6.0%	9.7%	12.8%	15.5%	18.1%
0%	4.8%	8.7%	12.0%	14.8%	17.4%
+10%	3.6%	7.8%	11.1%	14.1%	16.8%
+20%	2.2%	6.7%	10.3%	13.3%	16.1%

In an economy like northern Sudan which is industrialising relatively rapidly, the cost of agricultural labour may increase relatively faster than other cost elements in agricultural budgets. Nevertheless, the Table below suggests that this is unlikely to have a dramatic impact on project performance. Many agricultural activities are mechanised, even on the tenant farmer area.

Table 6-20 Sensitivity of EIRR to Changes in Crop Price and Cost of Crop Inputs

Change in cost of agriculture labour	Change in Crop Price				
	-20%	-10%	0%	+10%	+20%
-20%	5.9%	9.6%	12.7%	15.5%	18.1%
-10%	5.4%	9.2%	12.3%	15.2%	17.7%
0%	4.8%	8.7%	12.0%	14.8%	17.4%
+10%	4.3%	8.3%	11.2%	14.5%	17.1%
+20%	3.7%	7.8%	11.2%	14.1%	16.8%

MOM costs are entirely attributed to farmers, on the assumption of full cost recovery. A small increase in MOM (required for example if not all tenants participate in the proposed project) combined with a small change in crop price would have a strong negative impact on economic performance, reducing EIRR to about 8%. The impact would be even greater in financial terms at farm level.

Table 6-21 Sensitivity of EIRR to Changes in Crop Price and MOM

Change in cost of MOM	Change in Crop Price				
	-20%	-10%	0%	+10%	+20%
-20%	5.5%	9.3%	12.5%	15.3%	17.9%
-10%	5.2%	9.0%	12.2%	15.1%	17.7%
0%	4.8%	8.7%	12.0%	14.8%	17.4%
+10%	4.5%	8.5%	11.7%	14.6%	17.2%
+20%	4.2%	8.2%	11.4%	14.3%	16.9%

Assumptions on crop yield increments have been modest, and substantially below the technically possible. RIS is difficult agronomically, requiring particularly timeliness and attention to the application of irrigation and crop chemicals. So far (and after 30 years) there is little evidence that the majority of tenants have developed the necessary skills to achieve technically high levels, or will do so in the next few years despite the extension packages budgeted in project costs. The sensitivity analysis below suggests that failure to meet modest yields could be disastrous, while substantial benefits accrue to improvements. It would be good to be sure of the impact of the extension component, but so much is dependent on the availability of a large well qualified, well-resourced and motivated extension service for RIS. A large budget allocated in the project costs by no means guarantees that such a service will materialise.

Table 6-22 Sensitivity of EIRR to Changes in Crop Price and Crop Yield

Change in crop yield	Change in Crop Price				
	-20%	-10%	0%	+10%	+20%
-20%	-7.1%	0.5%	4.7%	7.9%	10.6%
-10%	0.6%	5.2%	8.7%	11.6%	14.2%
0%	4.8%	8.7%	12.0%	14.8%	17.4%
+10%	8.1%	11.7%	14.9%	17.7%	20.4%
+20%	10.8%	14.4%	17.5%	20.4%	23.1%

Similarly, if the tenant farmer area is not achieved in full, the economic return will be prejudiced; the Table shows that even if crop price is maintained if the with project tenant farmer area achieved is only -20% of that assumed then the EIRR falls to less than 5%. The proposed project economic performance is therefore very sensitive to this parameter.

Table 6-23 Sensitivity of EIRR to Changes in Crop Price and Tenant Farmer Irrigated Area

Change in area developed	Change in Crop Price				
	-20%	-10%	0%	+10%	+20%
-20%	2.8%	3.9%	4.8%	5.7%	6.4%
-10%	6.8%	7.8%	7.8%	9.6%	10.6%
0%	10.0%	11.0%	12.0%	12.8%	13.6%

7 SUMMARY AND CONCLUSIONS

7.1 Performance of RIS

The Study Team was commissioned to carry out two tasks in this assignment. The first was to assess the performance of RIS using a range of indicators, both formal and informal, and compare the scheme's overall performance rating with that attributed by EWUAP's LSI Study. The second task was to prepare an Action Plan for remedial works, cost it and evaluate the expected benefits, and carry out a cost benefit analysis.

