The Republic of the Sudan

THE FEASIBILITY STUDY
ON
THE HURGA AND NUR EL DIN PUMP SCHEME
REHABILITATION PROJECT

ANNEXES

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AUGUST 1991

Japan International Cooperation Agency
(JICA)

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FINAL REPORT

FOR

THE FEASIBILITY STUDY

ON

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ANNEX A : TOPOGRAPHY AND GEOLOGY

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1. DATA COLLECTION AND FIELD SURVEY

1.1 Data Collection and Field Survey

The topographic maps and other data related to the Project area were collected mainly at the Survey Department, MOI. Data collected are tabulated in APPENDIX-II. The following field surveys were carried out during October, 1991 and January 27, 1992 (Work-I period) by the JICA Study Team in collaboration with MOI:

- Reconnaissance and surface geological survey in and around the Project area;
- Establishing temporary bench marks at the existing Hurga and Nur El Din pumping stations;
- Soil investigations at an alternative pumping site by portable cone penetrometer and hand auger boring;
- Reconnaissance and interview survey on river bank erosion around the existing pumping stations and at the alternative pumping site; and
- Reconnaissance survey on quarry site and borrow pits.

During the same period, the following surveys and investigations were conducted by Survey Department and Hydraulic Research Station (HRS):

- Topographic survey around the existing and alternative pumping sites;
- Profile and cross section survey for tentative route of link canal connecting the alternative pumping site with the existing main canals;
- Inventory survey of the existing structures in the Project area;
- Levelling between Wad El Nau gauging station and the existing pumping stations;
- Levelling between National Bench Marks and Hag Abdallah gauging station, and Wad El Nau gauging station; and
- Hydrographic survey (cross section survey by echosounder in wet parts and level in dry parts) of the Blue Nile at the existing and alternative pumping sites.

After subsequent study and analysis conducted in Japan, geotechnical investigation at the alternative pumping site was carried by a local contractor under supervision of the JICA Study Team between late May and middle of June 1991 for further confirmation of soil condition at the site and groundwater level, etc.

2. TOPOGRAPHY

2.1 Bench Marks

There exist two bench marks (BM) each in the Hurga and Nur El Din areas (Project area), locations and description of which are shown in Fig. 2.1 and Table 2.1, respectively. According to the Survey Department, MOI, these BMs were reportedly established based on the national BM No.667, whose reduced level was derived from the Sudanese Standard Datum, so called Irrigation Datum of EL. 360.000 at Khartoum. Location and description of BM No.667 are shown in Fig. 2.2 and Table 2.2, respectively.

Aiming to confirm elevations of the said BMs established in the Project area, existing zero elevation of the Wad El Nau gauging station and existing zero elevation of the Hag Abdallah gauging station, a levelling survey was conducted during the Study period by HRS between:

i) the national BM No.102 in Wad El Nau established based on the said Irrigation Datum and the Wad El Nau gauging station;

ii) BM No.102 and the BMs established in the Project area; and

iii) the national BM No.114 and Hag Abdallah gauging station.

Location and description of BM No.102 and No.114 are shown in Fig. 2.2 and Table 2.3, respectively.

According to the levelling survey, some discrepancies were found between reduced elevation obtained by said levelling and the existing elevation of BMs in the Project area, which implies that the existing elevation given in Table 2.1 are actually arbitrary ones but have not respected to the national BM. The result of the survey is summarized as follows:

Code of Bench Marks		Elevation Established	Result of Levelling	Discrepancy (cm)
Hurga	H-1	EL. 411.373	EL. 412.185	(-)0.812
Hurga	H-2	EL. 410.618	EL. 411.357	(-)0.739
Nur El Din	N-1	EL. 410.418	EL. 411.167	(-)0.749

The said survey revealed also a discrepancy in elevation between the existing zero elevation and the surveyed one of the Wad El Nau and Hag Abdallah gauging stations and the result of the survey is shown below:

Gauging Station	Elevation Established	Result of Levelling	Discrepancy (cm)
Wad El Nau	EL. 389.500	EL.388.585	(+)0.915
Hag Abdallah	EL. 387.220	EL.387.384	(-)0.164

For the convenience of field survey for the Study, three temporary BMs have been established at the existing pumping stations, one (KBM-1) for the Nur El Din and two (KBM-2 & -3) for the Hurga, whose location are presented in Fig. 2.3. Reduced elevations of these KBMs were derived from arbitrary elevations of H-1 (EL. 411.373) for Hurga and N-1 (EL. 410.418) at first, and then adjusted based on the result of the above check survey. Results of adjustment are summarized as follows:

Code of Bench Marks		Elevation Established	Adjustment (cm)	Actual Elevation
KBM-1	Nur El Din	EL. 401.678	(+)0.749	EL. 402.427
KBM-2	Hurga	EL. 405.387	(+)0.812	EL. 406.119
KBM-3	Hurga	EL. 392.341	(+)0.812	EL. 393.153

2.2 Topography

(1) Topography

The Project area, extending over the flat plain on the right bank of the Blue Nile, is located at about 30 km southeast of Wad Medani and 220 km southeast of Khartoum in route distance.

The Project area gently slopes down toward north along the Blue Nile at an inclination of 20 to 25 cm/km. The topographic features of the right bank of the Blue Nile are broadly classified into; (i) those characterized by stepped slopes seen in the upper reaches of the Nur El Din pumping station and upper reaches of the Hurga pumping station; and (ii) those forming low-lying terrace stretching between downstream of the Nur El Din pumping station and upstream of the alternative pumping site.

The Nur El Din pumping station is located at the concave part of the river, while the Hurga pumping station is at the edge of the concave part where the flow is almost straight along the right bank. The alternative pumping site is situated at 700 m upstream of the Hurga pumping station and 1,300 m downstream of the Nur El Din pumping station.

(2) River Cross Section

Cross sectional survey of the Blue Nile was carried out by HRS, MOI at the Hurga, Nur El Din and alternative pumping sites during the Study period. The Results are shown in APPENDIX-I.

2.3 Existing Topographic Maps

The topographic maps covering the Project area are those on a scale of 1:10,000, 1:20,000 and 1:250,000. The one on a scale of 1:10,000 with a contour interval of 0.25 m was prepared separately for the Hurga scheme and for the Nur El Din scheme during 1954 - 1955 by private sector. Later, these maps were combined and reduced to a scale of 1:20,000. Altitudes presented in these maps are based on arbitrary elevations of the BMs established in the Project area, which is used for the Study.

3. GEOLOGY

3.1 Geology

The project area is situated in the Central Clay Plain extending over a vast terrain between the Blue Nile and White Nile Basin. General geological map of the Central plain is shown in Fig. 3.1.

It is believed that the substrata of this area consists mainly of sandy strata which settled as sediment from the Pliocene of Neogene Tertiary to Pleistocene of Quaternary Period, and it is known as the Umm Ruwaba deposits. This layer is widely overlain by thick flood deposits (Pleistocene to Holocene), which originate from basaltic igneous rocks and metamorphic rocks of Ethiopian Plateau.

The flood deposits are composed of clay, silt, sand and gravel with a total thickness of more than 50 m. According to the existing drilling data shown in Fig. 3.2, the thickness of the deposits around Wad Medani is considered to be 50 - 60 m in depth from the ground surface.

The faces of the stratification in these deposits differ from place to place. It is judged from the existing geological profiles at Es Suki and Meina shown in Figs. 3.3 and 3.4 and field reconnaissance conducted during the Study period that there is no significant change in the order of stratification even between Wad Medani and Es Suki or Meina more than 100 km away each other, and same distribution of strata is recognized.

The deposits is broadly divided into upper and lower portions in respect of the stratification. The upper portion (from surface to 18 - 25 m deep) consists mainly of clayey materials and the lower portion mainly of sandy material predominated by fine grained sands.

Upper portion of the flood deposits between the Nur El Din and Hurga on the right bank of the Blue Nile are classified into four (4) major stratifications. They are, in ascending order, reddish/light brown colored stiff clay, alternations of sand and clay, sandy clay and clay.

The upper most clay stratum, known as Black Cotton Soil, is rich in montmorillonite and contains random calcareous nodules, with thickness ranging from 5 to 8 m.

The second stratum, composed of alternating layers of sand and clay, contains calcareous nodules in upper portion, thin layers of fine sands are intercalated in the lower portion. The thickness of this stratum ranges from 4 to 8 m.

The third stratum from the surface is composed of alternating layers of clay (or silt) and well-sorted, fine-grained sand. The thickness of each of alternating units varies so widely as from several centimeters to 2 m including frequent alternations at every few centimeters thick. Total thickness of this stratum is estimated to be 6 to 8 m. It is believed that the thickness of each alternating unit and its stratification are closely related with the occurrence of river bank erosion.

The Upper three strata are thought to be the flood deposits of Holocene, and their combined thickness is 10 to 18 m.

The lower most stratum, which is composed mainly of stiff clay, unconformably underlies the above three strata. This stratum is spread extensively along the right bank of the Blue Nile. The thickness of this stratum is estimated to be 2 to 8 m or more, however this could not be confirmed by the field survey during the Work-I period since the lower portion of this stratum is beneath the river water. This stiff clay layer is partially overlain by coarse sand and in some areas gravel as much as 10 cm thick containing gravel stones of 1 to 8 cm in diameter. Also, a scattered oyster fossil bank was found at the surface of the stiff clay. This suggests that this stiff clay layer is most likely Pleistocene sediment, but the field reconnaissance survey has not confirmed this much.

The summary of stratigraphic sequence of the upper portion of the sediments in the Project area is shown in Fig. 3.5.

The existing Nur El Din pumping site is founded on the stiff clay layer, and the Hurga's site is founded on either the same layer or on the underlying sandy layer. The alternative pumping site is probably on the stiff clay foundation or on the sandy one. The stratigraphic profiles of the above mentioned three sites are represented in Figs. 3.6 to 3.8.

The groundwater level around the project area was estimated at the Work-I period to be approximately 12 m below the ground surface of the flat irrigation area where the elevation is between EL. 410 and EL. 411 m. The groundwater level in the area of the alternative pumping site probably stands within the layer of stiff clay (about EL. 399 m), and may vary in accordance to the water level of the Blue Nile.

3.2 River Bank Erosion (Recession of River Bank)

Topographically, the river bank of the Blue Nile in the Project area is broadly categorized into: i) stepped gentle slopes; and ii) low-lying wide terrace, illustration of which are shown in Figs. 3.9 and 3.10. The stepped gentle slope is seen at the Nur El Din pumping site and upstream of the Hurga pumping site, and the low-lying wide terrace is found both upstream and downstream sides of the Nur El Din pumping site, which is exposed to air during low water stage.

These different topographic features seems to be attributed to the thickness of alternation of sand and clay stratum and the order of stratification above stiff clay stratum. In case the river bank is constituted of the said alternation with sand rich stratum, it is easily eroded due to its low resistibility to erosion, thus resulting in a formation of low-lying terrace. In case, on the other hand, the clay stratum is predominant in the alternation strata constituting the river bank, the bank forms the stepped gentle slopes resulting from high resistibility of the alternation stratum to erosion.

The Nur El Din pumping station is located on such stepped gentle slopes sandwiched by low-lying terraces extending both upstream and downstream of the pumping station. The Hurga pumping station is also situated on the stepped gentle slope. According to interview survey at the site, it is reported that very less progressive erosion has been recognized at both pumping sites since its construction. This demonstrates the high resistibility of clay rich alternation stratum to erosion, and further rapid expansion of side erosion is not expected under ordinary river current.

It is therefore unlikely that in future the river bank at both the existing pumping sites and the alternative pump site will be eroded seriously. Nevertheless, it is recommendable that some sort of preventive measures to protect the banks around the pumping station be executed for the safe since the strata at the sites are of unconsolidated soils and clays.

3.3 Estimation of Allowable Soil Pressure at Alternative Pumping Site

As geotechnical investigation at the alternative pumping site had not been carried out during the Work-I period, allowable soil pressure at the alternative site was estimated by using existing data available. Assumptions and methodology employed for the estimation are discussed hereunder.

(1) Allowable Bearing Capacity of Foundation Ground

As previously stated, the supporting stratum at the alternative pumping site is presumed to be stiff clay or sand. The bearing capacity of the foundation ground at the alternative pumping site was examined assuming that soil conditions at the site are almost the same as those shown in available data on the clay and sand stratum being found extensively throughout the Nile River basin. The foundation of the pump house was assumed to be mat foundation with a size of 9 m wide and 29 m long.

The long term allowable bearing capacity having a safety factor of 3.0 was computed by the following equation :

$$q_a = \frac{1}{3}(\alpha c Nc + \beta \gamma_1 BN\gamma + \gamma_2 Df Nq) \ (t/m^2) \quad \text{-----------------} \quad (1)$$

(K. Terzaghi,1963 revised)

where;

- q_a : long term allowable bearing capacity (t/m^2)
- c : cohesion of foundation ground (t/m^2)
- γ_1 : unit weight (t/m^3) of ground underlying foundation base
- γ_2: average unit weight (t/m^3) of ground overlying foundation base, see Fig. 3.11
- α, β : shape factor
- Nc, Nr, Nq : bearing capacity factor, see Fig. 3.12

Df : penetration depth of foundation (m)

B : minimum width of foundation base (m)

Shape Factor

Form of Foundation Base	Continuous Footing	Square	Rectangular	Circular
α	1.0	1.3	1.0+0.3(B/L)	1.3
β	0.5	0.4	0.5-0.1(B/L)	0.3

B: Short Side L: Long Side

a) Sandy layer

Based on the general design criteria for the Meina pumping station, the coefficients of the soil were assumed as follows:

ø = 30°

$\gamma_1 = \gamma_2 = 1.75\ t/m^3$; unit weight

$\gamma'_1 = \gamma'_2 = 1.75 - 1 = 0.75\ t/m^3$; unit weight below ground water level

The internal friction of the sandy layer at the Project site was assumed to be ø 30°. The long-term allowable bearing capacity thus estimated is:

$q_a = 20.7\ t/m^2 = 203(KN/m^2)$

The Relation Between N-value - Relative Density -Internal Friction

(Meyerhof, 1956)

Sand Condition	Relative Density (Dr)	N-Value	Internal Friction (ø)
Very loose	<0.2	<4	<30
Loose	0.2 - 0.4	4 - 10	30 - 35
Compact	0.4 - 0.6	10 - 30	35 - 40
Dense	0.6 - 0.8	30 - 50	40 - 45
Very dense	>0.8	>50	>45

b) Cohesive soil

The c and ø values of the cohesive soil along the Blue Nile are greatly diverse (c = 1.76 - 32.97 t/m^2, ø = 0° - 29°), as is shown in Fig. 3.13.

Case I (c = 12 t/m^2, ø = 7°) is used as a clay sample, Case II (c = 6 t/m^2, ø = 20°) is taken as a representative sample of sandy clay, and the soft cohesive soil of Case

III ($c = 3.87\ t/m^2$, $\phi = 0°$) were calculated and plotted in Fig. 3.13. Results of calculation are:

Case I	:	q_a	= 27.2 (t/m^2) (= 267KN/m^2)
Case II	:	q_a	= 26.0 (t/m^2) (= 255KN/m^2)
Case III	:	q_a	= 10.8 (t/m^2) (= 106KN/m^2)

The cohesive soil in the Case III is the loosest soil among the data collected from the relevant reports. In order to obtain bearing capacity greater than 15 t/m^2, which is the assumed load of the structure, the cohesion should be greater than 6.0 t/m^2 in the case of $\phi = 0°$. Meanwhile, in case the average cohesion value among the same data is $c = 10.0\ t/m^2$ ($\phi = 0°$), the long term allowable bearing capacity is computed to be; qa = 22.6 (t/m^2) (= 222KN/m^2).

Excepting the Case III, the long term allowable bearing capacity of the sand and clay strata at the alternative pumping site could be expected to be more than sufficient to accommodate the building load.

(2) Settlement Analysis

Since the supporting stratum of the alternative pumping station was assumed to be either sand or stiff clay, the consolidation settlement was analyzed on the cohesive soil of the Case III above. Taking into account the available data which showed generally the cohesive soil with 5 - 7 m thick, the clay stratum was assumed at 8 m thick. Based on the alternative plan of Alt-2e, see ANNEX-E, the building load was assumed at 15 t/m^2. The other conditions employed for estimating the consolidation settlement are presented in Fig. 3.14. The clay stratum is separated into two layers A and B. The ground water level was set at EL. 398 m considering the high water level of the Blue Nile. The pre-consolidation stresses were calculated using an estimated surface elevation of EL. 410 m. Taking such factor as the river bank erosion into account, the clay stratum is considered to be over consolidated clay, however, it is regarded as normally consolidated clay in this analysis, and its consolidation settlement was computed using the following formula:

$$S = \Sigma \frac{Cc\Delta H}{1 + e_o} \log_{10} \frac{\sigma_{2z}'}{\sigma_{oz}'} (cm) \qquad \text{--------------------} \qquad (2)$$

where,

S :	consolidation settlement (cm)
Cc :	compression index
e_o :	initial void ratio
H :	total thickness of cohesive soil
ΔH :	thickness of intercalated layer
σ_{2z}' :	effective post-construction ground stresses within the intercalated layer (t/m^2)
σ_{oz}' :	pre-consolidated stresses at the same point

a) Calculation of pre-consolidation stress: σ_{oz}'

A layer $\sigma_{oz}' = 1.75 \times 12 + 0.75 \times 9 + 2 \times 0.81 = 29.37$ t/m^2
B layer $\sigma_{oz}' = 1.75 \times 12 + 0.75 \times 9 + 6 \times 0.81 = 32.61$ t/m^2

b) Calculation of consolidation stresses: $\Delta\sigma_{oz}'$

Assuming that the effective load is that 3/4 of the weight of the displaced soil is deducted from the load:

$$q = 15 - (1.75 \times 1 + 0.75 \times 9)\,3/4 = 8.63 \text{ t/m}^2$$

A vertical load ($\Delta\sigma_{oz}'$) at the center of each clay layer is computed as follows:

\- at the center of the mat foundation -

A layer; $m = 2.25,\ n = 7.25$
$\Delta\sigma_{oz}' = 4 \times q \times f(m, n) = 4 \times 8.63 \times 0.242 = 8.35$ t/m^2

B layer; $m = 0.75,\ n = 2.42$
$\Delta\sigma_{oz}' = 4 \times q \times f(m, n) = 4 \times 8.63 \times 0.177 = 6.11$ t/m^2

\- at the edge of mat foundation -

A layer; $m = 4.5,\ n = 14.5$
$\Delta\sigma_{oz}' = q \times f(m, n) = 8.63 \times 0.25 = 2.16$ t/m^2

B layer; $m = 1.5,\ n = 4.83$
$\Delta\sigma_{oz}' = q \times f(m, n) = 8.63 \times 0.23 = 1.98$ t/m^2

where; f (m, n) is given in Fig. 3.15.

As it is considered that the building would settle evenly due to its sturdiness and stability, the consolidation stresses are averaged as follows:

A layer; $\Delta\sigma_{oz}' = (8.35 + 2.16)/2 = 5.26$ t/m^2
B layer; $\Delta\sigma_{oz}' = (6.11 + 1.98)/2 = 4.05$ t/m^2

c) Effective ground stresses after construction: $\Delta\sigma_{2z}$

A layer; $\Delta\sigma_{2z}' = 29.37 + 5.26 = 34.63$ t/m^2
B layer; $\Delta\sigma_{2z}' = 32.61 + 4.05 = 36.66$ t/m^2

A compression index Cc has the following relation to a liquid limit WL(%) for normally consolidated clay of a small sensitivity ratio:

$Cc = 0.009\,(WL - 10)$ (A.W. Skemptom)

The compression index can be obtained from this equation.

$Cc = 0.0094\,(44 - 10) = 0.31$

An initial void ratio e_o of saturated soil is:

$$e_o = (1 + Wn/100)\,\rho_s/\rho_e - 1$$

where,
- Wn : natural water content ( )
- ρ_s : specific gravity
- ρ_e : unit weight (t/m^3)

Thus, $e_o = (1 + 38/100) \times 2.82/1.81 - 1 = 1.15$

Therefore, consolidation settlement of the clay layer is:

A layer; $SA = (Cc\Delta H)/(1+e_o)\log(\sigma_{2z}'/\sigma_{oz}')$
$= (0.31 \times 400)/(1+1.15)\log(34.63/29.37) = 4.13$ cm

A layer; $SB = (Cc\Delta H)/(1+e_o)\log(\sigma_{2z}'/\sigma_{oz}')$
$= (0.31 \times 400)/(1+1.15)\log(36.66/32.61) = 2.93$ cm

Then,

$S = SA + SB = 7.1$ cm

This value demonstrates that mat foundation for reinforced concrete structure is applicable at the alternative pumping site in the case of normally consolidated clay.

Judging from topographic and geological condition around the alternative pumping site, the clay layer of the assumed bearing stratum is considered to be the overconsolidated clay, and hence no consolidation settlement is expected to occur after construction.

In case a sand layer is the bearing stratum, an allowable bearing pressure (qs) at given settlement values can be calculated by the following equation:

$$q_s = Sa\,(1.36N - 3)\left(\frac{B + 0.3}{2B}\right)^2 \left(0.5 + \frac{Dw}{2B}\right) + \gamma^2 Df \;\; t/m^2 \quad \text{-----------------} \quad (3)$$

where,
- Sa : allowable settlement (cm)
- q_s : allowable bearing pressure (t/m2) at a certain Sa
- Dw : depth from the foundation to the ground water level. In case the ground water level is over the foundation, Dw = 0 (m).

N : N-value

γ^2 : average unit weight of the soil located above the foundation (t/m^3)

B : minimum width of the foundation (m)

Df : penetration depth (m)

In case of the conditions given in Fig. 3.16, allowable bearing pressures at assumed settlements of 2.5 cm, 3.0 cm and 4.0 cm, with respective internal frictions of 30, 32 and 35, are:

Allowable Bearing Pressure of Sand Foundation

(Unit: t/m^2)

Internal Friction		30 (N=18)	32 (N=24)	35 (N=35)
Settlement	2.5 cm	10.6	10.6	17.4
	3.0 cm	12.0	15.3	20.2
	4.0 cm	14.9	19.2	25.8

(3) Allowable Soil Pressure

Except for the soft clay strata examined as the Case III, the cohesive clay widely distributed along the Blue Nile has a long term allowable bearing capacity of about 22 t/m^2. In the case of sand stratum in the Project area, it is about 20 t/m^2 as discussed previously.

On the other hand, the consolidation settlement of the cohesive clay of the Case III was computed at 7.1 cm in the case of building load of 15 t/m^2, which is less than the allowable settlement for mat foundation. Therefore, the allowable bearing pressure of the cohesive soil is expected to be more than 15 t/m^2.

Although the above values are estimated based on indirect information without subsurface investigations at the alternative pumping site, bearing strata of the pumping station is supposed to be stiff clay, the consolidation settlement estimated above is considered to be on the safe side.

In case foundation ground is of sand strata, the allowable bearing pressure of more than 15 t/m^2 could be expected with conditions of either: internal friction of 30° under allowable settlement of 4 cm or more; or internal friction of 32° under allowable settlement of 3 cm or more.

Since the allowable bearing pressure is considerably influenced by the settlement, it is important to estimate the settlement precisely based on the direct information to be obtained through field investigations. Although the above estimation is considered reliably safe side, detailed subsurface investigations are indispensable prior to proceed to implementation of the pumping station. Considering a possibility of existence of a buried channel around the alternative pump site, exploratory drilling should be conducted during further design stage to clarify the depth of the stiff clay.

3.4 Bearing Capacity at the Existing Site

(1) Nur El Din Pumping Site

The Nur El Din pumping station is located on stiff clay. The long term allowable bearing capacity (qa) of this stiff clay is estimated to be 36 t/m^2 (= 353KN/m) based on findings obtained through field investigation by portable cone penetrometer.

(2) Hurga Pumping Site

The foundation of this site seems to be located on stiff clay or its underlying strata, but this could not be verified through the site survey. If rehabilitation of the pumping station calls for increasing the load considerably, exploratory drilling is necessary to confirm information on the bearing strata and check the allowable bearing pressure.

3.5 Geotechnical Investigation at Alternative Pumping Station Site

3.5.1 General

The alternative pumping station site was selected between existing Hurga and Nur El Din pumping stations through the alternative study of the Work-I stage of the Project. Additional geotechnical investigation was performed in the Work-II stage in order to clarify soil condition at this site and to obtain basic data for foundation design of the structure. After the preparation of the Technical Specifications by the JICA Study Team, geotechnical investigation was carried out by a contractor, Amin Enterprises Ltd., under the supervision of the JICA Study Team. The investigation was started in the late May 1991 and completed by the middle of June 1991.

Field works conducted on the geotechnical investigation included;

i) Test boring of 60 m in total at 3 locations, and

ii) Standard penetration tests of 58 times in these boreholes.

The boring work with standard penetration tests was done by using US-made boring machine, Acker Model AD-II, of truck mounted type.

3.5.2 Geotechnical Condition

The investigation site forms the cliff facing to the Blue Nile river, low-lying terrace at about EL. 398 m, the steep slope in the section between EL. 398 m and EL. 408 m, and the widely extending plain at about EL. 408 m topographically. The proposed pumping station was planned to situate at the location between the low-lying terrace and the edge of the bank.

Among three boreholes, two holes, BH-1 and BH-2, were drilled at the low-lying terrace where the pump units are to be installed. The last hole, BH-3, was drilled on the plain where the anchor blocks of outlet pipe are to be located. The location of each borehole is shown in Fig. 3.17, Location Map of the Geotechnical Investigation.

Three boring logs and soil profiles were produced as shown in Figs. 3.18 to 3.22 based on the geotechnical data obtained through test boring and standard penetration tests.

As seen in the soil profiles, soils at the proposed pumping station site are principally composed of sandy strata such as fine sand, medium sand and silty sand except the uppermost silty clay and lower stiff clay. These strata lie nearly horizontally, although showing poor continuity of strata in a direction to across the river stream.

The silty clay, dark brown coloured, reaches a depth of 3 m from the ground surface or about EL. 405 m at the BH-3, and is widespread as the uppermost layer in the Project area. The layer section between EL. 402 m and 405 m is composed of fine sand layer and it grades to medium sand of lower stratum. The layer between EL. 398 m and EL. 402 m is composed of medium sand layer. Below EL. 398 m, the soil condition reflects the original depositional environment, and allows a distinction to be made between the river side area and the hill side area. At the river side area, the stiff clay with the thickness of 4 m to 5 m, fine sand with the thickness of 4 m to 5 m and medium sand layers appear in the both BH-1 and BH-2. In contrast to the river side area, the silty sand layer appears in the BH-3 which located at the hill side area. Accordingly, these layers are probably deposited as interfingering shape. The fine sand layer of the BH-1 and BH-2 is gradually changes to medium sand layer. The silty sand layer of BH-3 deposited below the depth of 10 m or EL. 408 m, and gradually changes to more silty at the depth of 17 m or EL. 391 m.

The foundation layer of the proposed pump house is composed of the medium sand which appears at the depth of 9 m in the BH-1 and 8 m in the BH-2, respectively. It consists of grains with uniform size and round-shape sands.

N-value, blow number of standard penetration test, measured in three holes showed more than 50 in the uppermost layer of silty clay. In the stiff clay layer, it ranged from 31 to more than 50. In the fine sand layer, it varied from 20 to more than 50, of which the average was 30. In the medium to silty sand layers, the N-value raged from 21 to more than 50, of which average was 35 in the upper section, and more than 50 in the lower section, respectively.

Underground water tables in the boreholes appeared at the depth of 7 m in the BH-1 and BH-2 and 17.5 m in the BH-3 from the ground surface. These groundwater levels were almost the same with the water level of the Blue Nile. The above observation suggested that the groundwater level at the proposed pumping station fluctuate according to the water level variation of the Nile; higher during the flood season.

3.5.3 Bearing Capacity of Strata at Proposed Pump House

(1) Scale of the Proposed Pump House

Size of the proposed pump house is planned to be 9 m wide and 29 m long. Bottom of the base floor to be excavated is planned at EL. 388.5 m or about 9.5 m below from ground surface at the test boring points of BH-1 and BH-2. Design load of the pump house is estimated at around 15 t/m^2.

