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Final Report

Annex 1: Climatology, Hydrology and Water Resources

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Annex 1
Climatology, Hydrology and Water Resources

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ABBREVIATIONS AND ACRONYMS

Fiscal Year:
Egypt: 01 July – 30 June
Ethiopia: 08 July – 07 July
Sudan: calendar year

MEASURES

km	=	kilometre
km^2	=	square kilometre
m	=	metre
m^3	=	cubic metre
mm	=	millimetre
Mm^3	=	million cubic metres
BCM	=	billion cubic metres
1 ha	=	2.38 feddans
1 feddan	=	0.42 ha

ABBREVIATIONS

ADB/F	African Development Bank/Fund
AGS	Addis Geo Systems
ANRS	Amhara National Regional State
API	Aerial Photo Interpretation
ARBID/MPS	Abbay River Basin Integrated Development Master Plan
ASTM	American Society for Testing of Materials
BCM	Billion Cubic Meters = 1 km^3
B/C ratio	Benefit Cost ratio
BH	Borehole
BS	British Standards
CEC	Caution Exchange Capacity
CS	Complementary Surveys
DC	Direct electrical current
DIU	Dams Implementation Unit (Sudan)
DOCS	Date of Commencement of Services
dS/m	deci-Siemens per meter
d/s	downstream
EC	Electrical conductivity
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EMA	Ethiopian Mapping Agency
ENCOM	Eastern Nile Council of Ministers
ENPV	Economic Net Present Value
ENTRO	Eastern Nile Technical Regional Office
ENSAP	Eastern Nile Subsidiary Action Program
ENSAPT	Eastern Nile Subsidiary Action Program Team
ENCOM	Eastern Nile Council of Ministers
EPMS	Environmental Protection Monitoring Strategy
ESP	Exchangeable Sodium percentage
ESCP	Ethiopian Standard Code of Practice
EWA	Ethiopian Water Authority
FAO	Food and Agriculture Organization

FNPV	Financial Net Present Value
FIRR	Financial Economic Rate of Return
G	Gravity
GOE	Government of Egypt
GFDRE	Government of the Federal Democratic Republic of Ethiopia
GOS	Government of Sudan
GPS	Geographical Positioning System
GRP	Glass reinforced polyester
GTZ	German Technical Cooperation Agency
Ha	hectare
HDPE	high density poly ethylene
HP	hydro power
HQ	High Quality (classification for drilling core)
ICCON	International Consortium for Co-operation on the Nile
ICT	International Consultants and Technocrats Pvt Ltd.
IEE	Initial Environmental Examination
ISL	Isambert Salembier Lino Consultants
LUT	Land Utilisation Type
LUR	Land Use Requirement
masl	Meters above sea level
MC	Main Conveyor
MCA	multi-criteria analysis
mcm	Million Cubic Meters
MoIWR	Ministry of Irrigation and Water Resources (Sudan)
MoWR	Ministry of Water Resources (Ethiopia)
mS	micro Siemens
N1, N2	Land suitability classes
NBI	Nile Basin Initiative
NEDECO	Netherlands Engineering Consultants (Consulting Firm)
NELSAP	Equatorial lakes subsidiary action programme
NELT	North East Lake Tana
NGO	Non-Governmental Organization
Nile-SEC	NBI Secretariat
Nile-COM	Nile Council of Ministers
NQ	Normal Quality (classification of drilling core)
OIDA	Oromiya Irrigation Development Authority
ONRS	Oromya National Regional State
O&M	Operation and Maintenance
P	Pumping
PA	Peasant Association
PF	Pre-feasibility
PFS	Pre-feasibility Study
PMO	Project Management Office
PS	Pump station
RfP	Request for Proposal
RQD	Rock Quality Designation
S1, S2, S3	Land suitability classes
SAP	Subsidiary Action Programmes
SAR	Sodium Adsorption Ration
SEIA	Social and Environmental Impact Assessment
SDS	Small Disturbed Sample
SPT	Standard Penetration Test
SPT-N	Standard Penetration Test-Normal

SVP	the Shared Vision Programme
TAMS	Tippets-Abbett-McCarthy-Stratton Engineers and Architects
tc	ton of cane
T_c	time of concentration (only used in hydrological calculations)
TCC	Technical Coordinating Committee
TDS	Total Dissolved Solids
TLU	Tropical Livestock Unit (metabolic weight equivalence)
TOR	Terms of Reference
TRBID/MPS	Abbay River Basin Integrated Development Master Plan
TTB2	a set of geological formations
UA	Unit of Account
u/s	upstream
USBR	United States Bureau of Reclamation
UTM	Universal Trans Mercator
VES	Vertical Electric Sounding
WAPCOS	Water and Power Consultancy Services (India) Ltd.
WB	World Bank
WRMP	Water Resources Management Policy
WUA	Water Users Association
WWD&SE	Water Works Design and Supervision Enterprise

CONVERSION FACTORS
0.42 ha = 1.00 feddan

1. CLIMATOLOGY

1.1 SUDAN CLIMATE

Although Sudan lies within the tropics, the climate ranges from arid in the north to tropical wet-and-dry in the far southwest. Temperatures do not vary greatly with the season at any location; the most significant climatic variables are rainfall and the length of the dry season. Variations in the length of the dry season depend on which of two air flows predominates dry north-easterly winds from the Arabian Peninsula or moist south-westerly winds from the Congo River basin.

From January to March, the country is under the influence of the dry north-easterlies. There is practically no rainfall countrywide except for a small area in north-western Sudan in where the winds have passed over the Mediterranean bringing occasional light rains. By early April, the moist south-westerlies have reached southern Sudan, bringing heavy rains and thunderstorms. By July the moist air has reached Khartoum, and in August it extends to its usual northern limits around Abu Hamad, although in some years the humid air may even reach the Egyptian border. The flow becomes weaker as it spreads north. In September the dry north-easterlies begin to strengthen and to push south and by the end of December they cover the entire country. Yambio, close to the border with Zaire, has a nine-month rainy season (April-December) and receives an average of 1,142 millimetres of rain each year; Khartoum has a three-month rainy season (July-September) with an annual average rainfall of 161 millimetres; Atbarah receives showers in August that produce an annual average of only 74 millimetres. In some years, the arrival of the south-westerlies and their rain in central Sudan can be delayed, or they may not come at all. If that happens, drought and famine follow. The decades of the 1970s and 1980s saw the south-westerlies frequently fail, with disastrous results for the Sudanese people and economy.

Temperatures are highest at the end of the dry season when cloudless skies and dry air allow them to soar. The far south, however, with only a short dry season, has uniformly high temperatures throughout the year. In Khartoum, the warmest months are May and June, when average highs are 41° C and temperatures can reach 48° C. Northern Sudan, with its short rainy season, has hot daytime temperatures year round, except for winter months in the northwest where there is precipitation from the Mediterranean in January and February. Conditions in highland areas are generally cooler, and the hot daytime temperatures during the dry season throughout central and northern Sudan fall rapidly after sunset. Lows in Khartoum average 15° C in January and have dropped as low as 6° C after the passing of a cool front in winter.

The haboob, a violent dust storm, can occur in central Sudan when the moist south-westerly flow first arrives (May through July). The moist, unstable air forms thunderstorms in the heat of the afternoon.

The initial down flow of air from an approaching storm produces a huge yellow wall of sand and clay that can temporarily reduce visibility to zero.

1.2 REGION CLIMATE

The Blue Nile Region comprises two sub-regions, the Blue Nile River and its two tributaries Dinder and Rahad. The climate within the Blue Nile varies from North to South. For the propose of estimating irrigation water requirements, the region has been divided into representative hydro meteorological zones, the boundaries of the zones being taken at 100 m intervals isohyets as shown in Figure 1.1. Annual evaporation is shown in Figure 1.2. The meteorological stations used for this analysis, their mean annual rainfall (mm) and mean annual evaporation (mm/day) are shown in Table 1.1.

Evaporation data are the Penman values calculated by Sudan meteorological services from basic climate data. Note that the record used is for the period from 1960 to 2000.

