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ANNEX 7

HYDRAULICS AND IRRIGATION ENGINEERING

Table of contents

List of tables

List of figures

List of Appendices

1. DIVERSION AND MAIN CONVEYANCE SYSTEM

1.1 Rahad River

Rahad Barrage will be located just upstream of Wad Meskin village from where the barrage takes its name. Rahad is a seasonal river flowing from June to October and running dry in the rest of the year. The reach of the river there is straight and narrow although the river is a notoriously meandering one. The river overflows its banks during relatively high floods.

Statistical analysis of the yearly daily peak floods from the records of El Hawata gauging station (located about 40 km downstream the barrage site), shows that the 3-parameter log-normal distribution fitted well the observed data. The 100-year daily peak flood discharge (Q_{100}) is 218m^3/s. This value is taken as the design discharge for the barrage as there are no significant in- or outflows between the gauging station and the barrage site. The 200-and 250-year daily peak flood discharges are marginally higher with a value of 225m^3/s as Table 1.1 below shows.

Table 1.1: Flood Flows for Hawata gauging station

Return Period T YEARS	5	10	20	50	100	200	250	500
Q_T (m^3/s)	184	194	203	212	218	225	225	231

A rating (stage-discharge) curve was computed using Manning formula at the location of the barrage site where a number of the river cross-section measurements were made in the vicinity. When developing the rating curve, it was assumed that Manning's n is 0.03; longitudinal bed slope is 12cm/km and that a retrogression of 1.5m is anticipated downstream the barrage

1.2 Rahad Barrage

The Barrage will be a gated reinforced cement concrete structure. Keeping with the standard size of gates at the existing Abu Rakham Barrage, the gates of this Barrage will be manually operated with a unified width of 4.0m. This particular gate width proved to be amenable to manual operation in the Gezira and Rahad schemes and elsewhere. Pier thickness is kept at 1.2m, while the crest level is set at RL 446m i.e. about one meter higher than the mean river bed level there so as to keep a reasonable afflux upstream the Barrage for the safety of the many villages up there.

The Barrage is designed to offer minimum resistance to the peak daily flood flows. For the 100-year peak daily flood flow, the water level upstream the barrage pond is expected to be maintained at RL 448.5m plus an afflux of 0.30m i.e. upstream water level will be at RL 448.8m, while downstream water level will be at RL 448.5m with only 0.30m head across the Barrage. For such conditions, all the Barrage gates(9 in number) will be fully opened with a computed combined capacity of 224m^3/s, considering the crest of the Barrage as a broad-crested weir. The barrage will have two sediment sluices situated close to the canal off takes to control coarse sediment entry into the canals. In emergency situations, these sluices can be used to augment the flood passing capacity of the other Barrage gates. Another function of these sluices is to drain water downstream the Barrage when the pond level is below the Barrage crest for purpose of inspection and repairs of the structure.

In the design of the Barrage's stilling basin, four flow scenarios were considered as follows:

- a- flow at (Q_{100}) with all gates opened without retrogression in the downstream river bed
- b- same as above +20% discharge concentration+ retrogressed downstream river bed
- c- normal flood (Q_5 =184 m^3/s) at pond level with only few gates opened to pass the flood
- d- same as (3) +20% discharge concentration and a retrogressed downstream river bed level.

Scenario (d) was the most critical one resulting in an incoming Froude Number of 6.17 in the stilling basin. Thus the basin is designed as type III stilling basin according to the United States Bureau of Reclamation (USBR, 1987). Details of the design are given in Wad Meskin Barrage drawings. The downstream profile of the weir crest is made parabolic in shape so that the water issuing from the barrage gates adheres to the profile without inducing negative pressure there and approaches the stilling basin smoothly. Results from the geotechnical investigation showed that seepage underneath the Barrage is expected to be very low. Nevertheless, provision is made for sheet pile cut-off wall at the upstream end of the concrete apron as a safety measure. Because of the many similarities in the design of this barrage to that of El Dinder, design particulars and calculations will be given later when dealing with Salsal Barrage.

1.3 Main Canal Offtakes

In Phase I the main canal will have a design discharge of 10m^3/s, whereas in Phase 2 a design discharge of 100m^3/s is required. For Phase 2, the Phase 1 main canal will be deepened and widened on the outside of the scheme where the Phase 1 cut-off drain is located. The main canal will take off at an angle of 60^0 with respect to the direction of the river flow. The offtakes for the Phase 1 and Phase 2 canal are reinforced cement concrete gated structures. In Phase 1 the offtake will have twin gates each 2.0m wide, whereas in Phase 2 the Phase 1 offtake will be extended by seven openings each with a gate of 4.0m wide. The offtake will be equipped with breast walls to prevent flood water from overtopping the gates and getting into the main canal. The offtake is designed to pass the required discharges with a head difference of 1.0m. Because of the low turbulent energy produced downstream of the gates, there is no need for special energy dissipation arrangements other than the reinforced concrete apron and riprap protection further downstream the concrete apron.

1.4 DINDER BARRAGE

This Barrage is located on Dinder river at Salsal, just downstream the boundary of Dinder National Park. The Dinder River is similar to Rahad as a seasonal stream. However, it is larger and flows longer than Rahad. The river is gauged at Gwaisi gauging station located some 100 km further downstream the Barrage site. The most important contribution to Dinder flows downstream the Barrage site is from Khor El Atshan which joins Dinder river few kilometres upstream the gauging station.