In respect of performance, RIS is a poor performer. While the LSI Study rated RIS as the second best performer in Sudan, this team's conclusions are that it is beset with difficulties.

In respect of water and engineering indicators (see section 3.1):

- Adequacy (the satisfaction of crop demand) was rated poor (0.72), with a high variance
- Dependability (temporal variability and planning reliability) was rated poor ().82) with a moderate variance
- Equity (spatial distribution) was rated consistently poor over the analysis period (0.7)

In respect of agronomic indicators (see section 3.2):

- In Actual EC (CWC) is about 5,800 m^3 per ha overall and the Crop Water Deficit is about 440 m^3 per ha using very crude calculations based on the HHS. These compute to indicators of 3.1 and 3.0 respectively, which compare favourably with the LSI study.
- .Comparing all the performance indicators from the LSI study with the pilot study, found that 4 indicators were agreeable, while 4 were not agreeable. Two indicators were not evaluated.

In respect of institutional indicators (see section 3,3):

- Government institutions: due to budget constraints and the dependency attitude of the farmers, functionality of the scheme deteriorated in the last 5 years; overall functionality of institutions is rated poor (4).
- Farmers Institutions: overall, performance of farmers' institutions in Rahad on MOM, O&M, and others is poor (4)
- Extension services: performance assessment is poor (4).

In respect of environmental and economic indicators (see section 3.4):

- the yield of main crop per scheme hectare (30 year average) was 1,005 kg/ha which is very low
- The Relative Water Cost indicator over the last years has increased to about 0.30: payment for water is the principle cost in tenant farmers' gross margins
- The O&M fraction is calculated as 0.53: this is a very poor value, and accounted for by RAC overhead salaries and administration
- The MOM funding indicator is the cost of MOM to the farmer as a ratio of net farm income: it has been calculated as 0.27 which is very high
- The scheme level Crop Area Ratio shows steady growth to about 0.8 in 1981, and improved to nearly 0.9 in the mid 1990s. Since 1995 the trend has been steadily downwards with marked dips in 1998 and 2003 which were flood years and caused widespread crop losses; now the CAR is about 0.6 which is very low
- Dependability is poor: a reduction in main delivery in August and September (due for example to late Rahad River flow or problems at Meina Pump Station) can reduce the planted to harvested area ratio

significantly: and lead to financial losses of about SDG 0.015 per m^3 in crop inputs and unrealised yield

- The scheme first made a positive FIRR in 1993 and achieved quite good financial progress until 1996, when the net value of crop production declined until 1999. Since then slow but consistent increases in scheme return have been made and by 2007 the FIRR of the scheme was 2.7%. This is a very low return on the investment cost of US$ 400 million and does not include deferred maintenance, which is being made good by the on-going rehabilitation programme.

7.2 The RIS Action Plan

7.2.1 Hydraulic Engineering

RIS was reached an all time low in its performance. An action plan has been prepared to reverse its fortunes, acknowledging the fact that Kanana Sugar Company has already taken over management of 50% of the command area, and is undertaking cultivation on behalf of tenants on a further 40,000 feddan. Further, rehabilitation funded by Islamic Bank and OPEC is in progress and will only begin to impact on production in the 2010/11 cropping season. The Study Team consider both of these activities part of the present situation. The "future with project" must analyse the impact of recommendations made by this study, assuming that with or without the recommendations made by this Study, Kanana Sugar will have water allocation to irrigate to maximum irrigation design on their share of the command area. However, without the recommendations made in this study, the Study Team envisages that the rehabilitation works presently being carried out will be effective for only five years, in which case the water share of tenant farmers will be eroded to nothing. These observations provide the justification for analysing the costs and benefits identified by this study exclusively on the operational area of tenant farmers: 130,000 feddan. However, it is acknowledged that Kenana Sugar may benefit from reductions in operational costs (in particular a reduction in the need for de-silting) as a result of the civil works proposed for the feeder and main canals.