Table 1.1: Mean Annual Evaporation Rates in the Blue Nile Region

Station	Mean annual Rainfall (mm)	Mean annual evaporation mm/day
Kamlin	247	7.5
Wad Medani	362	7.3
Sennar	472	6.9
Singa	579	6.4
Roseires	647	6.1
Hawata	610	6.3
Abu Naama	572	6.2

Other important climatic data necessary for the calculation of crop water requirements are given in Tables (1.2, 1.3, 1.4 and 1.5) for major towns in the area

Table 1.2: Sennar Normals 1971 – 2000

Month	Max Temp °C	Min Temp °C	Relative Humidity %	Sunshine Hrs	Wind speed Ms^{-1}
J	33.4	13.2	38	10.4	1.5
F	35.5	14.8	33	10.2	1.5
M	38.8	17.8	26	9.8	1.9
A	41.4	21.2	26	10.1	1.9
M	40.8	24.3	36	9.2	1.9
J	39.0	24.3	47	8.7	2.2
J	35.5	22.6	62	6.8	2.2
A	34.0	22.1	69	7.1	2.2
S	35.3	22.2	65	8.1	1.9
O	37.7	22.0	52	9.3	1.5
N	36.7	17.7	38	10.3	1.5
D	34.0	14.3	40	10.3	1.5

Table 1.3: Wad Medani Normals

Month	Max Temp °C	Min Temp °C	Relative Humidity %	Sunshine hrs	Wind speed ms^{-1}
J	32.9	14.1	34	10.4	2.2
F	34.7	15.9	27	10.2	2.2
M	38.1	18.9	22	10.3	2.2
A	41.2	21.8	21	10.3	1.9
M	41.5	24.6	32	9.8	1.9
J	40.3	25.1	42	9.0	3.1
J	36.6	23.4	59	8.5	3.1
A	35.1	22.6	68	8.1	2.8
S	36.2	22.3	65	8.9	1.9.
O	38.3	22.0	50	9.9	1.2
N	36.7	18.4	36	10.6	1.9
D	33.7	15.4	37	10.4	1.9

Table 1.4: Damazin Normals

Month	Max Temp °C	Min Temp °C	Relative Humidity %	Sunshine hrs	Wind speed ms^{-1}
J	35.2	16.6	30	10.2	1.9
F	36.9	18.3	23	10.4	2.8
M	39.5	21.7	20	9.8	2.2
A	40.6	24.2	25	10.0	1.5
M	38.5	24.8	44	9.3	1.5
J	35.3	22.6	61	7.3	1.5
J	32.1	21.4	74	6.1	1.5
A	31.3	21.0	79	6.1	1.2
S	32.5	20.9	76	7.4	1.0
O	34.9	21.3	67	8.8	1.0
N	36.8	19.0	40	10.0	2.2
D	35.6	16.9	33	10.3	2.5

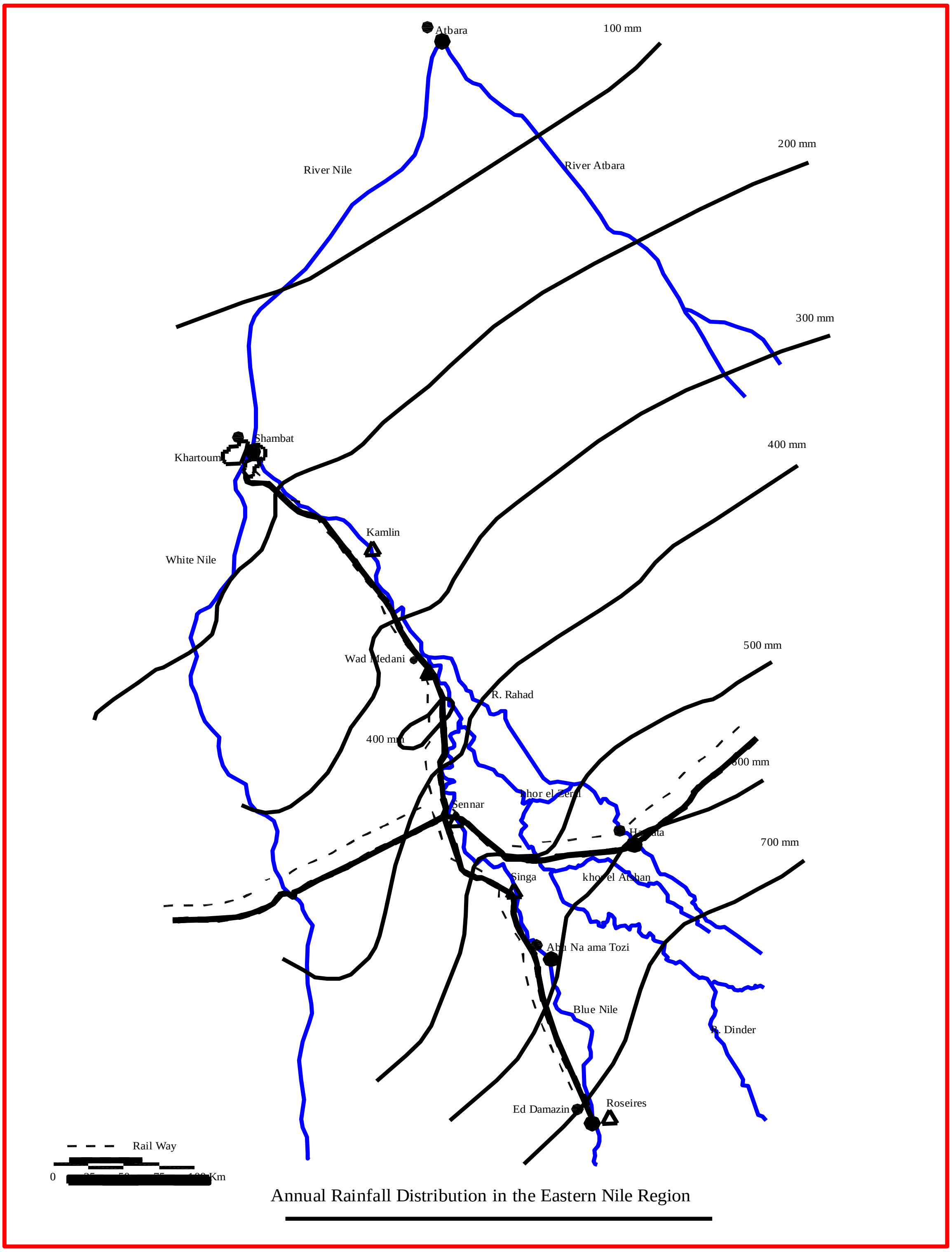

Figure 1.1: Annual Rainfall Distribution in the Blue Nile Region

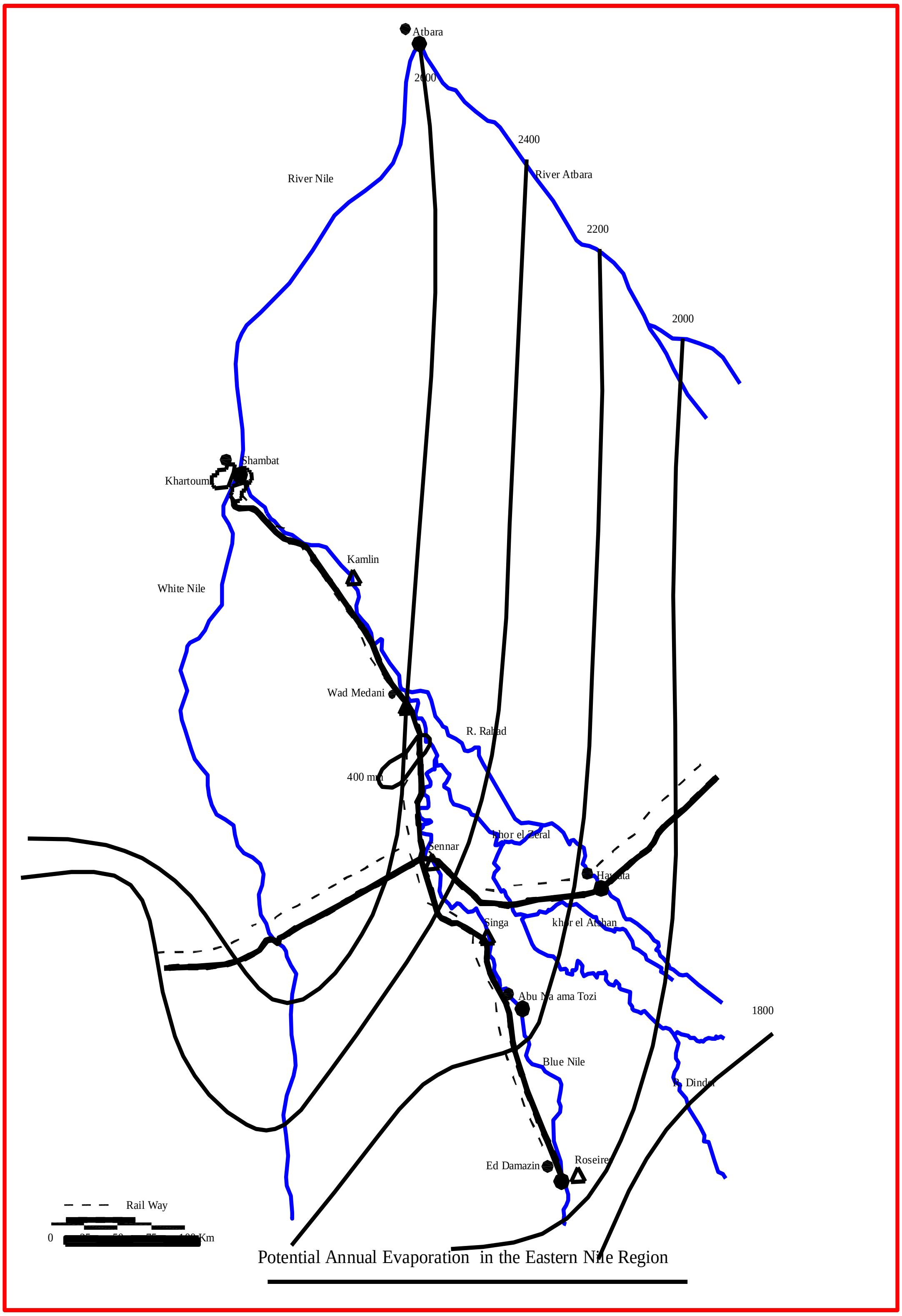

Figure 1.2: Potential Annual Evaporation in the Blue Nile Region

2. Hydrology

2.1 Water Resources

2.1.1 The Blue Nile

The Blue Nile and its tributaries all raise on the Ethiopian Plateau at an elevation of 2,000 to 3,000 meters above M.S.L. The river has cut a deep gorge through the Ethiopian Plateau, which is in some places 1,200 meters below the terrain level on either side. Numerous rock outcrops occur in the riverbed, the last of which are a few kilometres South of Rosaries, some 1,000 km from its source beyond Lake Tana, and known as the Damazin rapids. The Blue Nile emerges from the Plateau close to the Western border of Ethiopia, where it turns north-west and enters the Sudan at an altitude of 490 meters above M.S.L. Just before crossing the frontier, the river enters the clay plain, through which it flows over a distance of about 735 km to Khartoum. At this point, the Blue Nile joins the White Nile to form the main stem of the Nile River. The average slope of the river between Lake Tana and the Ethiopian frontier is about 1.6 m/km. From the frontier to Khartoum the slope is much less, about 15 cm/km. The Blue Nile Basin has a catchments area of approximately 324,530 km^2. The greater part of this catchment is located in Ethiopia. Two dams have been constructed on the Blue Nile, one at Sennar and one at Roseires, respectively at some 350 and 620 km southeast from Khartoum. The Sennar dam was completed in 1925, with an initial storage capacity of about 0.9 milliards m^3. By now, its live storage has been reduced to about 0.4 milliards m3, according to a recent bathymetric survey. The dam has been constructed for irrigation of the Gazira scheme.