(2) Average N-value of the Foundation Layer

According to the N-values obtained from standard penetration test, foundation stratum of the medium sand layer can be classified into two sub-layers in respect of N-value. The upper sub-layer would be the foundation layer of the structure, and after excavation for the structure it would remain 4 m to 7 m thick. The N-value of the upper sub-layer varies from 28 to more than 50 with its average N-value of N=35, while that of the lower sub-layer was more than 50.

(3) Strength of the Foundation Layer

Concerning the relationship between N-value and internal friction angle of sandy strata, formulae have been proposed by Terzaghi-Peck, Meyerhof, Dunham and Osaki as shown in Fig. 3.22. As the foundation layer consists of grains with uniform size and round-shape sands, the following Dunham's formula was adopted for obtaining the internal friction angle.

$$\phi = \sqrt{12N} + 15$$

Strength of sandy material is generally estimated by adopting average N-value. In this study, estimation by the minimum value was also done for checking the most critical condition in addition to the standard procedure mentioned above.

Taking the average N-value of 35 and minimum N-value of 28 in the foundation layer, an internal friction angle of the foundation layer was obtained at $\phi = 35°$ and $\phi = 33°$, respectively.

(4) Allowable Bearing Capacity of the Foundation Ground

Allowable bearing capacity on the sandy layer ground was estimated by using the both Terzaghi's formula, equation (1) and the following Meyerhof's formula.

$$q_a = \frac{1}{3} q_d = \left(\frac{1}{2} \times 3.3N\,(1 + Df/B)\right)\frac{1}{3}$$

where;
- q_d : bearing capacity (t/m^2)
- N : N-value
- Df : penetration depth of foundation (m)
- B : minimum width of foundation base (m)

According to the above computation, the allowable bearing capacity of the sandy layer at the foundation level of the pump house was obtained at 28 t/m^2 to 56 t/m^2 in case of N=35 or ø = 35. In case of value, ø = 33 or N=28, it was 23 t/m^2 to 35 t/m^2. This value shows sufficiently more than resultant load of the pump house of 15 t/m^2 either in the case of shallow foundation such as footing foundation and mat foundation. Based on the above condition, the mat foundation is technically and economically recommended as the optimum foundation type of the proposed pump house.

3.5.4 Settlement of the Proposed Pump House

Criteria for allowable settlement of reinforced concrete-made pump house on sandy ground is said up to 3.0 cm in standard value and up to 6.0 cm in maximum value.

In case that a settlement of the proposed pump house is tolerated up to 2.5 cm, the limit of the load pressure is 17.4 t/m^2 for the sand layers with the friction angle of 35°, and if a settlement of the pump house is tolerable up to 3.0 cm, the limit of the load pressure is 20.2 t/m^2 as shown in page A-11 and A-12. The resultant load pressure of the proposed pump house is estimated at 15 t/m^2, then settlement of the pump house would be within the standard value of the tolerance.

4. QUARRY SITE AND BORROW PIT

4.1 Quarry Site

A quarry site for crushed stones and gravel is located nearby the Jobel El Fau Range extending along the Wad Medani-Gedaref road, about 60 km east of the Project area in route distance. The quarry site in the Jobel El Fau Range produces crashed stone from rhyorite, welded tuff and granitic rocks, consisting mainly of granodiorite which are of mesozoic Triassic Palaeozoic and Permian in age. These rocks are hard enough for aggregates and sufficient in amount, and there is nothing to suggest unsuitability for aggregates according to visual observation. Six size of crashed gravel, from medium grain sand to cobble stone, are now being produced by a private contractor for his self-consumption.

4.2 Borrow Pit

A borrow pit for latritic soil is located nearby Miheila village, approximately 30 km northeast, in route distance, of the Project area. Miheila village is 3 km away from the Wad Medani-Gedaref road. Another borrow pit for the same reportedly exists in 1 km away from the Mihiela village but was not identified at field during the Study period. At the borrow pit nearby Miheila village, latritic soil is being produced by open-pit mining for lower base course of roads.

In the borrow pit at Miheila village, subround-round gravel strata are intercalated with lateritic soil, and extracted to use as natural gravel.

TABLES

Table 2.1 RECORDS OF BMs. IN HURGA AND NUR EL DIN SCHEME

Number of B.M.	Scheme	Description of Bench-Mark	Reduced Levels (Meters)
H-1	Hurga	The location is near the off take of major canal in Hurga Scheme and distance from off take of main canal is K. 0.824. Rivet crown of gate of major canal.	EL. 411.373
H-2	Hurga	The location of this Bench-Mark is between two villages (North of Elreihimab village and south of Elreih village), and the distance from the B.M. to Elreihimab village is 600 m. Bearing from B.M. to tank of water is 307°30' and also distance from the B.M. to Elreih village is 100 m. Bearing from B.M. to Mosque in Elreih village is 118°00', and also there is a beacon near this B.M.	EL. 410.618
N-3	Nur El Din	B.M. is located in Abd el Kerim village 200 m from the bridge of the main canal of Nur El Din.	EL. 410.418
N-4	Nur El Din	B.M. is located to the south of Elshedaida Agaleen village at about 900 m. Bearing from the B.M. to the mosque in the village is 353°00' also the distance between the B.M. and I.P. of main canal of Nur El Din is 500 m and the bearing from the B.M. to I.P. at K. 3.565 is 03°00'.	EL. 411.078
H-5	Hurga	New B.M. location is near I.P. of canal No. 2 at K. 3.910 and the distance between I.P. of the canal to B.M. is 8.0 m, and the bearing from the B.M. to the mosque in El Shabarga town is 312°00'.	Value is not yet taken
H-6	Hurga	New B.M. at Tennoba village. It is located the west of General Secondary School. The distance between the B.M. and School is 10 m. Bearing from the B.M. to the tank of water in the village is 43°00', and the distance is 105 m.	Value is not yet taken
H-7	Hurga	B.M. is located to the north of Hurga village. Distance between the B.M. and the edge of Hurga village is 900 m. Bearing from the B.M. to the mosque in the village is 183°30'. There is a beacon near this B.M. at about 2.70 m.	Value is not yet taken

Notes: – All data were collected at Projects Under-secretariate, MOI.
– These B. Ms. were established by Survey Section of Projects, MOI.

Table 2.2 RECORDS OF NATIONAL BM. No.666,667 WHICH ARE BASE OF PROJECT AREA BM

VIII. Precise Bench-Marks along the Rahad (Blue Nile).

(a) From Hantub (West Bank of Blue Nile opposite of Wad Medani) to Meshra Hedeiba.

Bench Mark.	Kind	Length	Distance from Telegraph Pole	Distance from Northern Proceeding B.M.	Nearest Holla and Remarks.	Reduced Level
		Metres.		Kilometres.		Metres.
665	Pile	4			Inside hedge on West side of road loading down to ferry at Wad Medani and 50 metres from descent into river bed ... Beaconed..................	396.904
666	Pile	2	3 Metres S.W.	3.2	On telegraph line running from Wad Medani to Meshra Hedeiba 1 1/2 kilos West of Nasim Village...Beaconed..	403.293
667	Pile	2	3 Metres E.	4.4	On telegraph line running from Wad Medani to Meshra Hedeiba 2 1/2 kilos West of Khidr...Beaconed..	401.991

(b) Along the Rahad (West Bank) from Meshra Hedeiba to Sherif Yakub.

Bench Mark.	Kind	Length	Distance from Telegraph Pole	Distance from Northern Proceeding B.M.	Nearest Holla and Remarks.	Reduced Level
668	Pile	2	4 Metres N. at the bend of the line.	3.7	On telegraph line from Wad Modani to Meshra EL Hedeiba 1 1/2 kilos East of EL Khider Village...Beaconed......................................	402.001
669	Pile	2		5.0	On Government road, 10 metres East of a large tundub tree at North end of Rawashda Village... Beaconed	403.865

COPY OF "SURVEYS B.M. RECORDS Vol. I, p.20"
(Central Survey Depertmnt MOD)

Table 2.3 BM. RECORDS NEAR BY WAD EL NAU AND HAG ABDULLAH GAUGING STATION

Number of Bench Mark	Reduced Values	Remarks
100	408.991 m	good condition, Wad El Nau
102	410.462 m	good condition, Wad El Nau
114	414.274 m	a little damaged, Hag Abdullah

Notes: Field reconnaissance on Dec. 8th, 1990
Reduced Values are from Surveys B.M. Records Vol. IV.

FIGURES

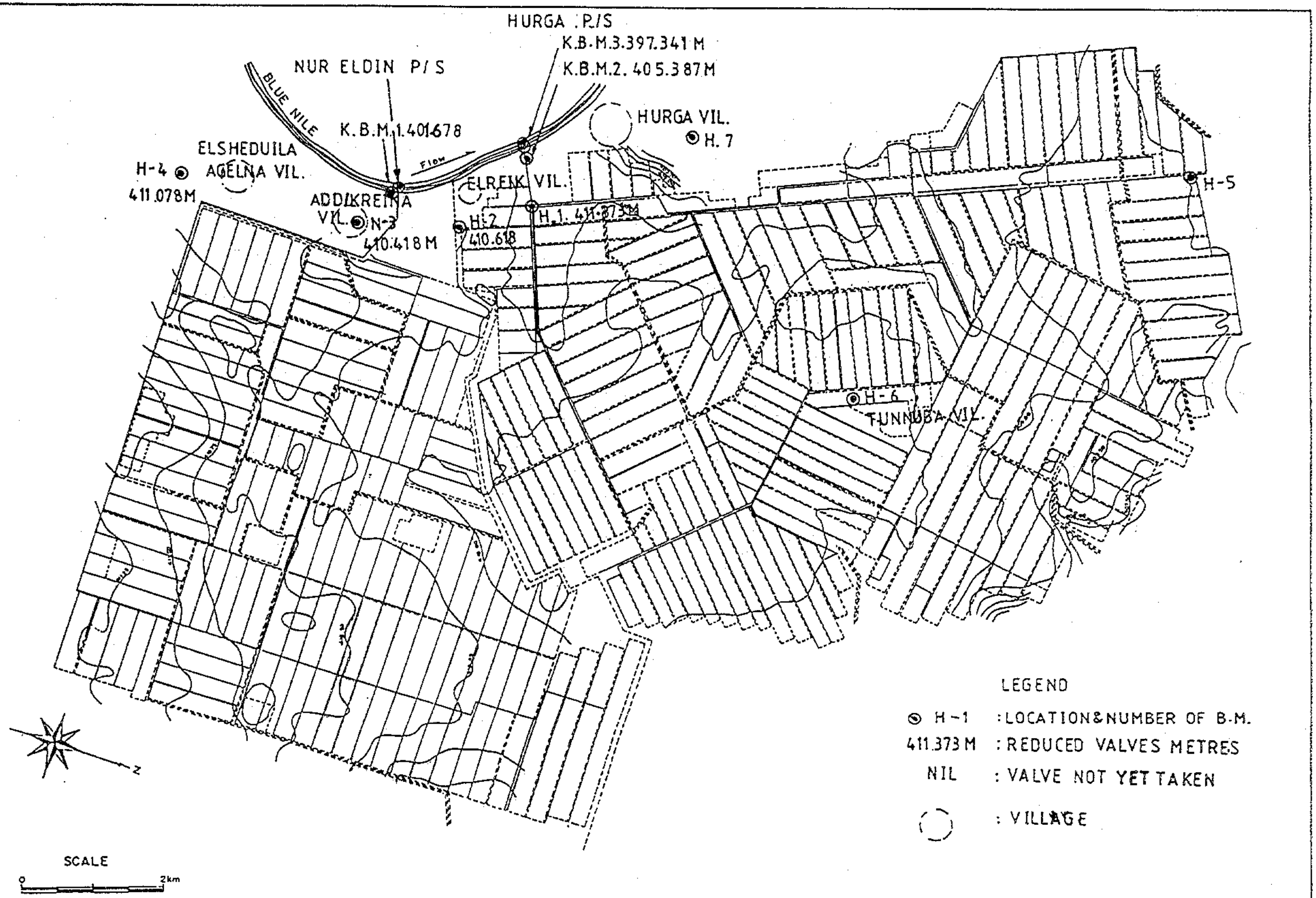


Fig. 2.1 LOCATION OF BENCH MARK

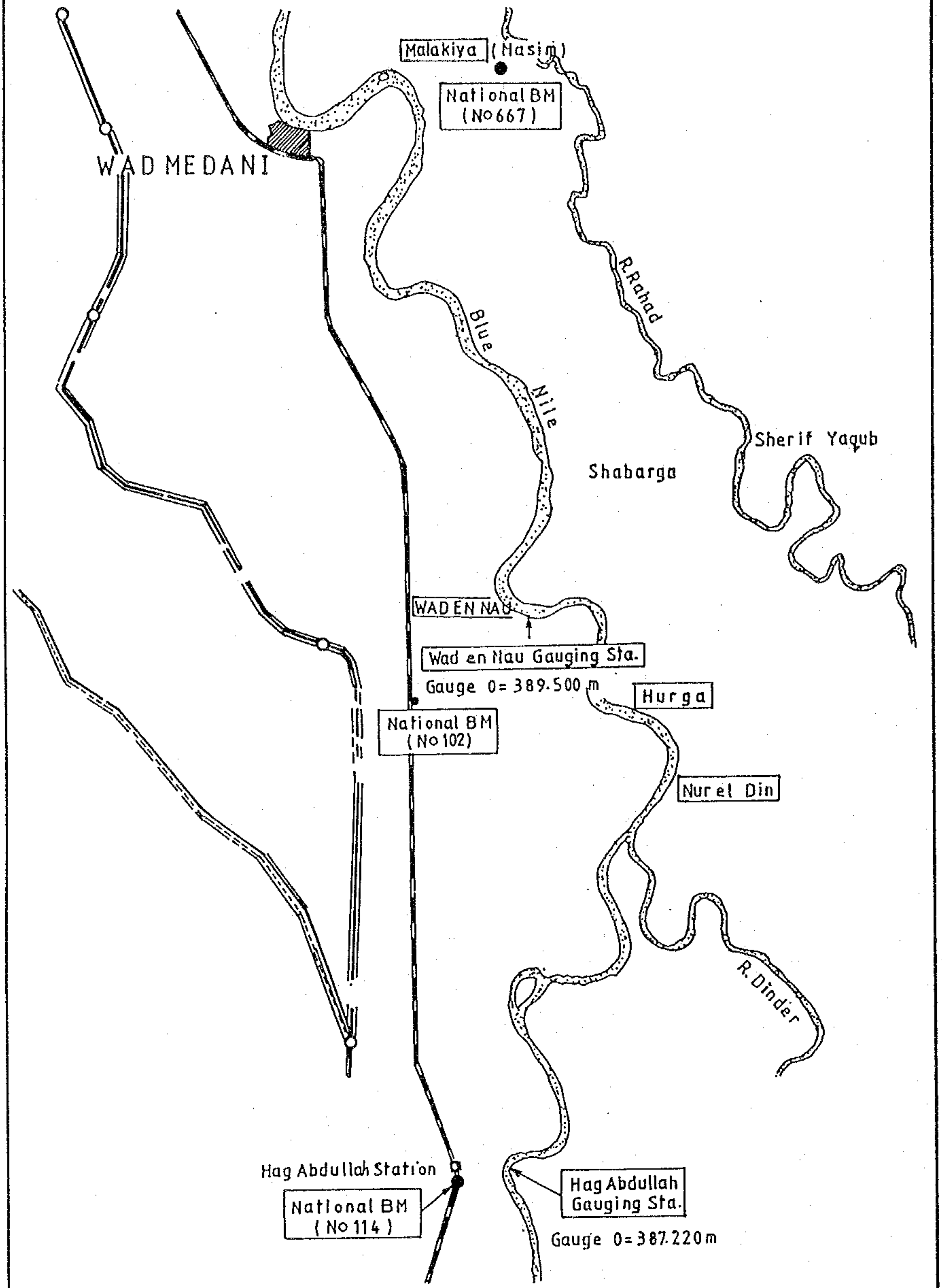


Fig. 2.2 LOCATION MAP OF SURVEY FIELD

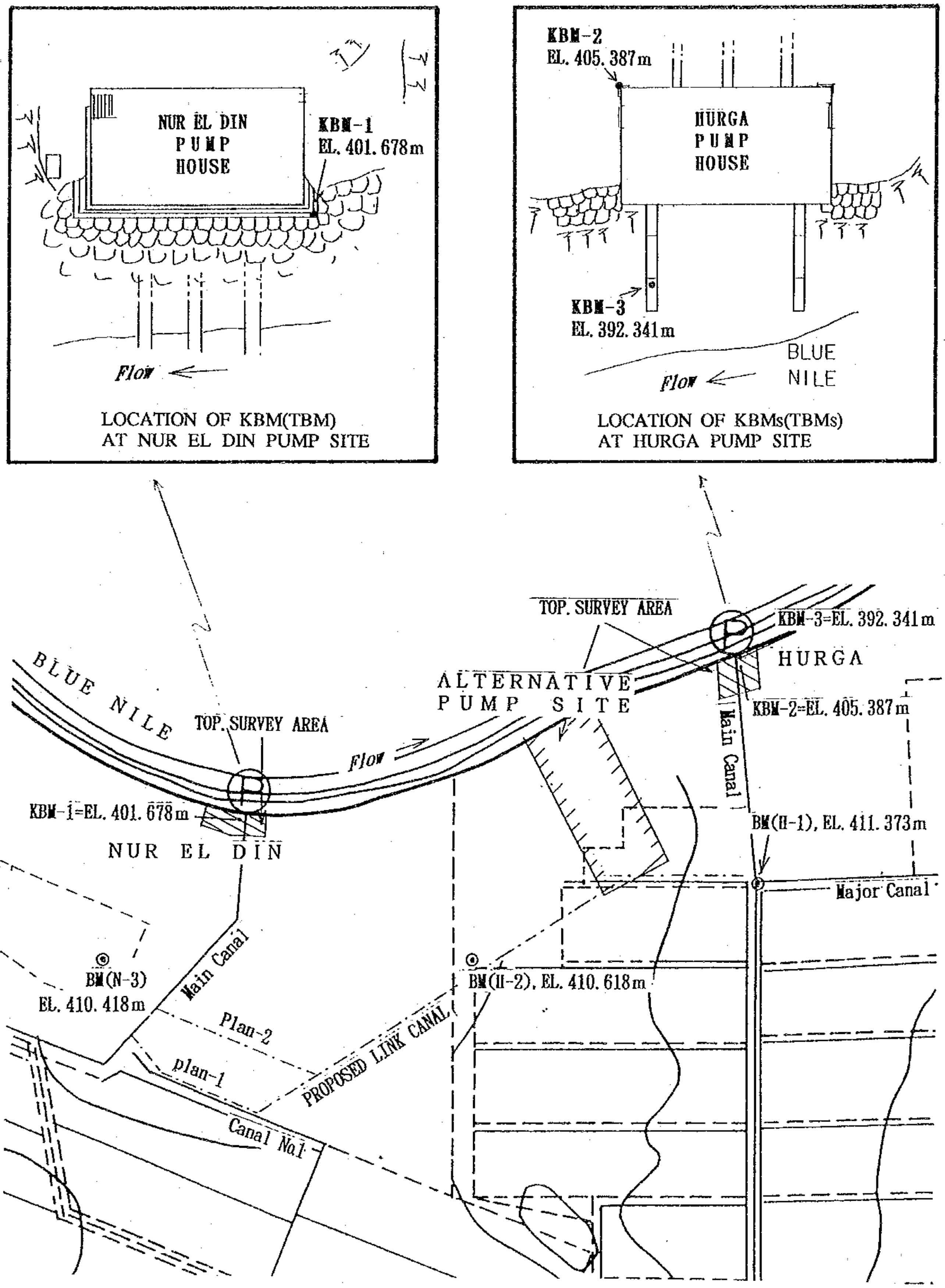


Fig. 2.3 LOCATION OF TEMPORARY BMS

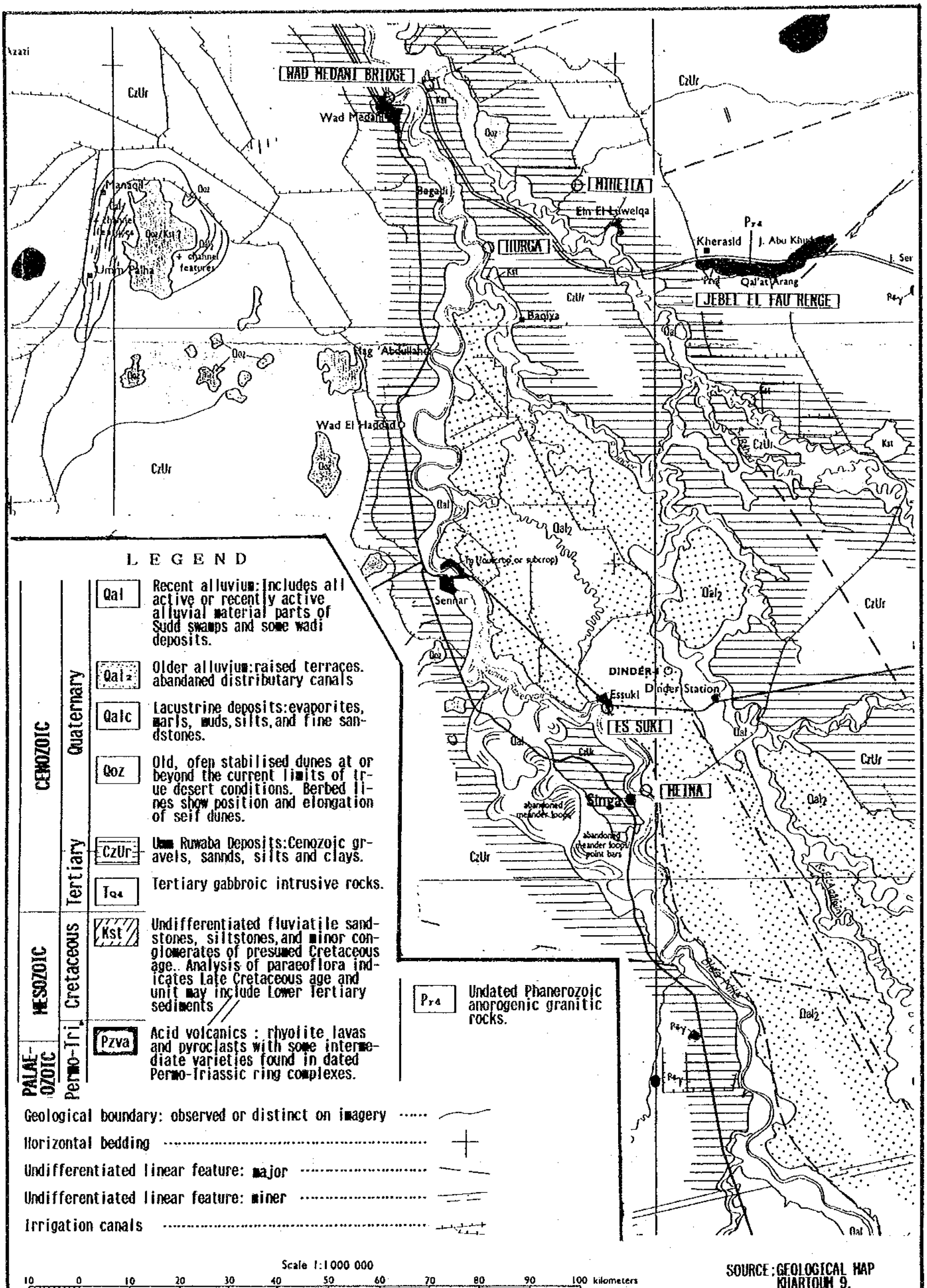
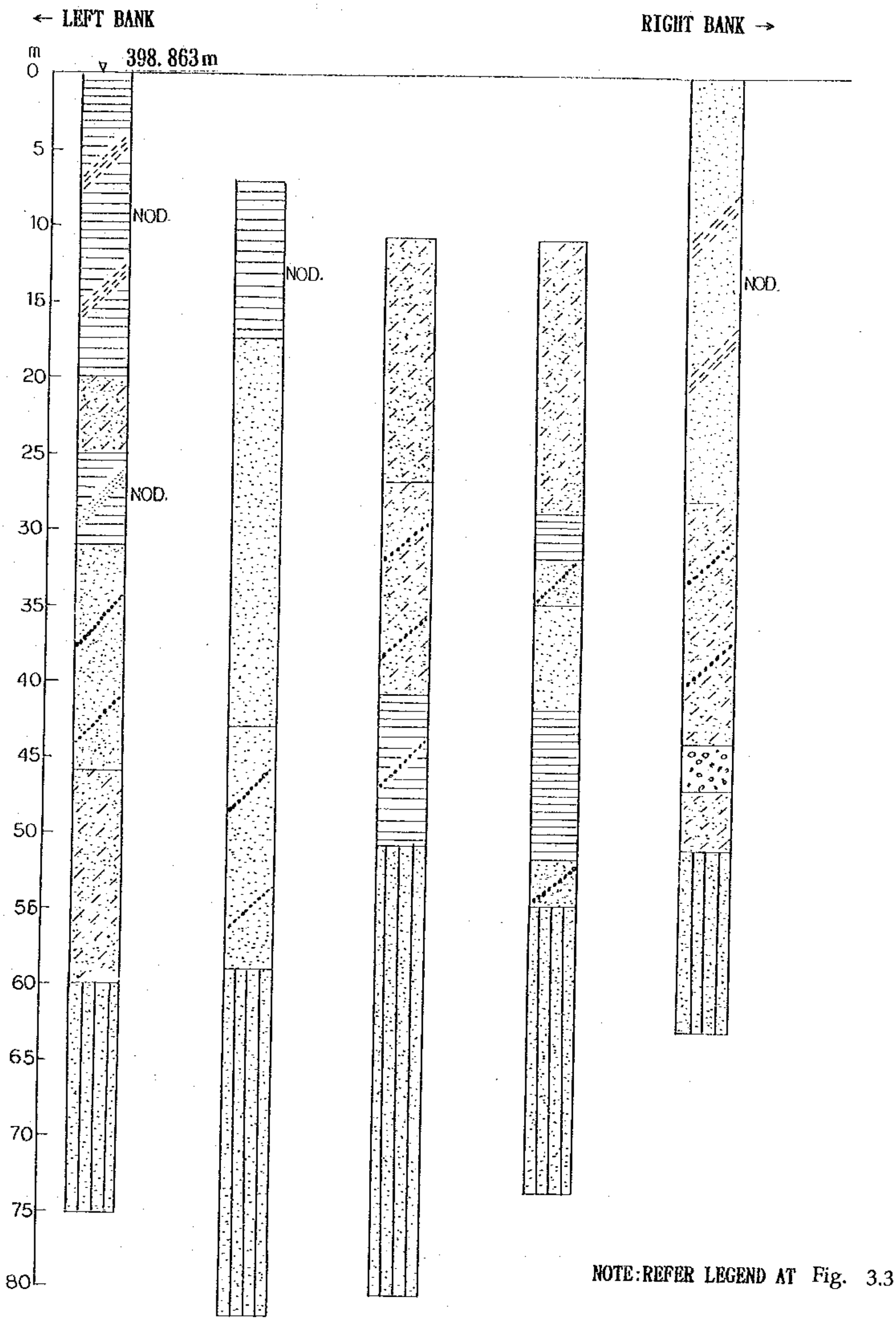