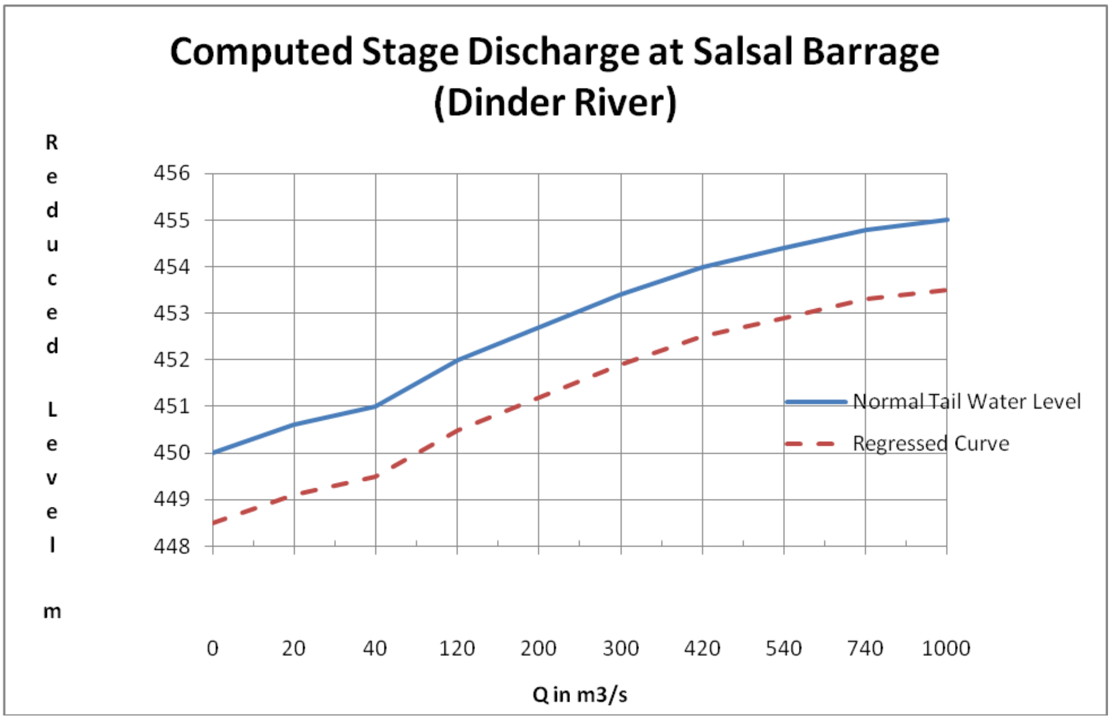
There is no abstraction from the reach between the Barrage site and the gauging station other than by seepage and flood plain spill over. During floods, it is assumed that the same flow passing the Barrage site will pass the gauging station on the assumption that the losses in this reach equates the contribution of El Atshan Khor to Dinder flows at the gauging station. Statistical analysis of the peak daily flood discharge of El Gwaisi gauging station showed that, similar to Rahad flood flows, a 3-parameter lognormal distribution fits the observed data very well. The results are shown in the following Table.

Table 1.2: Flood Flows for Gwaisi gauging station

Return Period T YEARS	5	10	20	50	100	200	250	500
Q_T (m^3/s)	683	781	872	985	1058	1149	1173	1254

From the Table, Q_{100}= 1058m^3/s which is taken as the inflow design discharge for the Barrage. The design procedure is very similar to that of Wad Meskin's. It starts with establishing anticipated stage- discharge curves for Dinder river at the Barrage site. These include normal tail water levels and retrogressed water levels assessed as 1.5m below the normal level. Excessive retrogression is not anticipated. From the measured cross-section, cross-sectional area, wetted perimeter and hydraulic radius were computed for different increments of the reduced level there. The corresponding discharges were computed by Manning's formula with a roughness coefficient of 0.03 and longitudinal river bed slope of 12cm/km. The results are shown in Fig. 1.1.

Figure 1.1: Computed Stage Discharge at Salsal Barrage (Dinder River)



From Fig. 1.1, the bank full discharge is 420 m^3/s which represents average mean flow in August and September. This occurs at RL 454m which is the retention level of the Barrage pond. When the flood exceeds that discharge, the river will overflow its banks. The rating curve is extrapolated beyond the bank full discharge up to RL 455m when the flood approaches Q_{100}.

The number of gates required to pass the design flood discharge is determined next. It is assumed that all the gates will be fully open to pass the flood and that the Barrage crests will act as a broad-crested weir. Initially the width of the barrage is chosen according to Lacey's formula:

$$P=4.83\ Q^{0.5}$$

Where:

P (in meters) is the wetted perimeter which approximately equals the river top width when the river is wide, and

Q is the dominant discharge (m^3/s).

The dominant discharge is vaguely defined. Sometimes it is defined as the bank full discharge, or as that discharge which makes the most morphological changes. Here we adopt the first definition resulting in a width of 100m. Accordingly, if we choose 22 gate openings, each 4.0m wide, and pier thickness of 1.2m, then the distance between the abutments will be 113.20m.

The discharge passing capacity of the barrage is estimated from the standard broad-crested weir equation, Garg (1999)

$$Q= C_S C_d L_e H_e^{1.5}$$

where:

C_s is a submergence coefficient depending on the downstream water level with respect to the weir crest;

C_d is the discharge coefficient which equals 1.705;

L_e is the effective width of the Barrage openings, and

H_e is the head over the crest including the velocity of approach.

For the design flood discharge, the submergence coefficient C_S = 0.60 (without retrogression), L_e =83.4m, and H_e = 5.45m. For these values, the resulting discharge from the above formula is 1086 m^3/s which is slightly larger than Q_{100} = 1054 m^3/s. Therefore the Barrage with its 22 gates will pass safely the design flood discharge when all the gates are fully opened.

In the design of the stilling basin, it was found that the most critical condition is at the rising stage of the flood when the later is about 120m^3/s and 4 gates are opened partially to pass the incoming flood and to maintain normal pond level, while the downstream tail water level rises slowly. This represents conditions in late July/ early August when the inflow discharge is about 100-150 m^3/s. Moreover, a 1.5m retrogressed river bed is assumed downstream the Barrage. For these conditions, the resulting Froude number at entry to the stilling basin was 4.22, while the energy loss across the Barrage was 3.3m. Accordingly a modified USBR type IV stilling basin is chosen-as this particular type is more suited to low flow Froude number. The apron level of the stilling basin is fixed by trial and error until the hydraulic jump stays within the apron.