The Roseires reservoir, completed in 1966 with an initial storage capacity of 3-milliard m^3 is operated in conjunction with Sennar with the purpose of satisfying the irrigation requirements upstream and downstream of the dam, and generating the maximum possible power. At a later stage, the volume of the reservoir was upgraded to about 3.35 milliard m^3. To avoid siltation of the reservoirs as much as possible, filling is delayed to the latest possible time during the falling flood. Nevertheless, by now the live storage of Roseires reservoir has been reduced to about 2.2 milliards m3.

2.1.2 Dinder and Rahad

Downstream of the Sudan border two tributaries of some importance join the Blue Nile in the reach between Sennar and Wad Medani, namely the Dinder and Rahad rivers. They join the Blue Nile 258km and 189 km respectively upstream Khartoum. Both rivers originate from the Ethiopian Plateau, about 30 km west of Lake Tana.

The two rivers which are sub basins of the Blue Nile have equal catchment areas of approximately 35,000 square kilometres each. Such catchment areas lie partly in Sudan and partly in Ethiopia. They are seasonal streams that flow from June/July to November/December, and they reduced to pools during the rest of the year. Figure 2.1 shows the average daily hydrographs for the Dinder and Rahad produced from daily record for the period (1973-2006).

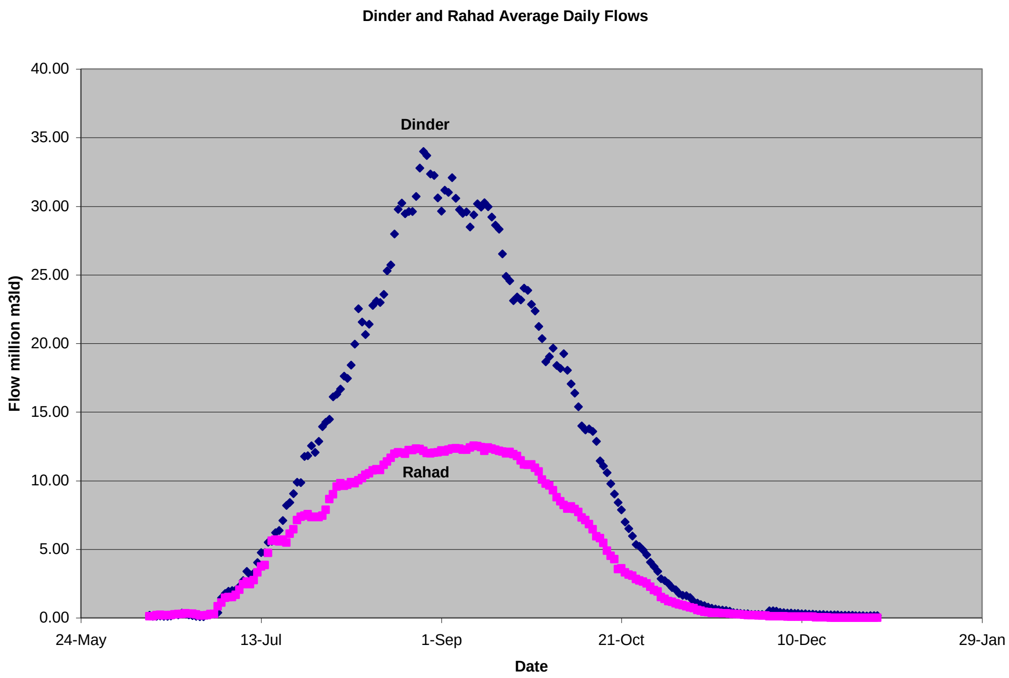

Figure 2.1: Dinder and Rahad Daily Flow Hydrographs

As can be seen that the two rivers have very similar flow patterns. The maximum flow occurs during the period 20 August to 20 September.

It is true that the Dinder and Rahad rivers although they have almost the same catchment areas and the same rainfall , the Dinder flow is almost three times the Rahad flow as measured at the gauging stations of Gwaisi and Hawata which are situated at the downstream side of the two rivers. The main reason is that, Rahad River loses much of its water through over bank spilling at its upstream reaches. The spilled water then flows down to fill in the depressions and low land areas including the Dinder Park depressions and part of this water discharges into the Dinder channel contributing to the Dinder flow itself. Another reason is that there are many Wadis discharging into Dinder River such as Khor Al Atshan.

2.1.3 Annual Flows of the Blue Nile, Dinder and Rahad

River flow data for the Blue Nile and its tributaries Dinder and Rahad which has been obtained from the Ministry of Irrigation and water Resources for the period 1973 to 2006 for three stations covering all tributaries (El Deim on the Blue Nile, Gwaisi on the Dinder and Hawata on the Rahad). The annual flow and flow characteristics are summarized in Table 2.1.

Table 2.1: Annual Flows for the Blue Nile, Dinder and Rahad

Tributary	Station	Total annual (bcm)	Flow characteristics
Blue Nile	Ed Deim	50.7	Average daily peak discharge falls from 535 mm/day in August to 11 mcm/day in April
Rahad	Hawata	1.09	Flow from Jun/ July to November/December
Dinder	Gwaisi	3.0	Flow from June/July to November/December

2.1.4 Flow Duration Curves for Dinder and Rahad

From the available daily flow, data an average daily hydrograph for the Dinder and Rahad have been obtained. Flow duration curves showing the percentage of time at a particular flow is equalled or exceeded have been developed as shown in Figures 2.2 and 2.3.