Fig. 3.1 GEOLOGICAL MAP

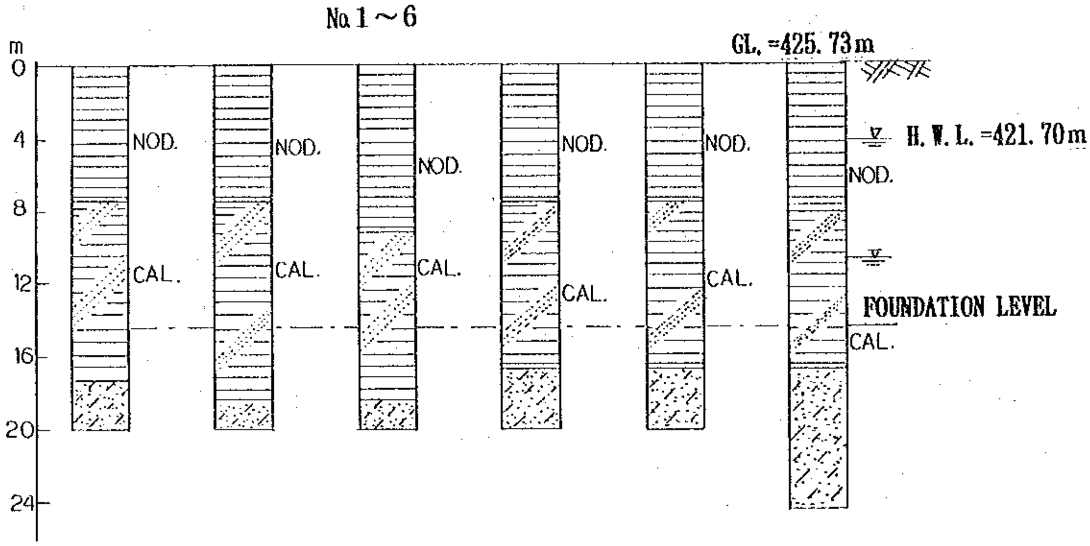
SOURCE: GEOLOGICAL MAP KHARTOUM 9, GEOLOGICAL RESEACH AUTHORITY OF SUDAN



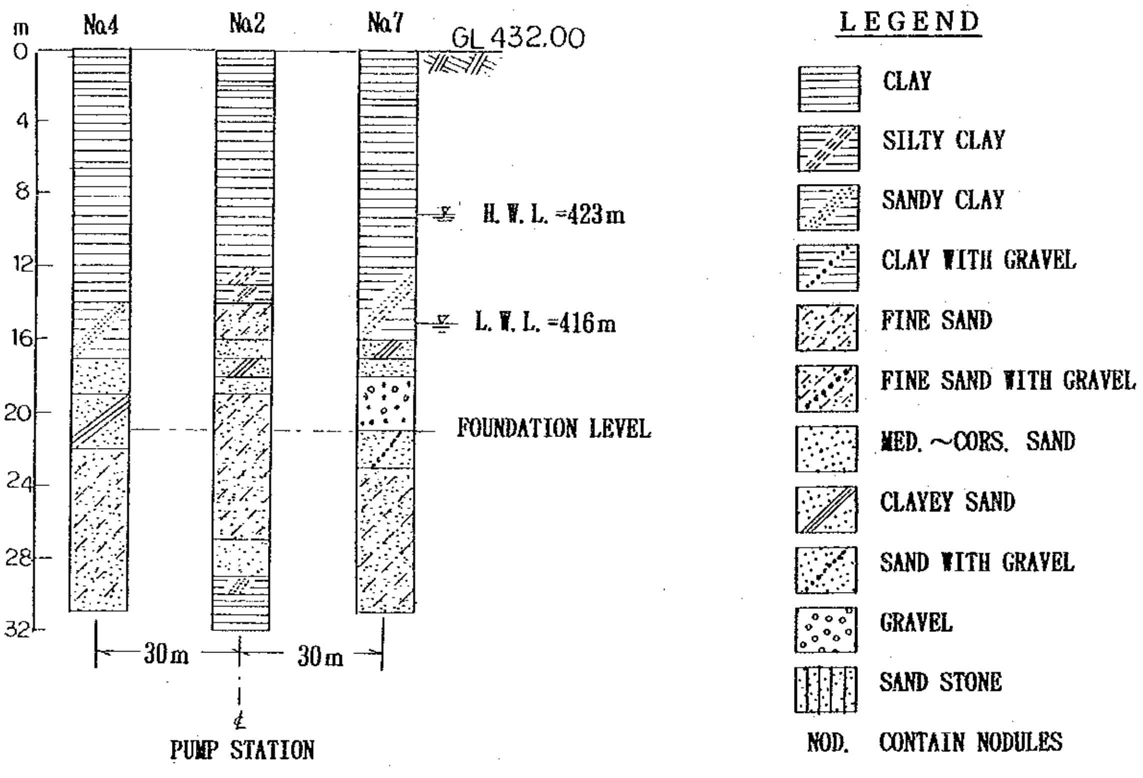
NOTE:REFER LEGEND AT Fig. 3.3

Fig. 3.2 BORE HOLE LOGS AT WAD MEDANI BRIDGE

SOURCE:GENERAL LAYOUT OF THE BRIDGE, MOR



ES SUKI PUMP STATION BORE HORE LOGS



MEINA PUMP STATION BORE HORE LOGS

Fig. 3.3 BORE HOLE LOGS AT ES SUKI AND MEINA PUMPING STATIONS

SOURCE:SHASHEINA-SUKI IRRIGATION PROJECT CONTRACT No.S1

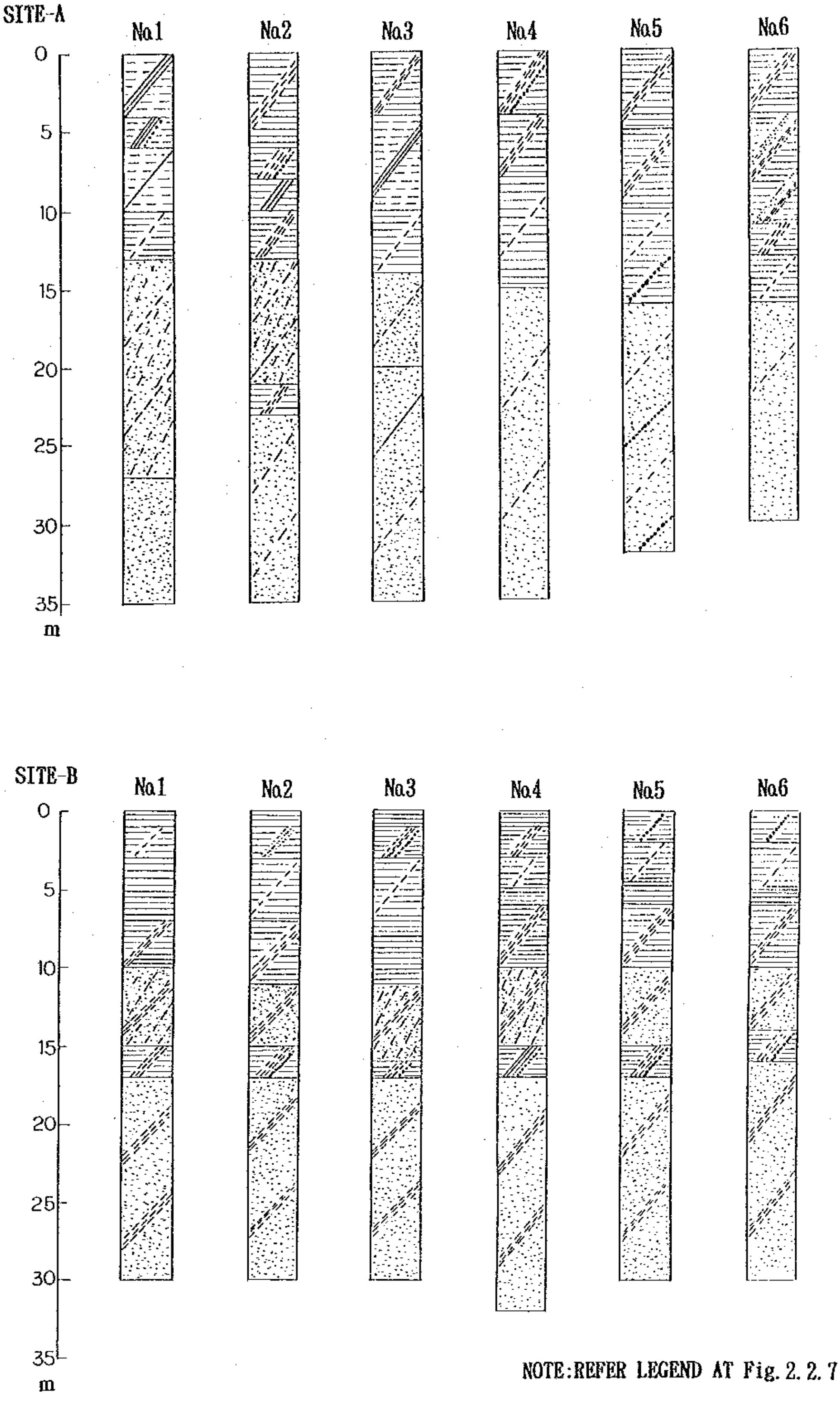
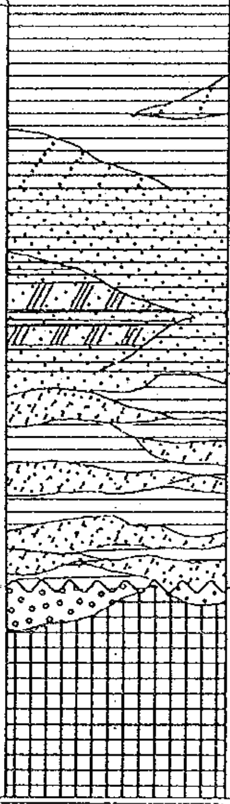


Fig. 3.4 BORE HOLE LOGS AT SHASEINA - SUKI PUMPING STATIONS, SITE-A AND -B

SOURCE:REPORT ON SOIL INVESTIGATION FOR SHASHIENA-SUKI PUMP STATION SITES

Fig. 3.5 SUMMARY OF STRATIGRAPHIC SEQUENCE IN THE PROJECT AREA

Age		Stratigraphy	Main rockfacies	Thickness	Description
Quaternary	Polocene		Clay~ clay with sand	5~8 m	With some calcarious nodules
			Sandy clay Alternation of sandy clay and ~ clayey sand	4~8 m	Sandy~silty clay with some calcarious nodules Consist of thin fine sands
			Alternation of fine sand and clay	6~8 m	Consist of well sorted fine-grained sands and clays Thickness of each strata attains ~ 2m
	? Pleistocene		Coarse to medium sand ~ gravel Stiff clay	2~8 m or more	Consist of Oyster fossil bank Thickness of sand and gravel are ~ 20cm Calcarious hard clay

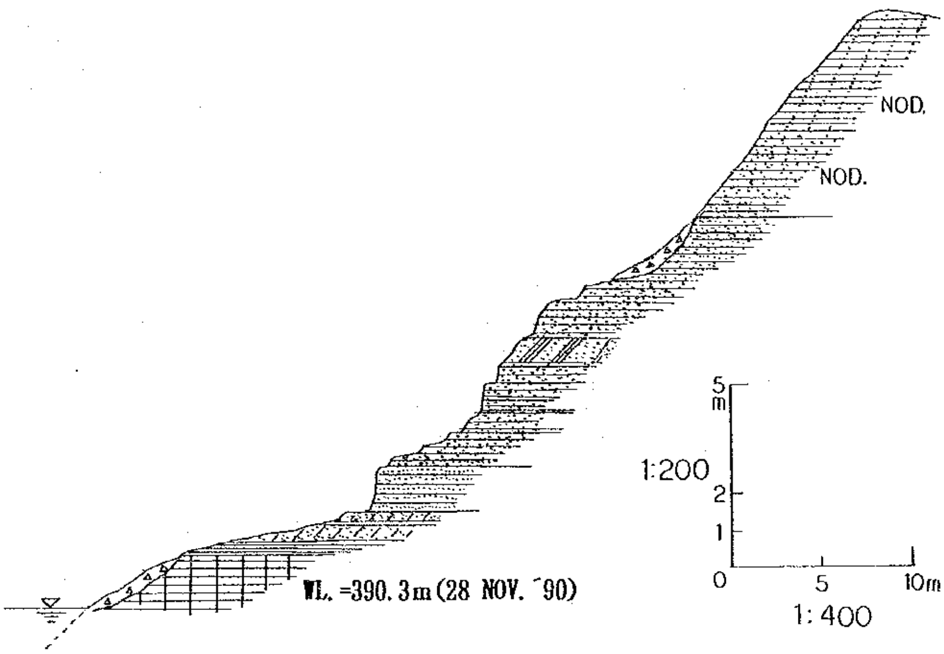


Fig. 3.6 STRATIGRAPHIC PROFILE AT HURGA PUMPING SITE

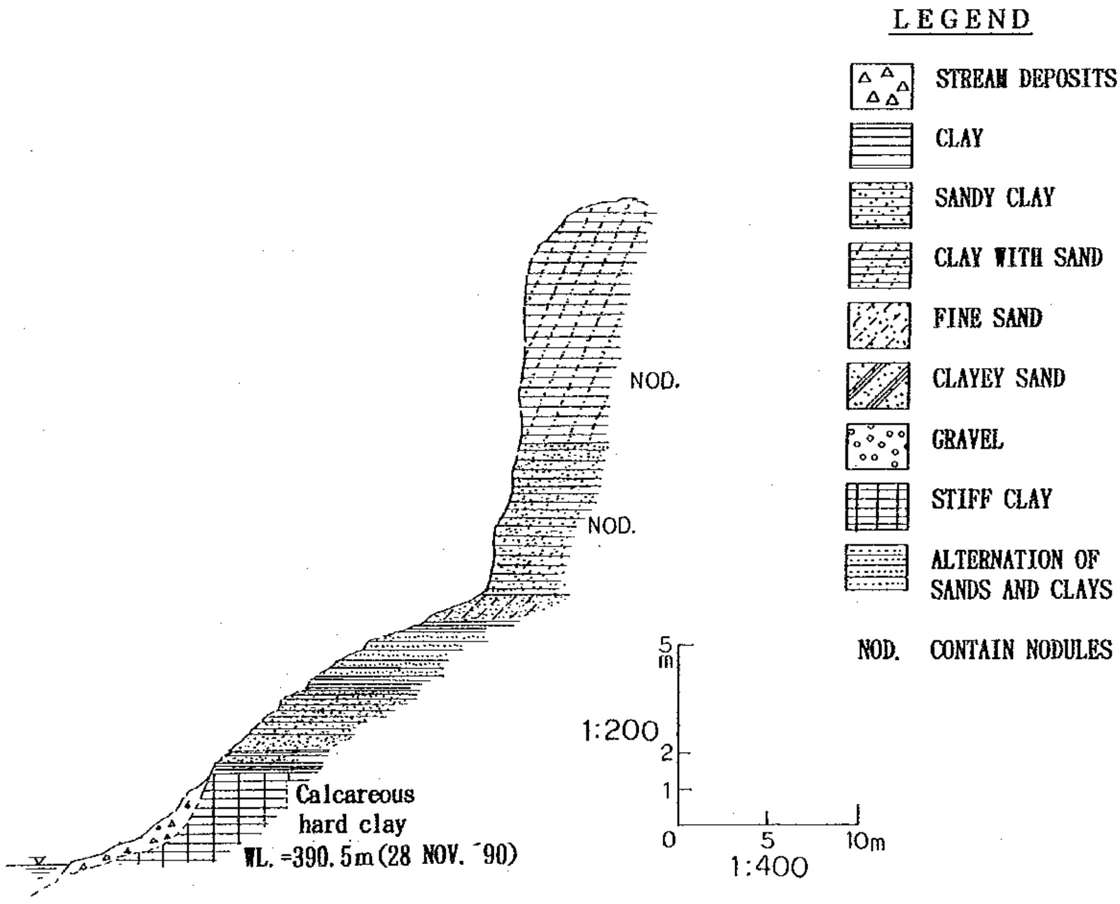


Fig. 3.7 STRATIGRAPHIC PROFILE AT NUR EL DIN PUMPING SITE

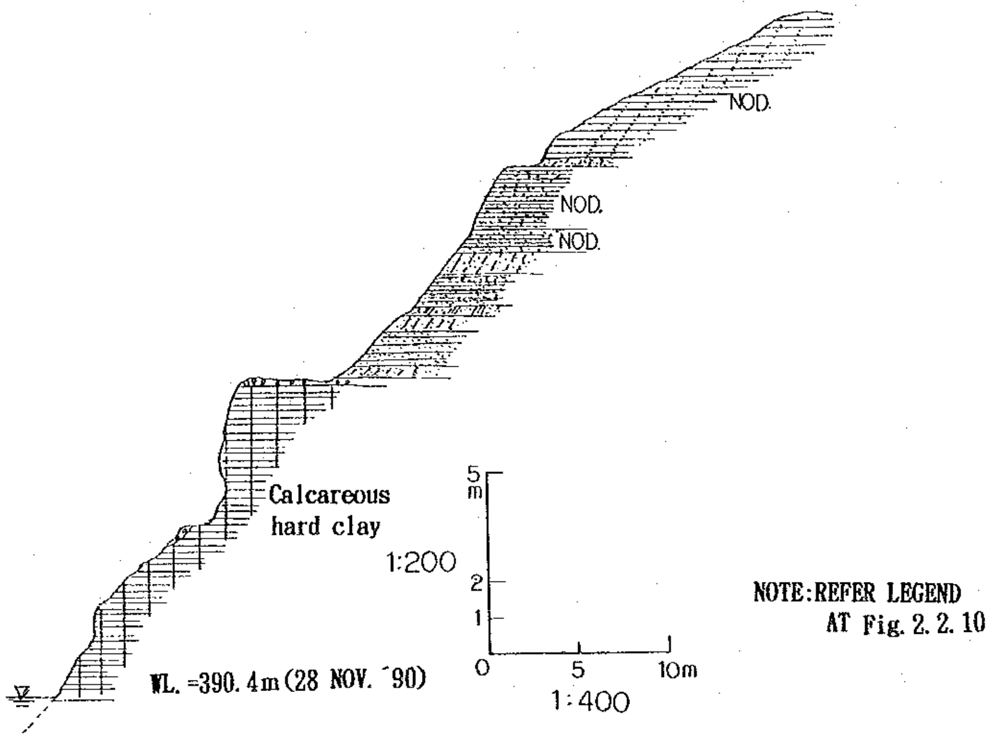


Fig. 3.8 STRATIGRAPHIC PROFILE AT ALTERNATIVE PUMPING SITE

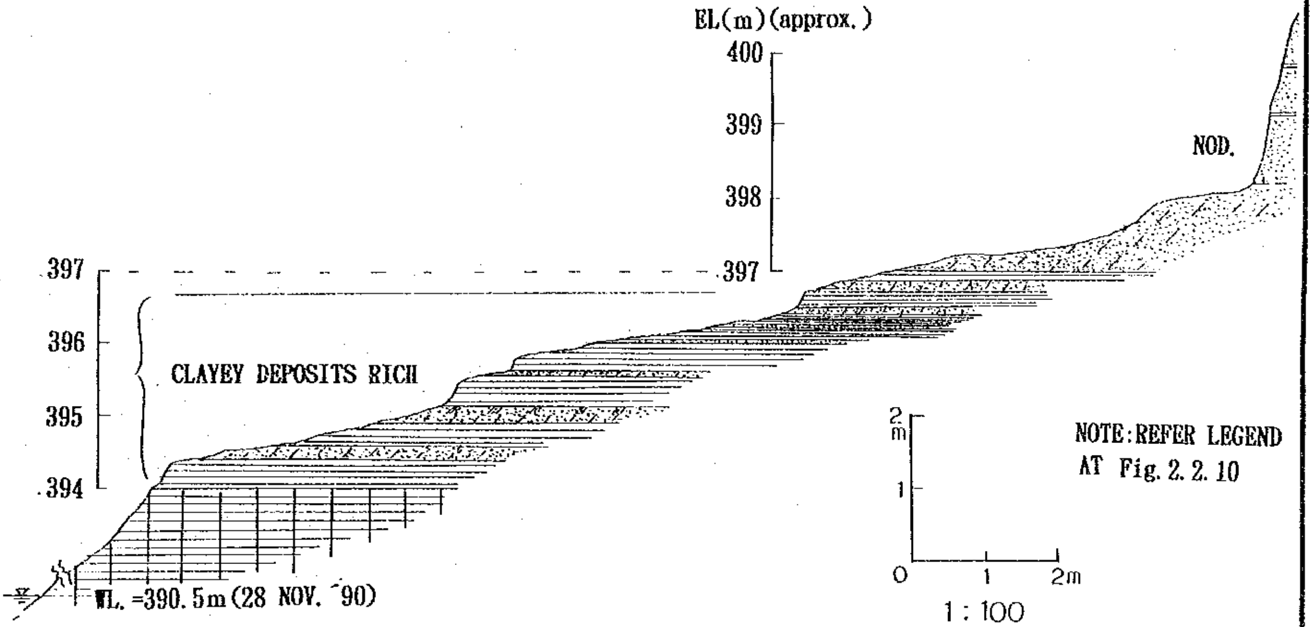


Fig. 3.9 RELATIONSHIP BETWEEN LANDFORM AND ORDER OF THE STRATIFICATION - CLAY RICH DEPOSITS - (UPSTREAM OF Nur El Din)

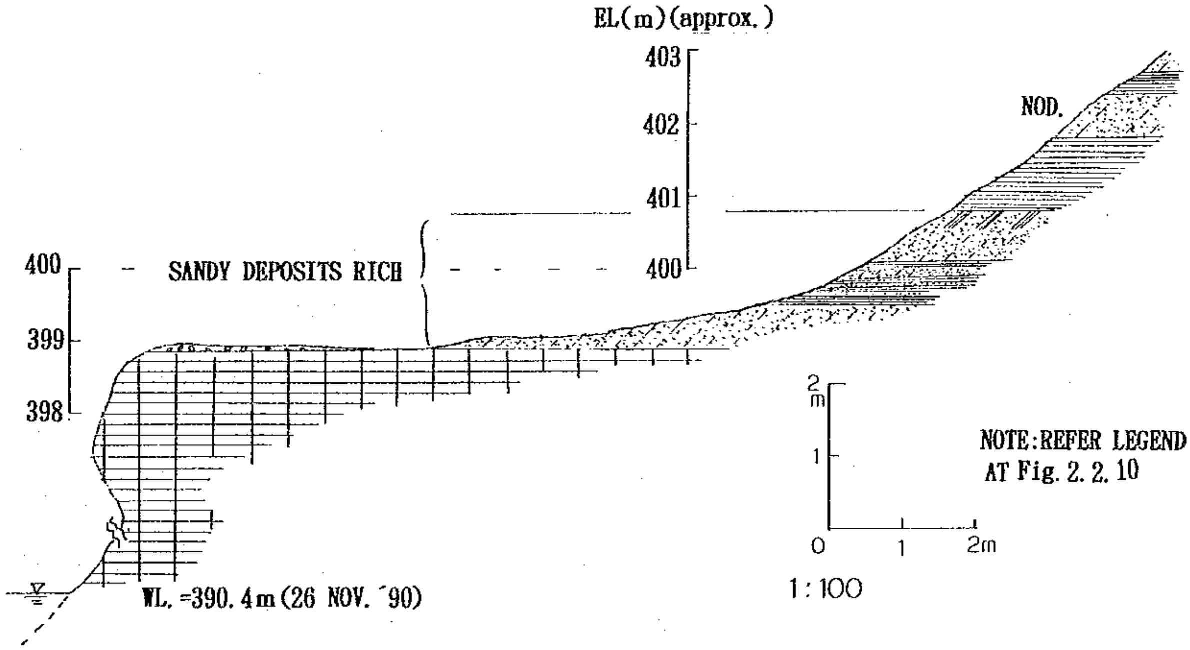


Fig. 3.10 RELATIONSHIP BETWEEN LANDFORM AND ORDER OF THE STRATIFICATION - SAND RICH DEPOSITS - (ALTERNATIVE PUMP SITE)

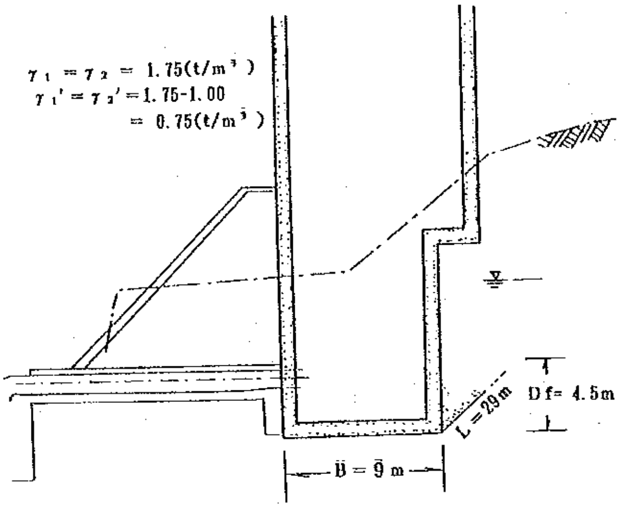


Fig. 3.11 CRITERIA FOR CALCULATION (BEARING CAPACITY)

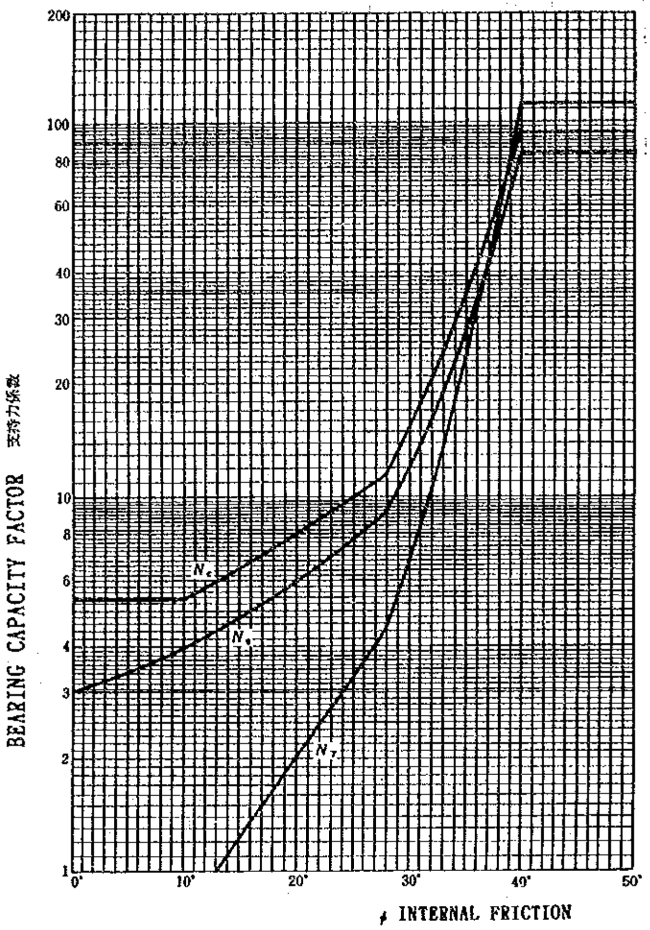


Fig. 3.12 BEARING CAPACITY FACTOR

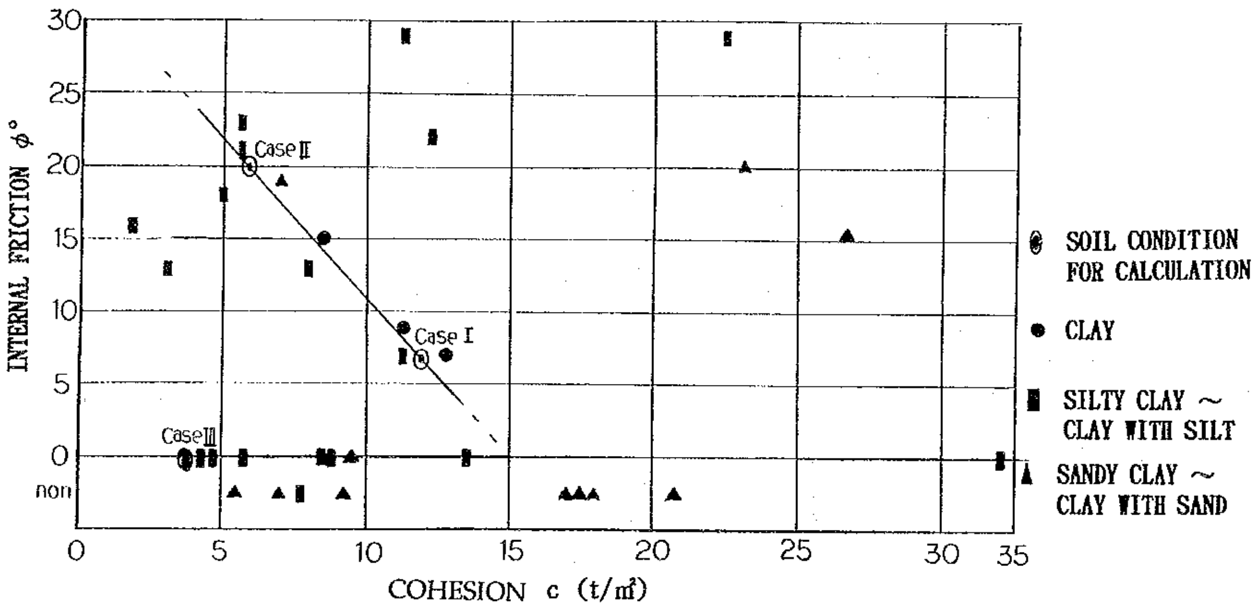


Fig. 3.13 INTERNAL FRICTION AND COHESION OF COHESIVE SOIL IN CLAY PLAIN

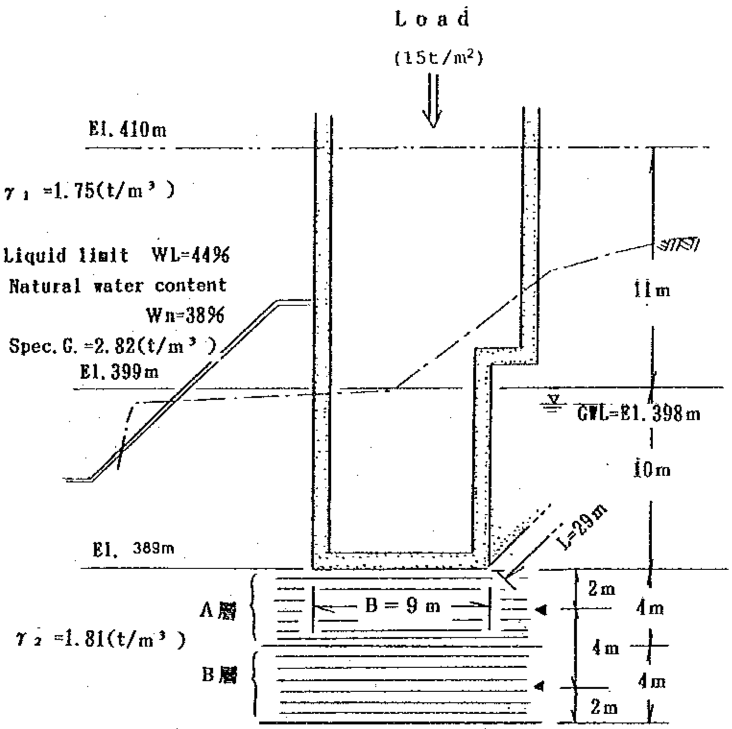


Fig. 3.14 CRITERIA FOR CALCULATION (CONSOLIDATION SETTELEMENT)