1.5 Link Canal Offtakes

The link canal takes water from the pond of the Dinder Barrage and conveys it to that of Wad Meskin's on River Rahad. The off taking structure is on the right bank adjacent to the Barrage. It is a reinforced cement concrete gated structure very similar to that of the Rahad II off take at Wad Meskin Barrage. Both off takes are designed to pass 100m^3/s with a head difference less than 1.0m.

The floor of the off take is made higher by one meter than the river bed to prevent coarser sediment material from entering into the link canal. Two sluices are provided in the Barrage, close to the off take to facilitate sluicing of deposited sediment in front of the off take. No special energy dissipation provision is made at the exit of the off take structure other than riprap pitching downstream the concrete apron.

The off take is also provided with a breast wall similar to the off take of Rahad II main canal at Wad Meskin Barrage.

1.6 The Link Canal

This is an open earth canal linking the two barrages at Salsal and Wad Meskin on Dinder and Rahad Rivers respectively. Its function is to convey part of Dinder waters to Rahad. The design flow of the link canal is 100m^3/s. It is 53.8 km long. The link canal route follows the original Mc Donald's canal route except in the first 9 km of its length. In its route, the canal crosses a number of khors; notable among them is Al Atshan. The natural ground slope along the canal route is about 0.10m/km. The link canal, for supplementary irrigation an area much larger than Wad Meskin, is expected to operate intermittently during the rainy season. Accordingly, heavy siltation is anticipated. In order to get rid of the fine suspended sediment that manages to enter the head works, and makes it to deposit at some specified places, provision of a settling basin in the head reach of the link canal is necessary. A settling basin there is important in reducing future maintenance costs: firstly by confining sediment clearance works at the head reach only instead of all along the canal length; secondly the maintenance of El Atshan siphon, with reduced suspended sediment load in the flow will be much easier and less costly. A wide and long settling basin is needed to settle suspended sediment in the range of very fine sand and smaller i.e. wash load. The longitudinal bed slope of the link canal is therefore made flat with a slope of 4cm/km and its bed width is made wide in order to settle a significant part of the suspended wash load. Calculations indicate that a basin having a bed width of 40m and a length of about 26.5km and a flow depth of 3.83m with side slope 2H: 1V is needed in order to settle down suspended sediment down to the size of coarse silt. After the settling basin, between km 26.623 and 38.296, the link canal will have a longitudinal bed slope of 8.6cm/km and a trapezoidal cross section with bed width of 30m, normal flow depth of 3.58m and side slope of 2H: 1V. This particular longitudinal slope was determined so that the resulting mean velocity (0.75m/s) will be the maximum allowed for the type of soil i.e. black cotton soil. At station 38.296km, the link canal crosses underneath khor El Atshan by a siphon. Thereafter, the same canal cross section is maintained up to the canal outfall at km 50.0. The outfall is a gated structure in every aspect very similar to the canal head works at Salsal. The outfall structure serves two purposes: to control the flow into Wad Meskin barrage pond, and to prevent the ponded water from getting into the link canal when the latter is dry. The suggested settling basin at the head reach of the Link Canal is very similar to the supply canal of Rahad Phase I project where the design discharge was 105 m^3/s with bed width of 35 m, normal flow depth of 3.5 m and a longitudinal bed slope of 5 cm/km. This supply canal experienced siltation in its entire length particularly in the first 20-30 km. In its operation life of about 35 years, the canal needed to be desilted only once. Because of the hydraulic similarity between the supply canal of Rahad Phase I and Wad Meskin Link canal, de-silting in the link canal is expected to be quite infrequent given the nature of sediment in transport by both the Blue Nile and Dinder rivers. Thus the cost of de-silting work will be quite reasonable. The design of the Link canal doesn't deviate significantly from that of regime canals with cohesive bed and banks as the following table shows for a design discharge of 100 m^3/s with appreciable suspended sediment load (mainly wash load) during the rainy season.

Table 1.3: Comparison between Link Canal and Regime canal

Design parameter	Wetted perimeter	Hydraulic radius	Long. Bed slope
Link Canal (settling basin)	57.1 m	3.19 m	4.0 cm/km
Link Canal (d/s settling basin)	46.0 m	2.89 m	8.6 cm/km
Regime Canal	47.0 m	2.94 m	6.8 cm/km

The route of the link canal in its first few kilometers requires considerable excavation to cut through relatively high terrain. This is unavoidable for three reasons: 1) moving the chosen barrage site further upstream is not possible as the present location of the barrage is just outside the boundary of Dinder Reserve Park ; 2) if the barrage site is moved further downstream, then the retention level will be less and consequently the command between the two barrages will decrease; and 3) if the barrage site is moved downstream, considerable and costly river protection work will be required to protect villages like Um Bagara which was the initial site chosen for the barrage and later discarded in favor of the present site at Salsal. For these reasons, the present site of the barrage is a good compromise between the capital expenditure of the construction work needed for the suggested canal route and the long-term loss of command and permanent threats to villages like Um Bagra.

1.7 El Atshan Siphon

The Link canal crosses many Khors in its path. Notable among these is El Atshan which is the biggest. This Khor runs parallel and close to Rahad River. The link canal crosses El Atshan at km 38.3 measured along the canal from the Dinder barrage. At the crossing, El Atshan is about 70m wide and 2m deep. The Link canal is made to pass under the Khor rather than over it. This is because the Khor is un-gauged one with unknown peak instantaneous flood flow. It is felt safer to pass the canal underneath the Khor and leave it undisturbed. The link canal, therefore, will pass underneath El Atshan by a siphon. The siphon will be very similar to the existing Dinder siphon for Rahad I project. The siphon will comprise three Reinforced Cement Concrete barrels, each 3.4m square. The top of the Siphon will be 2.3m below the Khor's bed level. The overall length of the siphon from inlet to outlet will be 115m. The computed head loss across the siphon is about 0.75m for a design discharge of $100m^3/s$. The maintenance of the siphon to remove deposited sediment is expected to be minimal because the settling basin in the first reach of the link canal will remove most of the sediment that manages to enter through the Link canal intakes.