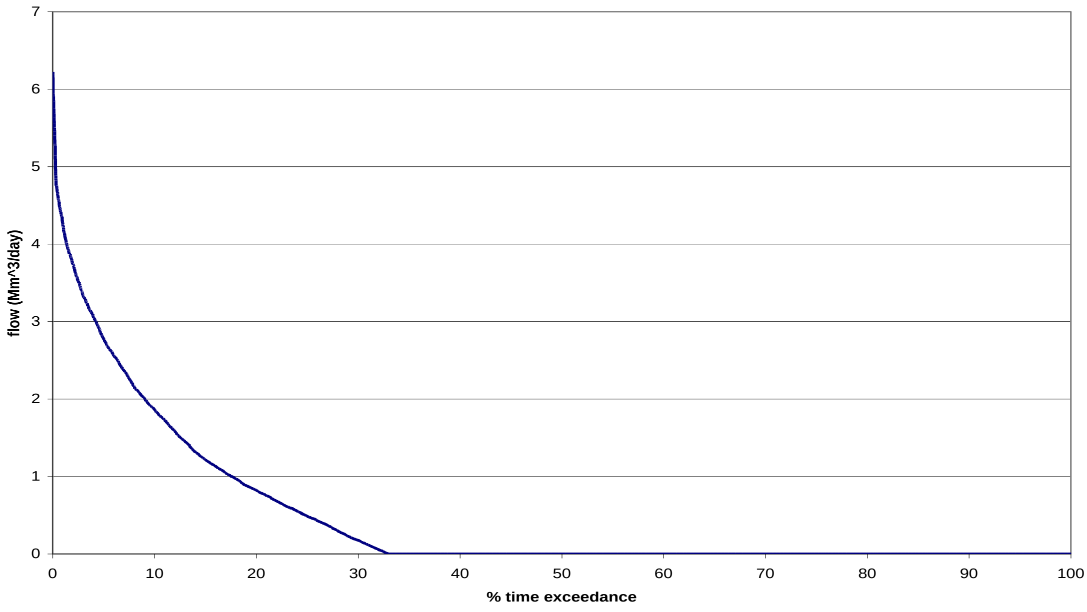

Figure 2.2: Dinder at Gwaisi flow duration curve

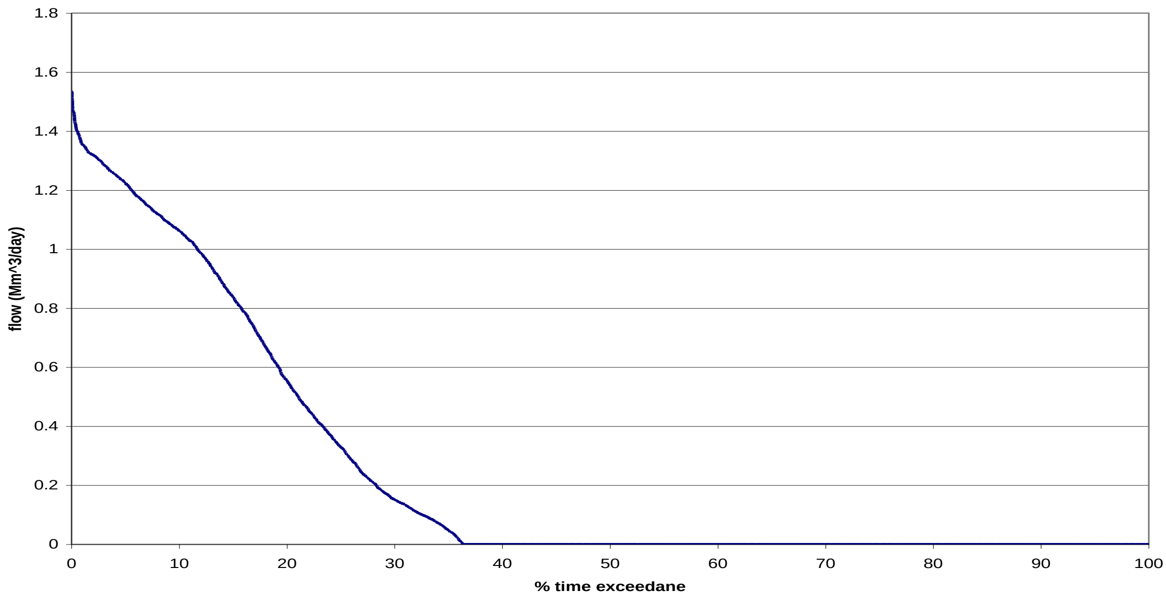

Figure 2.3: Rahad at Hawata flow duration curve

2.1.5 Flood Frequency Analysis for Dinder and Rahad

Flood frequency analysis for Dinder and Rahad flows has been carried out as follows:

1. Daily flow data for a period of 27 years, for two stations on the Dinder River, Rahad River were screened, missing data were filled and the annual maximum flood series for the stations were extracted for frequency analysis.

2. At site frequency, analysis was carried out at each station individually and the best distribution to fit the data was determined. The tested distributions were the Extreme value type I (EVI), 2-parameter log normal, 3-parameter log normal and Pearson type III distributions.

3. The best distribution was selected based on the Chi-square test, standard error of estimates of floods for various magnitudes and the root mean square error (RMSE).

4. The results shows that, in general, all the distributions tested were closely grouped but, the 3-parameter log normal is the best good.

5. It is true that when one looks visually at the curves of different distributions, the results look close for various return periods. However, when using objective criteria such as the Root Mean Square error or Chi-Square tests, the three parameter Log Normal Distribution is the one which gives the lowest values and hence it is considered as the best of all the tested distributions.

The maximum daily flow for various return periods is given in Table 2.2.

The daily row data were not included in the report because it is too many and requires almost 54 pages. However, the extracted annual maximum series for the two rivers which were used for frequency analysis are given in the Table at the end. The methodology employed for testing the data is the double mass curve. If there is any wrong value due to typing mistake for instance, it is clearly reflected in the double mass curve. As for filling the missing values, there were no big gaps in the data but it was found that very few daily values were missing. These were filled by taking the average of the day before and the day after the missing day.

Table 2.2: Estimated flood flows in Million m^3/day for various return periods for all stations

Time in years	Gwaisi (3LN)	Hawata (3LN)
5	58.99	15.9
10	67.48	16.8
20	75.32	17.5
50	85.10	18.3
100	91.48	18.8
200	99.30	19.4
250	101.35	19.5
500	108.37	20.0

As can be seen, the 50 and 100 years return period flows of Dinder are 85.1 and 91.48 million m^3/day respectively (equivalent to 983 and 1,060 m^3/sec respectively). Since the difference is not significant, it is advisable to adopt the 100-year flood as design flow.

The frequency analysis, Chi Square and the standard error of estimates are shown below in table 2.3.

Table 2.3: Chi Square and RMSE of Various Distributions for Dinder and Rahad Stations

Station	Parameter	EV1	2LNIII	3LN	PIII
Gwaisi Dinder	RMSE	21.23	20.49	17.83	25.34
	χ^2	5.93	5.93	5.52	5.93
Hawata Rahad	RMSE	18.44	10.36	9.85	12.23
	χ^2	9.49	8.42	7.82	9.49

2.1.6 Khor Al Atshan

Khor Al Atshan (Figure 2.4) drains an area of about 840 km^2 with an average annual flow of 60 million m^3 estimated by the Rational Model with a runoff coefficient of 10%. Upstream the crossing of the proposed canal, the catchment area was subdivided into one hour isochrones yielding a maximum sub area of 50 km^2. The Rational model was then used to estimate the peak discharge. Using the same runoff coefficient as above and a maximum hourly rainfall of 50 mm, the peak discharge was found to be 70 m^3/s.

Khor Al Atshan is not gauged and therefore its peak discharge was estimated using time area method as discussed in the report. No detailed rainfall data are available at Al Atshan catchment. However, looking at the daily rainfall over the Blue Nile area, a maximum daily rainfall of around 100 mm occurred in 1988 for a duration of approximately 2 hours. Therefore a rainfall of 50 mm /hr was selected as the maximum in record but it was not based on frequency analysis. Using a runoff coefficient of 10%, and a maximum one hour isochrone sub area of 50 km^2 (as obtained from catchment map), the maximum discharge is $Q^p = 0.1x50x50/3.6 = 70\ m^3/s$

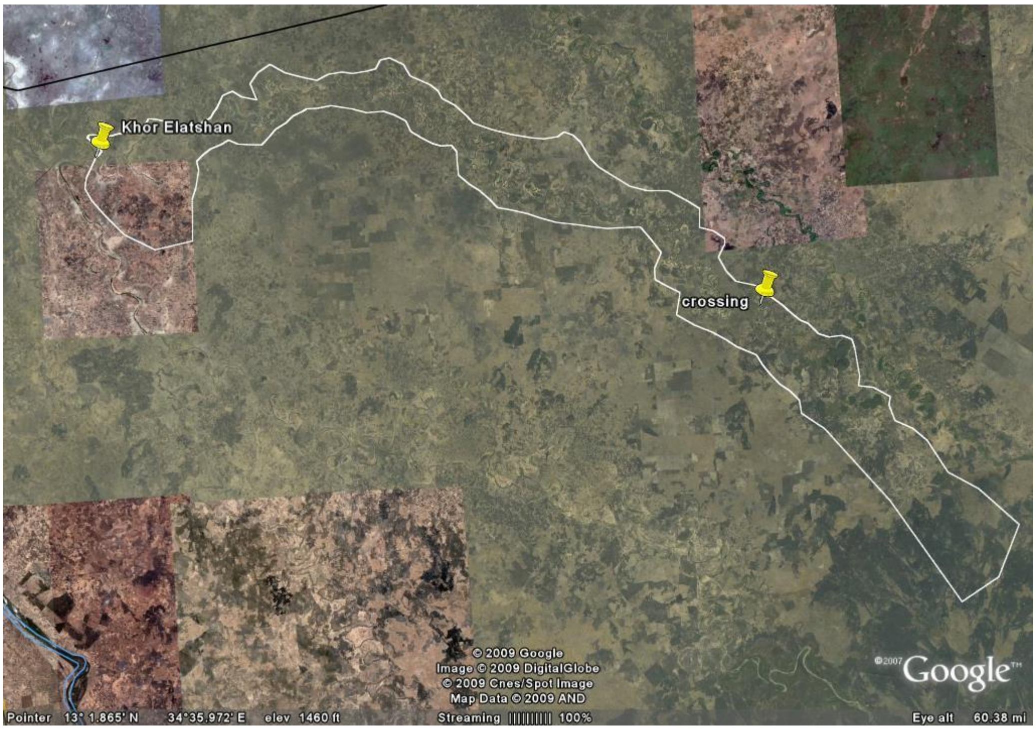

Figure 2.4: Khor Al Atshan Catchment

2.1.7 Water Quality

No water quality data for Dinder and Rahad were found. However, data for the Blue Nile downstream Rosaries are available and can be considered as similar to Dinder and Rahad. Summary of the data is given in Table 2.4 below. Therefore, the water quality is good varying from class C1-S1 for most of the year to C2-S1 at the period of low river flow (see Figure 2.3) .