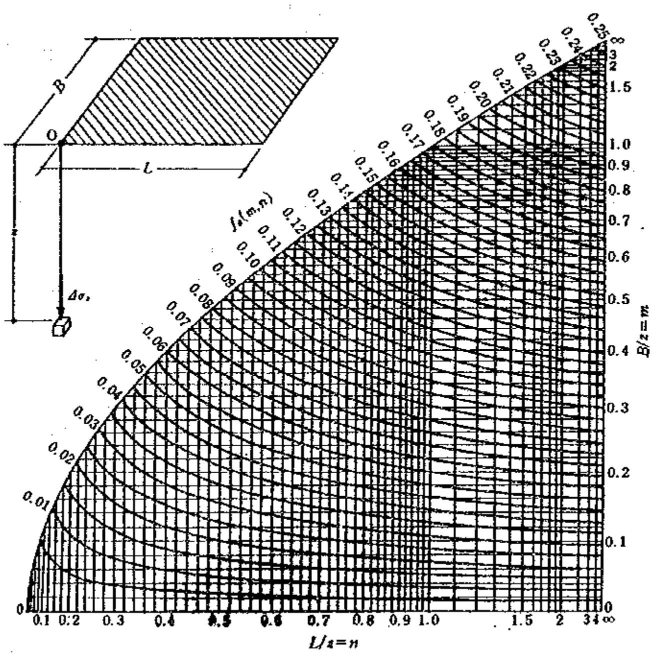


Fig. 3.15 f (m, n)

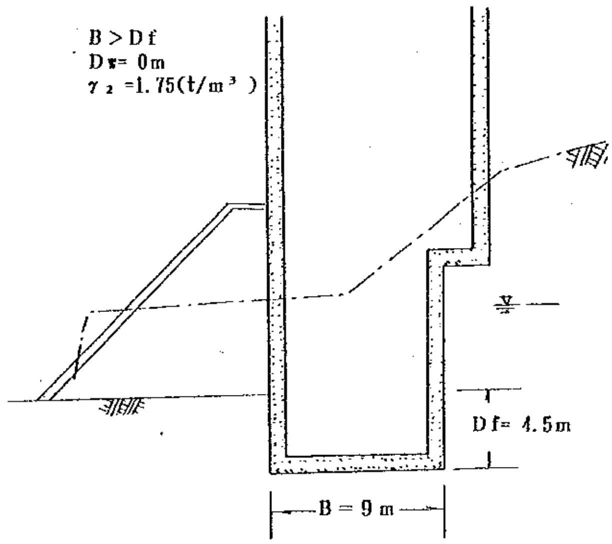


Fig. 3.16 CRITERIA FOR CALCULATION (BEARING POWER OF SAND)

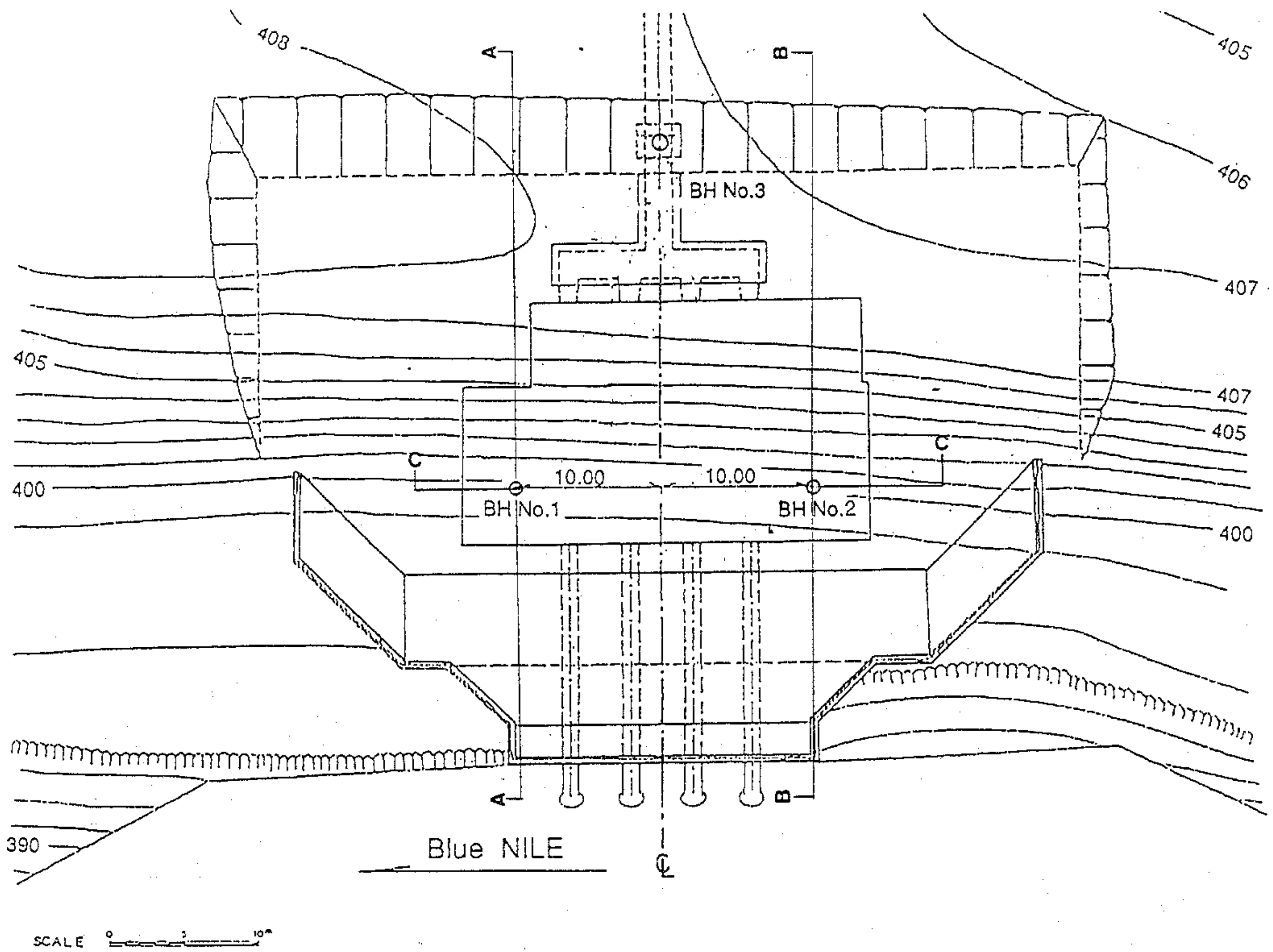


Fig. 3. 17 LOCATION MAP OF THE GEOTECHNICAL INVESTIGATION

Fig. 3. 18 (1/3) SUMMARY OF DRILL LOG

PROJECT HURGA & NUR EL DIN

HOLE NO. BH-1

DEPTH	ELEVATION	THICKNESS	COLUMN SECTION	ROCK TYPE OR FORMATION	DESCRIPTION	G. W. L.	CORE RECOVERY	R. Q. D	STANDARD PENETRATION TEST (N-value)
	397.936								
5.0	392.936	5.0		Stiff Clay	Brown coluored stiff clay. Generally dense.				
9.0	388.936	4.0		Fine Sand	Brown to pale brown coloured fine sand. Consisting of uniform grained size.	7.0			
20.0	377.936			Medium Sand	Brown coloured medium sand. Partly greyish brown coloured sand is found. This layer exhabits a graditional contact with overlying fine sand. Consisting of grains with uniform size and round-shape sands.				

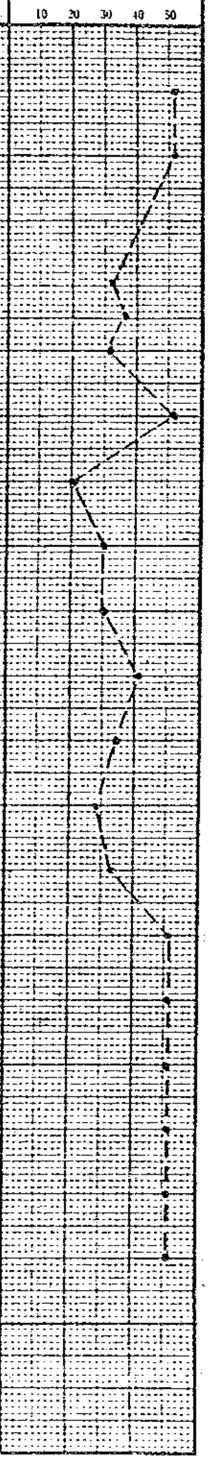


Fig. 3. 18 (2/3) SUMMARY OF DRILL LOG

PROJECT HURGA & NUR EL DIN

HOLE NO. BH-2

DEPTH	ELEVATION	THICKNESS	COLUMN SECTION	ROCK TYPE OR FORMATION	DESCRIPTION	G. W. L.	CORE RECOVERY	R. Q. D	STANDARD PENETRATION TEST (N-value)
	398.080								
4.0	394.08	4.0		Stiff Clay	Brown coloured stiff clay. Generally well consolidated.				
8.0	390.08	4.0		Fine Sand	Brown to pale brown coloured fine sand. Consisting of uniform grained size.	7.0			
20.0	378.080	12.0		Medium Sand	Brown coloured medium sand. This layer and overlying fine sand are intergraditinal. Consisting of uniform grain size and round-shape sands.				

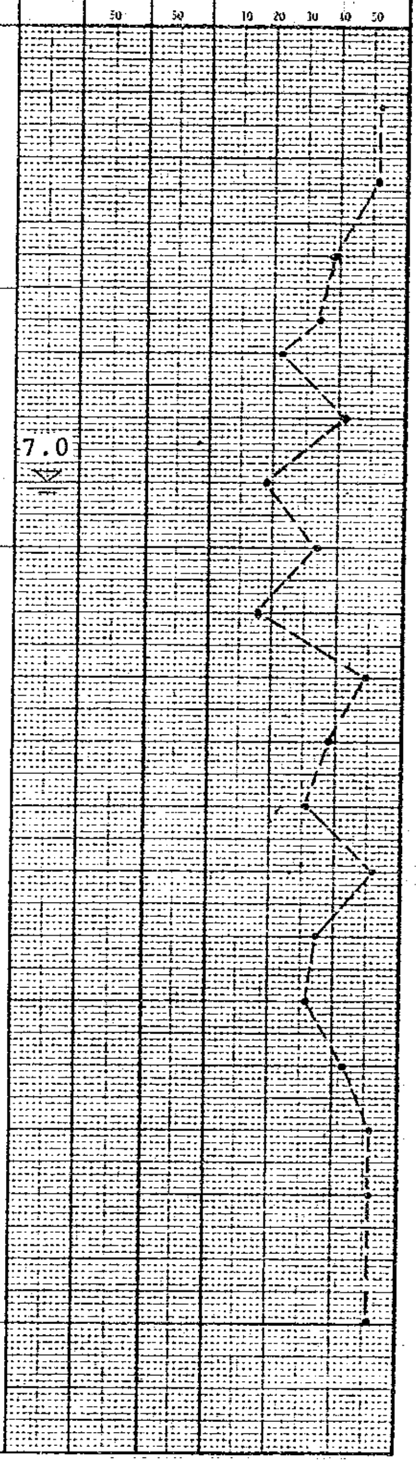
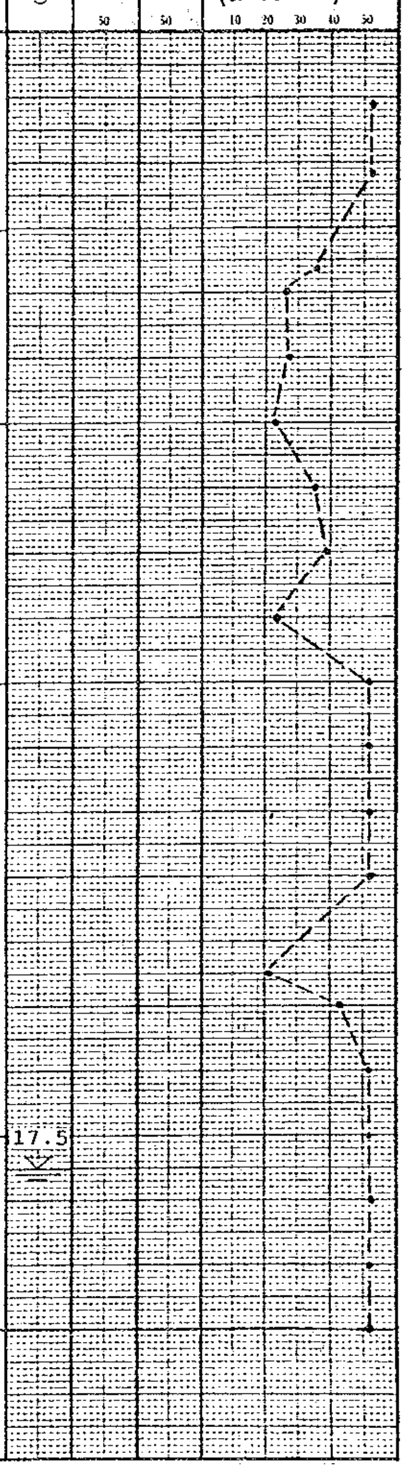


Fig. 3. 18 (3/3) SUMMARY OF DRILL LOG

PROJECT HURGA & NUR EL DIN

HOLE NO. BH-3

DEPTH	ELEVATION	THICKNESS	COLUMN SECTION	ROCK TYPE OR FORMATION	DESCRIPTION	G. W. L.	CORE RECOVERY	R. Q. D	STANDARD PENETRATION TEST (N-value)
	407.954								
3.0	404.954	3.0		Silty Clay	Dark brown to brown colored silty clay. Generally Very dense.				
6.0	401.954	3.0		Fine Sand	Brown to pale brown fine sand. Generally consist of uniform grained size.				
10.0	397.954	4.0		Medium Sand	Brown to pale brown medium-grained sand. Generally consist of uniform grained size.				
17.0	390.954	7.0		Silty Sand	Brown silty sand. Exhibits a graditional contact with overlying medium sand. Between 14-15.7m silty rich. Partly forms alternating beds of mudium sand and fine sand	17.5			
20.0	387.954	3.0		Silty Sand	Gradually changes to more silty rich sand.				



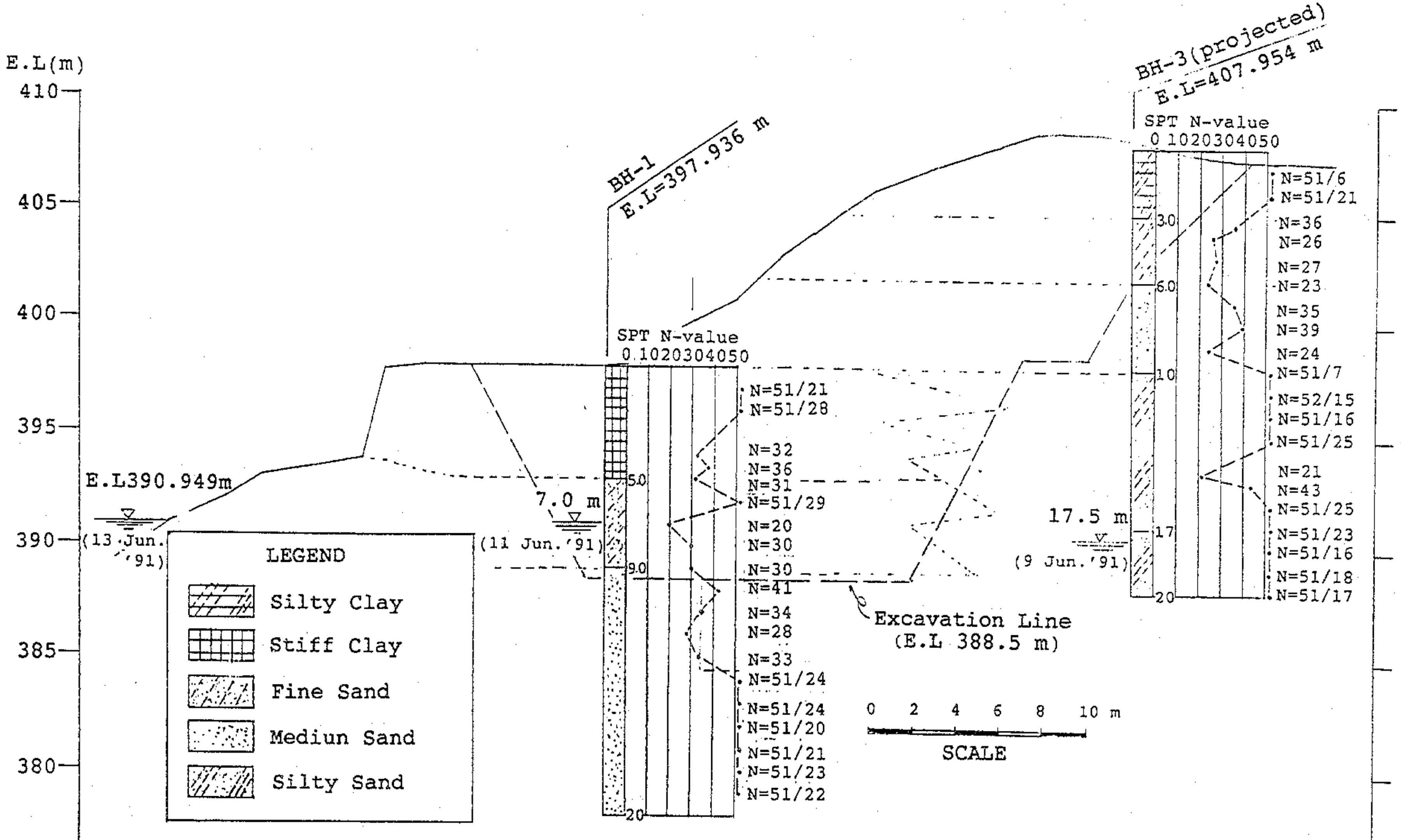


Fig. 3. 19 SOIL PROFILE ALONG THE SECTION A - A

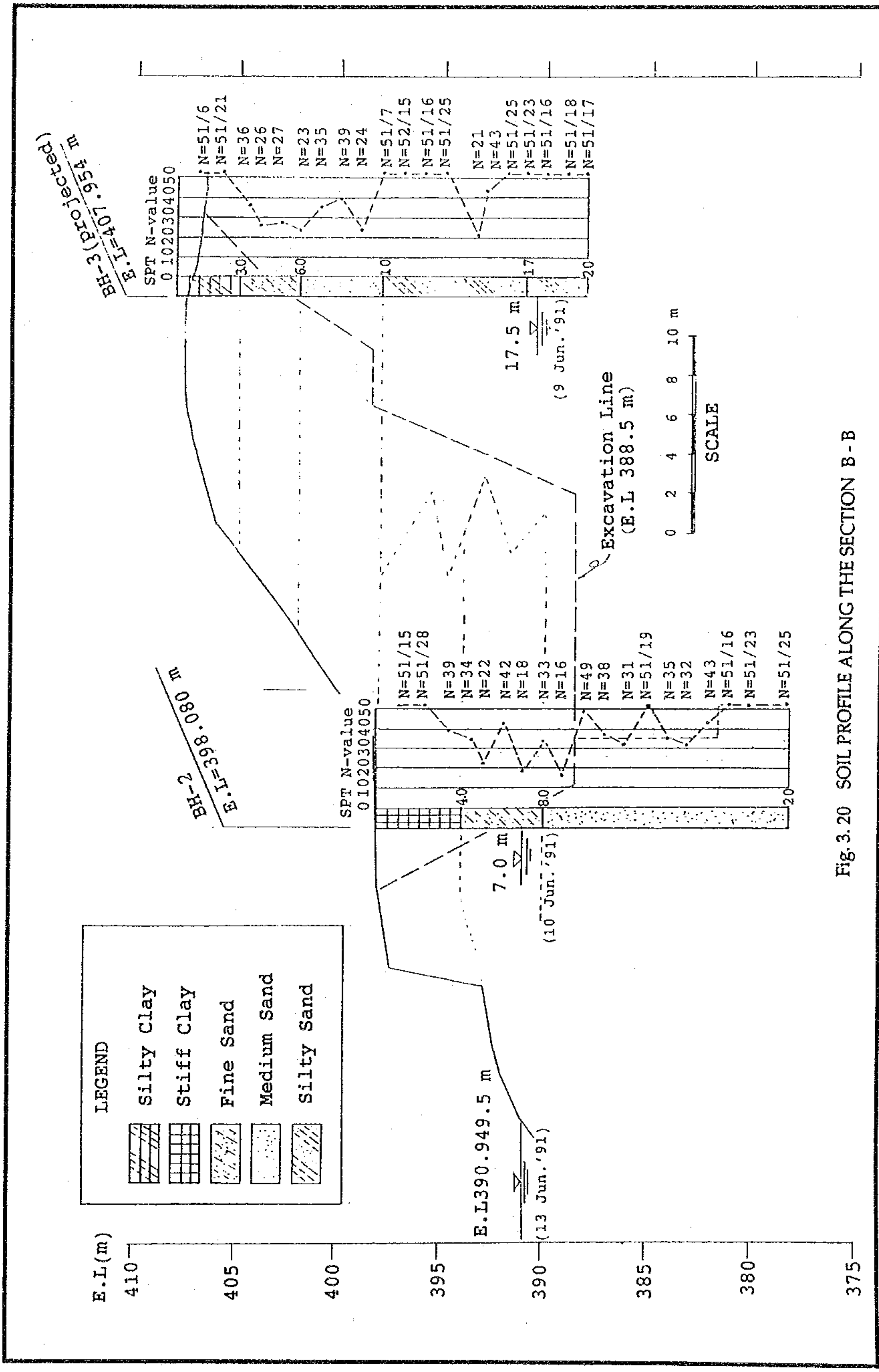


Fig. 3.20 SOIL PROFILE ALONG THE SECTION B - B

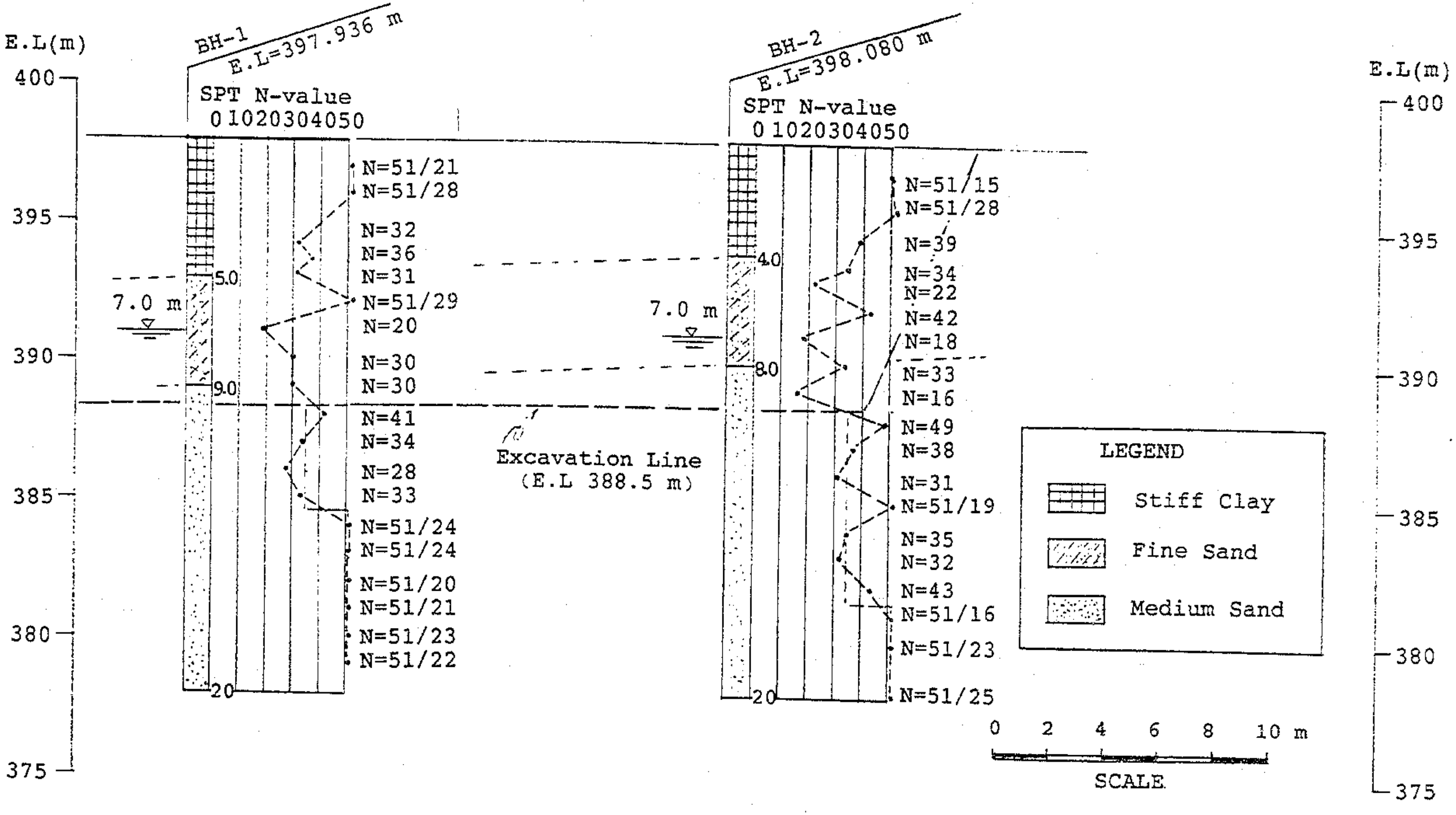
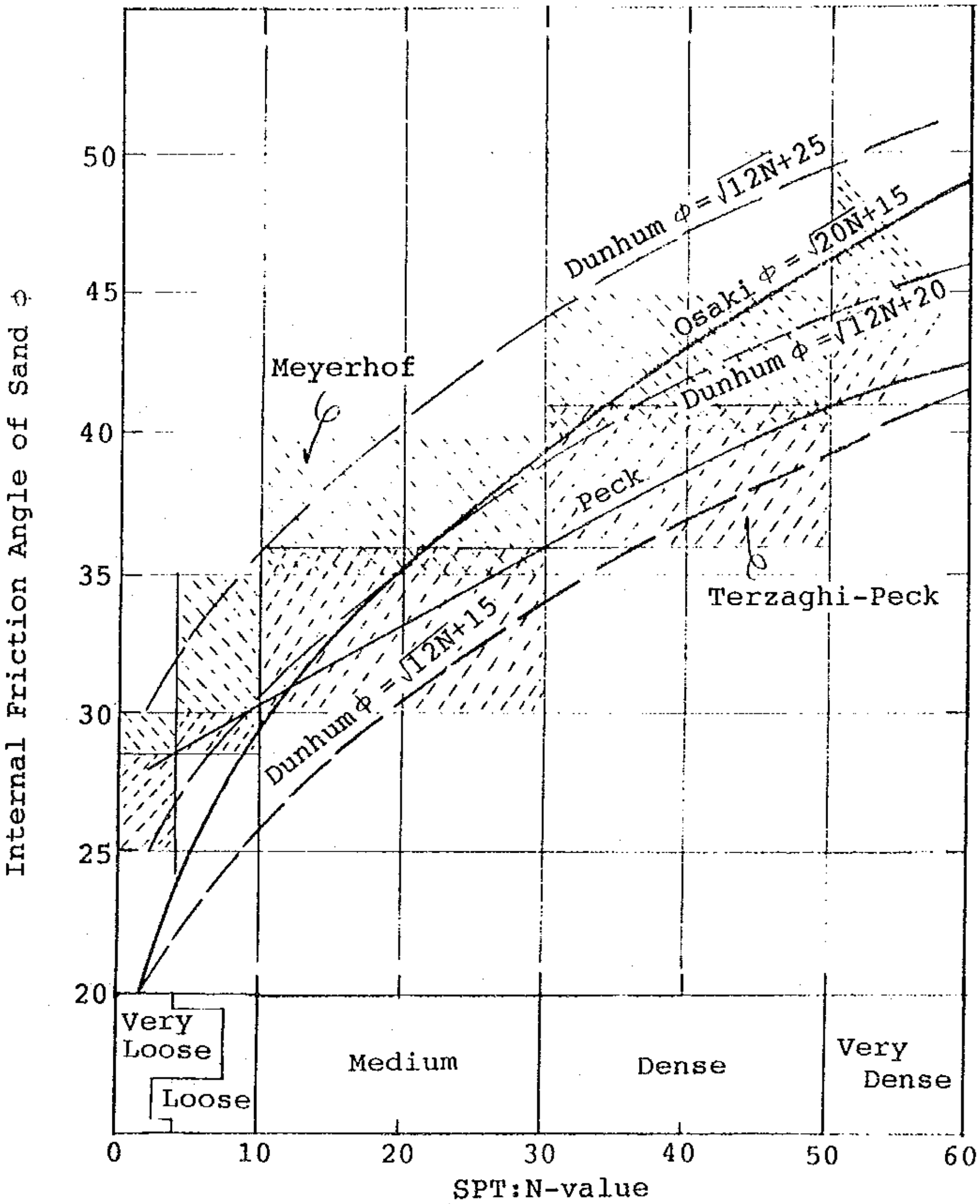


Fig. 3. 21 SOIL PROFILE ALONG THE SECTION C - C



Note; $\phi = \sqrt{12N}+15$: Grain with uniform size and round-shape

$\phi = \sqrt{12N}+25$: Grain with angilar-shape and well distribution

$\phi = \sqrt{12N}+20$: Grain with round-shape and well distribution, or Grain with uniform size and angular-shape

Fig. 3. 22 RELATIONSHIP BETWEEN ϕ AND N -VALUE

APPENDIX

MINISTRY OF IRRIGATION AND WATER RESOURCES

HYDRAULIC RESEARCH STATION

HYDROGRAPHIC SURVEY OF BLUE NILE

FROM NURELDEEN TO ELHURGA PUMP STATIONS

SUBMITTED TO:

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

BY

ENG. DAFFALLA M. YOUSIF

WAD MEDANI,
JANUARY 1991

INTRODUCTION

These cross-sections were taken across the Blue Nile as was requested by the Japanese team working in rehabilitating Elhurga and Nureldeen. The cross-sections are five and their locations are shown in Fig. (1).