2. IRRIGATION SCHEME WORKS

2.1 Canal System

2.1.1 Introduction

A number of options have been studied to irrigate the project area. The option to be applied is to construct two barrages at Dinder and Rahad Rivers. A barrage at Dinder River to divert the flow to Rahad River and the second barrage to be constructed at Rahad River to regulate the flow to the developed land. The water is diverted though the link canal between Dinder and Rahad. This option does not exclude or conflict with the option of construction of Rahad II water supply, the barrages and the link canal are designed to accommodate water requirements for the Rahad II Project.

2.1.2 Canal system

The canalization system follows the standard pattern for the schemes in central Sudan. The irrigation distribution system consists of a main canal which takes water from the water source and conveys it to the heads of the minor canals through pipe regulators. The minor canals then feed the water to the heads of Abu Ishreens through fields' outlet pipes controlled by a sliding flap valve on their upstream ends. This system is thus generally similar to that of the Gazira Scheme. The irrigation water flows from the head regulator through the main canal and the main canal will feed through a system of irrigation canals descending in size which begins from a major canal to minor canals to Abu XX and finally to Abu IV which is the smallest irrigation channel in the irrigation system and a farm channel in both the Ingaya and basin irrigation stem. In furrows system irrigation water is then conveyed to furrows form Abu XX.

The main canal is controlled by cross regulator to maintain upstream flow at constant levels to enable major canals to get the required quantities of water. Major canals have also cross regulators at each minor canal and the minor canals are provided with intermediate regulators in the form of storage weirs. The minor canals usually supply the tertiary canals (Abu XX) though circular gated field outlet pipes (FOP) where each Abu XX is designed to irrigate an area of 90 feddans (37.8 ha) which is called (nimra).

2.1.3 Irrigation System Development

The canal layout proposed for the project is shown in Volume Drawings. According to crop water requirement practice in the schemes of Central Sudan the system is designed for water demand of 33 m^3/feddan/day i.e. 78.57 m^3/ha/day. Water is to be conveyed from Wad Misken proposed Barrage. Total area of the scheme is 18,125 Feddans (7,612.50 ha). The main canal capacity in hectares is the area of the canalized area= 7,612.5 ha. The capacity of the main canal =10.0 m3/sec. In order to convey irrigation water to the project area enormous construction and excavation work is needed as below:

- Earthwork
- A link canal connecting Dinder and Rahad Rivers of length 37.7 km
- Major canal of length
- Minor canals of length
- Drainage system of length
- Construction work
- A barrage across Dinder River to convey water to Rahad River
- A barrage across Rahad river to regulate the flow to the project area
- Bridges and other infrastructures related to the irrigation network system
- Buildings connected with the irrigation system (offices, housing, workshops etc).
- Field roads

System components

The irrigation system components can be summarized as below:

- Length of main canal = 37.700 km.
- Length of major canals = 5.450 + 4.380 = 7.830 km. (2 Majors).
- Total length of minor canals = 63.250 km.
- Total number of Abu xx = 210
- Number of Pipe Regulators:
    - PR 0.76 m = 13
    - PR 0.91 m = 4
- Number of Field Out Let Pipes FOP = 210
- Number of Movable Weir Series II = 2
- Number of falls =13 in Minors No (12, 13, 14, 15 and 16)
- Number of falls in Major 1 = 2
- Number of falls in Major 2 = 3
- Total length of drains = 150 km.

Standard distances

Distance between Abu xx:

10 Feddan plots total net area of Abu xx is 90 Feddans.

Net distance = 280 m.

Width of Abu xx = 6 m.

Width of road = 6 m.

Distance between 2 Abu xx = 292 m.

Distance between Major canals:

Centre line of minor to outer toe = 9.5 m.

Width of road = 6.0 m.

1/2 width of Abu VI to centre line of minor /centre line of Abu VI =1.5 m.

Total of distance between major canals =17.0 m.

Net distance between minor canals =1,350 m.

Width of canals and road =30 m.

Centre line of canal to centre line of canal =1,420 m.

Net cultivated area of Abu xx = 1,350*280/4,200 = 90 Feddans (37.80 ha).

Net area between canals =1,350 m.

Net area between Abu xx =280 m.

The traditional unit of area used in Sudan is Feddan (F) used in canalization i.e. 1 F= 4,200 m2.

P.R = Pipe Regulator.

Abu xx = Abu Ishreen.

Abu VI = Abu Six

Total area of project =19,499 Feddan (8,189.58 ha)

Net area of canalized project =18,125 Feddan (7,612.50 ha).

Layout of Canalization

Total area of canalization = 18,125 Feddans (7,612.50 ha).

Main canal length = 37.700 km.

Area irrigated directly from main canal = 9,730 feddan (4,086.60 ha)

Major canal No.1 length = 5.450 km.

Area of Major canal No.1 = 3,255 Feddan (1,367.10 ha).

Major canal No. 2 length = 4,380 km.

Area of Major canal No. 2 = 5,140 Feddan (2,158.8 ha).