Table 2.4: Water Quality parameters

Parameter	Highest recorded	Lowest Recorded
TDS (mg/l)	220	100
EC (mmohs/cm)	430	120
SAR	1.6	1.2

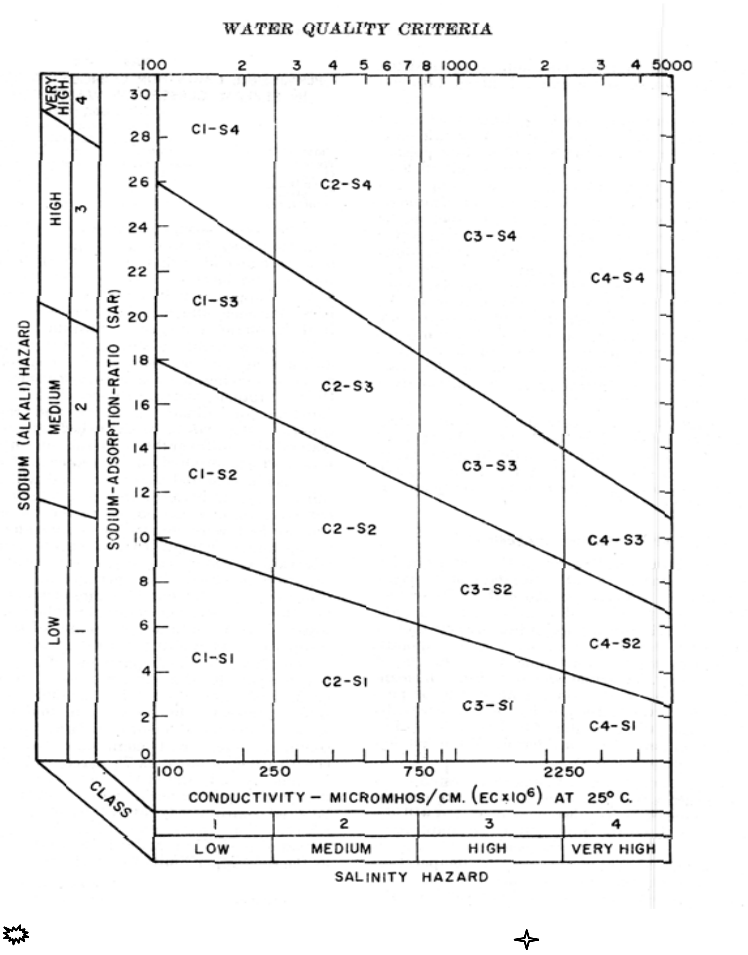

Figure 2.5: Suitability of Water for Irrigation

2.2 EXISTING IRRIGATION SCHEMES

Large-scale irrigation began in the 1920's with the construction of Sennar Dam on the Blue Nile and the commissioning of the first part of the Gezira scheme in 1925. During the early 1960's major expansions took place in the Gezira and other schemes. The major Existing schemes and their approximate cultivable areas in feddans as follows (see Table 2.5):

Table 2.5: Areas of Existing Irrigation Schemes (feddans)

Scheme	NCA	Totals
Blue Nile upstream of Sennar		
Private pump schemes	7,971	
PAPC pump schemes	235,788	
Abu Naama (Kenaf)	30,000	
Es Ski	86,920	
NW Sennar (Sugar)	49,142	
Gazira/Manage	2,081,692	
Blue Nile downstream of Sennar		
Private pump scheme	55,478	
PAPC pump schemes	34,620	
Hurga, Nur ed Din	22,256	
Guneid (sugar)	38,270	
Guneid extension	45,367	
Total Blue Nile		2,687,504
Atbara		
New Halfa	401,000	
Total Atbara		401,000

2.3 FUTURE PROJECTS

According to the Master Plan, the future irrigation projects that make use of the Eastern Nile water are shown in table 2.6.Table 2.6: Future Irrigation Projects in the Blue Nile and River Atbara regions

Project	Area (feddan)	Area (ha)
Blue Nile		
Rahad II	300,000	126,000
Kenana (I,II,III,IV)	1,200,000	504,000
Rosaries	425,000	178,500
Atbara		
Upper Atbara	595,000	249,900
Lower Atbara (GW)	63,000	26,460

2.3.1 RAHAD PROJECT PHASE II

Project Location:

Rahad Project Phase II lies within latitudes 13° – 40' and 15° – 10' and longitude 33° – 40' to 34° – 20' E. The project area, which lies on the eastern bank of Rahad River, is shared between Gazira and Gadarif States.

Background:

The net irrigated area for this phase of the project is "440,000 Fed" 185,000 ha. The project was planned to be irrigated by gravity from Roseires Dam, after the implementation of Roseires Dam heightening. A link canal from Roseires Dam crosses Dinder River through siphon then joins Rahad River at Wad Misken Barrage. This barrage is proposed to regulate the river flows to satisfy the requirement of Rahad Project Phase I summer crops, during rainy season "autumn" through Rahad Barrage at Abu Rakham, and divert water to Rahad Project Phase II through a main canal.

Due to the financial constrains the Roseires Dam Heightening been delayed. In addition, the idea of saving water at the Dam for more power generation before releasing it down stream has been found more valuable than diverting the whole amount of water directly by gravity to this phase of the project. Therefore Rahad Phase I has been implemented first, by diverting part of Rahad River flows, during flood season, by constructing Abu Rakham Barrage across the river. This barrage regulates the river flows and diverts part of its flows to irrigate the agricultural land, of an area 125,000 ha, during flood period "summer crops". In addition to this barrage a supply canal, from Maina Pump Station at the Blue Nile River, was constructed to supply the project with water for winter crops. This supply canal crosses Dinder River through siphon. This supply canal released its flows up stream Abu Rakham Barrage. Originally Rahad Project (355,000 ha) was planned to be irrigated by gravity from Roseires Dam after heightening.

The proposal now under study is to start Rahad Project Phase II by constructing a barrage across Dinder River to divert part of the river flows to Rahad River, to be released at Wad Misken Barrage. The Dinder River contribution in irrigating the project could be done by constructing a link canal between Dinder and Rahad Rivers, to convey the required flow.

Sudan finds out that it is feasible to start Rahad Project Phase II early by constructing Dinder and Rahad barrages using a link canal. Dinder river water, which starts early in June and ends later in November, with an average annual flow exceeds Rahad river annual, with these two major infrastructures completed Rahad Project Phase II could be started. Irrigating summer crops as a supplementary irrigation for the rain fed lands; the possible irrigable area could be up to 85,000 ha. This is possible if producing quick maturing crops that sown early in July harvested early in November; the proposed crops like Medium Stable Cotton, Groundnuts, Light Dura "Gadam al Hamam, Hageen, Wad Ahmed and Maiow".

After the completion of Roseires Dam Heightening project a link canal between Roseires Dam and Dinder Barrage with its infrastructures could be implemented to release water from Roseires Dam to complete Rahad Project Phase II to its designed area "185,000 ha". With this action, diverting water from Roseires to the project area, the winter crops could introduce using gravity irrigation for the whole project. By these means, we are utilizing part of floodwater from both Rahad and Dinder rivers, saving water at Roseires Dam for hydropower generation.

How this system works?

Wad Misken barrage across Rahad River regulates the flood flows during rainy season, for Dinder and Rahad rivers so as to satisfy the needs of Rahad Project Phase I, through Abu Rakham barrage as a dawn stream regulator, and to divert water to Rahad Project Phase II for summer crops, "now and in future", through the main canal.

This same barrage regulates water transported from the Roseires Dam, after the heightening project completion, with the link canal through Dinder River barrage to the project.

Rahad Project Phase II Supplementary Irrigation Phase:

- The site for the proposed Wad Misken barrage across Rahad River has been studied.
- Cross sections from the site up to the affected area, by the backwater curve, are available.
- A report for the geological formation at Wad Misken barrage site, is available "Mainly clay".
- The profile of the proposed link canal from Dinder river barrage up to Rahad river barrage, at Wad Misken, is available.
- The topographical survey map proposed land for irrigation (100,000 ha), between Rahad river up to Jebel Al Faw with a grid 200 x 200m is available.
- The proposed main canal profile, from Wad Misken barrage (Rahad River), was set and surveyed.

Facts for Consideration:

- Dinder river maximum discharge during flood is about 430 cubic meters per second, bed width 200 meter and depth is 4.00 meter.
- The link canal from Dinder River up to Rahad River crosses many Khors and Wadis, the major one is Khor Al Atshan with a maximum discharge 70 cubic meters per second, bed width 100 meter and depth 4.00 meter.
- Rahad riverbed width is about 150 meter and depth about 4.00 meters.
- The main canal from Wad Misken barrage crosses Khor Abu Farga, the main watercourse in the area.

3. Ground Water Resources

3.1 Introduction

The climate conditions at Hawata Locality are simply of very hot summer and hot winter, with irritate rainfall varies in both time and place. Its amount on average is .about 400mm/y. This year in particular the drought is very severe to the extent that very limited rainfall confined to August only and then it stopped. Even in the catchment of Dinder River and Rahad River the amount of rain this year at the higher lands in the border-area and at the extension of the catchments of those rivers inside Ethiopia is tremendously low. Consequently, the runoff is very low. Along Atshan River there is no runoff at all. The limited rain water caused the pasture areas to have no grasses as a result the animals are in bad situation within the locality.

The green cover including the reserved forests is hardly affected by the fit of drought. The irrigated agricultural schemes are as well suffer from the low level of the rivers. Many problems are facing the animal herds in the locality due to less fodder and shortage of water. Hence it seems to be urgent to find suitable solution to the existing crises.

The locality is blessed with abundant resources of both ground and surface waters. Unfortunately, the population is not distributed in the same pattern as are the water resources, and the hydrologic cycle does not operate at steady state. As a result, local water shortages have already occurred in most parts of the locality and it may be expected to increase in frequency in the coming years.

3.2 Geological Setting of the Area

The area under consideration has the following geological units starting from younger towards older depth wise.

3.2.1 Superficial deposits which belong to quaternary and recent

They consist of alluvial sediments brought about by running water along the seasonal Khors and small Wadis and the sheet flow; or along the seasonal rivers of Rahad, Dinder and Atshan. The superficial deposits are also found near foot of out crops as they are derived by gravity to form what is called (Talus), of course sands and boulders. The superficial deposits of what is called (Azaz) consist of the clays of the plains. In the alluvial deposits some groundwater can be extracted from shallow wells either hand dug or by machines as slim boreholes installed by hand pumps

3.2.2 Atshan Formation

This is composed of sands, clays and gravels of unconsolidated conditions. It shows rapid facies changes vertically and laterality. It most of the time overlies the Basement Complex uncomfortably. The thickness ranges from few meters to 100 m in the deep basins which were formed tectonically, pre Umm Ruwaba formation or post Nubian episodes. These sediments are contental deposits.

