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Drainage System in Irrigated Sector Key for Better Water Management Gezira Scheme—Sudan

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Abstract: The agriculture remains a key sector and the pillar of Sudan life, is representing the main driving force for its economy and as an income generating sector for more than 50% of households. The sector accounts for about 31% of GDP (Central Bank of Sudan CBOS-Report, 2015); the irrigated subsector as part of agricultural sector is the core for production of cash crops (cotton and sugar cane…) and cereals. In mega irrigation schemes such as GIS (Gezira Irrigation Scheme), the forerunner of all major schemes in Sudan with an area of about 0.882 million ha, the drainage (surface) system plays significant role as well as irrigation system. Water logging and hence the significant reduction in crop production, coupled with the negative environmental impacts stand as strong obstacles against harnessing the available water resources for better livelihoods. This paper is a contribution to Sudan government effort towards upgrading GIS. The drainage system within the scheme didn't receive enough attention and had witnessed severe deterioration due to several reasons taken place during the life of the scheme, which accelerate the spread of silt and weeds in the network system of the scheme. The paper discusses and attempts to diagnose, analyze the performance of the GIS drainage system through identifying its arrangement, design, capacities, and adequacy to contribute in solution of water management constraints to sustainable development, and provide a set of amendments and improvements to the existing system including revision of its design criteria and how that improvement, if implemented properly, can result in better water management and enabling environment for production.

Key words: Surface drainage, water logging, design criteria, Gezira Irrigation Scheme, water management.

1. Introduction

Sudan, with an area of 1,882,000 square kilometers, and a population of about 40 million is an agricultural-based economy; that agriculture remains a key sector and the core of Sudan life, is representing the main driving force for its economy and as an income generating sector for more than 50% of households. The sector accounts for about 31% of GDP [1]. *The irrigated agriculture sub-sector* is also a key factor in agriculture, which contributes to the stability of the country agricultural production, and includes 100% production of sugar cane and more than 80% of cotton.

The GIS (Gezira Irrigation Scheme) is huge in size and dominates the entire irrigated subsector in Sudan, approximately 47% of the entire total irrigated area in Sudan [2].

The Gezira scheme was designed in the 1920s after prolonged experiments had been carried out on a prototype scale. It was designed with the main objective of producing cotton, as a single cash crop. The irrigation and drainage of the scheme *was* laid out to suit the size of tenancy and crop rotation. The flat and featureless topography was favorable to the adoption of regular gridiron layout. The basic unit is a group of four adjacent fields of 90 fed (1 feddans = 0.38 ha) each called a Number. One crop is grown on each number following the four rotation system. Each number is divided into 18 tenant fields of 5 fed (called hawasha) (Farmers do not own their lands; they are

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tenants and arrangements for endorsement of land ownership which is a very complicated problem since the 1921 Gezira Land Ordinance). The tenants fields are divided by a network of cross-bunds for irrigation by basins (now it transferred to furrow) [2] (Figs. 1 & 2 show the scheme location and the standard field layout).

The irrigation system comprises twin main canals running from head-works at Sennar dam with a design combined capacity of 354 m^3/s, and a network of irrigation and drainage canals. The main, branch, and major canals are designed as regime conveyance channels. The minor canals are designed for distributing water continuously flowing from the major canals. According to the design principle the field outlet gates serving the "numbers" are open 12 hours per day at a nominal flow of 116 1/s (5,000 m^3/12 hour). The irrigation and drainage system main features include [2]:

- 2 main canals of total length of 261 km with conveyance capacity ranging from 168 and 186 m^3/s at headwork to 10 m^3/s at the tail; 11 branch canals of total length of 651 km with conveyance capacity ranging from 25 to 120 m^3/s.
- 107 major canals of total length 1,652 km with carrying capacity ranging from 1.5 to 15 m^3/s; and 1,498 minor canals of total length of 8,119 km, a delivery capacity ranging from 0.5 to 1.5 m^3/s; 29,000 water courses called "Abu Ashreens" Abu XX of total length of 40,000 km with 116 L/s capacity; and 350,000 field channel called "Abu Sitta" (Abu VI) of total length of 100,000 km with 50 L/s capacity.
- All canals have headwork and cross-regulators (types are: sluice gates, well head regulator and pipe regulators, and Butcher weirs).
- The drainage system comprises:

- The present surface runoff drainage system consists of minor surface drains of total length of about 6,000 km and major drains totaling about 1,500 km in length
- Escape drains in the Gezira Main Canal with total escape capacity of 67 m^3/s; and protective drain of 130 km.

2. Background

Since its establishment, the GIS have experienced many changes. The SGB (Sudan Gezira Board) replaced the former managing Sudan Plantation Syndicate in 1950. Production relations have undergone several modifications. The JAS (Joint Account System) was modified in 1946, 1950, and in 1970, and was replaced by the IAS (Individual Account System) in 1980/81 up to date [3].

2.1 The Cropping System

Based on the tenancy agreement, decisions on crop choice, crop mix and crop rotation are the domain of the Gezira Board. The Agricultural Committee (a sub-committee of the Board of Directors) is the body that makes decisions on crop rotation, though with technical support including all agricultural activities. The initial crop mix in the Gezira Scheme included, besides cotton as a major crop, sorghum and lubia (dolichos lablab). These crops were grown in a three-course rotation: cotton-sorghum/lubia-fallow. The crop mix and crop rotation were subjected to various changes for technical and economic reasons in the course of time between the early 1930s and the early 2000s. Following the intensification policy in 1975/76, a unified four-course rotation was adopted all over the irrigated area. This rotation was expanded in the early 1980s to a five-course rotation to introduce fodder cultivation as a basis for the integration of livestock production into the scheme's cropping system but not adopted. All these developments lead to many changes of the cropping rotation adopted [3] (Table 1). Crop Rotation in the Gezira Scheme after 2005 Act adoption is not defined as liberization of cropping system allows farmers to cultivate freely (not obliged), and SGB is just planning and supervising.