Table 2.1: Details of canalization system

Minor No	Area (Fed)	Area in ha	No of Abu XX	Minors Length (km)	Regulator off take structure	Position	Remarks
Minor No 1A	810	340.20	9	2.50	P. R. 0.076	Main canal kilo 12.55	All AXX off take structures are P.R. 0.33 M.
Minor No 1	990	415.80	11	4.00	P.R. 0.76 m	Main canal kilo 14	All AXX off take structures are P.R. 0.33 M.
Minor No 2	900	378.00	10	3.50	P.R. 0.76 m	Main canal K 15.420	
Minor No 3	1,220	512.40	16	5.50	P.R. 0.91 m	Main canal K 16.840	
Minor No 4	990	415.80	12	3.25	P.R. 0.76 m	Major No.1 K 1.680	Off take of Major No.1 moveable weir series II 0.80 m.
Minor No 5	760	319.20	9	2.50	P.R. 0.76 m	Major No.1 K 3.980	
Minor No. 6	860	361.20	10	3.00	P.R. 0.76 m	Major No.1 K 5.400	
Minor No.7	645	270.90	10	4.00	P.R. 0.76 m	Major No.1 K 5.420	
Minor No.8	1,740	730.80	18	5.50	P.R. 0.91 m	Major No.2 K 4.360	Off take of Major No.2 moveable weir series II 0.80 m.
Minor No.9	1,240	520.80	15	5.50	P.R. 0.91 m	Major No 2 K 2.440	
Minor No.10	1,080	453.60	11	3.00	P.R. 0.76 m	Major No.2 K 1.520	
Minor No.11	1,080	453.60	11	3.00	P.R. 0.76 m	Major No.2 K 0.100	
Minor No.12	1,220	512.40	14	4.00	P.R. 0.91 m	Main canal K 32.00	
Minor No.13	1,170	491.40	13	3.50	P.R. 0.76 m	Main canal K 33.420	
Minor No.14	1,170	491.40	13	3.50	P.R. 0.76 m	Main canal K 34.840	
Minor No.15	1,080	453.60	12	3.50	P.R. 0.76 m	Main canal K 36.260	
Minor No.16	1,170	491.40	13	3.50	P.R. 0.76 m	Main canal K 37.680	
Total	18,125	7,612.50		63.25			

Table 2.2 : Calculations of Earthworks, Summary of minor canals volume

All bed width = 2.00 m

Minors	Length in km	Volume in m³
Minor 1 a	2.5	29,460
Minor 1	4	31,508
Minor 2	3.5	41,368
Minor 3	5.5	38,438
Minor 4	3.25	41,105
Minor 5	2.5	18,983
Minor 6	3	20,948
Minor 7	4	26,888
Minor 8	5.5	48,795
Minor 9	5.5	50,725
Minor 10	3	24,360
Minor 11	3	30,040
Minor 12	4	28,730
Minor 13	3.5	30,303
Minor 14	3.5	29,360
Minor 15	3.5	23,913
Minor 16	3.5	28,618
Total Cubes	63.25	543,538

2.2 DRAINS

The irrigation system consists of a drainage system, for each main, major and minor canal a drain is designed to protect it. The protective drain which is located in parallel to the main canal is designed to protect the main canal form the upland floods which is originated from the eastern part of the project. The main drain is a single sided drain and of 47.5 km in length. Each major and minor drains are located beside the associated canal. Table 2.23 shows the excavation work needed for the irrigation drainage system.

2.3 IRRIGATION REGULATING STRUCTURES

To regulate the flow in the canal system a number of Pipe Regulators (PR) is needed:

Pipe regulators =17

Number of Moveable Weirs =2

Number of F.O.P (Field Outlet Pipes) =210

Number of falls =21

Each fall 100m2 pitching and 5m3 masonry wall total 21*5 =105m.

25 concrete pipe culvert to 1.00m stone pitching 50 m2 downstream each regulator install of F.O.P one meter deep diameter 0.35 m excel pipe cost.

The number of F.O.P =210

Number of pipes 210*5 =1050

Quantity calculations are presented in Appendix B whereas cost tables are presented in Annex 13.

2.4 Roads

Roads are needed inside the project area for the transport of people, machinery and products, all roads are constructed from the excavated materials of the canals, roads details are as below:

1-Access road 3.5 m wide parallel to minors = 65 km.

2-Service 3.00 m wide parallel to Abu xx =315 km.

3-Regional road 6.00 wide parallel to main canal and majors =37.700+7.83=45.83 km.

Quantity calculations are presented in Appendix A whereas cost tables are presented in Annex 13.

2.5 Project Management Facilities

2.5.1 Offices and Housing

To operate an irrigation project management offices and housing are required. It is proposed that the project headquarters should be set up on the outskirts of El Hawata town. This would provide a reasonably good location, having also the advantage of the facilities available at the town, where, in addition, it is possible to make use of the existing building so cost savings can be made. It may be possible to accommodate staff in existing housing in Hawata Town, but for the purpose of the economic and financial analyses it is assumed that new buildings will be required for the project.

The most reasonable site for the proposed project headquarters is Hawata. Two divisions are needed to manage the water supplied to the scheme: one division at the site of Wad Misken Barrage to control the water entering the scheme from Rahad River, the other division at the site of the Dinder Barrage to control the water discharge diverted from River Dinder.

In other development schemes in Sudan there have been difficulties in attracting and retaining a high calibre of management staff, often it is the prospect of living in remote areas, in poor accommodation and with few amenities which is the basic cause of the problem, by setting up the management headquarters and housing close to towns like Hawata and large village like Wad Misken, many of these difficulties could be overcome. It should be recognized that efficient management is vital to the success of the project and attempts should not be made to over-economies on staff housing and facilities.

2.5.2 Building Requirements for Project Management

Project Headquarters Hawata:

- Senior houses 4 nos.
- Junior houses 6 nos.
- Worker's houses 10 nos.
- Offices 300 m^2.
- Store 1 nos.

Subdivision at Wad Misken:

- Senior houses 1 nos.
- Junior houses 2 nos.
- Worker's houses 3 nos.
- Offices 100 m^2.

Subdivision at Dinder Barrage:

- Senior houses 1 nos.
- Junior houses 1 nos.
- Worker's houses 2 nos.
- Offices 100 m^2.

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Total:

- Senior houses 6 nos.
- Junior houses 9 nos.
- Worker's houses 15 nos.
- Offices 500 m^2.
- Store 2 nos.

3. COSTS

3.1 Main Conveyance System

The costs tables for the main system components are presented in Annex 13. A summary is shown in the table below.