3.2.3 Umm Ruwaba Formation

Umm Ruwaba formation is typical Tertiary sediments in Sudan. It covers about 17% of the Sudan area. It is a good groundwater aquifer and oil is extracted from this sediments. In the area of interest, Umm Ruwaba may not found in considerable size or considerable extension. But Atshan formation and Gezira formation are considered as the same as Umm Ruwaba since all are Tertiary sediments and all are contental and all have same facies changes and deposited in post-Nubian tectonic troughs.

3.2.4 Gezira Formation

It also belongs to Umm Ruwaba group. They are unconsolidated, with rapid facies changes and differ in their thickness and contain potable water, most of the time. In the area under study Gezira formation is not found, but it is replaced by Atshan formation which has the same typical characteristics with exception that Gezira formation has two layers. The upper zone and the lower zone. Lower zone is a good aquifer with potable water, but the upper zone has water, but it is salty in many locations and the upper aquifer is exposed to hazard and contamination.

3.2.5 Volcanic Rocks

These are found near Qala El Nahal and near El Gadarif. These volcanic rocks if they are found as a Tertiary rocks, then they are found overlie Nubian Sandstone formation called (Gadarif Formation). Sometimes the volcanic rocks outcrop near El Gadarif and Doka, otherwise they may be found to a sheet nature with limited thickness. But in the particular area they do not exist as particular volume that can attract the tension.

3.2.6 Basement Complex Rocks

These rocks consist in the area from young granite as isolated low outcrops in the southern part of the area. The description of fresh hand specimen is found as follows: Pink and light in colour. Hence it is acidic granite. The composition shown by normal eye gives the following:

- Feldspar,
- Quartz
- Bitonite.
- Muscovite

- Hornblends

And may be some other minerals need microscopic examination.

To the east Basement rocks turn to be schists and grieises. The outcropping of the Basement rocks is dominated the southern and eastern part of the area. As well as the subsurface Basement rocks are found under all the sedimentary cover. The depth to the subsurface Basement varies from place to other according to:

- The thin thickness of the overlain sedimentary.
- The undulation of the subsurface profile.
- The effects of tectonic elements of fissure, fractures, faults, folds and others.

The Basement Complex formation is not an aquifer but groundwater can be found in fissures and weak zones, provided that either the rainfall is adequate or nearby water course seasonal and preneil in this case recharge is surely found. The almost flat plain of the Blue Nile valley, in general is interrupted in many places by, small jebels forming inselberlge type of landscape. These either of Basement Complex rocks or sometimes of Nubian Sandstone.

The jebels crop out in almost flat plain and have very high gradient, with very little debris. Two conspicuous shapes were noticed in the field. The first one is the conical rigged shape associated with acid gneisses and granites of the Basement Complex. The second type which is almost Linear blocks of Nubian Sand stone silicification is the main reason. (Abdel Latif, 1976).

3.3 WATER RESOURCES

The water resources in Hawata area and in the Gadarif State are found in nature either as rain-water, seasonal streams (Wadis and Khors) or as groundwater. Rainfall constitutes the important water component in the state. The rainfall rates are less than 300 mm/y, in the northern parts, and it reaches about 900 mm/y at the east southern parts. Meanwhile it ranges between these two limits. The runoff constitutes the Blue Nile tributaries in the locality namely Rahad River, Dinder River and Atshan River. These are originated from the Ethiopian Plateau heading along the bed plains to meet with the Blue Nile somewhere with the exception of Atshan which it used to be a tributary to Dinder on the good rainy seasons.

The groundwater is only confined in its occurrence to the north western parts of the locality where what is called Atshan Formation is prevailing. This is a rich aquifer with quantity and good quality. This is because it is of good permeability and porosity. It is recharged yearly from Dinder, Rahad, Atshan River the Blue Nile and from direct rainfall.

In the southern and eastern parts of the locality have no continuous and developed aquifers because of the occurrence of Basement Complex rocks.

Hence the groundwater may occur in the fissured, fractured, faulted and weak zones or in the weathered Basement rocks found beneath thin cover of alluvium. The water sources on these areas provide limited quantity of water to supply small communities and their animal. Sometimes the water quality may come to be slightly saline.

The groundwater within the area under study is occurred mainly in the sedimentary cover which is consisted of the alluvial deposits at the beds and banks of the seasonal rivers (El Rahad, El Dinder and El Atshan). Some small amounts are occurred at the fissures and weak zones, Hand dug wells reaching depth of (10-15) m. are prevailing along these rivers. Slum borehole installed with hand pumps are also exist to provide small villages and (Forgans) belonging to nomads. The other option is using of the pools remain within the rivers beds after stopping of the runoff after the ceasing of rainfall, due to the end of rainy season.

At other places of some distances from the rivers banks, artificial hafirs are constructed scattered here and there among villages. All what is said above is confined to the southern part of Hawata Locality, where the Basement Complex rocks are prevailing as out crops, very near to the ground surface with thin sedimentary cover or the subsurface Basement rocks with a relatively thick sedimentary rocks but lagging groundwater occurrence.

The northern part of the locality, at slightly kilometres south Wad El Agilie village begins what is called Atshan Formation aquifer. This is very rich in ground water and extending up to Blue Nile eastern bank. This aquifer is recharged from El Rahad, Dinder River, and Atshan Rivers and directly from rainfall and Blue Nile.

All the villages north of Wad El Agilie enjoy groundwater supply through water station (Donkies), where there are deep wells installed with pumps and fitted with water tanks and sometimes networks to supply houses connection are found here and there. The water productivity is good as well as the water quality.

This year the drought fit has a severe negative impact on the locality in particular, and in the state as a whole. The drought fits come after (7-10) years as they are experienced by the people in the locality when they were asked about the separation between a drought fit and the expected one. The situation needs to be evaluated and urgent solutions have to be planned for. As well as plans for future, are to be outlined efficiently and probably. It becomes very important to concentrate on the following:-

- To maintain and rehabilitate the already existing water sources wells, hafirs and dams).
- To find new resources to be used to increase the demand coverage.
- To increase the research and implementation of surface and rainfall water through water harvesting techniques.

- To drill wells wherever they are successful of both fair quantity and quality to be transported by pipe lines to where water is needed.
- To construct hafirs that can be filled through pumping at the flooding time of the Rahad, Dinder and Atshan and from the rainwater at suitable catchments.
- To make use of the meandering of Rahad, Dinder and Atshan rivers through studying the possibility of design to cut some parts of many bends of those rivers to enhance the rivers profiles after the flood seasons leaving behind some pools that can be useful in the dry seasons.
- To irrigate suitable types of fodder using groundwater wherever wells are possible.
- Sketching a programme for thinning the number of animals in a way that new varieties are replaced to increase their productivity within limited amount.
- The camels and goats are stronger to pass the drought fits without much sacrifice.
- To launch on an excessive program of awareness among the livestock owners.
- If any irrigated scheme is planned for, within the area, then let it be with livestock as one of the important component.
- Any economical activity within the area has to be an integrated package that includes animal, plantation and forestation.
- People of the locality have to support a complete and efficient friendship with the environment.

3.4 Groundwater Evaluation

Not many works on groundwater resources have been accomplished with the locality of El Hawata. Nevertheless some limited studies are found among what are present now as theses. The first thesis is written by Abdel Latif Mohd. Ali on 1976 "On Geology and Hydrogeology of the Sedimentary Basin of the Blue Nile and its tributaries between Wad Medani and Abu Huggar". In his work he described the geological setting, the existing aquifer the water quality and quantity. He even mentioned the physical profile of El Rahad and other tributaries describing the extensive meandering and its causes. What is mentioned in this connection is very important for groundwater occurrence in term of natural and artificial recharge especially when the Basement rocks dominate. He also talked about the rivers shifting leaving behind abandoned channels. Again, this gives high potential for application of hydro geophysical investigations to target buried channels within the project area. It might locate suitable sites for successful drilling. The other thesis is written by El Mesalami (1996) in which some geophysics, hydrogeology and isotope measurements are conducted at El Atshan River. This is a good help to have some information of the part of the area.

The third thesis is written by Abdalla Mohamed Kheir in evaluation of Wad El Agili Groundwater Sources in terms of pumping test, analysis of the drilling samples, monitoring of the aquifer parameters etc. A German company investigated for groundwater in the area to locate some good sites. The investigation located Wad Al Agilie Project as constructed to supply 49 villages including two small towns (El Hawata and Qala El Nahal). Groundwater is transported to supply these villages through pipeline with length of 250 km. To the North from Hawata a Sudanese-Malaysian Company is busy drilling to explore petroleum shows. Up to now they found plenty of water East to Dinder town.

It seems that groundwater, in the locality and within Wad Misken Project, needs more concentration on research for the following:-

- To apply remote sensing to show if any locations can be of interest for more investigation.
- To apply suitable geophysical methods to survey the above assigned locations by remote sensing.
- To use auguring or shallow slim drilling to reach water level in the confirmed locations outlined by both remote sensing and geophysics.