LOCATION OF X-SECTIONS

The first x-section, named R1, is taken along the centre line of Nureldeen pump station and is starting from the pump house. The second cross-section, R2, is taken at a distance of 40 m upstream of the centre line of the New Pump Station, while R4 is taken at 40 m downstream of it. The third cross-section, R3, and the fifth one, R5, are taken respectively along the centre lines of the New Pump Station and Elhurga pump station. R5 is starting from the pump house.

DATA COLLECTION

1/ The survey was carried out using level and staff from the known bench marks up to the edge of water. In wet parts echosounder was used for finding depths in the relatively deep parts and the staff was used in the relatively shallow ones.

2/ The cross-sections were extended on both sides to the marks of maximum water levels, except on the right side of sections R1 and R5, where the cross-sections were not extended because of the buildings of the pump houses.

RESULTS

The results are used in drawing cross-sections R1, R2, R3, R4 and R5 (drawings attached in Appendix A).

ACKNOWLEDGEMENT

My thanks are due to Tech. Engs. Osama A. Mohamed, Babiker Fadul and Faisal M. Elamin and other HRS team's members who participated in the collection of data.

LOCATIONS OF X – SECTIONS

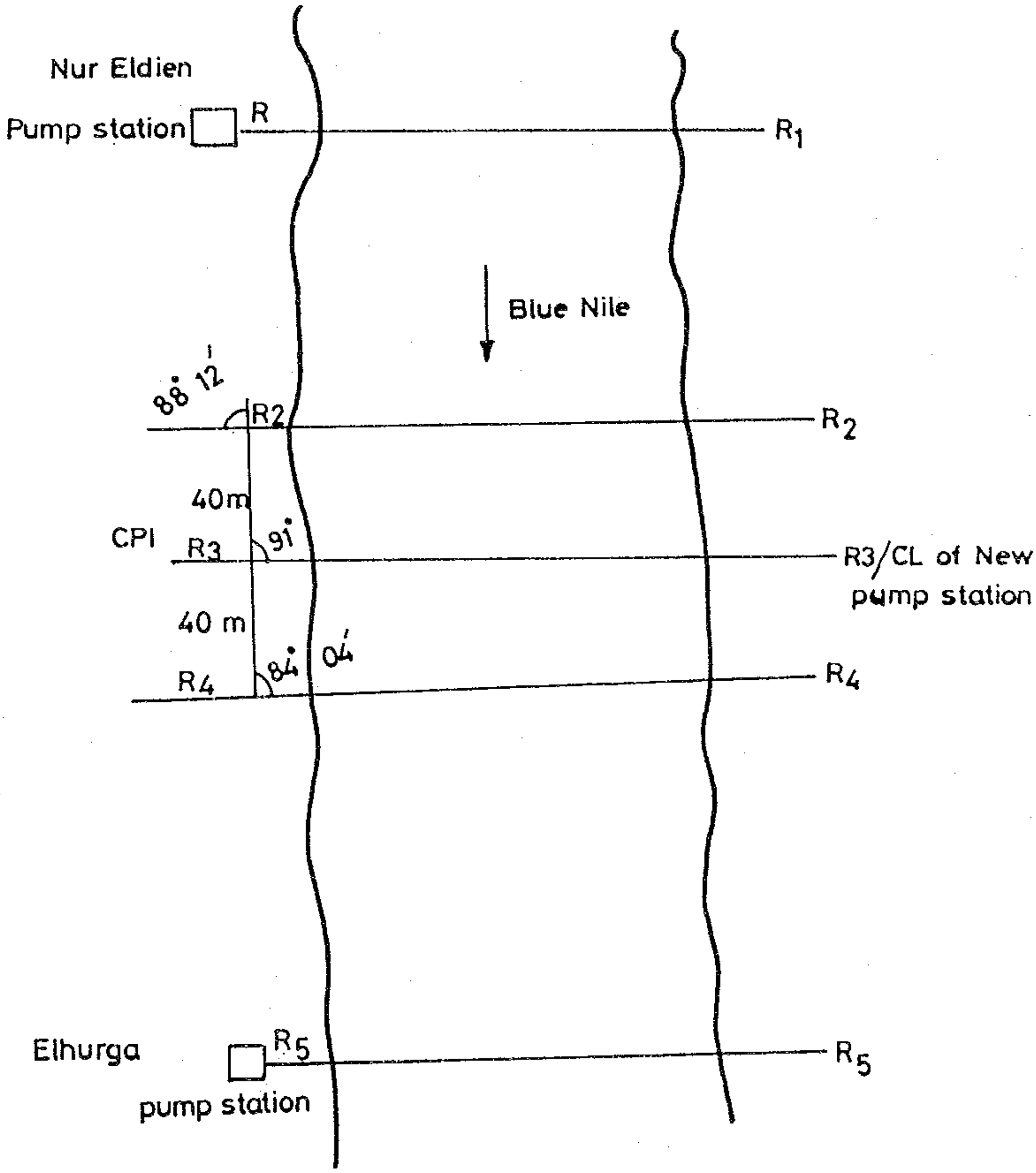
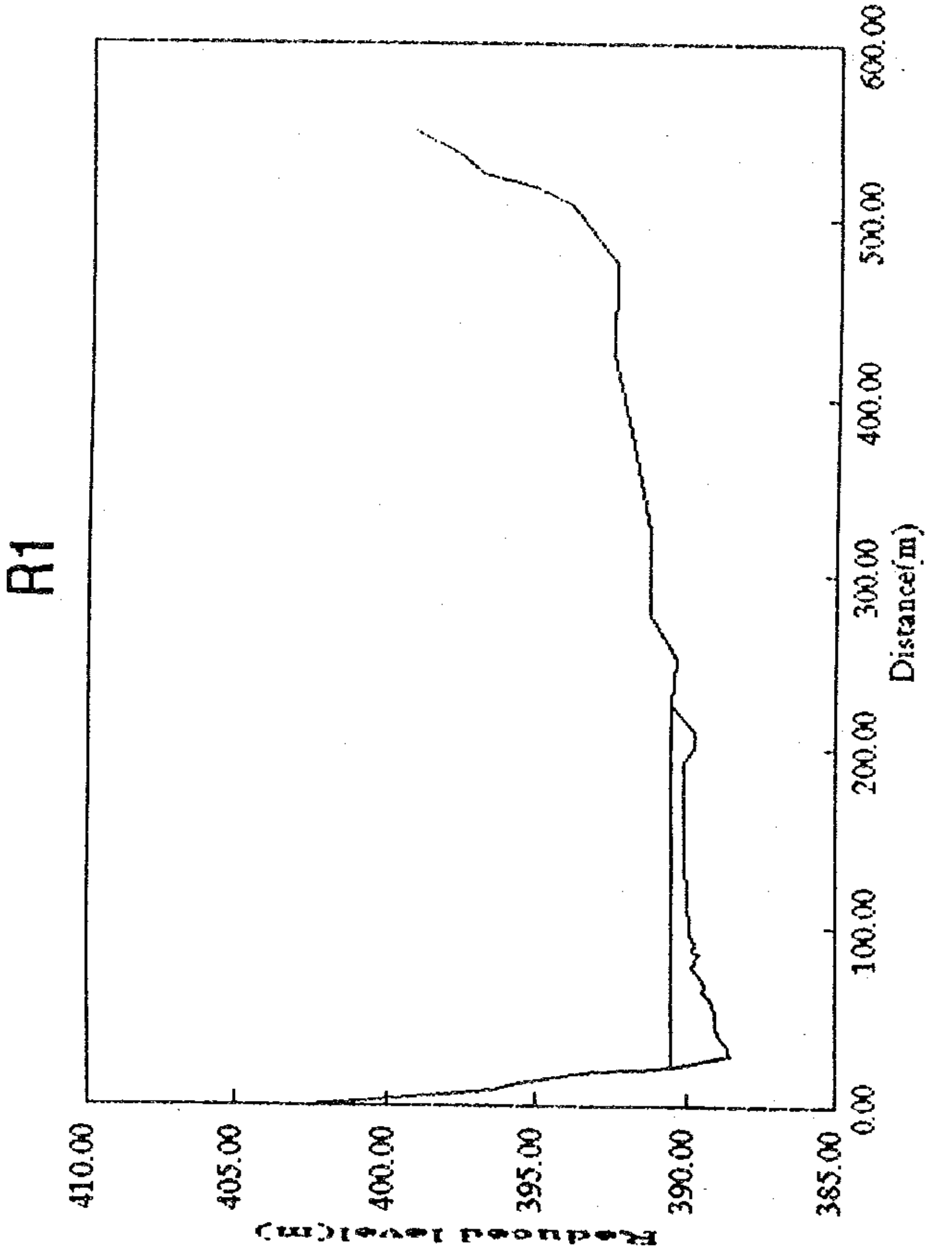


Fig. (1)

* Not to scale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390.00
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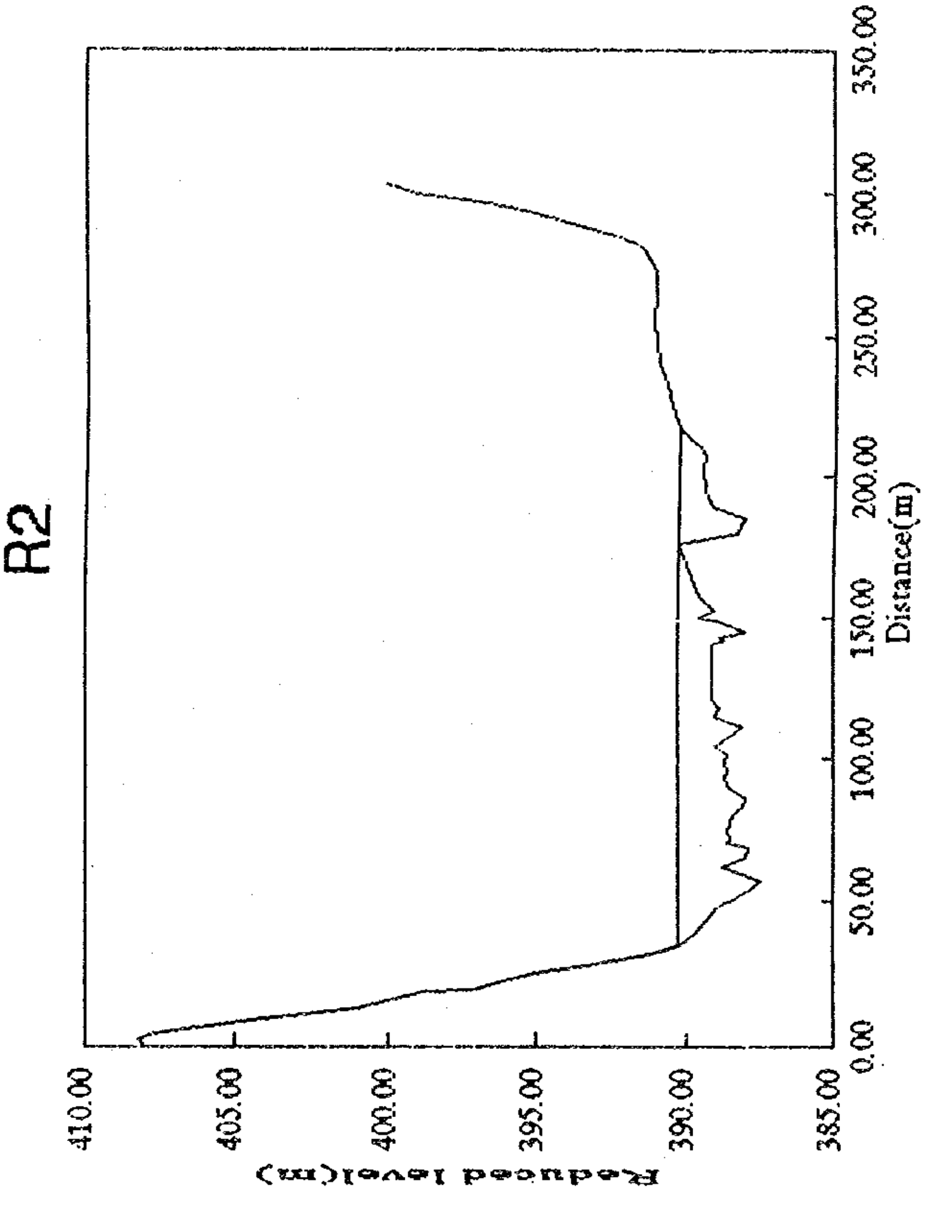
200.00
300.00
400.00
500.00
600.00
Distance(m)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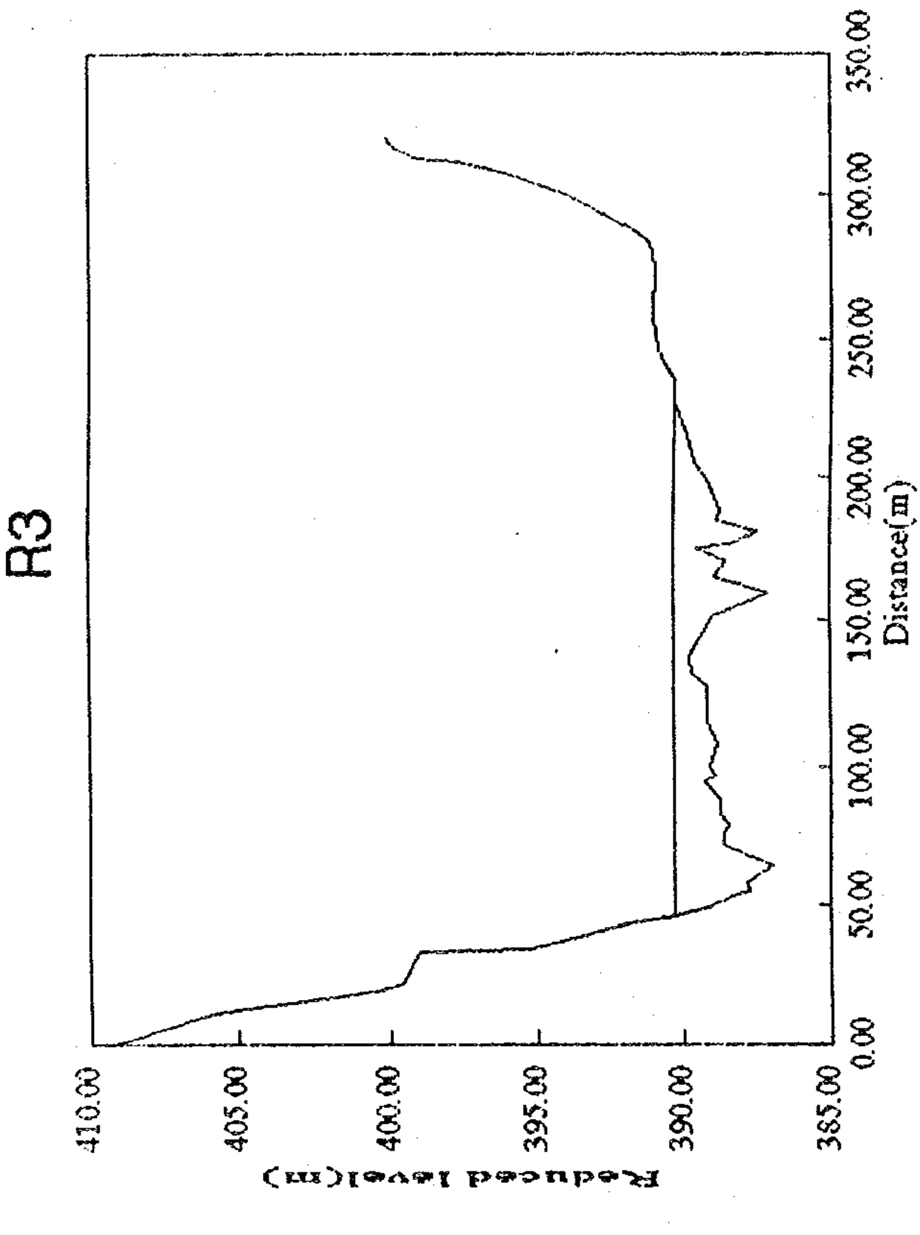
300.00
350.00
Distance(m)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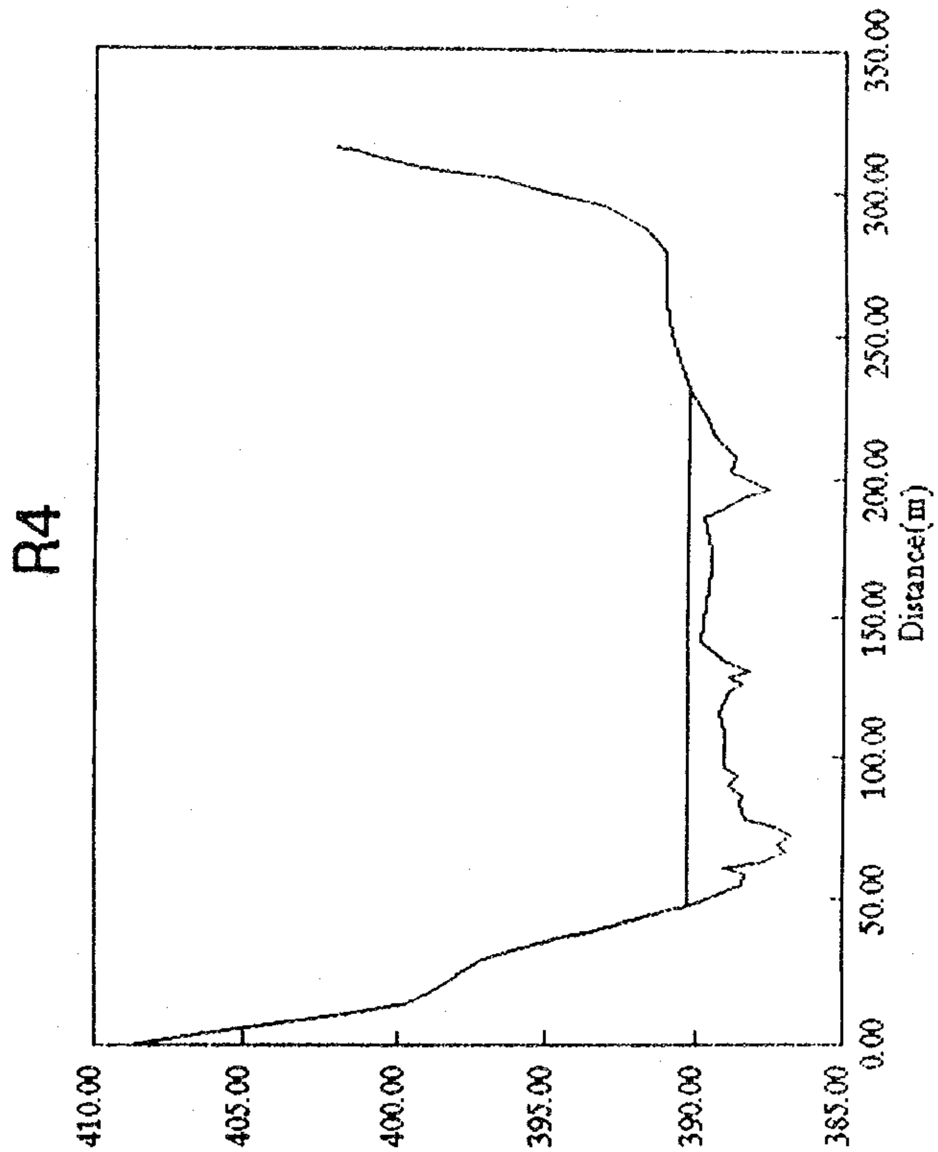
250.00
300.00
350.00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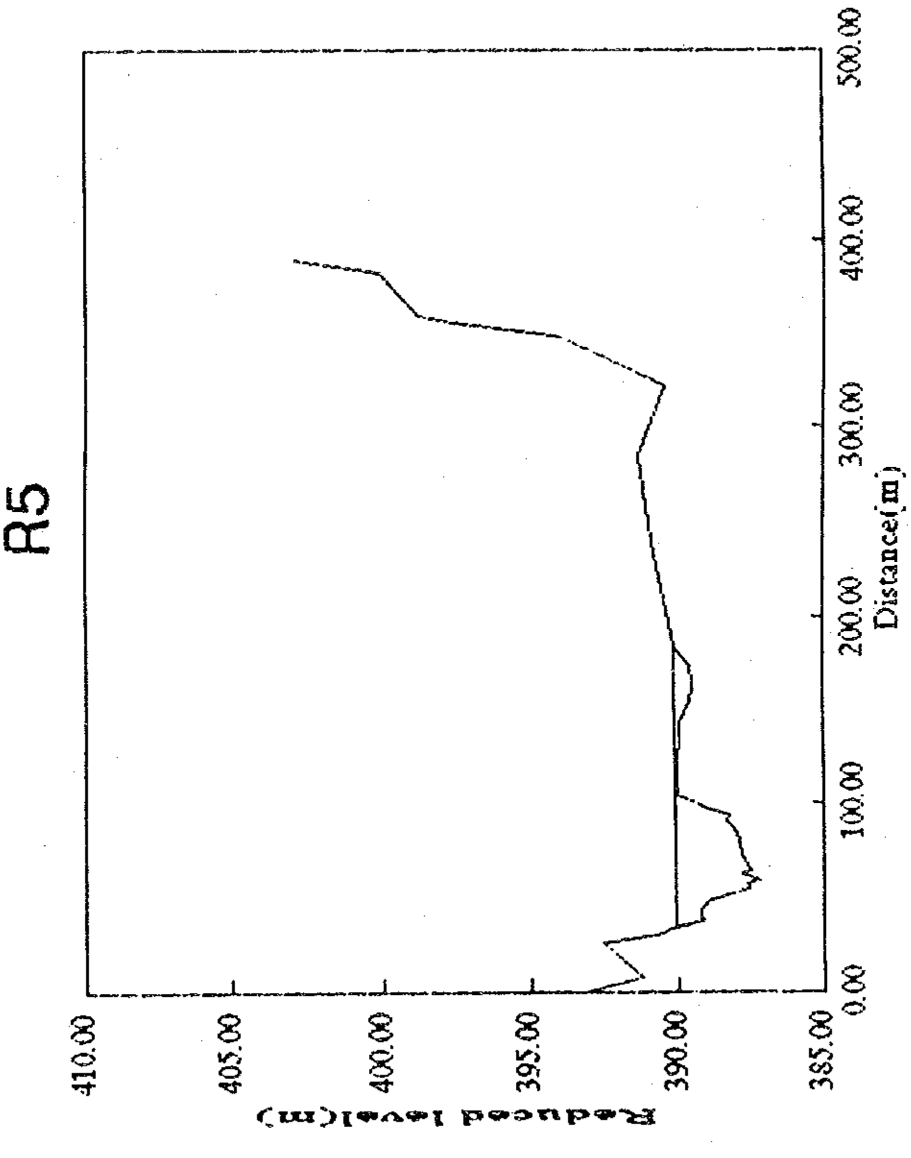
250.00
300.00
350.00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400.00
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390.00
385.00
Distance(m)
0.00
100.00
200.00
300.00
400.00
500.00

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TG-103	MOI & H.E.P, B.N.P Gezira District - Nar El Din 2-24" Pump Scheme, Scale 1:10,000, MIR/77-3918, 1955 (Topographic Map)
TG-104	MOI, Data of Elevation of National B.M No.100, 102, 114
TG-105	MOI, Data of Canal Levellings in Hurga & Nur El Din Pump Schemes, 1990
TG-106	MOI & H.E.P, Nur El Din 2-24" Pump Scheme - Block No. 107 & Hurga Pump Scheme 2-30" Pump Block No.106 scale 1:20,000, MIR/81-14849 Supersedes MIR/77-3418 & MIR/77-3419 (Topographic Map)
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Note:

MOAI	:	Ministry of Agriculture and Irrigation
MOFE	:	Ministry of Finance and Economics
MOR	:	Ministry of Road
MOD	:	Ministry of Defence
MOI	:	Ministry of Irrigation
HEE	:	Hydro-Electric Energy
H.E.P.	:	-
S.S.D	:	Sudan Survey Department

ANNEX-B

METEOROLOGY AND HYDROLOGY

FINAL REPORT
FOR
THE FEASIBILITY STUDY
ON
THE HURGA AND NUR EL DIN PUMP SCHEME REHABILITATION PROJECT

ANNEX B : METEOROLOGY AND HYDROLOGY

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1. METEOROLOGICAL AND HYDROLOGICAL OBSERVATION STATION

(1) Meteorological Data

All necessary meteorological records were collected at the Wad Medani observatory, where the most reliable and integrated agro-meteorological data were available in the vicinity of the Project area. Some of the monthly meteorological data for a limited period were also collected at other stations. However, the data in the above observatory were judged as the representative data for the Project.