Table 3.1: Summary of Cost Estimate Diversion and Main Conveyance System

Ref	Structure	Cost in USD
	Preliminaries (mobilisation, camps etc)	1,000,000
1	Total Salsal Barrage cost (BARRAGE & SETTLING BASIN)	2,594,391
2	TOTAL Head Works at Salsal Barrage	758,609
3	TOTAL Link Canal	24,150,544
4	TOTAL Atshan Khor CROSS DRAINAGE STRUCTURE TYPE I	425,983
5	TOTAL Head Works at US Wad Misken Barrage	781,912
6	TOTAL Wad Misken Barrage AND SETTLING BASIN	1,232,926
7	TOTAL Head Works at DS Wad Misken Barrage	762,764
	TOTAL all works	31,707,130
	contingencies 15%	4,756,070
Total cost including contingencies		36,463,200

3.2 Irrigation Scheme

3.2.1 Irrigation System

The total cost of the irrigation system which contains the project area components, main canal, major canals, minor canals, bridges and roads is presented in table 3.2.

Table 3.2: Summary of Cost Estimate Irrigation System

No	Description	Quantity	Unit	Rate SDG	Amount SDG	Rate USD	Amount USD
	GENERAL						
1	Land clearing, medium vegetation.	7,743	ha	1,600	12,388,800	680.85	5,271,830
2	Land clearing, dense forest.(estimation)	2,000	ha	4,000	8,000,000	1,702.13	3,404,255
	EARTHWORKS						
3	Excavation main canal	299,142	m³	6	1,873,038	2.55	358,970.40
4	Excavation major canals	137,412	m³	6	824,472	2.55	350,839
5	Excavation minors canals	543,541	m³	6	3,261,246	2.55	1,387,764
	DRAINS						
6	Protective drain	498,750	m³	6	2,992,500	2.55	1,273,404
7	Minor drains	150,000	m³	6	900,000	2.55	382,979
8	Collective drains	157,500	m³	6	945,000	2.55	402,128
	ROADS						
9	Access road 3.5 m wide gravel 0.2.0m thick	65	km	67,500	4,387,500	28,723.40	1,867,021
10	Service road 3.00m wide 0.2 thick gravel layer	315	km	66,000	20,790,000	28,085.11	8,846,809
11	Regional road 6.00 m wide parallel to main canal	46	km	96,600	4,443,600	41,106.38	1,890,894
12	Install of pipe for roads 1.00 m deep diameter 0.35 m (excluding pipe)	1,050	m	200	210,000	85.11	89,362

Table 3.2: Summary of Cost Estimate Irrigation System (Cont)

No	Description	Quantity	Unit	Rate SDG	Amount SDG	Rate USD	Amount USD
	STRUCTURES						
13	Pipe regulators	17	No.	3,700	62,900	1,574.47	26,766
14	Moveable weirs	2	No.	98,555	197,110	41,938.30	83,877
15	Field outlet pipes(F.O.P)	210	No.	350	73,500	148.94	31,277
16	Falls	21	No.				
17	Stone pitching 0.2 m thick.	100	m^2	120	12,000	51.06	5,106
18	Masonry in walls of falls 0.5 m thick basaltic stone	105	m^2	320	33,600	136.17	14,298
19	Concrete pipe culvert 1.00m (25*20) for cross drainage structures (main canal & drains)	500	m	570	285,000	242.55	121,277
	OFFICES AND HOUSING						
20	Senior houses	6	Ea	100,000	600,000	42,553.19	255,319
21	Junior houses	9	Ea	60,000	540,000	25,531.91	229,787
22	Worker's houses	15	Ea	20,000	300,000	8,510.64	127,660
23	Offices	500	m^2	2,400	1,200,000	1,021.28	510,638
24	Stores	1	Ea	30,000	30,000	12,765.96	12,766
	TOTAL				64,350,266		27,349,821
	Contingences @ 15%						4,102,473
	Total Cost for Irrigation and Drainage System						31,452,294

Table 3.3: Cost of offices and housing

Item	Building type	Unit	Quantity	Rate in SDG	Rate in USD	Total in USD
1	Senior houses	Ea	6	100,000.00	40,000.00	240,000.00
2	Junior houses	Ea	9	60,000.00	24,000.00	216,000.00
3	Worker's houses	Ea	15	20,000.00	8,000.00	120,000.00
4	Offices	m^2	500	2,400.00	960.00	480,000.00
5	Stores	Ea	1	30,000.00	12,000.00	12,000.00
Total for offices and housing						1,068,000.00

APPENDIX A: CALCULATION OF VOLUMES OF EARTHWORKS IRRIGATION SCHEME

List of tables

Table 2A.1

Calculations of Earthworks

Main Canal

Side Slope 2:1 Bed width =6.00m

Km	Depth to dig in m	Area of cut in m^2	Volume in m^3
-	3.00	31.25	7,812.50
0.50	2.25	22.88	11,440.00
1.00	2.25	20.00	10,000.00
1.50	1.50	13.50	6,750.00
2.00	0.75	5.72	2,860.00
2.50	1.25	10.74	5,370.00
3.00	1.25	10.74	5,370.00
3.50	1.25	10.74	5,370.00
4.00	1.25	10.74	5,370.00
4.50	0.75	5.72	2,860.00
5.00	1.30	11.18	5,590.00
5.50	1.45	13.02	6,510.00
6.00	1.25	10.74	5,370.00
6.50	1.40	12.32	6,160.00
7.00	1.25	10.74	5,370.00
7.50	1.15	9.40	4,700.00
8.00	1.30	11.18	5,590.00
8.50	1.25	10.74	5,370.00
9.00	1.45	13.02	6,510.00
9.50	1.00	8.00	4,000.00
10.00	1.00	8.00	4,000.00
10.50	1.10	8.85	4,425.00
11.00	1.50	13.74	6,870.00
11.50	1.50	13.74	6,870.00
12.00	1.75	16.74	8,370.00
12.50	1.80	17.28	8,640.00
13.00	1.90	18.35	9,175.00
13.50	1.50	13.74	6,870.00
14.00	1.00	8.00	4,000.00
14.50	1.00	8.00	4,000.00
15.00	1.00	8.00	4,000.00
15.50	1.00	8.00	4,000.00
16.00	0.90	6.83	3,415.00

Table 2A.1 (Cont. 1)