These above integrated trials combined together to give almost complete package of investigations system.

The hydro geological work has to be, as well, meeting the required water occurrence, water quantity calculation and water quality laboratories analysis. Hence successful constructed wells as results of previous activities mentioned above, have to be pumping tested, its water sampled and productivity measured.

It worth mentioning that in areas of water scarcity water sites of available water found at any place away from the place of need does not differ if water can be transported within an affordable means to them.

Concerning groundwater quality especially in the southern part of the locality, which in most of the time it may contains salts due to the presence of Basement rocks. Well, due to the development of technology nowadays, using devices of water desalination can give good solution with suitable sizes and volumes. Of course, some investigations in this connection have to be exercised.

In the north part of the locality and in Sennar State at the part northern to the locality the aquifer of Atshan occurs. The water quality is fair almost potable. El Hawata-Wad El Agilie project which supplies Hawata town and other 48 villages is taking its water from this aquifer. Tables show some laboratory analyses as samples for August 2009 and for September 2009.

The water quality of the hand dug wells at Atshan Riverbeds is fairly salty, the nomadic communities dwelling nearby drink it and the population said that the water is good for their animals because it contains salts.

3.5 GROUNDWATER MANAGEMENT

If the groundwater component will be part of the project then it is important to be put in consideration the following items:-

- Drafting an outlined awareness program for the community.
- Groundwater staff and the decision makers.
- The component has to be designed efficiently with affordable technology. El Hawata, Wad El Agilie can give very convincing example.
- The groundwater has to depend on its own financial resources with an independent managerial authority elected from the stockholders within the concept of Was Misken Project.
- The running, maintenance, rehabilitation and replacement have to be facilitated from the beginning onward with conceivable understanding reflected in cleared programs.
- The community with other stakeholders has to be fully understood that the component is their own.
- The on-job training is very essential for all concerned staff. It has to be repeated periodically with advanced steps.
- The monitoring for both groundwater quality and quantity shall meet the flow of updating of data collection of the system.
- The evaluation and re-evaluation of the system shall be done from time to time to derive lessons that can be implemented for the enhancement of the system.
- Construction of surface pools to be filled from floods to be used for plantation of animal fodder and at the same time they can be used as source of artificial groundwater recharge the same can be made by construction of hafirs and dams.
- The concept of artificial recharge for groundwater has to be positively considered in the planning and enriching the groundwater shortage.
- It is most important to detach the undesirable species of trees as Meskites which can extract plenty of groundwater.
- The reduction of water losses from badly connections of the systems is advisable.
- To protect the groundwater resources from hazard and contamination is essential.

3.6 WATER DEVELOPMENT

To develop the water resources within the Mahalia, it seems to be essential to concentrate on water harvesting programmes as follows:-
Rainfall water harvesting through:

- Rehabilitation of the existing hafirs and dams.
- To establish hafirs and dams.
- Natural pools

- To enhance the natural pools land ponds left after the end of the floods of the seasonal rivers (Rahad, Dinder and Atshan).
- To establish big troughs to be filled during the flood seasons and closed them to be used after the end of Kharif. They can be used either for irrigation or animals watering.
- To implement the groundwater occurrence in the Northern part of the Mahalia by drilling wells
- Located through hydro geophysical investigation.
- The water supply can be transported through distances following Hawata-Wad El Agilie Scheme example.
- To concentrate on well sitting verification (using Geophysics) to select the expected successful sitting for slim boreholes drilling in fractured and faulted places to supply water for distant small communities, these can be supplemented by small hand dug hafirs as well.
- With some amendment on the dwelling huts and tents roofs the rainwater can be collected and stored to be used later as what the case is in across Eastern Africa countries.
- Through geological and hydro geological research and investigation artificial recharge might be possible if the prevailing conditions are encouraging. Hence the rainfall water, runoff water and seasonal rivers floods water can be stored to be used later in the dry season.
- Whenever Tebaldi species trees are found can be used for rainfall water storage as was the case in Kordofan For example.

3.7 AVAILABLE DATA AND DATA RESOURCES

The most important data of groundwater regime in Wad Misken area is what available in water bodies in Gadarif State, Sennar State and Wad El Agile – Hawata Water Corporation, where some of drilling data of machines - drilled boreholes – most of the time the villages bore-hole not completed. Only the drilling reports describing the performing the attitude of drilling. But in most of the time the drilling sample were not described, not sieved analyzed. Consequently the wells designs sometimes are absent. The recent drilled wells have neither technical files nor investigation geological and hydro geophysical reports. But the most complete and consistent is what concerns Wad Ell Agilie Water Project.

The sites investigation was accomplished by German experts together with Sudanese experts from the former National Corporation for Rural Water Development (dissolved 1994).

The drilling data is completed in files for nine wells each has its separate file. That includes the litho logy, static water table depth. The results of chemical and bacteriological analyses. The important tasks used to be done periodically are the monitoring of the wells for drow down; water quality, mechanical and electrical conditions at each instant all the required data can be known, this is due to automatic operational and monitoring system.

The groundwater, data resources are available in what mentioned above and other bodies which can be listed as follows:-

- Wad El Agilie – Hawata Water Corporation – at Hawata Town office.
- Gadarif State Water Corporation, - at Gadarif Office.
- Sennar State Water Corporation – at Sennar Office.
- Groundwater Directorate – Ministry o Irrigation and Water Resources – Khartoum.
- The Public Corporation of Geological Research – Khartoum.
- The Department of Geology – College of Science, U. of K.
- The Public Corporation of Water – Khartoum.
- The library at Gamhoryia Street, Univ. of Khartoum.
- The UNICEF and the Public Corporation joint venture, water and Sanitation Project (WES) at Gadarif town.

The groundwater data of the area is found in the abovementioned bodies in different forms e.g. theses, reports, maps, and well's logs, sections, etc. The groundwater quality in the area under study is affected by the geological setting up if the area, the possibility of recharge and the hydraulic parameters prevailing.

Generally speaking, the groundwater quality is of two kinds in the area. In the southern and south-western parts, the Basement Complex rocks are found. They have of course, only secondary porosity and other secondary hydraulic parameters. The recharge potential is secured by fair rainfall and fair rivers' and Wadis floods in the fractured weak zones, faulted places and the jointed Basement rocks.

The groundwater in various quantities can be found, with different qualities as well. In hard times when drought affects the area as this year (2009) and the previous year, the limited aquifers will be less efficient to sustain the demands provided that even the surface water in the beds of Rahad, Atshan and Dinder will not be adequate.

The groundwater distribution in Wad Misken area differs in the southern and northern parts of the area. In the southern part where the rocky cover is mainly of Basement Complex type, some time, is overlain by thin layer of recent sediments of alluvial type or of aerial deposits of winds. Consequently the groundwater occurrence is limited only by the degree of development of the secondary porosity, and/or degree of weathering of the Basement rocks under the Khors, Wadis and rivers beds.

In the northern part the groundwater aquifer is developed as a marginal on some distance to south of Wad El Agilie. From Wad El Agilie north, the aquifer is very rich of groundwater of fair quality and of good quality of course, near the banks of Rahad, Dinder and Atshan. The drilled shallow boreholes are successful.

Hence if there is cooperation and collaboration between the neighbour states water can be transported from where plenty of water is available to the placed of no or poor water potential. The very successful experience already exists in Wad El Agilie-Hawata Water Supply Project.

3.8 HAWATA AND WAD EL AGILIE WATER CORPORATION CASE STUDY

This is a very water successful project. It was a joint venture between the previous Rural Water Corporation and the Federal Government of Lower Sacsonia – Germany, The project drilled nine deep wells of average depth of 350 ft. in a well field at Wad El Agilie village about 30 Km north El Hawata. The Wad El Agilie belongs to Sennar State. The well-field supply about 4000 m3/day through a pipe line to a reservoir at El Hawata. The water is operating with remote control at Hawata (30 Km. away from the wells field). At the reservoir the water is treated and then raised to an elevated tank by pumping to, again, elevated tank on a mountain at village called Bob and then the water is distributed to the system by gravity to supply 49 villages among them two small towns, El Hawata and Qala El Nahal. The total length of network is 250 Km. Therefore the project has some details as follows:-

- Phase one started by rehabilitation of Hafirs El Hawata and its water distributed by network. The network supply Kiosks in the streets. This phase cost about 60 million German Marks. The main phase included drilling boreholes at Wad El Agilie after conducting hydro geophysical survey according to which the drilling sites were selected. The phases also include the construction of a lifting station and a concrete storage trough from which the water is distributed to other parts of the network for the different villages. This phase include, as well the construction of another concrete trough on the highest part of Jebel Ban with iron pipes in 1986-1988.
- The following phase on (1988-1990) includes the extension of the network to Gala El Nahal. The next following network in (1990-1991) was extended to Umm Sagat village. From that time on up to 2003 many villages requested to be supplied within the project activities. In most of the time, the project accepted their request and an extension for the network is constructed to supply them through finance from the concerned locality, from the State Government or sometimes from the Federal Government. These latter extensions of the project did not affect the designed amount of water since from the first such request were expected and arranged for.

In 1989 an executive directorate was established to run the project according to a signed protocol signed between the Sudanese Ministry of Finance representing the Sudan Government and the German Reconstruction Bank representing Federal German Government. In the protocol the two governments agreed that the project is going to be run through a board of directors formed from:

- The executive managerial staff.
- The beneficial community.