The observatory is located at a latitude of 14°23' north and a longitude of 33°29' east, where the altitude is 405 m above mean sea level. The data available and collected at this observatory are listed in Table 1.1.

(2) Hydrological Data

The daily river discharge of the Blue Nile at the Sennar Dam and the gauge readings of the river water level along the Blue Nile and in the vicinity of the Project area were collected during the period from 1958 to 1990 at the Downstream of Sennar, Wad El Haddad, Hag Abdallah and Wad El Nau gauging stations. The basic information of the gauging stations is summarized in Table 1.1. Water level records at other related gauging stations such as Wad Medani, River Dinder were also collected for limited period.

The approximate location of these gauging stations is illustrated in Fig. 1.1.

2. CLIMATE

2.1 General

The climate of Sudan is mainly influenced by seasonal movement of the sun and the associated inter-tropical convergence zone (ITCZ). During the winter months, the ITCZ lies to the south of the equator and Sudan experiences dry north to north-easterly winds. With northward movement of the sun, the ITCZ moves together with its associated south-westerly winds and rainfall. The start of the rains coincides with this northward passage of ITCZ, occurring in April in the far south of Sudan, in about June in central Sudan, and July in northern Sudan.

During northward movement, the ITCZ weakens, resulting in reduced rainfall towards the northern parts of the country. Near the northern frontier, the occurrence of a proper rainy season is very infrequent, since the ITCZ rarely reaches far northern parts of the country. With the subsequent change of seasons, the ITCZ retreats and brings the rainy season to a close. This occurs in August in the north of Sudan, around September in central Sudan, and in October in the far south. The annual rainfall is related to the length of rainy season and this varies from almost zero in the far north to as much as 1,500 mm in the far south (Ref. No.HM-004).

2.2 Climate in the Project Area

The Project area is situated in the Central Sudan, along the right bank of the Blue Nile. It is located at about 30 km southeast of Wad Medani, with a latitude and a longitude of 14°10' north and 33°40' east, respectively, where the altitude is about 410 m above mean sea level.

The climate of the Project area can be characterized by a hot and dry climate with moderate wind.

(1) Rainfall

The Project area is classified approximately in the boundary between low rainfall savanna (south of the area) and semi-desert grassland (north of the area) with a yearly mean rainfall of approximately 300 mm, as shown below:

Monthly Mean Rainfall (mm)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
80-89	0	0	0	0.2	19.2	27.5	67.9	102.1	51.4	8.2	3.2	0	279.8
51-80	0	0	0	1.0	13.0	30.0	107.8	128.0	49.0	15.0	0	0	343.0

This clearly indicates that the yearly mean rainfall of the past 10 years decreases remarkably by 20% from the same for 30-year's mean from 1951 to 1980. This has mainly resulted from the severe drought which continued for three years from 1982 through 1984. The annual rainfall in 1990 was recorded at only 115 mm, which is 20% lower than the lowest annual rainfall observed over the last 10 years (Table 2.1).

The probable rainfall is calculated by the normal probability analysis and shown in Tables 2.11 and 2.12. The results of the analysis show that the maximum daily rainfall occurred in 1985 (93.4 mm) corresponds to a 100-year probable rainfall, while the minimum annual rainfall recorded in 1990 (115.4 mm) corresponds to the probable annual rainfall with a 25-year return period.

(2) Temperature

The yearly mean temperature in the area is 29℃, with a maximum average of 41.5℃ in April and a minimum average of 14.7℃ in January (Tables 2.2 and 2.3).

Monthly Mean Temperature (℃)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Maximum	33	35	38	41	42	40	37	36	36	39	37	33	37
Minimum	15	16	20	22	25	25	24	23	23	23	19	16	21
Mean	24	25	29	31	33	33	30	29	30	31	28	24	29

(3) Sunshines Duration and Radiation

Monthly mean daily sunshine hour is more than 10 hr/day during the dry period from November through April. It begins to decrease in May and drops to 7.5 hr/day in July (Tables 2.4 and 2.5).

(4) Wind Speed and Direction

The maximum monthly mean wind velocity is 4.1 m/sec. and the minimum one is 1.6 m/sec. as shown in Table 2.6 and summarized below. The maximum daily mean wind speed of 8.0 m/sec. was recorded on July 21, 1990.

Monthly Mean Wind Speed (meter/second)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Speed	2.4	2.4	2.5	2.4	2.8	4.1	4.1	3.3	2.1	1.6	2.0	2.1	2.7
Direction	N	N	N	N	SW	SSW	S	S	S	S	NNW	N	

(5) Evaporation

The average annual pan evaporation is as high as 5,000 mm, with the maximum monthly average recorded in April at 18.9 mm/day and the minimum in September at 8.9 mm/day (Table 2.7).

Monthly Mean Pan Evaporation (mm/day)

Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
11.9	13.9	17.3	18.9	18.2	17.0	12.6	10.3	8.9	11.1	12.9	11.3

(6) Relative Humidity

The yearly average relative humidity is 40%, with a maximum average of 83% in August and a minimum of as low as 13% in April (Table 2.10).

Monthly Mean Relative Humidity (%)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Maximum	52	42	36	29	44	61	76	83	82	64	47	49	55
Minimum	19	16	14	13	21	26	37	41	38	27	20	21	24

3. HYDROLOGY OF THE BLUE NILE

3.1 General

(1) River Feature

The upstream tributaries of the Blue Nile which rise in the Ethiopian Highland at heights of up to 4,400 m, once empty into and are regulated by Lake Tana where the altitude is 1,840 m above mean sea level. The Blue Nile flows along the Ethiopian escarpment forming cataracts and gorges, and reaches the Roseires Dam in Sudan where the altitude is about 450 m. From Lake Tana to the Roseires Dam there is about 940 km by river (Ref. No.HM-001). Then the Blue Nile flows into the central plain and reaches the Sennar Dam, 270 km downstream of the Roseires Dam, and passes along the Project area. The River Dinder and River Rahad flow into the Blue Nile at the upstream and the downstream of the Project area, respectively.

At a distance of 1,560 km from Lake Tana, the Blue Nile finally joins with the White Nile at Khartoum and forms the main Nile. The distance from this confluence to Alexsandria via Aswan Dam is 2,790 km, i.e., 4,350 km in total from Lake Tana. The entire Blue Nile basin is about 325,000 km^2 and the mean discharge at the Roseires Dam is 50 milliard m^3 per annum. Fig. 3.1 shows the yearly discharge of the Blue Nile and the related main rivers.

Discharges from the River Dinder and River Rahad are minimal as indicated in Fig. 3.2, in spite of their large catchment areas, i.e., 35,000 km2 each, and their discharges are only available for three to five months between July and December.

Table 3.1 outlines the salient features of the Sennar and the Roseires Dams, which were completed in 1925 and 1966, respectively. As indicated in this Table, the total live storage of both dams was 3.1 milliard m^3. However, it has been rapidly decreasing due to the recent and marked increase of the sediment load in the Blue Nile. In order to cope with this situation, a scheme of heightening the Roseires Dam was studied and updated in 1987, as outlined in Table 3.1.

On the other hand, both annual and dry season discharges at the Sennar Dam do not indicate such a marked reduction trend, while the average discharge from December to March have been gradually reducing as illustrated in Fig. 3.3. This may be mainly attributed to the strict reservoir operation of the Roseires Dam during the dry season.

The mean annual discharge from the Sennar Dam is about 30 milliards m^3, with the maximum monthly mean discharge of 386 million m^3/day in August, and with 10 to 15 million m^3/day during December to April as tabulated in Fig. 3.3.

(2) River Profile

i) River profile

The Blue Nile which enters the vast plain at the Roseires Dam (altitude of 430 m at its downstream) meanders markedly and reaches Khartoum (altitude of 370 m and 600 km downstream of the Roseires Dam). The river profile of this reach, and the high and low water levels between the Sennar Dam and Khartoum are illustrated in Figs. 3.4 and 3.5, respectively. The river gradient in this reach, including the existing pump station of the Project, is estimated at approximately 1/10,000.

ii) River cross section

The width of the Blue Nile at the Hurga and Nur El Din pumping stations are about 400 m and 500 m, respectively. The maximum difference between the water levels during flood and low water stage is estimated at 12 m. The main course of the Blue Nile between these two pumping stations flows stably along the right bank. The marked sand bars appear every year during low flow period at the upstream of the Nur El Din pumping station, where several minor streams are observed changing their courses every year. However, such sand bars are not observed between the two pumping stations.

(3) Bank Erosion

The right bank (east bank) where the existing pumping stations are located, forms a large concave curve, while the left bank shows convex curve. The marked undercut slope is observed above the high water level of the right bank, while the vast sediment deposition is observed slightly above the low water level of the left bank side.

As mentioned in ANNEX-A, TOPOGRAPHY AND GEOLOGY, the progress of this bank erosion was judged to be very slow in general, according to the field reconnaissance and interview surveys. More specifically, the bank protection works with the stone masonry which were provided at both of the pumping stations in the latter period of the 1950's have not been scored. Over the past 30 years, however, two to three meters of erosion has occurred at the upstream and the immediate downstream of the Nur El Din pumping station, and less than five meters has occurred at far downstream. While little erosion was observed at the Hurga pumping station.

3.2 Low Flow Analysis

(1) Low Flow Discharge

Discharges of as little as one to three million m^3/day were observed in the release record at the Sennar Dam during the period from 1958 to 1966 when the Roseires Dam was completed.

With its completion, the Regulation Rules for both reservoir operation had been prepared in 1968 and the said reservoirs have been operated generally in accordance with the Rules.

These Rules prescribe:

- to meet the requirements of irrigation from the reaches of the river upstream or downstream of Sennar Dam,

- to maintain a minimum flow in the river downstream of Guneid (between Khartoum and the confluence with River Rahad), of five million m^3/day (for the purposes including amenity consideration for Khartoum), and

- to maintain through Sennar Dam Power Station so far as may be possible the flows of water requisite for the generation of power.

Table 3.2 represents the yearly minimum discharges at the downstream of the Sennar Dam over 21 years from 1970 to 1990. Of these, the discharges below four million m^3/day occurred only for a few days, while the discharges between four to five million m^3/day generally lasted only within 10 days and was surrounded by discharges more than five million m^3/day.

With respect to available water, the quantity of water from the Nile that may be utilized by Sudan is governed by the Nile Waters Agreement concluded by and between Sudan and Egypt in 1959. This Agreement permits the Sudan to abstract 18.5 milliard m^3/yr, calculated at Aswan High Dam as follows:

	milliard m^3/yr
Sudan	18.5
Egypt	55.5
Reservoir loss in Lake Nubia	10.0
Total	84.0

There are no restrictions as to where the water is abstracted or in which season. The allocation of Nile water for the Sudan is more conveniently expressed in terms of its equivalent at Sennar. This figure is 20.55 milliard m^3, which allows for a 10% loss from seepage and evaporation between Sennar and Aswan (Ref. No.HM-005).

A result of the actual allocation of the water resources in 1990 reveals that Sudan tapped only 14.5 milliards m^3, while Egypt received more than 55.5 milliards m^3.

Such inadequate water use in Sudan mainly occurs due to the limited capacity of irrigation facilities in the country, such as intakes, canals, and pumping stations, etc. In other words, Egypt receives more water during normal years, while Sudan continues to receive the same volume as mentioned above. This fact indirectly suggests and guarantees the available water resources for the rehabilitation of the Project in Hurga and Nur El Din.

Tables 3.4 and 3.5 indicate water use of 1990 in Sudan and the future use (19 milliards m^3 in 1995) after completion of the proposed and ongoing rehabilitation schemes, and indicate less water use than the agreed amount.

(2) Low Water Level

The water levels at Hurga and Nur El Din pumping stations in terms of the Irrigation Datum are derived from the proportional distance and the water levels recorded at the two nearest water level gauging stations of the Blue Nile, i.e., Wad El Nau, 12 km downstream from Hurga pumping station, and Hag Abdallah, 26 km upstream from Nur El Din pumping station which is located about 14 km from Wad El Nau gauging station.

Tables 3.2 and 3.3 show two cases of the estimated water levels for the pumping stations; (i) the minimum discharge oriented low water level (Table 3.2), and (ii) the recorded minimum reading oriented low water level (Table 3.3). In the former, the estimated low water level was derived from the lowest level observed within, in principal, one week after the yearly minimum discharge released at the Sennar Dam. In the latter, the estimated low water level was derived from the yearly recorded lowest water level.

The results of these two cases show that all of the low water levels at the pumping stations estimated in the case of (ii) are slightly lower than that in the case of (i) the minimum discharge oriented level. This is mainly because of the minimum discharge which lags behind and is involved in the subsequent larger discharge, since to reach the pump stations from the Sennar Dam, the traveling time of the low flow discharge is estimated at around three days or more, in general, while the larger discharge takes less traveling time; and partly because of the river profile, etc., which could not be clarified due to insufficient data. Although the differences in the above two cases are minimal, the case (ii) was adopted for safer planning.

A tendency of the yearly fluctuation of the river water level are also examined and illustrated in Fig. 3.6. In this Figure, the 10-day mean water level at Wad El Nau gauging station is sorted in recessing order and averaged by the following four periods:

(i) Nine years from 1958 to 1965, or one year before the completion of the Roseires Dam,

(ii) Nine years from 1966 when said dam was completed, to 1974,

(iii) Eight years from 1975 to 1982 when severe drought started,and

(iv) Five years from 1985 (gauge was not read in 1983 and 1984 and new gauge reader was then assigned) to the middle of December 1990.

In this Figure, averaged water levels during the last five years clearly show about one meter degradation, though the released discharge was not significantly reduced during the same period, as discussed precedingly.

(3) Riverbed Fluctuation

In order to clarify the recent fall of the water level, especially during the low water stage discussed above, the riverbed fluctuation has also been indirectly examined in terms of the water level fluctuation at Wad El Nau, as depicted in Fig. 3.7. Since no time-series cross sections of the Blue Nile is available in the vicinity of the Project area, the riverbed fluctuation has been examined in such a way that.:

- find days lasting more than three days or preferably 10 days when a discharge of approximately 10 million m^3/day was released at the Sennar Dam for each year, by so doing the aforementioned time lag could be eliminated to a certain extent;

- read the water levels at Wad El Nau during the periods mentioned above; and

- average the above discharges and water levels respectively, then graphically show them.

The same procedure was adopted to the discharges with five million m^3/day, which were only observed in the limited years.

Thus obtained Fig. 3.7 indicates the recent fluctuation of the yearly water level, which was observed during a discharge of 10 million m^3/day was released continuously. This fluctuation of water level suggests possible fluctuation of the riverbed.

The graph depicted at lower portion of the same Figure indicates the water level or the conceivable riverbed fluctuation above and below their average. The results represent the recent 10-year's yearly fluctuation within a range of (+)1.2 m and (-)0.8 m which is much wider than that with a maximum of (+)0.3 m and (-)0.2 m for 14 years after the completion of the Roseires Dam. The fluctuation was also examined for the gauging stations at Hag Abdallah and Wad Medani. The results are shown in Figs. 3.8 and 3.9, respectively, which indicate more sensitive fluctuation compared with that of Wad El Nau.

These facts do not clearly reveal the relation between the completion of the Roseires Dam and the subsequent fluctuation. But it seems that the marked fluctuation which started in the 1980's may have been caused by the recent massive soil erosion in upstream basin in Ethiopia. The sediment load in the Blue Nile may be deposited and be flushed easily by the yearly flood, due to the small size of its particles, such as clay and silt, as discussed in the subsequent Chapter 5.

The results also do not show the continuous increasing or decreasing tendency of the elevation of the riverbed. However, the similar fluctuation of degradating and raising may repeat within the limited range as shown in Figs. 3.7 to 3.9, or sometime become parallel to the average river gradient of 1/10,000.

(4) Lowest Water Level at Pumping Station

The lowest water level of EL.394.02 m was recorded during the period of June 4 to 7, 1990 at Hag Abdallah gauging station since its installation in 1920. While EL.389.40 m was recorded during June 4 to 11, 1990 at Wad El Nau gauging station. The corresponding water levels at the pumping stations were tentatively estimated at EL.390.84 m for Nur El Din and EL.390.63 m for Hurga, as shown in Tables 3.2 and 3.3 and Fig. 3.10.

In order to verify the interpreted water level at the pump stations, a temporary gauging staff was installed in the immediate upstream of each pumping station. The lowest water levels observed during the current study period on these temporary gauges by the JICA Team were EL.390.78 m and EL.390.32 m at Nur El Din and Hurga pumping stations, respectively.

The gauge readings on the same date at Hag Abdallah and Wad El Nau gauging stations were EL.394.70 m and EL.389.83 m, respectively, as shown in Fig. 3.10. Thus, the proportionally estimated water level derived from the same procedure employed in the previous section (2) "Low water level" can be explained as follows:

Nur El Din	:	(394.70-389.83) x 14 km/45 km + 389.83	= 391.35 m
Hurga	:	(394.70-389.83) x 12 km/45 km + 389.83	= 391.13 m

Accordingly, the difference in elevation between obtained through the actual observation of the temporary gauges and those of the above estimations is summarized as follows:

	Nur El Din	Hurga	
Estimated	EL.391.35	EL.391.13	(on Irrigation Datum)
Observed	EL.390.78	EL.390.32	(on Irrigation Datum)
Difference	0.57	0.81 m	

The differences between the estimated elevation and the observed ones are caused by the reason that: the estimated one is derived from assumption that the river gradient between Hag Abdallah and Wad El Nau gauging stations be uniform. Actually, however, the river gradient is different from a part to another.

The corresponding lowest low water levels at respective pumping stations, tentatively estimated and shown in Tables 3.2 and 3.3, are finally adjusted taking the above differences into consideration as follows:

		Estimated Lowest WL		Difference from actual		Lowest Low WL
Nur El Din	:	390.84	-	0.57	=	390.27
Hurga	:	390.63	-	0.81	=	389.82

Furthermore, the monthly mean water level at respective pumping stations is also estimated based on data shown in Table 3.6, in the same manner, as indicated in Table 3.7.

3.3 Flood Flow Analysis

(1) Maximum Discharge

The reservoir water level during flood season, from June to September, is controlled in conformity with the Regulation Rules for Roseires and Sennar Dam. Accordingly, the flood inflows to the reservoirs are released without storing, however, peak flood inflows are regulated by the surcharge height of the reservoir and also by the long river course to reach the Project site. The flood level fluctuation at the pumping stations is, therefore, relatively gradual.

The yearly maximum discharges from the Sennar Dam, the recorded water level at the gauging stations, and the estimated water level at the pumping stations are shown in Tables 3.8 and 3.9, which were prepared in the same procedure employed in the previous Table 3.2 for "low water level". In these Tables, most of the date of the recorded high water levels well correspond to the date of the maximum discharge, with a time lag of about one day.

The maximum flood discharge during the last 20 years occurred in 1988, with a daily discharge of 719 million m^3/day (8,300 m^3/sec.) which corresponds to the probable flood at about 20-year return period as shown in Table 3.10. During this flood, the high water level lasted for more than 10 days, as illustrated in Table 3.9.

(2) Highest Water Level

Tables 3.11 and 3.12 present the probable high water levels with return periods for respective Nur El Din and Hurga pump stations. The information related to the high water level can be summarized as follows:

		Nur El Din	Hurga
Recorded high	(1946)	404.05	403.87
	(1988)	402.41	402.20
100-year probable		403.08	402.91

Floods, which occurred once every few years, inundated the the river bank along the convex side. However, most of the houses and farm land are situated in higher areas, and hence no flood damages were reported. In the Project area and its vicinity, flood damaged have not been observed.

4. WATER QUALITY OF THE BLUE NILE

In November 1990, the JICA Team collected 6 water samples at several different locations along the Blue Nile, i.e., existing pumping sites, the Sennar reservoir, Gezira Main Canal near Pilot Farm, and two wells in the Project area. These samples were analyzed by the Laboratory of the Soil Survey Department.

The results of the analysis are shown in Table 4.1, which reveal the appropriateness of using surface water for irrigation. The water samples which were collected from shallow wells in the Project area had higher electric conductivities of 2.68 ms/cm, and were less appropriate for irrigation than surface water.

5. SEDIMENT

5.1 General

The excavated volume in the desilting work from the canal network in the Gezira Scheme was estimated by the MOI at five to six million m^3/yr in recent years. This is supposed to be mainly due to the recent rapid increase in the volume of the sediment load transported by the Blue Nile from the Ethiopian Plateau. It is said that an significant vegetational change, such as deforestation, is progressing, resulting in massive soil surface erosion. This sediment load in the Blue Nile in the Sudan territory is characterized by having a higher content of suspended solid composed mainly of clay and silt, with as high as about 90% of the total load.

In the Gezira Scheme, the main and major canals were designed to avoid the siltation of such fine particles, while the minor canals, where so-called night storage is adopted in irrigation practice, facilitates siltation. However, since there are about 1,500 minor canals, the desilting work has recently involved constraints in the budgetary arrangement, necessary number of the earth moving equipment, etc.

Under such circumstances, the MOI established the Basic Research and Sediment Movement Unit in the Hydraulic Research Station and has initiated an intensive study since 1988 to observe, analyze and solve the sediment problem.

The result of the study by the Unit revealed that 33% of the total suspended solid deposited in the minor canals, while 22% in the major canals and 11% even in the main canal, and remaining 33% passed to the field. These particles, once deposited in the canal, becomes highly cohesive and cannot be flushed by the design velocity of the canal discharge. Thus, the same Unit conceived a plan to provide intensive sediment storage facilities, such as a settling basin at the head of the main canal, or along the canal, where circumstances allow, in order to economize the yearly desilting work, because the topography does not provide adequate tractive force to discharge the sediment by increasing the canal slope due to the flatter land.

5.2 Sediment Concentration of the Blue Nile

Figs. 5.1 to 5.4 show the respective sediment concentration of the Blue Nile observed at Khartoum in 1969, the Ethiopian border (Ed Deim) in 1975, and the downstream of the Roseires Dam from 1981 to 1985 (Ref. No.HM-003 and -005). All of the data indicate that the peak sediment concentration was recorded at the earlier stage of the flood season. These peak values (in p.p.m.) are as tabulated hereunder:

Place:	Khartoum	Ed Deim	Roseires				
Year:	1969	1971	1981	1982	1983	1984	1954
p.p.m.:	3,500	7,000	8,000	13,000	16,000	7,000	12,000

Although some of the concentration at as high as 23,000 p.p.m. has also been observed, the Sediment Movement Unit recommended to adopt 15,000 p.p.m. as the average peak concentration. On the other hand, the same concentration during the dry season is only around 100 p.p.m.

5.3 Sediment Yield of the Blue Nile

According to the study in the Basic Research and Sediment Movement Unit, 60% of the entire sediment yield discharges only within 6 weeks from the middle of July to the end of August which corresponds to the earlier stage of the flood season.

The Unit clarified this phenomena by depicting a histeresis loop as shown in Fig. 5.5. In this Figure, the sediment discharge stage is classified into three stages, i.e., rising zone, transition zone and falling zone, and the sediment yield can be estimated in this Figure by the proportion of (10-day flow)/(peak 10-day flow).

Based on this Figure, the sediment yield of the Blue Nile is estimated as shown in Table 5.1, which shows the countable sediment discharge starts from the last 10-day in June and ends at the first 10-day in October.

The peak sediment discharge occurs in the first and second 10 days with 3.2 million tons/day, and the yearly average sediment yield is estimated at about 165 million tons at downstream of Sennar. Thus a considerable amount of the suspended solid would be abstracted with irrigation water by the pumps, and be transported to the Project area through the canal system.

5.4 Grain Size

In order to examine the grain size of the pumped sediment load, the bed material in the river and canal was collected by the JICA Team and was analyzed by the laboratory of the Hydraulic Research Station. The samples were collected at the right bank of the Blue Nile immediate upstream of the Hurga and Nur El Din pumping stations, at the immediate downstream of the pump discharge basin, and at the middle and end of the main canal for each of pumping stations. The results of this grain size analysis are attached in Figs. 5.6 to 5.9.

Based on these results, the maximum pumped grain size was estimated at 1.0 mm with D (50%) of 0.1 mm focusing on the samples collected at the canal bed downstream of the discharge basin for each of pumping stations.

6. WATER ASSOCIATED DISEASES

6.1 General

Since the completion of the Hurga and Nur El. Din pumping stations in the late 1950's, beneficiary tenants of the Project area had been enjoyed cotton and sorghum production under irrigated farming until the end of 1970's. However, due to sharp decrease in pumping discharge and allowing for limitedly operating only for the high water stage, growing cotton has been discontinued since then. And irrigation areas have been decreased further for the recent decade, and only 15% (3,500 feddans) of the Project area (22,620 feddans) was irrigated between July and October for sorghum in 1990.

The Project aims at revitalizing present depressed agricultural production as originally expected or more through the rehabilitation/renovation of the existing pumping station as well as the irrigation and drainage systems. It is, therefore, considered that the implementation of the Project would not cause any extreme environmental changes in and around the Project area, but probably minor effect on water associated diseases.

Implementation and full swing operation of the Project would provide more favourable conditions for the vectors and intermediate hosts of water associated diseases particularly malaria and schistosomiaisis.

The source of drinking water of every village within the Project area mostly come from drilled wells. The water quality is good that there are no serious problems concerning water borne diarrheal diseases.

6.2 The Blue Nile Health Project

The Blue Nile Health Project (BNHP), aiming at controlling the water associated diseases of malaria, schistosomiasis and diarrheal diseases, commenced in 1979 and is expected to continued until 1991. It covers the service areas of the Gezira/Managil scheme as well as the Rahad scheme. With full financial support of the government of the Sudan, BNHP has been carrying out the following programme to achieve the goal of the project:

i) Health education and establishing the village health committees;

ii) Improvement of water supply and sanitation;

iii) Diagnostic surveys, diagnostic laboratory, chemotherapy, surveillance for malaria, schistosomiasis and diarrheal diseases;

iv) Controlling the malaria vectors and the schistosomiasis intermediate host snail; and

v) Monitoring and research.

River Blindness affected only two areas, the River Jur (the uppermost tributary circumference of the White Nile) and Abu Hamad (300 km downstream of Atbara), and is therefore not an object of BNH's study. There is also no possibility of an outbreak within the Project area.

6.3 Malaria

In 1974/75 there was so severe epidemic malaria in the Gezira/Managil scheme that a parasitological survey among school children showed the prevalence rate of 20.4%. After the introduction of the control programme to the scheme by BNHP, the prevalence rate has so drastically dropped as below 1.0% for years. In 1989 it showed 0.66%, which was slightly higher than 0.49% in the previous year (Ref.No.HM-013).

During the current survey period the JICA Study Team conducted a questionnaire survey on farm economy and others to 50 sample tenants each in the Hurga, Nur El Din and Gezira areas. In the survey, it was questioned if a responder and/or his family have an experience of outbreak of malaria in the past and month of outbreak, if experienced. The answers are summarized in Table 6.1. In the Hurga and Nur El Din areas, outbreak of malaria concentrates during the rainy season and shows coincidence with rainfall distribution pattern in the area, while in the Gezira area, it takes place throughout a year with a peak during the rainy season. This implies that intensive and perennial irrigation provides favourable circumstances for breeding mosquitos throughout a year and outbreak pattern changes from seasonal to perennial as a consequent.

6.4 Bilharzia (Shistosomiasis)

In the Gezira/Managil scheme, the prevalence of schistosomiasis has been reduced from about 50% in 1981 to about 10.2% in 1988 and 6.1% in 1989 in the controlled area. By contrast the prevalence of schistosomiasis in the uncontrolled area is very high.

The BNHP divided the Gezira/Managil scheme into four areas, and have been implementing stepwise the water associated deceases control program. The implementation commenced in Study Zone, and extended to the Blue Area, Yellow Area and Red Area.