2.2 Scheme Operation

Before the adoption of 2005 Gezira Act the operation of the scheme is centrally controlled: The management is divided between the MOI (Ministry of Irrigation) which is responsible for the irrigation network (23

Table 1 Development of planned crop rotation in the Gezira scheme.

Season	Crop rotation	Land use %	Remarks
Gezira: 1925/26-1930/31	C-S/L-F	66.30	
1931/32-1974/75	1931/32 First change crop rotation in crop rotation to combat cotton infestation, followed by many changes affected by diversification policy	33.30, 44.75, and 69.75	Eight course rotation was established
1975/76-1980/81	C-W-G/S-F	75.00	
1981/82-2005/06	C-W-G/S-F-Fo	75.00	Fo-Not adopted
Managil extension			
1975/76-1980/81	C-W-G/S-F	100.00	
1981/82-2005/06	C-W-G/S-F-Fo	75.00	Fo-Not adopted

C = cotton; F = fallow; Fo = fodder; G = groundnuts; L = lubia; S = sorghum; W = wheat.
Source: Galal [4], remarks are added to the table, and recent seasons are amended.

subdivisions) and the SGB (Sudan Gezira Board) (106 blocks), which is responsible for agricultural operation. The water orders (or indents) are passed to the MOI engineers, summed out throughout the system up to head-works at Sennar dam… MOI (Ministry of Irrigation) delivers the required discharge up to the head of the minor canals, and SGB is responsible for the delivery of water to the tenants.

The Gezira scheme is not a sophisticated one by present day standards. The design, however, took the best advantage of some favorable and unique features of Gezira: (1) the flat topography; and (2) the adopted tenancy system. The adoption of the night storage system resolved the issue of night irrigation found in many schemes, and provided a remarkable solution to the complex problem of adjusting water releases at the head-works. A negative characteristic of the minor canal, which was probably overlooked, is its ability to trap the silt released into the system. For about 40 years, the Gezira scheme was operated satisfactorily on the basis of the original design and operational concept. The management of GIS ran into problems in the early 1970's shortly after the scheme reached its present extension and application of intensification [2]. Because of the lack of financial resources, MOI was not able to cope with removal of silt and weed clearance. Poor maintenance led to a reduction in the transit capacity of canals, which wear out of regulatory system.

2.3 The Drainage System in the Scheme

Basically, the scheme design surface runoff drainage system consists of minor surface drains of about 7,800 km length, collective or major drains of about 2,900 km length, escape drains, in Gezira Scheme main canals; it is characterized by a very limited capacity for runoff of surplus water. Tables 2 & 3 show drainage capacities.

The original design of the Gezira Irrigation System recognized that because of the nature of the soil and absence of a high water table, there was no need for, and indeed no means of providing sub-surface drainage of the fields. The only need for drainage, therefore, was for dealing with surface runoff from rainfall or excess irrigation. The system of drains which exists in various areas in the Gezira has been provided with the object of carrying off rainwater from the land as soon as possible after it has fallen. Although there are no field

Table 2 Scheme escape drains (Sources: Gezira Regulation Handbook).

Item	Escape	Authorized capacity (Mm^3/day)	Remarks
1	K.57 Escape	1.80	Closed
2	K.77—Wad El Nau	0.40	Closed
3	K. 108—Beika Escape	0.90	Feed University of Gezira farm
4	K.169—Abu Usher	1.20	
5	Managil Escape (k65)	1.5	Closed
	Total	5.80	

Table 3 Scheme collective, protective, and minor drains.

Description	Scheme administrative divisions				Scheme total
	North Gezira	South Gezira	East Managil	West Managil	
Total irrigated areas (fed)	834,000	435,274	445,726	485,000	2,200,000*
T. length of minor drains (km)	1,825	2,710	1,465	1,865	7,865
No of collective drains	20	35	16	17	88
T. length of collective (km)	602	843	471	957	2,873
Shawal protective drain-in km					130

* This total includes pump station schemes within Gezira, like Hurga & Nur el Din, etc.).
Source: Ministry of Water Resources, Irrigation and Electricity (MOWRIE).

drains parallel to the Abu XX to take runoff from the fields, minor drains settings (Figure 2), are run parallel to minor canals discharging into collector drains which generally follow the lines of natural drainage and lead the runoff water to outfalls. The collective drains ideally outfall beyond the cultivation boundaries to natural drainage lines (depressions) or thence to the Blue or White Nile. However, several drains terminate in large local depressions usually on land which is unsuitable for agriculture; after that the runoff water is allowed to pond up and then evaporate.