The Study Team propose the following Action Plan. Starting at the top (South) of the project, at Maina Pump station the following action is planned:

The Meina Pump station has inadequate protection from siltation. The solution to this problem is to move the pump station to the river and reduce the deposition during flood flows. As this cannot happen, the river can be moved to the pump station, by opening the banks and allowing the river to flow directly past the pump intake, cleaning as it passes. A section of the Nile bank for 400 m upstream and 400 m downstream could be removed and a zone of gabion protection can be incorporated for 100 m either side. Once the protection is complete, the river could be opened using the cheapest form of soil removal, the dredger, allowing the river to clean away any deposited sediment. Pumping could then continue un-interrupted for year to come.

The Dinder siphon has proved to be a major bottle neck in the operation of the supply canal. The main reason for this is the operation of the pumps during the high sediment flows (July to September) which deposit large quantities of sediment in the canal. Poor operation of the siphon by opening too many barrels reduces the velocity and leads to deposition. For the siphon to be self cleaning (non-depositing) the velocity needs to maintained at a high level of about 3.0 m/s. The study looked at the possibility of turning the siphon into an aqueduct. The existing roof to the siphon barrels would be demolished at the entrance and exit of the siphon and a new floor cast for the aqueduct. There is sufficient capacity below the proposed aqueduct to pass the maximum Dinder flood. The structure will be built directly on top of the existing siphon, using the buried barrel as a foundation.

Sediment transport into RIS needs to be reduced from its current estimated level of 500,000 m^3 per year. Sediment concentrations in the Rahad River were plotted against river flows, canal flows and pumped flows and show that when the concentration is multiplied by the Rahad River flows there is a peak rate of sediment transport in July, which drops off sharply in August and September. These three months represent the greatest movement of sediment, and it is during these times that maximum effort is needed to reduce its importation. This study proposes to construct a large settling basin right beside the head works at Abu Rakham where some old low lying ox-bow depressions are found. A survey was made of these depressions which are very suitable for constructing this settling pond. The main method of settlement would be slow moving water. The design flow would be appropriate for the water requirements at that time of year when sediment is highest, in July. The effectiveness of the settlement will change from year to year as different concentrations are found, but this system can be improved by adding inclined tube clarifiers to increase deposition. The settlement ponds would only operate for three months of the year, July, August and September. The following three months would be used to clean the ponds using a floating dredger.

Canal automation should be introduced. Since the construction of the Gezira Scheme, Sudan has utilised centralised control of its irrigation using indenting or 'fixed-rate arranged scheduling. This all breaks down when there is little supply of water to control, and the main problem remains as zero flexibility. For this reason, the study recommends the installation of downstream control systems to change over from upstream central control to downstream user control. By this on-demand system, the farmer has complete control over time and amount of irrigation. Combined with this change should be a method of water charge based on water use, not on area irrigated. This will discourage wastage and allow the farmer much more freedom to irrigate at times suitable to his needs. Different crops can also be irrigated giving more freedom for farmers to grow crops with higher returns. With the strengthening of the WUA, farmers should be more inclined to police other water users who are wasting water. Central to this premise is that farmers have to be re-educated from "trained to wait" to "trained to take the initiative". The proposed structure for this downstream control is the Automatic Diaphragm Valve (ADV). The only place where the farmer controls his application is at the head of each abu-xx or d/abu-xx. By using 'Hydroflume' type delivery system, the only gate that needs to be controlled is the one in the 'Hydroflume' at the head of the level furrow. Thereafter all canal flows are automatic. With a proposed furrow irrigation set of 11.0 hours, the farmer can irrigate at night or day, and have a long time free to do other tasks.