These choose the Board of Directors. The project should be independent. It depends on its running, maintenance rehabilitation and its innovation on the selling of water. The water sake has to be according to the actual cost. (No profit).

This project is a successful project since its opening in 1983 up to now. After the Presidential Decree on 1997 the project moved from its federal set up to be totally belonging to Gadarif State. Consequently its name changed to be Hawata-Wad El Agilie Water Corporation. This to suits the fact that the project supplies villages from State of Sennar (Wad El Agilie itself in Sennar) and other villages from the State of Gadarif.

The groundwater resources that provide the project with its water seem to be adequate in quantities that will last for long=long time and of good quality. After detailed research in the area; the Wad El Agilie site was chosen at a distance of 30 Km to the north-east from Hawata small town. The investigation showed that at the selected site is a rich groundwater basin at a forest at which Khor Atshan ends probably at a fault or a weak zone of the formation. The pumping test study shows plenty of water of good quality. It appears that there is continuous recharge from El Atshan and from other rivers in the region. The project is supplied from nine wells at the selected sites working six of them at a time and three remain standby. These wells are connected with an iron line to be channelled in one line goes to Al Hawata with length of 31 km. The monitoring system of water quality and water quantity which is conducted periodically shows that no serious draw-down shown during 20 years of the working age of the project. The water quality is well, found to meet the international and Sudanese standard.

The following tables show results analyses for water quality in August and September of2009. The other table shows the analyses of Blue Nile water analyzed 1954 and Dinder water samples analysis in different places shown by their coordinates. These tables result to help the comparing between the groundwater quality and the rivers water quality especially in terms of salts contents.

The project is operated through automatic system that the control panels for all operational tasks are done at Hawata min operation control room. This reduces the cost of labour and makes exact operational task through specialized able staff (Technologists). The significance of this project is its characteristics of supplying from one wells-field many village of various distance from each other through water transportation. The other merits its ability in taking water from places of plenty to places of scarcity. The Hafirs executed during the first phase are connected by the system. They operate when needed; otherwise they standby to operate at any main failure in the groundwater supply.
It is expected that the replication of the same system in many other places in Sudan will be a success.

Table 3.1: Water Samples taken from Hawata and Wad El Agilie Wells field

Chemical Analyses – August 2009

Location	K+	P	PO_4^{-3}	P_2O_5	CI_2	TCI_2	I^2	CI	F	SO_4^{-2}	AI^{+3}	Al_2O_3	CN
Well (3)	0.6	0.03	0.08	0.12	0.03	0.04	0.09	2,1	0.11	4.00	0.00	0.00	0.001
Well (5)	0/5	0.02	0.06	0.12	0.03	0.05	0.06	2.0	0.43	2.10	0.01	0.02	0.002
Well (7)	0.6	0.02	0.07	0.10	0.03	0.05	0.06	1.6	0.24	5.00	0.01	0.02	0.002
Well (8)	0.4	0.03	0.08	0.11	0.07	0.08	0.09	1.7	0.25	3.00	0.00	0.00	0.001
Al Nahal	0.8	0.05	0.10	0.13	0.02	0.05	0.06	2.3	0.41	4.00	0.02	0.04	0.001
Bela(2)	0.7	0.04	0.10	0.13	0.03	0.04	0.07	2.6	0.38	3.00	0.01	0.01	0.001
Galbi (1)	0.6	0.03	0.08	0.11	0.04	0.06	0.08	1.8	0.33	3.00	0.02	0.04	0.002
Galbi (4)	0.6	0.05	0.11	0.15	0.02	0.05	0.07	2.4	0.44	5..00	0.00	0.01	0.001

Table 3.2: Water Samples taken from Hawata and Wad El Agilie Wells field

Physical Analysis =August 2009.

Location	Colour	Taste	Turbidity	pH	Conductivity	TDS	Temp
Well(3)	Normal	Normal	0.00	7.81	26.3	381	26.3
Well(5)	Normal	Normal	0.00	7.35	281	422	26.3
Well(7)	Normal	Normal	0.00	8.02	396	602	26.3
Well(8)	Normal	Normal	0.00	6.96	302	461	26.3
Al Nahal	Normal	Normal	0.00	7.23	329	490	26.3
Bela (2)	Normal	Normal	0.00	7.85	324	488	26.3
Galbi(1)	Normal	Normal	0.00	8.01	327	489	26.3
Galbi(4)	Normal	Normal	0.00	7.56	332	495	26.3

Table 3.3: Water Samples taken from Hawata and Wad El Agilie Wells field

Chemical Analysis – September, 2009

Location	K+	P	PO_4^{-3}	P_2O_5	CI_2	TCI_2	I^2	CI	F	SO_4^{-2}	AI+³	Al_2O_3	CN
Ban 4	0.6	0.04	0.12	0.09	0.03	0.02	0.07	1.4	0.63	2.00	0.02	0.04	0.001
Wadi El Naeem	0.6	0.03	0.10	0.07	0.02	0.05	0.05	2.0	0.13	1.00	0.03	0.05	0.001
Al Dihaima	0.6	0.03	0.08	0.06	0.02	0.02	0.08	1.6	0.06	2.00	0.02	0.03	0.001
Hawata 1	0.13	0.08	0.25	0.19	0.02	0.02	0.07	0.3	0.29	1.00	0.00	0.00	0.001
C.W.R.	1.4	0.19	0.58	0.43	0.04	0.01	0.05	8.7	0.27	1.00	0.03	0.06	0.001

Table 3.4: Water Samples taken from Hawata and Wad El Agilie Wells field

Physical Analysis – September, 2009.

Location	Colour	Taste	Turbidity	pH	Conductivity	TDS	Temp
Ban (4)	Normal	Normal	0.00	8.16	530	255	24.7
Wadi El Naeem	Normal	Normal	0.00	8.18	555	367	24/6
Al Dihaima	Normal	Normal	0.00	7.94	528	348	24.6
Hawata(1)	Normal	Normal	0.00	7.67	549	360	24.6
C. W. R.	Normal	Normal	0.00	7.74	548	359	28.6

Table 3.5: Analysis Results of Water Samples from Dinder River and Blue Nile River

Test	St. No.1	St. No.2	S.No.3	Blue Nile Water
Coordinates	067045E 142723N	069320E 140575N	Not Known	Locality not known
E.C.	0.42	0.76	0.28	152
pH Creative	6.5	6.4	6.7	7.9
Na^+	0.9	1.0	1.0	0.24
$CA^{++} + Mg^{++}$	3.6	8.0	2.8	Ca^{++} 1.0 Mg^{++} 0.3
K^+	0.1	0.03	0.1	0.04
CO^{3-}	0.00	0.00	0.00	0.00
HCO^3_-	0.80	0.80	1.5	1.45
Cl^--	0.70	0.70	1.2	0.03
SO^{-4}	3.1	7.5	0.9	0.12
SAR	0.67	0.5	0.86	0.3

3.9 THE ABANDONED CHANNELS

The Blue Nile is a meandering river, the active channel is meandering and at some time many abandoned channels were recognized.
The photographic interpretation of aerial photos indicates that at least two conspicuous meandering systems associated with Blue Nile can be recognized, e.g. between Blue Nile and the Dinder, two main abandoned meandering systems, running north-west across the centre of the area, one cuts across to join the Blue Nile just north of Kassab pump scheme, part of the other join the Dinder. The drainage of the abandoned meander channels contains several depressions known locally as (Maya's) where the water collects and subsequently evaporates. However, when flood rises many of the abandoned channels, especially the most recent ones acts as a spill way or distributaries in which water of the flood flows in. The size of these abandoned channels varies according to age. It has been noticed that most recently abandoned channels are comparable in dimensions to the present day rivers suggesting a greater discharge during a former wetter period in aerial photos the majority of the abandoned appear as discontinuous gray bands, often conspicuous for their three cover in otherwise graded area.

It appears that these abandoned meandering channels have played a role in the distribution of the population. Population is more or less concentrated around these abandoned channels especially to the west of the Blue Nile. It is most probable that, the presence of some perched shallow water connected with these abandoned meandering channels has attracted human settlement. The migration of the meandering system could be explained as a result of several factors, among them which the following are most important:-

- Retreat of the slope during pediplantion to the east.
- The present abandoned channel course of the Blue Nile is perhaps elevated by 3 meters.
- With gradient l meter: 3 km. i.e. 1: 3,000.

However retreat in the slope may not be the only reasons for the Migration of the meanders.

3.10 EFFECT OF WIND

The prevailing wind in the area during a long time of the year is the south-western lies blowing in a north-east direction, especially in flood time. This will add to the deflection of line of maximum velocity of the meandering river in the direction of wind blow and subsequently leads to the migration of the meandering system (Leoold and Langbein (19 66). In case of the tributaries, Dinder and Rahad a third important factor contributing to the migration of the meandering system may be, the Blue Nile itself.

The Blue Nile pushes its tributaries to the east because of the load carried and the deposition of low levees on both sides of its banks, which ultimately prevents the tributaries from reaching the main stream by the shortest routes. (Fritz Machatschek, 1969).

Also a uniformity accepted effect of the earth's rotation may be an important factoring the migration of meandering. It has been recognized that irrespective of the type 0of bank, river displacement takes place under the influence of earth's rotation. For flowing meanders water like any other body in motion, is deflected to the right in the northern hemisphere and to the left in the southern hemisphere.

The rivers running periodically to higher latitudes experience acceleration to the east (Von Baer Law). This can be applied to Blue Nile and its tributaries.

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