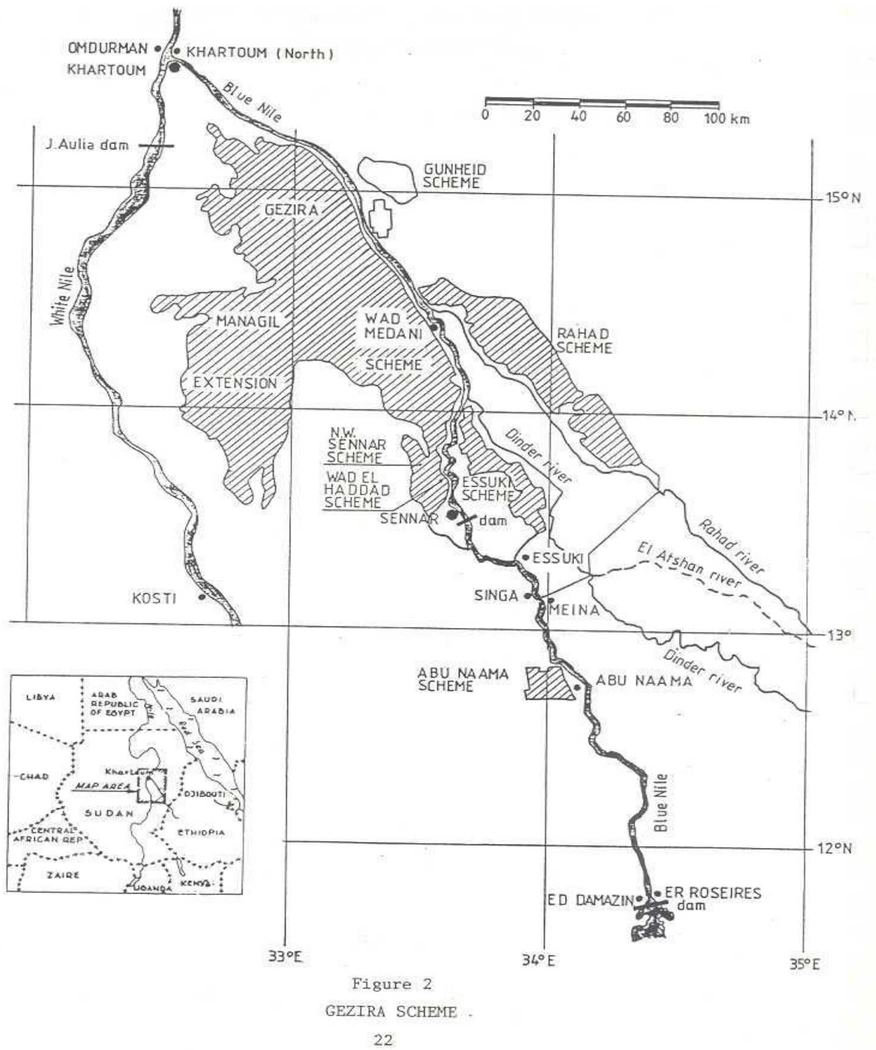

Fig. 1 Gezira irrigation scheme location map (Source: Williams [5]).

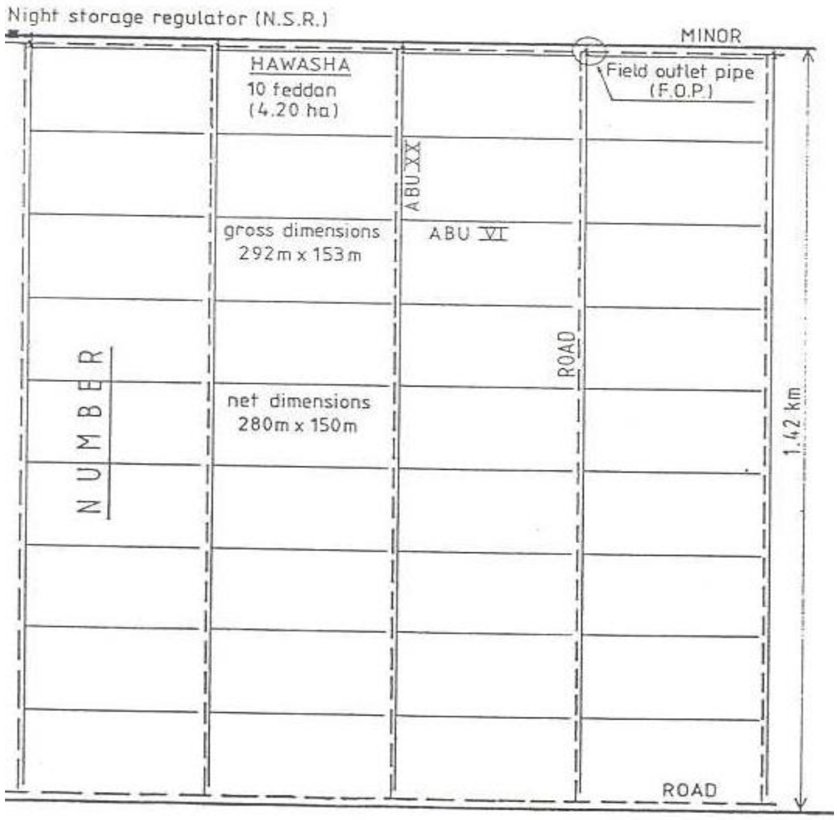

Fig. 2 GIS standard typical field layout (Source: Williams [5]).

The drainage system design capacities were originally based on empirical formulae derived from experience of basin irrigation according to the relationship: (MOI—Design Sheet File DSF),

$Q = CA^{2/3}$,

where:

Q = discharge in m^3/day;

A = Catchment area in fed (Feddan);

C = runoff factor, a constant depending on intensity of rain, soil permeability, geographical zone and other climatic factors (=150 for North of the Scheme and 270 for far South of the Scheme) (according to DSF specification). This relationship is developed for the cultivated area under basin irrigation and assumes considerable storage of potential runoff on the field and some storage in fallow area.

The drainage channel system was set as complementary to the canal system. Minor drains and collective drains channel sections are designed based upon the Manning equation (principally based on 0.20 m free board from ground level for various slopes of minor drains and side slope 1:1—DSF and other parameters are set accordingly).