On-farm irrigation improvements are essential. In Rahad, there is definitely a need for land smoothing. Most fields in RIS have underdone re-shaping due to the sediment importation and cultivation practises that have existed over the last 30 years. Fields have ended up as dish-shaped with high spots either side of the Abu-XX leading to local flooding. As well as land smoothing field drains must be constructed to improve irrigation efficiency and productivity. Kanana Sugar Company are expected to introduce some innovative approaches to on-farm irrigation but the Kanana Estate is very steep (up to 300 cm/km) relative to RIS at 20 to 40 cm/km. This makes the Kanana long furrow approach difficult to implement. The study put attention on the in-field efficiency of the furrow irrigation with the intention of identifying the most efficient system of irrigation these very flat soils. Two furrow design equations were evaluated in different conditions of slope and furrow length to determine and compare efficiencies. The results show that the very flat slopes give very poor irrigation efficiencies. Furrow irrigation on these flat slopes is going to be inefficient, no matter what length. With the very poor furrow efficiencies experienced at Rahad, the attraction of mechanical irrigation becomes large. With efficiencies of 90 to 95%, and high uniformity, drip and centre pivot irrigation are definitely worth consideration. Both centre pivot and linear move irrigation are already widely used in Sudan with good back up services. This study does not however consider the inclusion of these systems for small tenants at this time. The 'Hydroflume', (a plastic lay-flat pipe with screw gates for controlling flows) eliminates the use of siphons which are labour intensive and disliked by Rahad tenants. This study therefore recommends the adoption of combining at least two numbers into one new number and cleaning out one abu-xx. This would have to be combined with land smoothing of all abu-xx to remove all evidence of the dish-shaped fields and the construction of field drains. Minor drains need to be deepened by at least 1.0 m for at least half their length. New culverts will have to be installed at the exit to the collector drain. There is also other permanent loss of land from annual flooding. Deepening of the minor drains will require that all collector and main drains should also be deepened. This will benefit the whole project which sees annual local flooding in most of the fields.

7.2.2 Agriculture

All farmers interviewed during the FDGs showed high awareness about importance of water for high yields. Despite that, most of them, they do not actually apply this in their daily farming practice. The reasons for this are partly economic – the reliability of water supply and its cost being not least. The performance indicators show that RIS is in a down-spiral of performance, with poor technical performance and high costs - high O$M costs mostly due to silting of drains and canals and very high management costs as a legacy of RAD. Costs are high in relation to household incomes and tail enders go out of irrigation, the irrigated area contracts, overhead costs rise per unit area and more farmers go out of business.

Therefore an intensive training of farmers will be suggested to take place regarding the necessity to improve productivity. This will be done on two fronts. One will be concerned with new approaches to in-field irrigation; the second will be to train the farmers "not to wait". Farmers will be advised on a new approach to production – higher input, higher yield and higher gross margins. More self help will be encouraged through the promotion of local water user organisations. Credit for incremental crop inputs will be made accessible.

The impact of this extension effort – and the proposed hydraulic engineering interventions - will be seen through farmers' consumption of water and the means of paying for it. RIS farmers find it difficult particularly difficult to meet this cost because of low productivity, which is several times lower than the productivity of irrigated crops should be. However, without the inclusion of a water charge that meets the sustainability of the project, the project should be closed down. It is this very aspect of lowering the water charge that starts the downward cycle of poverty because it goes hand in hand with the provision of water. If the administration cannot meet the needs of maintenance, as in the past, then there is a rapid spiral to un-sustainability. So what comes first, adequate maintenance paid by an outside source, or adequate production with sufficient income to pay the high water charge and support the level of maintenance required? In fact, both must be maintained at a high level from the start. Also the method of determining the charge should be changed to one if not by volumetric basis, at least one per irrigation basis. This is an essential component of changing the farmer's view of water. He must pay for what he uses, not by area. Payment by area leads to wastage on a large scale as there is no incentive for farmers at the head to use water efficiently. Only when farmers pay by usage will they respect water and its conservation. The proposed water charge is calculated by dividing the total annual maintenance budget by the total volume of water delivered, which equates to 0.0242 SDG/m^3. Using the standard daily rate of 33m3/fd/day and a 14 day cycle, each irrigation would deliver 462 m3, or an irrigation charge of SDG 11.18 /irrigation/feddan.

7.2.3 Institutional Strengthening

It is recommended to organize a WUO in the Rahad Scheme that will be under the umbrella of the FU but with a semi-autonomous status. The WUO will have its own Executive Committee parallel to that of the FU who will be mainly responsible for overseeing and monitoring irrigation water management, and operation and maintenance at the main system level in close coordination with the KIASCo Rahad Directorate ad Kenana Corporation management. Under the WUO Executive Committee will be the Block Committees who will be mainly responsible for overseeing and monitoring irrigation water management, operation and maintenance and water charge/fee collection covering the major canal system and then below will be the Sub-Block Committees mainly responsible for the MOM and O&M of each minor/sub-minor canal. Below the Sub- Block Committees will be the Farmers' Groups (existing now as Financing Groups) who will take care of the tertiary facilities and field channels. There is a very positive indication for expanding the existing FGs and integrating these into the Water Users Organization. The existing FGs can be expanded to represent one tertiary unit.