Calculations of Earthworks

Main Canal

Side Slop 2:1 Bed width =6.00m

Km	Depth to dig in m	Area of cut in m^2	Volume in $m^3$3
16.50	0.75	5.72	2,860.00
17.00	0.75	5.72	2,860.00
17.50	0.75	5.72	2,860.00
18.00	0.60	4.32	2,160.00
18.50	0.40	2.72	1,360.00
19.00	0.60	4.32	2,160.00
19.50	0.75	5.72	2,860.00
20.00	0.25	1.28	640.00
20.50	1.00	8.00	4,000.00
21.00	0.75	5.72	2,860.00
21.50	0.80	6.08	3,040.00
22.00	0.90	7.02	3,510.00
22.50	0.95	7.61	3,805.00
23.00	1.00	8.00	4,000.00
23.50	1.00	8.00	4,000.00
24.00	1.00	8.00	4,000.00
24.50	1.00	8.00	4,000.00
25.00	1.00	8.00	4,000.00
25.50	0.60	4.32	2,160.00
26.00	0.50	3.50	1,750.00
26.50	0.50	3.50	1,750.00
27.00	0.25	1.98	990.00
27.50	0.20	1.28	640.00
28.00	-	-	-
28.50	-	-	-
29.00	-	-	-
29.50	-	-	-
30.00	-	-	-
30.50	0.20	1.28	640.00
31.00	0.20	1.28	640.00
31.50	0.90	7.02	3,510.00
32.00	1.50	10.50	5,250.00
32.50	1.50	10.50	5,250.00
33.00	1.50	10.50	5,250.00

Table 2A.1 (Cont. 2)

Calculations of Earthworks

Main Canal

Side Slop 2:1 Bed width =6.00m

Km	Depth to dig in m	Area of cut in m^2	Volume in $m^3$3
33.50	1.25	8.22	4,110.00
34.00	1.20	7.68	3,840.00
34.50	1.25	8.22	4,110.00
35.00	0.75	4.06	2,030.00
35.50	0.75	4.06	2,030.00
36.00	0.75	4.06	2,030.00
36.50	0.75	4.06	2,030.00
37.00	0.75	4.06	2,030.00
37.50	0.80	4.48	1,120.00
Total Volume of Earthworks- Main Canal			299,142.5

Table 2A.2

Calculations of Earthworks

Major 1

Side Slop 2:1 Bed width = 4.00 m

km	Depth to dig in m	Area of cut in m^2	Volume in $m^3$3
-	2.75	28.75	7,187.50
0.50	2.50	24.98	12,490.00
1.00	2.25	18.98	9,490.00
1.50	1.75	13.02	6,510.00
2.00	1.50	10.50	5,250.00
2.50	1.25	8.22	4,110.00
3.00	1.25	8.22	4,110.00
3.50	1.75	13.02	6,510.00
4.00	1.50	10.50	5,250.00
4.50	1.50	10.50	5,250.00
5.00	1.25	8.22	4,110.00
5.50	0.70	3.64	1,820.00
6.00	0.50	2.50	1,250.00
6.50	0.50	2.50	1,250.00
7.00	0.50	2.50	1,250.00
7.50	0.50	2.50	1,250.00
8.00	0.50	2.50	1,250.00
Total for major 2			78,337.50

Table 2A.3

Calculations of Earthworks

Major 2

Side Slop 2:1 Bed width = 4.00 m

km	Depth to dig in m	Area of cut in m^2	Volume in $m^3$3
0	2.6	23.48	5,870
0.5	2.5	22.48	11,240
1	20.25	18.48	9,240
1.5	2.2	18.48	9,240
2	1.5	10.5	5,250
2.5	1.5	10.5	5,250
3	1.25	8.22	4,110
3.5	1.25	8.22	4,110
4	0.9	5.22	2,610
4.5	0.6	3.12	1,560
5	0.3	0.88	440
Total for major 2			58,920

Table 2A.4

Calculations of Earthworks

Minor 1A

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	0.25	3.48	870
0.5	1.00	15.70	7,850
1	0.50	6.72	3,360
1.5	1.00	15.70	7,850
2	1.00	15.70	7,850
2.5	0.50	6.72	1,680
Total for minor 1A			29,460

Table 2A.5

Calculations of Earthworks

Minor 1

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	0.1	3.09	773
0.5	0.8	11.8	5,900
1	0.4	5.3	2,650
1.5	0.6	8.3	4,150
2	0.7	10.05	5,025
2.5	0.6	8.3	4,150
3	0.55	7.64	3,820
3.5	0.5	6.72	3,360
4	0.5	6.72	1,680
Total for minor 1			31,508

Table 2A.6

Calculations of Earthworks

Minor 2

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	0.25	3.48	870
0.5	0.7	10.05	5,025
1	0.3	4.05	2,025
1.5	0.5	6.72	3,360
2	1	15.05	7,525
2.5	1.5	22.05	11,025
3	1.25	18.05	9,025
3.5	0.7	10.05	2,513
Total for minor 2			41,368

Table 2A.7

Calculations of Earthworks

Minor 3

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	-0.6	3.09	773
0.5	-0.5	3.09	1,545
1	0.05	3.09	1,545
1.5	0.5	6.72	3,360
2	0.7	10.05	5,025
2.5	0.3	4.05	2,025
3	0.4	5.3	2,650
3.5	0.5	6.72	3,360
4	0.75	11.6	5,800
4.5	0.8	13.05	6,525
5	0.6	8.3	4,150
5.5	0.5	6.72	1,680
Total for minor 3			38,438

Table 2A.8

Calculations of Earthworks

Minor 4

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in $m^3$3
0	0.25	3.48	870
0.5	0.7	10.05	5,025
1	0.8	13.05	6,525
1.5	1.15	11.5	5,750
2	1.1	18.7	9,350
2.5	1	15.7	7,850
3	0.75	11.47	5,735
3.25	0	0	-
Total for minor 4			41,105

Table 2A.9

Calculations of Earthworks

Minor 5

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	0.25	3.48	870
0.5	0.3	4.05	2,025
1	0.6	8.3	4,150
1.5	0.6	8.3	4,150
2	0.7	10.05	5,025
2.5	0.75	11.05	2,763
Total for minor 5			18,983