3. The Problem and Constrains

Changes in agricultural field practices from basin irrigation to furrow system intensify the flow of surface water (rain or excess of irrigation) to the limited capacity drainage system, and the relationship (formula) used for design is no longer valid for application. Also the existing irrigation and drainage system is suffering since the late 1970's, when the Sudan Government was very much concerned about the general decline of the irrigated agriculture production particularly in the GIS. It was agreed to initiate a rehabilitation program (with the World Bank). The rehabilitation project initiated in 1984 concentrated on the restoration of the irrigation system and a package for rehabilitation of the drainage system were included within other components as:

"*To restore the drainage systems to original design standards the project includes removal of an estimated*

3.0 million m^3 of silt from major(collective) drains, construction of 190 km of new drain and rehabilitation of 4,000 km of silted up minor drains to their design sections. Five new drainage pumping station will replace the old ones which are out of operation. Two new siphons and six hundred road crossings along the major drains are also to be installed" [6].

Unfortunately the two important items namely: silt clearance of minor drains, and excavation of new minor drains were not executed, and other items are not fully implemented (no records). Accordingly the present drainage running without field and minor drains, the minor drains are completely buried and not exist.

The working drainage system inside the scheme is only collective drains with very limited capacities. Also depressions where most of the collector drains outfall have been silted up, covered with grass and partially with forest do no longer receive the drainage water effectively; even part of the them are used as township for labors (Kanabi). Eventually, the drainage water from collective drains inundates the nearby cultivated fields (water logging). This is also coupled with excess water from irrigation (as wear out of regulatory system), and in the absence minor drains the areas along & around collective drains are infested with weeds, leading to a wide spread of water covering other fields & field roads. It is also very common that farmers and villagers are suffering a lot during the rainy season even to reach their farms. The results are a very bad environment for production. Table 4 below shows the main impacts in the last rainy season (2016), and Malaria infection as recorded by health authorities.

Also the Gezira scheme has experienced many administration changes in the early 2000s, especially after adoption of 2005 Act (2009-2015), where the irrigation sector transferred from MOI to Ministry of Agriculture and liberation of cropping in the GIS without a comprehensive look to the consequences as:

- A non-defined cropping rotation (many crops per one block or Number);
- Interruption of indent-supply procedure (high indent for long periods almost full season), and water logging (very poor water management).

The results are an improper use of the system, and inefficient water management.

Effect of crop liberization: Before adoption of 2005 Act, the working crop rotation is 4 courses, which indicate that during rainy season 50% of the area will be not under cultivation (25% of cultivable area is fallow + 25% is for winter crops), and so 50% of the area is receiving ponding or storage of drainage water (especially rain cut irrigation water). Changing to 5 course rotation, theoretically 60% of the area will be under cultivation (10% excess); but in reality (and after adoption of 2005 Act) 75% will be under cultivation (no fallow, only winter crop area or not yet planted is remained) leading to reduction of ponding (storage capacity) areas by 25%.

4. Methodology and Material

4.1 Approaches

The problems related to the drainage system in the GIS have many dimensions such as technical, managerial (agricultural policy), and institutional complications. The approach proposed in this paper is based on the investigation, revision & check, and analysis for the real causes of the problem taking into consideration the following:

Table 4 Areas of main crops affected in the last rainy season (Jul.-Sept. 2016), and health impacts*.

Item	Crop**	Damaged crop area (fed)	Inundated crop area (fed)	Total crop area affected (fed)
1	Cotton	2,449	3,240	5,689
2	Groundnut	12,022	4,537	16,559
3	Sorghum	29,141	14,460	43,601
4	G. total	43,612	22,237	65,849

* Average Malaria infection inside Gezira during rainy season increases by about 2.7% (Source: Malaria Treatment Department—Gezira State Ministry of Health, Wad-Medani).

** Other crops no records; source of data is SGB.

• The scheme network is huge and it is not possible to cover a wider range for such a system in this part of the study.

• The approach concept of investigation and survey will select an area of study, collect basic data, information and carry out all checks and analysis for the selected area.

• The approach will deal with the application of developed techniques or formula following the design of the system and proved to be suitable to the system.

• Problems related to the system and not existing within the selected area, there will be a reference to that; and analysis results and solution proposed will be drawn with recommendations for the whole drainage system in the scheme.

In the essence, this approach returns to the original objectives of the study and attempts to ensure that the results and recommendations can be viable in practice.

4.2 Investigation and Revision

This investigation and revision for drainage design flow rate in the Gezira scheme is carried out concurrently with a reference to a report of a comprehensive study conducted to MOI by Sir M. MacDonald & Partners Consulting Engineer for Rahad Project under design review of irrigation canal and drainage system in 1977 [7]. Also the above report (*design review Report)* was referred to two reports as follows:

(1) An earlier report: Roseires Pre-investment Survey, Report No.5 "The Hawata Extension to the Rahad Project, Part III—Engineering", Sir M. Mac Donald & Partners, Hunting Technical Services Limited, October 1966) [8].

(2) Tambul Pilot Study for Long Furrow to Rahad Project in 1971.

The three reports will be named and mention in this study as: design review report, Report No. 5 Hawata Extension, and Tambul Report; respectively.

The Rationale to revise and use this study of Rahad to be applied in GIS is as follows:

• The two schemes are located within the Sudan Central Clay Plain, almost extended to same latitude, separated by the Blue Nile (Fig. 3), with comparable climatic conditions, similar topography (gentle slope), and identical soil properties.

• Climatic data used in review report is mainly for Wad-Medani data.

• The Gezira scheme principles and basics for design are used in the design of Rahad scheme (forerunner scheme).

Basically the used relationship ($Q = CA^{2/3}$) is for the cultivated area under basin irrigation and assumes considerable storage of potential runoff on the fields and some storage in fallow areas. The capacity of the designed drainage system for the north area can drain 10% runoff from a 100 mm storm on 10,000 fed in six days. In the south of the area the channels will drain 18% of a similar storm in six days [7]. However, the potential runoff from furrow irrigation is likely to be greater since the furrows will facilitate runoff from the fields. It is necessary and essential therefore to revise the design formula mentioned above; several alternative approaches are introduced by the *design review report* as:

(1) The drainage capacity may be designed to remove the potential runoff for a design frequency (say 1 in 5 years) thus reducing ponding on the fields to a minimum. However, this is likely to prove uneconomic both in terms of the drainage capacity required and capacity of downstream structures (bridges, culverts etc.).