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The detailed action plans proposed in the study should be discussed and implemented through the medium of "water users' schools" (WUS). The concept of a water users' school is not a new one, it was adapted from the farmers' field school approach (FAO, 2001) and was implemented in Rahad Scheme sometime in early 1990. The fundamental approach is one of learning by doing aimed at developing skills amongst the farmers and other key stakeholders (staff from concerned agencies/ institutions), through an effective programme of transfer of knowledge, using adult learning techniques. It can be an effective tool in building a commitment on the part of the WUO to participate in irrigation management, in understanding the issues and ways to solve problems, and in ensuring that *the process of institutional development is embedded in the community rather than being externally driven*.

7.2.4 Financial Strengthening

A complete change from the use of held over seed to improved seed will be required. The quantity of fertiliser used is expected to double and therefore the application rate will increase nearly five times, because farm size has halved. The use of crop protection chemicals is virtually zero at present, and will have to be introduced. The quality of land preparation will have to improve, though the availability of existing equipment is expected to increase substantially, as the present private fleets at village level will serve only half the tenant farm area. This will improve timeliness, but the quality of land preparation will need upgrading.

It is recommended that capital to finance the revolving fund is raised through the profit share on tenants' land envisaged in the agreement between Kanana Sugar Company and GOS. The arrangement will be that profits after all expenses are paid will be shared between the Company and the tenant, with 50% to the Company, 40% to the tenant and 10% to be paid into a fund for RIS social services. Assuming that Kenana Sugar achieve crop gross margins per feddan for groundnuts, maize and sunflower at least as good as estimated for tenant farmers with project at full development, then the tenants' share will be SDG 46 million a year, SDG 360 per feddan and an average of SDG 3,200 per household. In other words, the payment is equivalent to a doubling of the average tenant's farm income.

The Study Team does not agree with the concept of profit share between Company and tenant. One economic argument is that an additional source of income raises the opportunity cost of the tenant farmer's time, encouraging him to reduce the effort on his own farm rather than increase it. This being so, we recommend that a portion of the tenants' "share" is allocated to establishing and servicing a revolving fund for input supply on credit. After the initial payment for working capital of SDG 15 million, management costs of the fund are only about 6% of the expected share to be paid by Kenana Sugar Company to tenants. This is a small price to pay for timely, pre-funded inputs and would be a substantial benefit to the RIS community as a whole.

7.3 Cost Benefit Analysis

The FIRR is satisfactory at 20.6%, with an NPV at 10% discount rate over 30 years of SDG 191.69 million. The BCR is a 1.63. MOM is only just affordable by project farmers but there is considerable latitude for increasing yields over those estimated in this study. The satisfactory FIRR is obtained not from dramatic improvements in present production, but by avoiding the scenario where declining water supply and even more rapidly declining share of water supply forces tenants out of the farming business. The sustainability of tenant farmer production in RIS is expected to be achieved by the engineering initiatives proposed by this study, which will safeguard post rehabilitation irrigation supply at about a peak delivery of about 6.57 MCM per day. Without the works proposed, peak deliveries are expected to decline rapidly to pre-rehabilitation levels of about 4 MCM/day in Year 6 of the project. With project, tenant farmers are also expected to use water more efficiently, by increased water control and improved field irrigation practices. A higher cropping intensity is expected on the tenant farm which halves in size and the use of inputs will also intensify, leading to productivity and financial gains per farm and per feddan.

Sudan has a comparative advantage in the production of oilseeds and good economic benefits are expected. However, the economic benefit from food grain (sorghum) production is very small to negative. Sorghum is not an appropriate crop for large scale farming on a large mechanised pump irrigation scheme; it must compete with much cheaper production from labour intensive rainfed production elsewhere. In particular at the present levels of yield, and even future with project yields are hardly predicted to be high. For this reason the economic valuation of the project is less attractive than the financial. The EIRR is 12%, but above the discount rate of 10%, so the ENPV is positive SDG 30.75 million. The BCR is 1. On economic grounds the project is therefore appropriate for selection for implementation