Table 2A.10

Calculations of Earthworks

Minor 6

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	0.5	6.72	1,680
0.5	0.5	6.72	3,360
1	0.65	9.33	4,665
1.5	0.6	8.3	4,150
2	0.55	7.64	3,820
2.5	0.25	3.48	1,740
3	0.45	6.13	1,533
Total for minor63			20,948

Table 2A.11

Calculations of Earthworks

Minor 7

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	-0.25	3.09	773
0.5	0	3.09	1,545
1	0.25	3.48	1,740
1.5	0.5	6.42	3,210
2	0.7	10.05	5,025
2.5	0.65	9.33	4,665
3	0.65	9.33	4,665
3.5	0.55	7.32	3,660
4	0.5	6.42	1,605
Total for minor 7			26,888

Table 2.12

Calculations of Earthworks

Minor 8

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	0.75	9.68	2,420
0.5	1	15.7	7,850
1	0.65	9.33	4,665
1.5	0.6	8.3	4,150
2	0.55	6.64	3,320
2.5	0.5	6.32	3,160
3	0.45	6.13	3,065
3.5	0.65	9.33	4,665
4	0.7	10.05	5,025
4.5	0.65	9.33	4,665
5	0.6	8.3	4,150
5.5	0.55	6.64	1,660
Total for minor 8			48,795

Table 2A.13

Calculations of Earthworks

Minor 9

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	0.5	6.72	1,680
0.5	0.65	9.33	4,665
1	0.55	7.64	3,820
1.5	0.6	8.3	4,150
2	0.8	11.17	5,585
2.5	0.75	9.68	4,840
3	0.55	7.64	3,820
3.5	1	15.7	7,850
4	0.65	9.33	4,665
4.5	0.6	8.3	4,150
5	0.55	7.64	3,820
5.5	0.5	6.72	1,680
Total for minor 9			50,725

Table 2A.14

Calculations of Earthworks

Minor 10

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	0.55	7.64	1,910
0.5	0.75	9.68	4,840
1	0.7	10.05	5,025
1.5	0.65	9.33	4,665
2	0.7	10.05	5,025
2.5	0.3	4.05	2,025
3	0.25	3.48	870
Total for minor 10			24,360

Table 2A.15

Calculations of Earthworks

Minor 11

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	0.25	3.48	870
0.5	0.5	6.42	3,210
1	1	15.7	7,850
1.5	0.95	14.78	7,390
2	0.6	8.3	4,150
2.5	0.6	8.3	4,150
3	0.75	9.68	2,420
Total for minor 11			30,040

Table 2A.16

Calculations of Earthworks

Minor 12

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	0.2	3.09	773
0.5	0.7	10.05	5,025
1	0.4	5.3	2,650
1.5	0.7	10.05	5,025
2	0.7	10.05	5,025
2.5	0	3.09	1,545
3	0.6	8.3	4,150
3.5	0.3	4.05	2,025
4	0.7	10.05	2,513
Total for minor 12			28,730

Table 2A.17

Calculations of Earthworks

Minor 13

Half bed width = 1.00 m

km	Command m	Area of cut in m²	Volume in m³
0	0.2	3.09	773
0.5	0.6	8.3	4,150
1	0.7	10.05	5,025
1.5	0.5	6.42	3,210
2	1.25	18.05	9,025
2.5	0.4	5.3	2,650
3	0.2	3.09	1,545
3.5	1	15.7	3,925
Total for minor 13			30,303

Table 2A.18

Calculations of Earthworks

Minor 14

Half bed width = 1.00 m

km	Command m	Area of cut in m²	Volume in m³
0	0.25	3.48	870
0.5	1.25	18.05	9,025
1	0.4	5.3	2,650
1.5	0.3	4.05	2,025
2	0.7	10.05	5,025
2.5	0.25	3.38	1,690
3	0.6	8.3	4,150
3.5	1	15.7	3,925
Total for minor 14			29,360

Table 2A.19

Calculations of Earthworks

Minor 15

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	0.2	3.09	773
0.5	0.3	4.05	2,025
1	0.7	10.05	5,025
1.5	0.2	3.09	1,545
2	0.55	7.64	3,820
2.5	0.4	5.3	2,650
3	0.6	8.3	4,150
3.5	1	15.7	3,925
Total for minor15			23,913

Table 2A.20

Calculations of Earthworks

Minor 16

Half bed width = 1.00 m

km	Command m	Area of cut in m^2	Volume in m^3
0	0.3	4.05	1,013
0.5	0.7	10.05	5,025
1	0	3.09	1,545
1.5	0.5	4.42	2,210
2	0.7	10.05	5,025
2.5	0.3	4.05	2,025
3	1	15.7	7,850
3.5	1	15.7	3,925
Total for minor 16			28,618

Table 2A.21

Calculations of Earthworks

Drains Earthworks volumes

Protective Drain	Data
Length in km	47.50
Bed Width in m	4.00
Depth to Dig in m	1.50
Area of Cut in m²	10.50
Total volume of earthwork (protective drains- single bank)	498,750.00
Minor Drains	Data
Length in km	50.00
Bed Width in m	1.00
Depth to Dig in m	1.00
Area of Cut in m²	3.00
Total volume of earthwork (minor drains)	150,000.00
Collective drains	Data
Length in km	52.50
Bed Width in m	1.00
Depth to Dig in m	1.00
Area of Cut in m²	3.00
Total volume of earthwork (collective drains)	157,500.00
Grand total for drains	806,250.00

Table 2A.22

Calculations of Earthworks

Summary of Earthworks volumes

Structure	Length in km	Volume in m³
Main canal	37.700	299,142.50
Major 1	7.750	78,337.50
Major 2	5.250	58,920.00
Minors	63.250	543,537.50
Protective drains	47.500	498,750.00
Minor drains	50.000	150,000.00
Collective drains	52.500	157,500.00
Total EW volume	263.950	1,786,187.50