(2) Alternatives could be made to accept a certain amount of ponding in the fields that would not affect the crop or damage properties, and would reduce the drains size.

(3) The *design review report* is referred to a report produced for Tambul Pilot Study for long furrow irrigation for Rahad Project (Tambul is a town in North Rahad Scheme—within the Gezira State) attempted to adopt the drainage design formula, $Q = CA^{2/3}$, to allow for increased runoff from irrigation areas using straight

furrow system. A number of changes were introduced. Firstly, ponding within the cultivated area was reduced to 48 hours. Secondly, the surface runoff from a small area was assumed to be about 88 mm from a design point rainfall value of 100 mm. Thirdly, the area rainfall reduction factor was increased from 0.667 to 0.9 for areas between 500 and 5,000 fed, and 0.8 for Northern Area and 0.86 for the Southern Area for areas between 5,000 and 2,0000 fed [7].

Comparison between the drainage rates derived from *Tambul Report* and Report No. 5 Hawata Extension to Rahad Project is shown in Table 5 below.

The design review report carries out a series of revision, checks, and comparison to the findings of the two reports to obtain a revised drainage rates and that includes:

- *Point Rainfall Analysis* for rainfall in the Rahad Project Area using average monthly distribution for Wad Medani and Gedaref (1941-1970).
- *Area Rainfall* to reduce the design point rainfall values (area reduction curves) was concluded a fair estimate to use and select W.M.O. 30 minutes duration curve.
- *Design Flow with Field Storage.*

The design flow may be calculated using a simple water balance equation

Q_o = RF - SMD - ET (mm), where: Q_o = design flow in mm, RF = rainfall, SMD = soil moisture deficit, ET = evapotranspiration.

The calculated design flow was carried with assumption of 24 hours and 48 hours duration under the following estimates:

- Open water evaporation of the order 6 mm/day for the month of August (would be applicable because surplus water would be ponded on the surface as the low infiltration capacity of the clay soils once they had been wetted).
- 10 mm soil moisture deficit (only small SMD is to be expected because August is generally the wettest month; and the results of calculations are incorporated for comparison (results are not included in this paper)).

- *Design Flows with no Filed Storage.*

This is made if no allowance for surface ponding using Unit Hydrograph (peaked hydrograph); the report uses the triangular hydrograph following the procedure laid down by the Soil Conservation Services, and design peak flows.

Eventually the design review report for Rahad made a comparison of results and plot curves relating design peak flows to catchment area based on the followings:

(1) Report No. 5 Hawata Extension;
(2) Tambul Pilot Study;
(3) Field storage of 24 hours duration;
(4) Field storage of 48 hours duration; and
(5) Discharge hydrograph estimates.

The plotted curves relating design peak flows to catchment area are shown in Fig. 4.

A recent comparison from Rahad irrigation scheme rehabilitation program showed that the drainage system of the Rahad scheme is the best in the irrigated subsector [9].

Table 5 Drainage rates obtained from previous reports (in m^3/sec).

Item	Drainage area (fed)	Tambul report		Report No. 5—Hawata Extension	
		North of Jebel el Fau	South of Jebel el Fau	North of Jebel el Fau	South of Jebel el Fau
1	1	0.002	0.002	0.0017	0.003
2	100	0.20	0.20	0.04	0.067
3	1,000	1.00	1.00	0.17	0.31
4	5,000	4.30	4.30	0.52	0.94
5	10,000	3.20	5.50	0.81	1.46
6	50,000	11.50	22.0	2.31	4.17
7	100,000	20.0	40.0	3.83	6.67

Source: MacDonald and Partners [7].