The following table shows the prevalence for each of blocks in the Gezira/Managil scheme as well as that of the Rahad scheme. Comprehensive disease control programme has been implemented in the Blue Area in phases from 1983 to 1986. The same was commenced in the Yellow Area occupying the northern part of the Gezira scheme in early 1988. The Red Area consisting of 40% of the Gezira/Managil scheme came under control of BNHP in 1989. In the Red area, a parasitological survey was carried out in school children in 1989, and the prevalence was found to be as high as 41.5%.

Prevalence of Schistosomiasis (%)

Year	Study Zone	Blue Area	Yellow Area	Red Area	Rahad Scheme
1982	53.6	-	-	-	-
1984	15.9	-	-	-	11.9
1985	13.2	-	-	-	11.3
1986	14.6	-	-	-	14.8
1987	10.9	17.1	-	-	13.2
1988	10.2	15.2	-	-	18.7
1989	6.1	11.2	18.8	41.5	14.1

(Source; Ref.No.MH-013)

TABLES

Table 1.1 STATION DATA AND COLLECTED DATA

1. METEOROLOGICAL STATION: WAD MEDANI OBSERVATORY
(LATITUDE:14-23 NORTH, LONGITUDE:33-29 EAST, ALTITUDE:405m)

2.GAUGING STATION OF THE BLUE NILE:

NAME OF GAUGING STN	WAD MEDANI	WAD EL NAU	HAG ABDALLAH	WAD EL HADDAD	SENNAR D.STREAM
READING STARTED	1906	1951	1920	1914	1921
KM FROM DELTA	2993	3043	3072	3094	3143
KM FROM ASWAN DAM	2047	2097	2126	2148	2197
ZERO OF GAUGE	377.09	388.6	387.22	389.17	400.00
MAX. READING	21.00=398.09		19.6=406.82	19.76=408.93	13.80=413.80
DATE OF READING	30.8.46		26.8.46	26.8.46	22.8.46
MIN. READING	8.61=385.70		6.56=393.78	8.06=397.23	3.68=403.68
DATE OF READING	12.5.41		10.5.41	10.5.45	9.5.45

(1) Gauge zero of Wad El Nau was corrected according to the recent survey.
(2) KMs for Wad EL Nau & Hag Abdallah need correction based on the actual location.

3. COLLECTED DAILY METEOROLOGICAL DATA AT WAD MEDANI OBSEVATORY:

YEAR	1960 1970 1980 1990
	I I I I I I I
RAINFALL	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
RADIATION	xxxxxxxxxx
SUNSHINE DURATION	xxxxxxxxxx
MEAN WIND SPEED	xxxxxxxxxx
VAPOUR PRESSURE	xxxxxxxxxx
MAX & MIN AIR TEMPERATURE	xxxxxxxxxx
MAX & MIN WATER TEMPERAT.	xxxxxxxxxx
EVAPORATION (CLASS A PAN)	xxxxxxxxxx
(PICHE)	xxxxxxxxxx
(ESTIMATED PENMAN)	xxxxxxxxxx
HOURLY RELATIVE HUMIDITY	xxxxx

4. COLLECTED DAILY DISCHARGE FROM SENNAR DAM: xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

5. COLLECTED DAILY WATER LEVEL AT:

WAD EL NAU	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
HAG ABDALLAH	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
SENNAR DOWNSTREAM	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
WAD MEDANI	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
WAD EL HADDAD	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
	I I I I I I I
YEAR	1960 1970 1980 1990

Table 2.1 RAINFALL
(METEOROLOGICAL DEPARTMENT, WAD MEDANI)

(Unit : mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1980	0.0	0.0	0.0	0.0	12.1	22.3	177.9	71.3	25.2	5.6	0.0	0.0	314.4
1981	0.0	0.0	0.0	0.0	15.8	14.4	106.7	84.0	87.2	8.1	0.0	0.0	316.2
1982	0.0	0.0	0.0	0.0	1.0	15.1	30.5	107.4	38.6	29.4	0.0	0.0	222.0
1983	0.0	0.0	0.0	0.0	12.4	28.8	48.2	58.6	67.8	0.0	0.0	0.0	215.8
1984	0.0	0.0	0.0	0.0	7.0	12.5	39.0	8.2	80.1	0.0	0.0	0.0	146.8
1985	0.0	0.0	0.0	0.0	51.9	45.0	71.3	220.3	45.0	5.2	0.0	0.0	438.7
1986	0.0	0.0	0.0	2.2	0.0	24.3	65.7	81.7	44.8	29.9	0.0	0.0	248.6
1987	0.0	0.0	0.0	0.0	43.1	26.7	37.9	111.2	48.8	2.2	0.0	0.0	269.9
1988	0.0	0.0	0.0	0.0	13.9	43.9	77.9	161.8	40.4	1.6	0.0	0.0	339.5
1989	0.0	0.0	0.0	0.0	34.5	41.5	24.0	116.8	36.4	0.3	32.3	0.0	285.8
1990	0.0	0.0	0.0	0.0	0.0	7.7	38.9	0.3	27.6	40.9	0.0	0.0	115.4
AVERAGE													
1980-89	0.0	0.0	0.0	0.2	19.2	27.5	67.9	102.1	51.4	8.2	3.2	0.0	279.8
1980-90	0.0	0.0	0.0	0.2	17.4	25.7	65.3	92.9	49.3	11.2	2.9	0.0	264.8
1951-80	0.0	0.0	0.0	1.0	13.0	30.0	107.0	128.0	49.0	15.0	0.0	0.0	343.0

ANNUAL MAXIMUM DAILY RAINFALL (Unit : mm)

1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	AVERAGE
48.6	49.0	47.2	30.3	30.0	93.4	31.6	64.2	70.4	31.5	37.7	48.5

Table 2.2 AVERAGE MAXIMUM TEMPERATURE
(METEOROLOGICAL DEPARTMENT, WAD MEDANI)

(Unit : Centigrate)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
1980	33.3	34.9	38.9	42.1	42.5	39.9	34.8	33.8	38.0	39.5	36.6	34.1	
1981	33.1	34.9	37.9	40.5	42.0	40.6	35.4	36.7	33.9	38.6	35.6	35.1	
1982	34.1	32.3	37.4		41.4	40.7	38.3	35.5	37.0	37.7	34.5	33.1	
1983		33.8	35.8	40.3	42.6	39.9	37.4	36.2	38.2	39.3	37.6	34.4	
1984	32.4	36.9	40.3	41.9	40.6	40.3	38.5	38.2	38.0	40.2	36.1	29.3	
1985	35.7	32.2	39.8	40.4	40.4	39.2	35.9	35.8	34.7	38.2	36.1		
1986	33.8	36.5	39.8	39.8	41.3	39.6	35.8	36.5	36.1	38.6	37.0	32.2	
1987	33.7	37.0	36.9	40.9	40.4	40.0	39.1	36.4	37.6	38.2	37.9	33.4	
1988	32.7	34.5	39.3	41.8	42.4	39.9		32.2	34.6	38.0	36.7	35.2	
1989	29.4	31.5	36.6	40.9	41.0	40.2	38.5	35.7	36.0	38.6	37.5	32.2	
AVERAGE	33.1	34.5	38.3	41.0	41.5	40.0	37.1	35.7	36.4	38.7	36.6	33.2	avg 37.2
AVERAGE 1951-80	33.1	35.1	38.4	40.9	41.5	39.6	35.7	33.4	35.3	37.8	36.3	33.4	

Table 2.3 AVERAGE MINIMUM TEMPERATURE
(METEOROLOGICAL DEPARTMENT, WAD MEDANI)

(Unit : Centigrate)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
1980	14.7	16.8	20.9	23.6	26.0	25.7	22.9	22.4	23.2	22.7	19.1	15.9	
1981	14.1	16.1	19.5	21.4	25.0	25.7	23.3	23.3	22.3	22.6	18.7	17.4	
1982	16.7	15.2	20.5		24.6	25.7	24.8	23.0	22.7	22.1	16.0	13.9	
1983		15.9	17.4	21.0	24.3	25.4	24.5	23.7	23.2	21.6	19.0	17.5	
1984	14.2	18.7	20.9	22.9	24.9	24.7	23.8	25.3	22.1	23.7	18.3	14.1	
1985	18.0	15.0	20.9	21.3	24.0	24.5	22.8	23.3	22.1	23.3	18.0		
1986	14.5	16.8	20.7	20.2	23.4	26.3	23.1	23.1	22.1	22.2	19.3	13.2	
1987	14.2	17.8	19.5	21.5	24.9	24.7	25.0	23.3	23.5	22.2	19.7	16.0	
1988	14.5	15.8	20.6	22.1	25.7	26.1		22.7	22.4	23.3	19.9	17.4	
1989	11.1	12.6	17.9	21.0	25.1	24.6	24.2	22.3	22.8	22.7	19.3	14.4	
AVERAGE	14.7	16.1	19.9	21.7	24.8	25.3	23.8	23.2	22.6	22.6	18.7	15.5	avg 20.8
AVERAGE 1951-80	14.0	15.7	18.7	21.5	24.3	24.6	22.8	22.1	21.9	21.6	18.2	14.8	

Table 2.4 SUNSHINE DURATION
(METEOROLOGICAL DEPARTMENT, WAD MEDANI)

(Unit : %)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1980	94	91	82	84	78	62	61	66	76	83	92	89
1981	88	90	82	84	72	71	58	70	67	86	90	93
1982	90	86	75		66	65	63	57	72	82	89	92
1983		88	84	85	73	62	53	67	69	85	91	92
1984	91	88	85	85	72	73	65	54	73	81	95	91
1985	87	81	78	81	70	69	58	66	68	82	87	
1986	91	93	87	87	83	68	56	65	73	83	92	93
1987	94		81						81			
1988	90	89	82	85	66	59		55	64	81	95	90
1989	94	90	83	85	69	68	63		74	86	93	90
AVERAGE	91	88	82	85	72	66	60	63	72	83	92	91
AVERAGE												
1958-80	92	90	86	84	77	70	58	61	72	84	93	92
HRS	10.4	10.5	10.4	10.5	9.9	9.1	7.5	7.7	8.8	9.9	10.7	10.4

Table 2.5 RADIATION
(METEOROLOGICAL DEPARTMENT, WAD MEDANI)

(Unit : M/J SQM)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1980			24.88	26.29	25.22	23.79	23.25	22.27	23.80	22.58	21.71	20.72
1981	20.85	23.90	25.23	26.84	24.37	24.22	21.64	25.24	23.20	23.04	21.67	21.36
1982	21.33	23.97	24.26		24.09	24.12	23.22	22.67	23.77	22.84	22.67	21.46
1983		23.89	25.49	26.83	24.89	22.90	22.53	23.81	22.94	23.71	23.05	22.56
1984	23.28	23.55		25.12	24.08	25.45	23.12	26.19	23.96	21.53	23.51	24.66
1985	25.92	24.01	23.43	25.17	23.72	23.51	21.86	22.85	22.50	21.13	20.89	
1986		22.99	27.42	28.99	27.90	25.11	23.96	23.17	24.20	23.25	22.34	24.34
1987	26.35	26.64	27.92	28.50	25.87	26.80	25.13	24.69			22.73	22.22
1988	22.79	24.65	24.49	27.84	24.40	24.59		22.84	24.31	25.23	23.52	22.18
1989	24.91	25.54	26.55	28.51	25.69	23.12		24.76	24.81	23.78	22.77	21.45
1990	22.79	25.28	26.99	28.08	26.95	25.80	24.55	27.50	25.43	25.07		
AVERAGE	23.53	24.44	25.67	27.22	25.20	24.49	23.25	24.18	23.89	23.22	22.49	22.33

Table 2.6 AVERAGE WIND SPEED
(METEOROLOGICAL DEPARTMENT, WAD MEDANI)

(Unit : MILES PER HOUR)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1980								6.20	4.84	3.30	4.80	4.70
1981	5.71	6.11	5.24	5.45	6.42	8.85	8.70	7.50	4.50	3.20	4.74	4.17
1982	4.78	5.57	6.28		5.72	7.94	8.94	7.68	5.22	4.10	4.70	5.00
1983		6.10	5.98	5.70	5.50	8.50	8.20	7.20	4.70	3.50	4.40	5.10
1984	6.13	6.30	5.50	5.90	6.80	8.00	8.40	7.07	5.33	3.07	5.13	5.34
1985	5.31	4.72	5.53	5.27	6.81	9.55	9.64	9.35	5.10	3.51	3.70	
1986	4.95	4.93	5.65	4.85	5.79	10.67	8.76	7.73	5.01	4.61	4.94	5.45
1987	4.60	4.89	5.63	6.03	6.89	8.88	10.00	7.52	4.66	4.71	4.64	5.45
1988	5.35	5.23	6.43	5.04	6.35	10.60		6.42	3.84	3.33	4.44	4.06
1989	5.47	5.31	4.59	4.30	6.20	9.10	11.50	8.12	5.09	3.34	4.28	3.83
AVERAGE	5.29	5.46	5.65	5.32	6.28	9.12	9.27	7.48	4.83	3.67	4.58	4.79
(M/SEC)	2.35	2.43	2.51	2.36	2.79	4.05	4.11	3.32	2.14	1.63	2.03	2.13
MAX. DAILY MEAN WIND SPEED (1980-90) :						18.09 MPH		= 8.03 M/SEC		(7.21.'90)		
MONTHLY AVERAGE WIND DIRECTION												
	N	N	N	N	SW	SSW	S	S	S	S	NNW	N

Table 2.7 EVAPORATION: CLASS A PAN
(METEOROLOGICAL DEPARTMENT, WAD MEDANI)

(Unit : mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1980	12.1	14.1	17.5	19.4	18.6	17.3	8.4	6.5	10.2	11.3	14.5	11.5
1981	12.9	15.2	17.6	20.6	17.4	17.8	10.8	12.0	6.4	11.5	14.3	11.3
1982	12.4	14.4	18.1		18.3	17.7	15.0	9.4	9.1	11.0	12.9	12.9
1983		12.8	17.5	19.6	18.6	16.0	13.4	12.1	12.2	12.3	13.7	12.6
1984	12.5	15.7	17.4	20.2	18.4	18.1	15.3	15.2	12.1	14.7	14.3	11.9
1985	13.2	14.5	19.2	19.8	16.0	15.8	12.5	11.5	8.0	11.4	13.8	
1986	14.0	16.8	19.3	19.6	19.8	20.2	10.1	10.7	8.2	10.3	12.8	11.7
1987	12.8	14.4	16.9	19.1	16.3	15.5	15.1	8.5	8.4	11.5	12.8	11.0
1988	10.5	12.9	17.0	18.0	15.9	16.4		5.9	6.5	7.9	10.8	9.2
1989	8.9	11.1	16.3	15.6	23.8	14.0	12.9	7.7	6.2	10.1	9.5	9.2
1990	9.7	11.4	13.4	16.8	17.4	18.2	12.4	14.1	10.5	10.3		
AVERAGE	11.9	13.9	17.3	18.9	18.2	17.0	12.6	10.3	8.9	11.1	12.9	11.3

Table 2.8 EVAPORATION: PICHE
(METEOROLOGICAL DEPARTMENT, WAD MEDANI)

(Unit : mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1980	12.7	14.7	18.1	19.9	19.1	17.7	8.9	6.8	10.6	12.0	15.1	12.1
1981	13.5	15.7	18.1	21.2	18.0	18.3	11.1	12.2	6.7	11.8	14.6	11.7
1982	13.0	15.1	19.1		19.0	18.3	16.0	9.9	9.7	11.9	13.9	12.8
1983		14.1	18.2	20.6	19.9	17.6	14.6	13.4	12.7	13.5	15.1	13.7
1984	13.7	16.5	18.5	21.2	19.2	19.0	15.9	15.8	12.4	15.4	14.9	12.6
1985	14.0	15.2	19.3	20.7	16.8	16.6	13.1	12.3	8.7	12.1	14.4	
1986	14.6	16.9	20.0	20.4	20.6	21.0	10.7	11.6	9.0	11.2	13.6	12.5
1987	13.6	15.4	17.8	20.6	16.3	16.5	16.2	9.2	9.2	12.5	13.8	12.1
1988	11.1	14.2	18.9	19.1	17.9	17.2		6.3	5.8	8.8	12.1	10.5
1989	10.4	12.3	14.3	17.3	15.9	15.7	15.2	9.1	7.3	11.3	10.7	10.3
1990	10.8	12.6	15.7	18.3	18.2	19.2	13.5	14.8	11.7	11.8		
AVERAGE	12.7	14.8	18.0	19.9	18.3	17.9	13.5	11.0	9.4	12.0	13.8	12.0

Table 2.9 EVAPORATION: PENMAN
(METEOROLOGICAL DEPARTMENT, WAD MEDANI)

(Unit : mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1980	6.3	7.3	8.3	8.8	9.4	10.0	7.8	7.1	7.5	6.6	6.4	5.8
1981	5.9	7.2	8.1	8.9	9.3	9.8	8.0	8.6	6.8	6.6	6.7	6.1
1982	6.1		8.3		8.8	9.5	9.2	7.5	7.5		6.4	
1983		7.2	8.1	8.9	8.9			8.5				6.6
1984	6.7	7.5	8.2	8.8	9.1	10.0	9.0	9.1	7.2		7.0	7.0
1985	7.7	7.5	8.0	8.3	8.6	9.5	8.3	8.2	6.6		5.8	
1986	5.8	6.8	9.0	9.0	9.6	10.7	8.9	8.1	7.5	7.0	6.7	5.9
1987			9.1									
1988	6.3	7.3	8.7	8.6	9.3	10.6		7.4	7.3	7.3	6.6	6.0
1989	6.5		7.9	8.7					7.8	7.0	6.5	
1990	6.4			9.1	9.3				8.6	8.0		
AVERAGE	6.4	7.3	8.4	8.8	9.1	10.0	8.5	8.1	7.4	7.1	6.5	6.2

Table 2.10 RELATIVE HUMIDITY
(METEOROLOGICAL DEPARTMENT, WAD MEDANI)

(Unit : %)

YEAR	JANUARY		FEBRUARY		MARCH		APRIL		MAY		JUNE		
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	
1986	51	19	36	13	33	12	31	13	29	14	58	26	
1987	50	19	39	17	31	13	26	14	51	25	62	25	
1988	52	23	37	14	33	12	26	11			58	29	
1989			47	16	37	14	33	15	53	23	65	25	
1990	53	14	50	20	45	21	30	12					
													avg
AVERAGE	52	19	42	16	36	14	29	13	44	21	61	26	31.0

YEAR	JULY		AUGUST		SEPTEMBER		OCTOBER		NOVEMBER		DECEMBER		
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	
1986	81	43	79	39	82	40	65	28	46	20	45	20	
1987	68	32	85	42	82	36	58	27	45	18	49	20	
1988	83	47	89	53									
1989	73	31	87	41	86	44	59	26	51	21	53	23	
1990	75	33	75	30	76	32	72	27					
													avg
AVERAGE	76	37	83	41	82	38	64	27	47	20	49	21	48.7

Table 2.11 PROBABILITY ANALYSIS FOR MAXIMUM DAILY RAINFALL AT WAD MEDANI

ORDER	YEAR	Xi	SORT YEAR	Xi	$(Xi-Xo)^2$	HAZEN W(Xi)
1	1980	48.60	1985	93.40	2012.7459	95.4545
2	1981	49.00	1988	70.40	478.0186	86.3636
3	1982	47.20	1987	64.20	245.3495	77.2727
4	1983	30.30	1981	49.00	0.2150	68.1818
5	1984	30.00	1980	48.60	0.0040	59.0909
6	1985	93.40	1982	47.20	1.7859	50.0000
7	1986	31.60	1990	37.70	117.4268	40.9091
8	1987	64.20	1986	31.60	286.8404	31.8182
9	1988	70.40	1989	31.50	290.2377	22.7273
10	1989	31.50	1983	30.30	332.5649	13.6364
11	1990	37.70	1984	30.00	343.5968	4.5455

TOTAL 4108.7855

AVG (Xo=) 48.536364 373.5260

$$\frac{1}{a} = \sqrt{\frac{2}{n}\sum_{i=1}^{n}(Xi-Xo)^2} = 27.33225$$

RETURN PERIOD	PROBABL. CONSTS.	PROBABLE RAINFALL
200	1.8215	98.32
100	1.6450	93.50
50	1.4520	88.22
20	1.1630	80.32
10	0.9062	73.30
5	0.5951	64.80
3	0.3045	56.86

Table 2.12 PROBABILITY ANALYSIS FOR MINIMUM ANNUAL RAINFALL AT WAD MEDANI

ORDER	YEAR	Xi	SORT YEAR	Xi	$(Xi-Xo)^2$	HAZEN W(Xi)
1	1980	315.00	1990	115.40	22344.81	95.4545
2	1981	316.20	1984	146.80	13943.31	86.3636
3	1982	222.00	1983	215.80	2409.02	77.2727
4	1983	215.80	1982	222.00	1838.85	68.1818
5	1984	146.80	1986	248.60	265.10	59.0909
6	1985	438.70	1987	269.90	25.18	50.0000
7	1986	248.60	1989	285.80	437.57	40.9091
8	1987	269.90	1980	315.00	2511.83	31.8182
9	1988	339.50	1981	316.20	2633.56	22.7273
10	1989	285.80	1988	339.50	5567.87	13.6364
11	1990	115.40	1985	438.70	30212.76	4.5455

TOTAL		82189.88
AVG	(Xo=) 264.88182	7471.81

$$\frac{1}{a} = \sqrt{\frac{2}{n}\sum_{i=1}^{n}(Xi-Xo)^2} = 122.24408$$

RETURN PERIOD	PROBABL. CONSTS.	PROBABLE RAINFALL
100	1.6450	63.79
50	1.4520	87.38
30	1.2971	106.32
20	1.1630	122.71
10	0.9062	154.10
5	0.5951	192.13
3	0.3045	227.66

Table 3.1 CHARACTERISTICS OF DAMS AND RESERVOIRS ALONG BLUE NILE

1. Sennar Dam				
Dam	Masonry Section	Length	1,600	m
		Max Height	39	m
	Embankment	Length	1,400	m
		Max Height	15	m
Reservoir	Retention Level		421.7	m
	Lowest Drawdown Level		416.0	m
	Reservoir Area		160	sqkm
	Storage Capacity	gross	930	Mcum
		live	700	Mcum
Power Facilities	Installed Capacity	(2x7.5MW)	15	MW
	Average Annual Energy		100	Gwh
2. Existing Roseires Dam				
Dam	Concrete Section	Length	1,000	m
		Max Height	68	m
	Embankment	Length	12,500	m
		Max Height	30	m
Reservoir	Retention Level		480	m
	Lowest Drawdown Level		467	m
	Reservoir Area		290	sqkm
	Storage Capacity	gross	3,024	Mcum
		live	2,386	Mcum
Power Facility	Installed Capacity	(3x30MW)	90	MW
	Average Annual Energy (potential with 3 units)		700	Gwh
3. Proposed Roseires Dam				
Dam		Length	24,000	m
	Concrete Section	Max Heigth	78	m
	Embankment	Max Heigth	40	m
Reservoir	Retention Level		490	m
	Reservoir Area		600	sqkm
	Storage Capacity	live	7,000	Mcum
Power Facilities	Installed Capacity	(7 units)	250	MW
	Average Annual Energy		1,710	Gwh

Source Updating of the Feasibility Study for the Heightening of the Roseires Dam

Table 3.2 LOWEST WATER LEVEL WITHIN ONE WEEK AFTER MINIMUM DISCHARGE AT SENNAR

G.STN YEAR	SENNAR DISCHARGE (MCM)	DATE	HAG ABDALLA W.LEVEL (M)	DATE	WAD EL NAU W.LEVEL (M)	DATE	HA-WEN (M)	ESTIMATED W.L.AT NurElDin (M)	ESTIMATED W.L.AT Hurga (M)
1970	4.5	3/12	395.09	3/12	390.48	3/18	4.61	391.91	391.71
1971	5.3	4/27	395.07	4/28	390.40	4/27	4.67	391.85	391.65
1972	7.3	3/16	395.07	3/19	390.60	3/18	4.47	391.99	391.79
1973	7.2	1/15	394.94	1/17	390.40	1/13	4.54	391.81	391.61
1974	4.8	2/18	394.45	2/16	390.58	2/20	3.87	391.78	391.61
1975	4.5	12/07	395.22	12/08	390.60	12/10	4.62	392.04	391.83
1976	3.8	4/13	395.42	4/12	391.10	4/13	4.32	392.44	392.25
1977	5.8	1/19	394.22	1/21	390.60	1/18	3.62	391.73	391.57
1978	3.7	12/10	395.82	12/10	390.80	12/17	5.02	392.36	392.14
1979	10.0	3/06			390.70	3/06			
1980	7.0	2/29	395.42	3/04	390.26	2/28	5.16	391.87	391.64
1981	6.0	3/03	395.27	3/09	391.50	3/04	3.77	392.67	392.51
1982	5.0	6/17	394.42	6/22	391.10	6/15	3.32	392.13	391.99
1983	5.0	2/04	394.72	2/10					
1984	6.0	1/14	394.40	1/18	389.55	1/17	4.85	391.06	390.84
1985	4.9	12/25			389.60	1/09			
1986	4.2	1/18	395.42	1/22	390.00	1/23	5.42	391.69	391.45
1987	5.4	1/05	394.52	1/05	389.60	1/08	4.92	391.13	390.91
1988	5.8	1/20							
1989	4.4	1/25	395.07	1/26					
1990	4.6	6/10	394.02	6/07	389.40	6/10	4.62	390.84	390.63

Table 3.3 RECORDED AND ESTIMATED LOWEST WATER LEVEL

G.STN YEAR	HAG ABDALLA W.LEVEL (M)	DATE	WAD EL NAU W.LEVEL (M)	DATE	HA-WEN	ESTIMATED W.L.AT NurElDin (M)	ESTIMATED W.L.AT Hurga (M)
1941	393.78	5/10					
1970	394.76	5/16	390.30	5/20	4.46	391.69	391.49
1971	394.92	5/19	390.30	5/18	4.62	391.74	391.53
1972	394.76	5/22	390.46	5/23	4.30	391.80	391.61
1973	394.82	4/22	390.32	4/18	4.50	391.72	391.52
1974	394.45	2/16	390.50	2/24	3.95	391.73	391.55
1975	394.72	4/24	390.60	6/02	4.12	391.88	391.70
1976	395.12	3/05	390.70	1/03	4.42	392.08	391.88
1977	394.22	1/--	390.40	5/01	3.82	391.59	391.42
1978	394.72	3/11	390.40	3/11	4.32	391.74	391.55
1979			390.50	3/18			
1980	395.37	2/11	390.18	1/24	5.19	391.79	391.56
1981	394.37	4/19	391.10	5/19	3.27	392.12	391.97
1982	394.22	3/--	391.10	5/08	3.12	392.07	391.93
1983	394.27	1/15					
1984	393.34	2/23					
1985	394.22	5/03	389.58	3/15	4.64	391.02	390.82
1986	394.34	6/12	389.60	6/03	4.74	391.07	390.86
1987	394.52	1/--	389.60	1/--	4.92	391.13	390.91
1988	393.85	12/08	389.68	12/18	4.17	390.98	390.79
1989	394.22	2/10	389.98	2/14	4.24	391.30	391.11
1990	394.02	6/4-7	389.40	6/4-11	4.62	390.84	390.63

* W.L. at Gauging Station & Pump Station are shown on Irrigation datum.