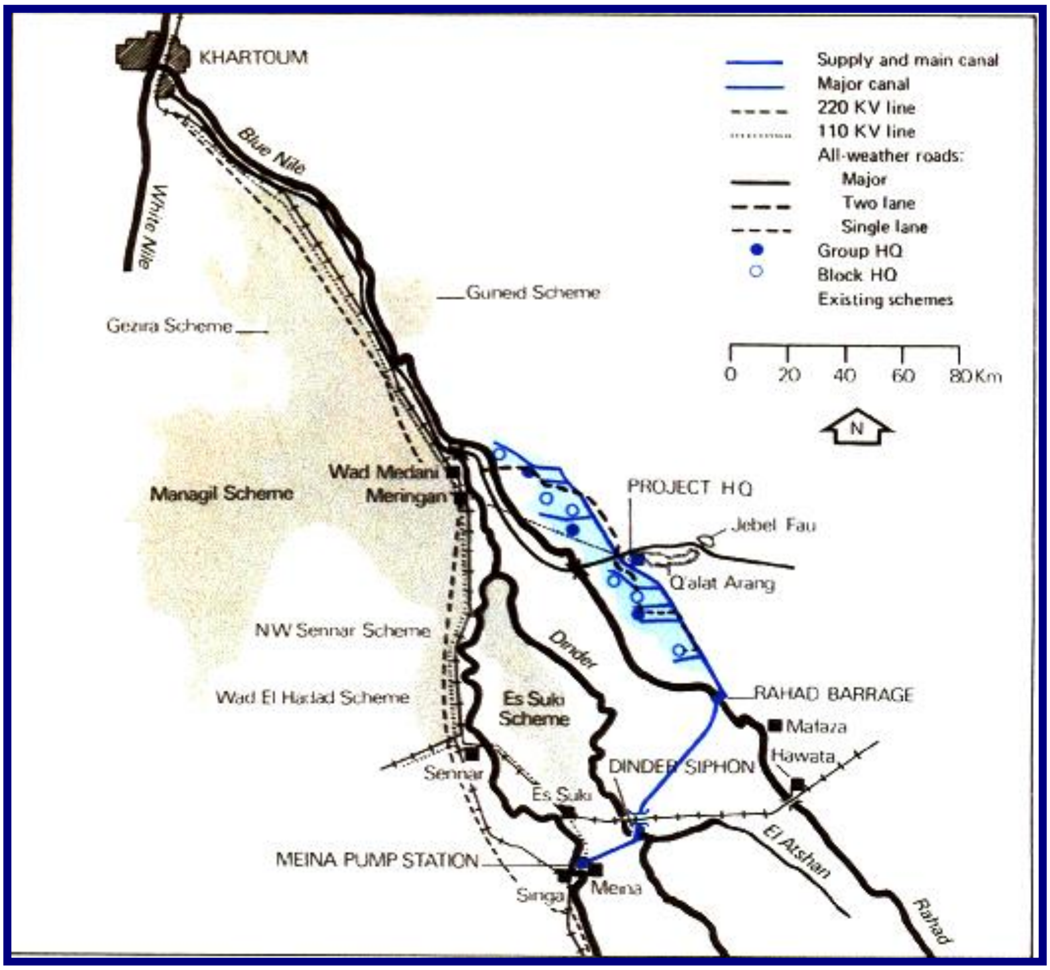

Fig. 3 Rahad scheme location map (Source: MOI Annual Report 1981).

5. Experimental Site Layout (Study Area)

5.1 Study Area

The selected area of the study is Bashkar collective drain, located in Tayba Block in the centre of the Gezira scheme and starting at the end of Ibrahim canal opposite to K 110 Gezira Main Canal (nearby Beika group of regulators k108) (Messelamia Sub-division North-West Wad-Medani by about 15 km), referring to Fig. 3.

Basic data of the collective drain is as follows:

- The drain was constructed with the scheme in 1920's.
- Remodeled in 1932; length 12.1 km, and outfall in Gezira main canal k121 (*drawing Longitudinal section No. G.C.S. 32-9076-Project Directorate—MOI*).
- The drain has three reaches with parameters as follows:

1st reach, drainage area: 1,800 F, Q = 0.27 m^3/s, bed width 2.0 m, slope 20 cm/k.

2nd reach, " ": 3,120 F, Q = 0.40 m^3/s, " " 3.0 m, slope 11 cm/k.

3rd reach, " " : 5,880 F, Q = 0.55 m^3/s, " " 4.0 m, slope 11 cm/k.

5.2 Technical Checks

Applying the formula used for design of the system (MOI—Design Sheet File (DSF) & technical notes): we get the followings:

$Q = CA^{2/3}$ m^3/day, C = runoff factor, is 150 for north, and 270 for south Gezira (DSF).

Then $Q = 150\ A^{2/3}$, A = catchment area in fed.

Reach 1 → $Q_1 = 150 \times (1{,}800)^{2/3} = 22{,}251$ m^3/day = 0.26 m^3/s.

Reach 2 → $Q_2 = 150 \times (3,120)^{2/3} = 32,114$ m^3/day = 0.37 m^3/s.

Reach 3 → $Q_3 = 150 \times (5,880)^{2/3} = 49,007$ m^3/day = 0.57 m^3/s.

The check shows that discharges are compatible with the design in accordance to the formula. From the preliminary investigation the drain is infested with sediment and weeds. Bashkar collective drain outfall structure (siphon 2 lines with 0.76 m size) was constructed in1932, and still in good condition, but the gates spindles are removed. Also it was noticed that the operation level during the past periods was changed.

6. Results and Discussion

From the investigated & revised relationship and curves relating design peak flows (Fig. 4), to use and apply these relationships to Gezira drainage system, the following could be raised:

- The area of study is in the mid part of Gezira and compatible with the classification (latitude and climatic condition) of the review report study, to be in North of Jebel El Fau (refer to Fig. 3).
- Hawata Extension Report No. 5 findings are based on the DSF formula under which the GIS was designed (it is identical to the original design of our area of study) and so it will not be used in our analysis.
- The criteria of no storage (hydrograph flow) have been considered in the analysis.

The result of new setting for Bashkar collective drain using the derived capacities relationships is as shown in Fig. 5, and Table 6, below.

Using the derived capacities from Table 6 above the design section parameters of Bashkar collective drain new setting are shown in Table 7, below (using Manning Formula with parameters as stated in the DSF).

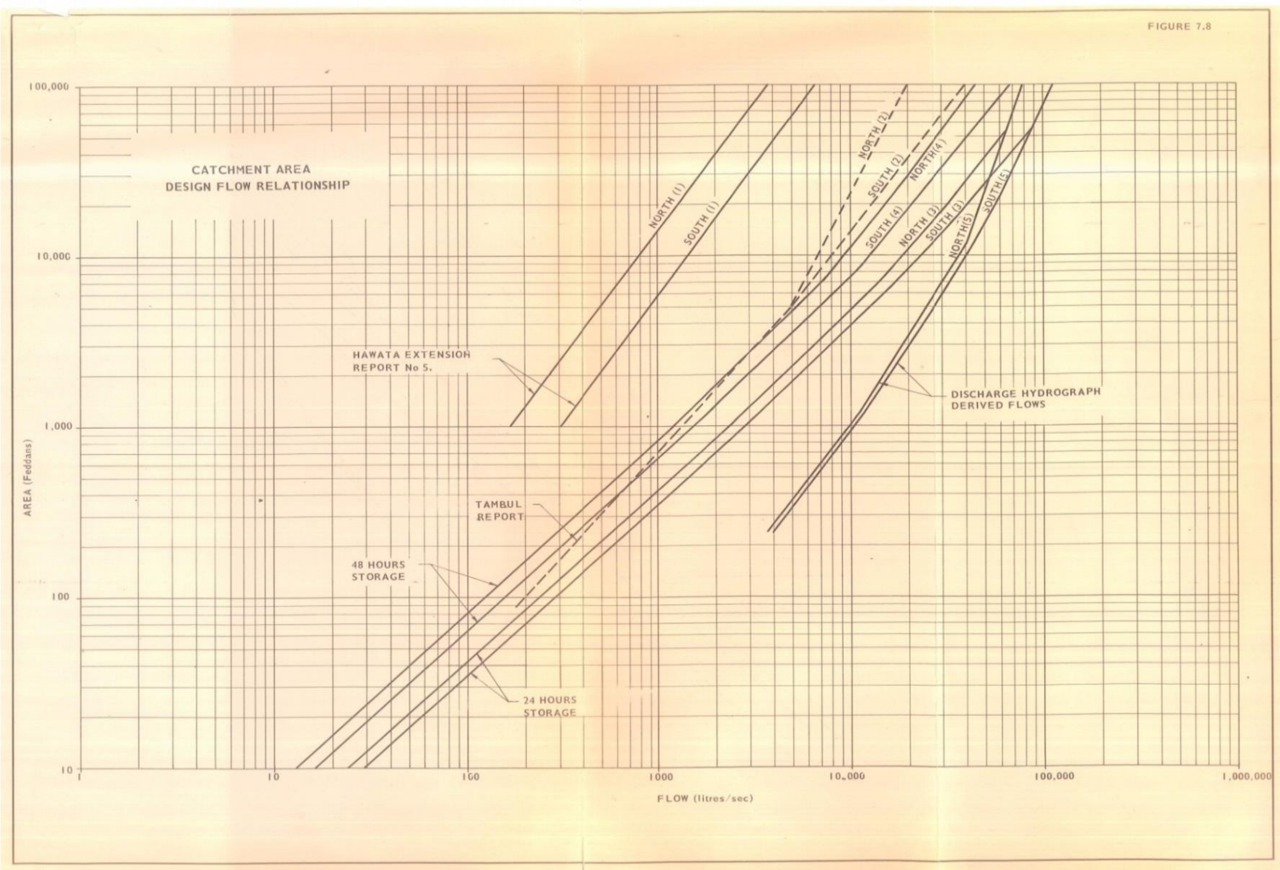

Fig. 4 Curves relating design peak flows to catchment area (Source: Design Review Report, 1977).

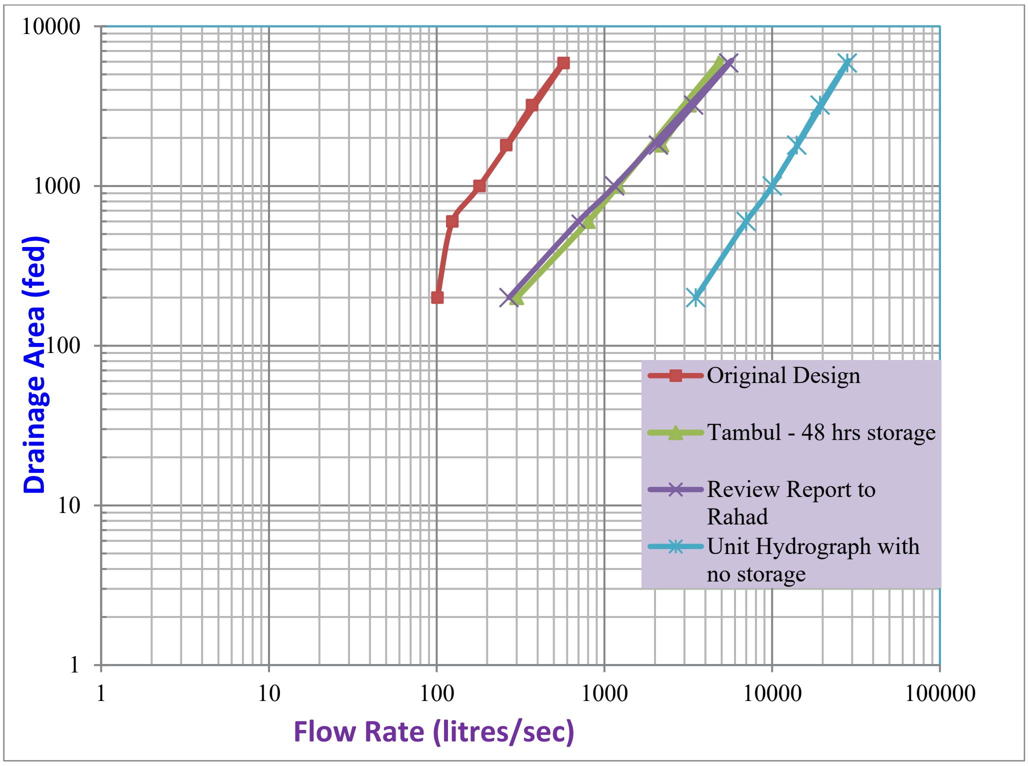

Fig. 5 Derived drainage capacities for Bashkar collective drain.

Table 6 Capacities derived for Bashkar collective drain.

Item	Collective drain reach	Drainage area (fed)	Drainage capacity (m^3/s)			
			Existing original design	Tambul report (48 hrs storage)	Review report to Rahad	Hydrograph flow (with no storage)
1	Reach 1	200	0.101	0.30	0.27	3.50
2		600	0.124	0.80	0.70	7.0
3		1,000	0.18	1.20	1.15	10.0
4		1,800	0.26	2.2	2.1	14.0
5	Reach 2	3,120	0.37	3.2	3.4	19.3
6	Reach 3	5,880	0.57	4.8	5.5	28.0

Table 7 Bashkar collective drain new setting design parameters.

Description	1st reach				2nd reach				3rd reach			
	Q	Bed width	Water depth	Velocity	Q	Bed width	Water depth	Velocity	Q	Bed width	Water depth	Velocity
	m^3/s	m	m	m/s	m^3/s	m	m	m/s	m^3/s	m	m	m/s
Drainage area (fed)	1,800 fed				3,120 fed				5,880 fed			
Drain bed slope	20 cm/km				11 cm/km				11 cm/km			
Existing design parameter	0.26	2	0.38	0.28	0.37	3	0.46	0.24	0.57	4	0.49	0.26
Tambal report—48 hrs storage	2.2	3	1.06	0.51	3.2	4	1.34	0.45	4.7	4	1.67	0.5
Design review report—48 hrs storage	2.1	3	1.03	0.5	3.4	4	1.39	0.45	5.5	4	1.82	0.52
Hydrograph derive flows	14.0	6	2.13	0.81	19.4	10	2.32	0.68	27.5	12	2.57	0.73

7. Conclusion

From the results of application of derived capacities for the selected study area, the following have been revealed:

(1) The Hydrograph derived flow (with no storage), is unsuitable to be used for its high values of flow rate, which implies higher design parameters (bed widths—reaches 12m); and difficulties to be implemented for an existing system (no enough room or space, difficulties with existing structures to pass these discharges), and the high cost expected from such a change.

(2) Despite some discrepancies mentioned in the Review Report about the flow rates derived from Tambul Pilot Study, we propose to use the Tambul Report with 48 hours storage derived values as it is:

(i) Higher discharges are less than those derived by the Design Review Report.

(ii) More suitable applied study to the existing Gezira drainage system facing difficulties with spacing in its route for widening its sections, amending its structures.

(iii) Valuable 48 hours storage is of high import to the existing drainage system and can be linked with the scheme cropping pattern

For minor drains the setting will be as originally designed with the old formula for the following reasons:

(1) It's difficult to apply the new derived relationship as the minor drains now not exist, and the space left between the end A/XX and the street and the next adjacent minor canal is short and the spoil sediment cover part of that space.

(2) The cost will be high; it will be a new excavation; removing of spoil in(i) (if any) is an extra tedious and costly job.

(3) Intension in this stage to recover the design system.

For depressions where collective drains are outfalls, it needs to be cleaned from debris, silt, weeds, and equipped with new pumps, and where township exists a new outfall system to be investigated (some collective drains are outfall in the main canals, e.g. Bashkar drain).

8. Recommendations

The applicability of the recommended revised and derived drain capacity from the Tambul Pilot Study is *not* an easy job, and after weighting up all the assumptions, revisions, and calculations which have been made, that the collective drain capacities should be calculated based on field storage of 48 hours and a constant surface runoff, and the following will be workable guidance for implementation of the study:

(1) Remodeling of drainage system using the new flow rates (changing as far as possible only for water depths, and minor changes to bed widths in accordance to collective drains routes).

(2) Changing of cropping pattern system to the 4 course rotation as it will be compatible to the design characteristic of the scheme and suitable to storage system during rainy seasons.

(3) The design criteria for minor drains will be as specified in the DSF, with extra amendments as follows:

(i) For minor drains with length less than 2 km the drain will be excavated with A/XX ditcher as small ditch with one bank, and one crossing at outfall to the collective drain.

(ii) For minor drains with length more than 2 km the drain will be excavated with A/XX ditcher to first 2.0 km and the remaining as parameter provided from the design, and with one bank, crossing should be in accordance to actual needs (farmers access).

(iii) In both above cases where the space is covered by the spoil from de-silting, it should be removed to the original ground surface and continue accordingly.

(4) A further study is needed for amending the outfalls of collective drains (depressions), outfalls to main canals, and rivers (Blue or White Niles) in accordance to the existing situation of each case and changes happened during the past periods.

References

[1] Central Bank of Sudan CBOS. 2015. *Report.*

[2] Plusquellec, H. 1990. "The Gezira Scheme in Sudan; Objective

Design and Performance." World Bank Technical Paper No. 120.

[3] Eldaw, A. M. 2004. "The Gezira Scheme: Perspectives for Sustainable Development." Report and Working Papers, German Development Institute Tulpenfeld 4-D-E 3113 Bonn.

[4] Galal, M. Y. 1977. *The Gezira Scheme: The Greatest on Earth*. Khartoum: Khartoum Press.

[5] Williams, D. T. 1988. *West Consultants, Inc. 5752 Oberlin, USA.* Report on Sedimentation Problems in Sudan; sponsored by World Bank.

[6] World Bank and International Irrigation Management Institute (IIMI). 1994. *The Gezira Rehabilitation Project—Technical Assistance to Sudan Gezira Board (SGB).*

[7] MacDonald, M., Sir, and Partners. 1977. *Consulting Engineers.* Demeter House—Cambridge CBI 2RS U.K.

[8] MacDonald, M., Sir, and Partners. 1966. *Hunting Technical Services Limited, Roseires Pre-investment Survey, Reports "The Hawata Extension to Rahad Project, Part III—Engineering to Ministry of Irrigation—Sudan (MOI).*

[9] YAM-CDC. 2014. A completion report to MOI about a rehabilitation Program to Rahad Scheme, produced by YAM Consultancy and Development-CDC Consultant Engineer, House No. 7, Street No. 17, el Amarat—Khartoum.

[10] MOI. 1957. *Design Sheet File (DSF), Standard Sheets for Design and Layout of Canalization System.*