Table 3.4 PRESENT WATER USE OF THE NILE IN 1990 (MCM)

MONTH	PERIOD	BLUE NILE P.S. U/S SENNAR	BLUE NILE P.S. D/S SENNAR	BLUE NILE GEZIRA, MANAGIL	BLUE NILE SUB-TOTAL	WHITE NILE	ATBARA	NILE MAIN	TOTAL
JAN	1-10	77	27	213	317	62	49	32	460
	11-20	71	26	224	321	61	48	28	458
	21-31	75	28	258	361	64	50	30	505
FEB	1-10	70	26	210	306	62	42	30	440
	11-20	51	26	194	271	61	42	34	408
	21-28	32	21	141	194	51	30	30	305
MAR	1-10	35	20	120	175	58	25	34	292
	11-20	33	19	82	134	57	23	36	250
	21-31	37	20	63	120	59	20	40	239
APR	1-10	32	17	31	80	39	18	37	174
	11-20	31	15	26	72	40	21	34	167
	21-30	31	16	20	67	42	16	32	157
MAY	1-10	34	16	20	70	43	17	28	158
	11-20	34	17	23	74	44	18	29	165
	21-31	36	18	25	79	48	20	30	177
JUN	1-10	38	18	35	91	42	17	27	177
	11-20	40	19	62	121	40	19	25	205
	21-30	43	21	93	157	37	19	24	237
JUL	1-10	63	25	125	213	34	19	25	291
	11-20	106	27	144	277	31	29	29	366
	21-31	110	31	226	367	30	46	32	475
AUG	1-10	101	28	220	349	26	53	29	457
	11-20	101	29	194	324	38	36	27	425
	21-31	111	35	153	299	46	59	29	433
SEP	1-10	122	33	150	305	43	62	27	437
	11-20	136	35	136	307	51	51	28	437
	21-30	148	35	244	427	63	53	30	573
OCT	1-10	166	35	288	489	75	69	32	665
	11-20	156	38	288	482	80	74	41	677
	21-31	164	40	314	518	90	86	52	746
NOV	1-10	133	33	288	454	85	79	53	671
	11-20	137	30	287	454	82	70	51	657
	21-30	102	28	297	427	78	62	49	616
DEC	1-10	94	28	281	403	70	62	45	580
	11-20	86	27	257	370	67	55	41	533
	21-31	90	30	259	379	69	50	38	536
YEAR TOTAL		2,926	937	5,991	9,854	1,968	1,509	1,218	14,549

Table 3.5 WATER USE OF THE NILE AFTER REHABILITATION IN 1995 (MCM)

MONTH PERIOD		BLUE NILE P.S. U/S SENNAR	P.S. D/S SENNAR	GEZIRA, MANAGIL	SUB-TOTAL	WHITE NILE	ATBARA	NILE MAIN	TOTAL
JAN	1-10	92	37	255	384	114	46	40	584
	11-20	87	36	239	362	111	45	35	553
	21-31	91	39	249	379	113	55	38	585
FEB	1-10	81	37	201	319	109	40	39	507
	11-20	75	36	192	303	104	40	45	492
	21-28	54	28	144	226	91	28	40	385
MAR	1-10	58	33	112	203	98	22	44	367
	11-20	55	31	97	183	105	20	46	354
	21-31	60	33	92	185	90	18	50	343
APR	1-10	50	30	62	142	50	18	45	255
	11-20	48	28	50	126	51	18	42	237
	21-30	47	30	43	120	54	18	39	231
MAY	1-10	48	31	48	127	54	18	36	235
	11-20	47	32	42	121	56	18	36	231
	21-31	52	36	92	180	61	20	37	298
JUN	1-10	49	33	197	279	53	18	34	384
	11-20	50	34	236	320	49	18	32	419
	21-30	61	36	254	351	46	18	30	445
JUL	1-10	82	36	235	353	42	23	32	450
	11-20	128	39	246	413	39	35	38	525
	21-31	129	44	267	440	40	52	42	574
AUG	1-10	122	40	232	394	34	60	37	525
	11-20	120	41	234	395	53	42	35	525
	21-31	131	48	250	429	65	66	37	597
SEP	1-10	147	44	254	445	95	72	36	648
	11-20	160	46	277	483	111	65	37	696
	21-30	172	47	302	521	122	68	40	751
OCT	1-10	192	46	312	550	131	69	41	791
	11-20	180	45	321	546	139	75	51	811
	21-31	186	43	353	582	155	85	62	884
NOV	1-10	152	40	318	510	144	80	64	798
	11-20	136	38	313	487	145	70	62	764
	21-30	118	36	308	462	140	60	59	721
DEC	1-10	109	36	292	437	132	56	55	680
	11-20	101	35	284	420	125	48	50	643
	21-31	103	40	303	446	131	48	46	671
YEAR TOTAL		3,573	1,344	7,706	12,623	3,252	1,552	1,532	18,959

Table 3.6 MONTHLY MEAN WATER LEVEL

(1) AT WAD EL NAU

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1974	391.24	390.64	390.77	390.81	391.06	392.62	396.18	399.24	398.24	395.00	392.55	391.16
1975	390.78	391.03	391.34	391.09	390.79	391.14	395.52	399.20	400.24	395.75	393.44	391.83
1976	391.08	390.91	390.97	391.22	391.97	392.43	397.02	398.78	396.91	393.91	392.64	391.20
1977	390.75	390.84	390.89	391.17	390.97	391.52	395.30	399.22	397.84	395.18	393.77	391.53
1978	390.95	390.72	390.50	390.95	390.99	391.80	395.58		398.56	396.64	393.41	392.15
1979	390.82	390.83	390.65	390.88	391.59	391.89	394.46	397.81	395.81	393.69	391.26	390.46
1980	390.36	390.24	390.42	390.85	391.07	391.07	395.11	398.62	396.85	394.64	392.46	391.61
1981	391.49	391.53	391.58	391.82	391.99	392.08	395.02	399.14	398.75	395.15	392.55	391.70
1982	391.61	391.65	391.48	391.89	391.69	391.74	394.42	398.21	396.26	395.60	392.53	391.57
1983												
1984												
1985	389.66	389.86	389.75	389.84	390.04	391.07	393.81	398.31	397.97	393.13	391.14	390.37
1986	390.31	390.25	390.15	390.46	390.38	390.73	394.59	396.83	395.42	392.91	390.37	389.75
1987	389.81	389.93	389.76	390.00	390.15	392.78	393.33	396.63	394.33	393.44	391.00	389.80
1988						392.02	395.30	400.21	399.66	396.74	392.87	391.00
1989		390.05	390.18	390.69	391.23	391.64	394.55	397.53	397.07	394.34	391.81	390.32
1990	389.77	389.76	390.19	390.88	390.54	389.84	392.88	397.83	396.55	393.85	390.96	389.93
AVERAGE	390.66	390.59	390.62	390.90	391.03	391.63	394.87	398.40	397.36	394.66	392.18	390.96

(2) AT HAG ABDALLA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1974	395.73	395.13	395.52	395.47	395.67	396.92	400.07	403.16	402.18	398.88	396.61	395.54
1975	395.10	395.35	395.80	395.26	395.18	395.76	399.55	403.08	404.20	399.26	397.41	396.18
1976	395.48	395.37	395.44	395.69	396.38	396.66	398.80	402.65	400.37	397.62	396.78	395.37
1977		394.95	395.18		395.25	396.27	399.63	402.78	401.08		397.91	396.12
1978	395.67	395.45	395.22	395.72	395.74	396.10	399.21	401.95	401.14	399.67	396.75	
1979						396.24	398.41	401.34		397.80	396.14	395.60
1980	395.50	395.46	395.47	395.64	395.69	395.73	398.74	402.68	400.18	397.92	395.90	395.42
1981	395.28	395.35	395.16	394.68	395.69	395.75	398.09	402.28	401.25	398.14	396.19	395.38
1982	395.52	395.52	394.37	395.79	395.50	395.48	397.97		395.49		395.84	395.17
1983												
1984												
1985	394.92	395.31	395.10	394.87	394.85	395.94	398.05	402.73	402.56	397.84	396.09	395.45
1986	395.58	395.63	395.24	395.14	395.19	395.17	398.65	400.94	399.60	397.37	389.68	
1987	394.76	395.04	394.70	394.90	395.21	397.66	398.57	400.99	398.74	398.10	395.29	394.12
1988	394.61		394.80	395.02	394.98	395.40	399.07	404.31	403.21	400.57	397.68	395.72
1989		394.60	395.07	395.69	396.13	396.39	398.90	401.48	401.26	398.62	396.73	394.93
1990	394.24	394.33	394.76	395.77	395.15	394.65	397.63	401.85	400.70	398.22	395.60	394.52
AVERAGE	395.20	395.19	395.13	395.36	395.47	396.01	398.76	402.30	400.85	398.46	396.04	395.35

Table 3.7 SUMMARY OF MEAN WATER LEVEL (1974-1990)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVERAGE
WAD EL NAU	390.66	390.59	390.62	390.90	391.03	391.63	394.87	398.40	397.36	394.66	392.18	390.96	392.82
HAG ABDALLA	395.20	395.19	395.13	395.36	395.47	396.01	398.76	402.30	400.85	398.46	396.04	395.35	397.01
HAG-WAD	4.54	4.60	4.52	4.46	4.44	4.38	3.89	3.90	3.49	3.80	3.86	4.39	4.19
NUR EL DIN	392.08	392.02	392.02	392.28	392.41	392.99	396.08	399.61	398.45	395.85	393.38	392.32	394.12
HURGA	391.87	391.82	391.82	392.09	392.22	392.79	395.91	399.44	398.30	395.68	393.21	392.13	393.94

* W.L. at gauging station & pump station are shown on Irrigation datum.

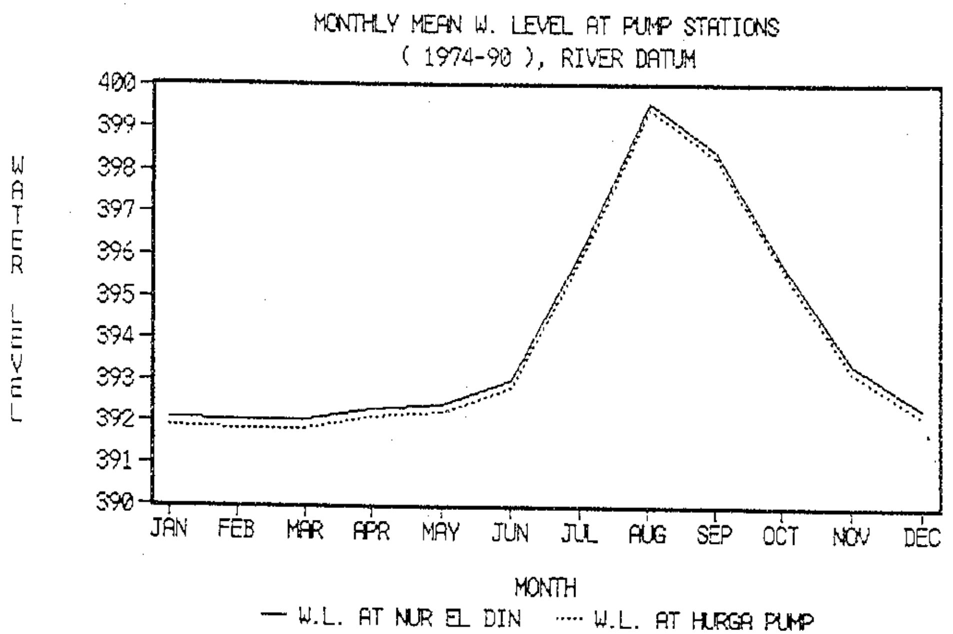


Table 3.8 HIGHEST WATER LEVEL WITHIN ONE WEEK AFTER MAXIMUM DISCHARGE AT SENNAR

G.STN.	SENNAR DISCHARGE (MCM)		HAG ABDLA W.LEVEL (M) (387.22)		WADEL NAU W.LEVEL (M) (388.60)		HA-WEN	ESTIMATED W.L AT NurElDin	ESTIMATED W.L AT HURGA
YEAR		DATE		DATE		DATE			
1946			406.82	8/26	402.80 (406.82-4.02)		4.02 (Mean)	404.05	403.87
1970	710.58	8/28	404.65	8/28	400.38	8/29	4.27	401.71	401.52
1971	636.27	8/10	403.95	8/22	400.00	8/23	3.95	401.23	401.05
1972	432.50	8/19	402.52	8/19	399.02	8/21	3.50	400.11	399.95
1973	661.37	8/19	404.17	8/21	400.06	8/25	4.11	401.34	401.16
1974	546.00	8/20	404.02	8/21	400.20	8/21	3.82	401.39	401.22
1975	703.00	9/17	404.92	9/18	400.80	9/17	4.12	402.08	401.90
1976	437.50	8/18	403.32	8/18	399.36	8/19	3.96	400.59	400.42
1977	594.00	8/17	403.97	8/17	401.00	8/17	2.97	401.92	401.79
1978	529.00	8/21	403.07	8/21	399.00	8/22	4.07	400.27	400.09
1979	486.00	8/08	402.32	8/09	398.50	8/09	3.82	399.69	399.52
1980	597.00	8/13	403.82	8/13	399.90	8/13	3.92	401.12	400.95
1981	508.00	8/04	402.89	8/05	399.80	8/04	3.09	400.76	400.62
1982	426.00	8/17			398.90	8/18			
1983	545.00	8/28	403.08	8/29					
1984	342.00	8/06							
1985	663.27	9/07	404.77	9/09	400.24	9/08	4.53	401.65	401.45
1986	464.63	8/03	401.96	8/04	397.80	8/03	4.16	399.09	398.91
1987	424.60	8/26	402.42	8/27	397.36	8/27	5.06	398.93	398.71
1988	719.23	8/21	405.62	8/22	400.96	8/22	4.66	402.41	402.20
1989	591.35	8/31	403.37	9/03	399.30	9/03	4.07	400.57	400.39
1990	486.34	8/20	403.15	8/20	398.86	8/21	4.29	400.19	400.00
MEAN	547.79		403.58		399.55		4.02	400.84	400.66

Table 3.9 HIGH WATER LEVEL IN 1988 FLOOD

DATE	SENNAR DISCHARGE (MCM/DAY)	HAG ABDLA W.LEVEL (M) (387.22)	WADEL NAU W.LEVEL (M) (388.60)
AUG 16	606.68	404.67	400.30
17	640.89	404.77	400.37
18	668.52	404.82	400.54
19	686.45	405.12	400.66
20	697.17	405.27	400.80
21	715.64	405.57	400.90
22	707.64	405.62	400.96
23	670.96	405.22	400.90
24	679.97	405.07	400.82
25	654.68	405.07	400.80
26	660.89	405.00	400.80
27	641.51	404.89	400.70
28	598.39	404.87	400.46

* All elevation at gauge station and pump station shown on Irrigation datum.

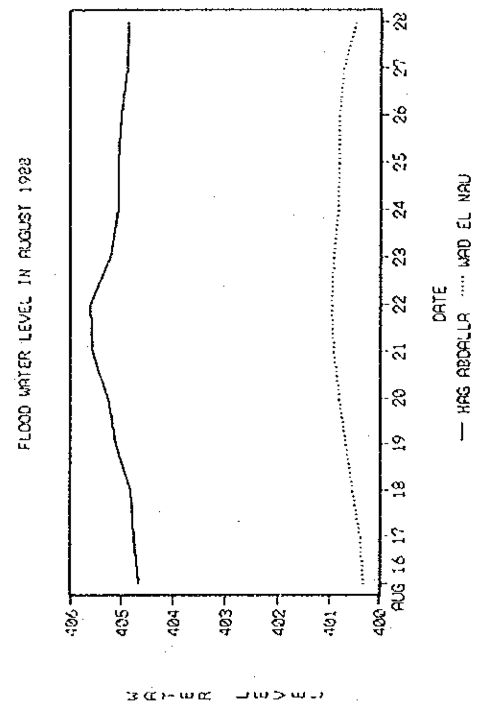


Table 3.10 PROBABILITY ANALYSIS FOR MAXIMUM DISCHARGE AT SENNAR DAM

ORDER	YEAR	Xi	SORT YEAR	Xi	$(Xi-Xo)^2$	HAZEN W(Xi)
1	1970	710.58	1988	719.23	29390.9	97.6190
2	1971	636.27	1970	710.58	26499.8	92.8571
3	1972	432.50	1975	703.00	24089.4	88.0952
4	1973	661.37	1985	663.27	13335.1	83.3333
5	1974	546.00	1973	661.37	12899.9	78.5714
6	1975	703.00	1971	636.27	7828.3	73.8095
7	1976	437.50	1980	597.00	2421.4	69.0476
8	1977	594.00	1977	594.00	2135.1	64.2857
9	1978	529.00	1989	591.35	1897.3	59.5238
10	1979	486.00	1974	546.00	3.2	54.7619
11	1980	597.00	1983	545.00	7.8	50.0000
12	1981	508.00	1978	529.00	353.2	45.2381
13	1982	426.00	1981	508.00	1583.4	40.4762
14	1983	545.00	1990	486.34	3776.4	35.7143
15	1984	342.00	1979	486.00	3818.3	30.9524
16	1985	663.27	1986	464.63	6916.0	26.1905
17	1986	464.63	1976	437.50	12164.4	21.4286
18	1987	424.60	1972	432.50	13292.3	16.6667
19	1988	719.23	1982	426.00	14833.4	11.9048
20	1989	591.35	1987	424.60	15176.4	7.1429
21	1990	486.34	1984	342.00	42350.5	2.3810

TOTAL		234772.4
AVG	(Xo=) 547.79238	11179.6

$$\frac{1}{a} = \sqrt{\frac{2}{n}\sum_{i=1}^{n}(Xi-Xo)^2} = 149.53018$$

RETURN PERIOD	PROBABL. CONSTS.	PROBABLE DISCHARGES
1000	2.1850	874.51
500	2.0350	852.08
200	1.8215	820.16
100	1.6450	793.77
50	1.4520	764.91
20	1.1630	721.69
10	0.9062	683.29
5	0.5951	636.78
3	0.3045	593.32

Table 3.11 PROBABILITY ANALYSIS FOR HIGH WATER LEVEL AT NUR EL DIN

ORDER	YEAR	Xi	SORT YEAR	Xi	$(Xi-Xo)^2$	HAZEN W(Xi)
1	1970	401.71	1988	402.41	2.4771	97.2222
2	1971	401.23	1975	402.08	1.5473	91.6667
3	1972	400.11	1977	401.92	1.1748	86.1111
4	1973	401.34	1970	401.71	0.7637	80.5556
5	1974	401.39	1985	401.65	0.6624	75.0000
6	1975	402.08	1974	401.39	0.3068	69.4444
7	1976	400.59	1973	401.34	0.2539	63.8889
8	1977	401.92	1971	401.23	0.1551	58.3333
9	1978	400.27	1980	401.12	0.0806	52.7778
10	1979	399.69	1981	400.76	0.0058	47.2222
11	1980	401.12	1976	400.59	0.0606	41.6667
12	1981	400.76	1989	400.57	0.0708	36.1111
13	1985	401.65	1978	400.27	0.3205	30.5556
14	1986	399.09	1990	400.19	0.4175	25.0000
15	1987	398.93	1972	400.11	0.5272	19.4444
16	1988	402.41	1979	399.69	1.3136	13.8889
17	1989	400.57	1986	399.09	3.0489	8.3333
18	1990	400.19	1987	398.93	3.6333	2.7778

TOTAL 16.8198

AVG (Xo=) 400.83611 0.9344

$$\frac{1}{a} = \sqrt{\frac{2}{n}\sum_{i=1}^{n}(Xi-Xo)^2} = 1.3670661$$

RETURN PERIOD	PROBABL. CONSTS.	PROBABLE WATER LEVEL
1000	2.1850	403.82
500	2.0350	403.62
200	1.8215	403.33
100	1.6450	403.08
50	1.4520	402.82
20	1.1630	402.43
10	0.9062	402.07
5	0.5951	401.65
3	0.3045	401.25

Table 3.12 PROBABILITY ANALYSIS FOR HIGH WATER LEVEL AT HURGA

ORDER	YEAR	Xi	SORT YEAR	Xi	$(Xi-Xo)^2$	HAZEN W(Xi)
1	1970	401.52	1988	402.20	2.3767	97.2222
2	1971	401.05	1975	401.90	1.5417	91.6667
3	1972	399.95	1977	401.79	1.2807	86.1111
4	1973	401.16	1970	401.52	0.7425	80.5556
5	1974	401.22	1985	401.45	0.6267	75.0000
6	1975	401.90	1974	401.22	0.3155	69.4444
7	1976	400.42	1973	401.16	0.2517	63.8889
8	1977	401.79	1971	401.05	0.1534	58.3333
9	1978	400.09	1980	400.95	0.0851	52.7778
10	1979	399.52	1981	400.62	0.0015	47.2222
11	1980	400.95	1976	400.42	0.0568	41.6667
12	1981	400.62	1989	400.39	0.0720	36.1111
13	1985	401.45	1978	400.09	0.3230	30.5556
14	1986	398.91	1990	400.00	0.4334	25.0000
15	1987	398.71	1972	399.95	0.5017	19.4444
16	1988	402.20	1979	399.52	1.2958	13.8889
17	1989	400.39	1986	398.91	3.0567	8.3333
18	1990	400.00	1987	398.71	3.7960	2.7778

TOTAL 16.9109

AVG (Xo=) 400.65833 0.9395

$$\frac{1}{a} = \sqrt{\frac{2}{n}\sum_{i=1}^{n}(Xi-Xo)^2} = 1.3707601$$

RETURN PERIOD	PROBABL. CONSTS.	PROBABLE DISCHARGES
1000	2.1850	403.65
500	2.0350	403.45
200	1.8215	403.16
100	1.6450	402.91
50	1.4520	402.65
20	1.1630	402.25
10	0.9062	401.90
5	0.5951	401.47
3	0.3045	401.08

Table 4.1 WATER QUALITY

Water-quality

	pH	EC	S.S.	Ca	Ca	Mg	Mg	Na	Na	HCO3	Cl	Cl	Hardness
		mmor/cm	gm/l	meq/L	ppm	meq/L	ppm	meq/L	ppm	meq/L	meq/L	ppm	
1	8.3	0.21	0.70	2.15	43	0.70	8.5	0.4	9.2	0.34	0.06	2.13	5.375
2	7.5	0.20	0.13	2.05	41	0.35	4.3	0.2	4.6	0.32	0.06	2.13	5.125
avg	7.9	0.21	0.42	2.10	42	0.53	6.4	0.3	6.9	0.33	0.06	2.13	5.250
3	8.1	0.29	0.04	2.35	47	0.95	11.5	0.6	13.8	0.48	0.04	1.42	5.875
4	7.9	2.68	0.04	2.95	59	2.00	24.3	0.5	11.5	0.62	0.42	14.9	7.375
5	7.9	0.19	0.13	2.10	42	0.57	6.9	0.4	9.2	0.44	0.06	2.13	
6	7.8	0.19	0.30	1.40	28	0.40	4.9	0.5	11.5	0.44	0.06	2.13	3.500

1	SSP	SAR	adj SAR	pHC	Ca+Mg+Na		Ca+Mg		Na	HCO3	
2					meq/L	pK2'-pk	meq/L	p(Ca+Mg	Meq/L	meq/L	p(Alk)
avg	12.0	0.30	0.24	8.6	3.25	2.2	2.85	2.9	0.4	0.34	3.5
3	10.3	0.18	0.13	8.7	2.60	2.2	2.40	3.0	0.2	0.32	3.5
4	11.2	0.24	0.19	8.6	2.93	2.2	2.63	2.9	0.3	0.33	3.5
5	15.4	0.47	0.47	8.4	3.90	2.2	3.30	2.8	0.6	0.48	3.4
6	9.2	0.32	0.38	8.2	5.45	2.2	4.95	2.7	0.5	0.62	3.3
	13.0	0.34	0.34	8.4	3.07	2.2	2.67	2.8	0.4	0.44	3.4

SSP: Soluble sodium perdentage
SAR: Sodium Adsorption Ratio

1 Blue Nile Water at Hurga
2 Blue Nile Water at Nur El Din
3 Well water, about 70 m from sufrace
4 Well water, about 12 m from surface
5 Gezira Main Cannal at Pilot Farm
6 Irrigation Water for Gezira at Sennar Dam

○ USDA classification of irrigation water salinity

Salinity class	EC range (micro S/cm)	
Cl Low salinity water	<250	mmor/cm=m S/cm
C2 Medium salinity water	250-750	
C3 Highly salinity water	750-2250	
C4 Very high salinity water	>2250	

Source; P302, adopted from Richards L A (Ed)(1954), Diagnosis and improvement of saline and alkaline soils
US Dept Agric Handbook 60, USDA, Washington DC.

○ FAO gnidelines for evaluating irrigation water quality

Soil property affected	Unit	No problem	Increasing problem	Severe problem
Crop water availability	mS/cm	< 0.7	0.7 -3.0	> 3.0
Permeability	mS/cm	> 0.5	0.5 - 0.2	< 0.2
	adj SAR	< 6	3 - 9	> 9

○ Specific ion toxicity(affects sensitive crops)
For Montmorillonite(2:1 crystal lattice)

	No problem	Increasing problem	Servere problem
Sodium adj SAR	<6	3 - 9	> 9
Chloride me/L	<4	4 - 10	> 10

For surface Irrigation
adj SAR = SAR*(9.4-pHc)
pHc= (pK'-pKc')+p(Ca +Mg)+p(Alk)
(pk'-pKc');(Ca2+)+(Mg2+)+(Na+)
p(Ca+Mg);(Ca2+)+(Mg2+)
p(Alk);(CO32-)+(HCO3-)

Source; P302 from Soil survey investigation for irrigation, Soils Bull No.42, FAO, 1979

○ USDA classification of irrigation water sodicity

Water Quality Sodium Class	SAR
S1: Low sodium water	< 10
S2: Medium sodium water	10 - 18
S3: High sodium water	18 - 26
S4: Very high sodium wat	> 26

SAR =(NA+) / √((Ca2+)+(Mg2+)) / 2))

Source; P302, adopted from Richards L A (Ed) (1954), Diagnosis and improvement of saline and alkaline soils
US Dept Agric Handbook 60, USDA, Washington DC.

Source; P302= Landon, J.R. (Ed) Booker Tropical Soil Manual, Pitman Press, Bath (1984)

Table 5.1 SEDIMENT LOAD

SUMMARY OF RELEASE FROM SENNAR DAM (1983-1989) (Unit : MCM / DAY)

PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1-10	6.95	8.62	9.17	13.98	19.07	32.21	80.68	335.06	354.28	129.93	40.40	14.25
11-20	6.90	8.26	9.34	16.14	21.33	44.50	146.61	368.52	252.45	108.45	22.93	12.93
21-END	8.04	8.64	11.81	18.50	21.61	54.36	224.36	414.52	183.85	86.57	16.43	14.41
MONTHLY	7.30	8.51	10.16	16.21	20.67	43.69	150.55	372.70	263.53	108.32	26.59	13.86

YEARLY MEAN 86.83

SUMMARY OF RELEASE FROM SENNAR DAM (1983-1989) (Unit : CUM/SEC)

PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1-10	80.42	99.80	106.18	161.86	220.75	372.78	933.76	3,878.04	4,100.50	1,503.85	467.54	164.98
11-20	79.85	95.63	108.15	186.84	246.84	515.08	1,696.84	4,265.24	2,921.84	1,255.22	265.36	149.65
21-END	93.09	99.97	136.71	214.09	250.06	629.12	2,596.73	4,797.69	2,127.84	1,001.98	190.20	166.73
MONTHLY	84.45	98.47	117.01	187.59	239.22	505.66	1,742.44	4,313.66	3,050.06	1,253.69	307.70	160.46

YEARLY MEAN 1,005.00

10 - DAY FLOW / PEAK 10 - DAY FLOW (Unit : PERCENT)

PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1-10	1.7	2.1	2.2	3.4	4.6	7.8	19.5	80.8	85.5	31.3	9.7	3.4
11-20	1.7	2.0	2.3	3.9	5.1	10.7	35.4	88.9	60.9	26.2	5.5	3.1
21-END	1.9	2.1	2.8	4.5	5.2	13.1	54.1	100.0	44.4	20.9	4.0	3.5

SEDIMENT LOAD OF BLUE NILE (Unit : M. tons /day)

PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1-10							0.45	3.20	1.90	0.20		
11-20							1.20	3.20	0.90			
21-END						0.20	2.30	2.50	0.40			

Table 6.1 HISTOGRAM OF OUTBREAK PERIOD OF MALARIA

	Hurga		Nur El Din		Gezira	
Month	Nos.*1	%*2	Nos.*1	%*2	Nos.*1	%*2
Jun	3	2%	0	0%	7	5%
Jul	26	17%	8	7%	12	8%
Aug	43	28%	33	28%	20	14%
Sep	46	30%	32	27%	25	17%
Oct	20	13%	27	23%	22	15%
Nov	11	7%	10	8%	8	5%
Dec	1	1%	7	6%	6	4%
Jan	2	1%	2	2%	4	3%
Feb	2	1%	0	0%	6	4%
Mar	0	0%	1	1%	9	6%
Apr	0	0%	0	0%	12	8%
May	0	0%	0	0%	16	11%
Total	154		120		147	

*1: Nos. of answer (Question: When is the outbreak period of malaria? "more than two answers accepted")
*2: Denometer is total nos of answers.

FIGURES

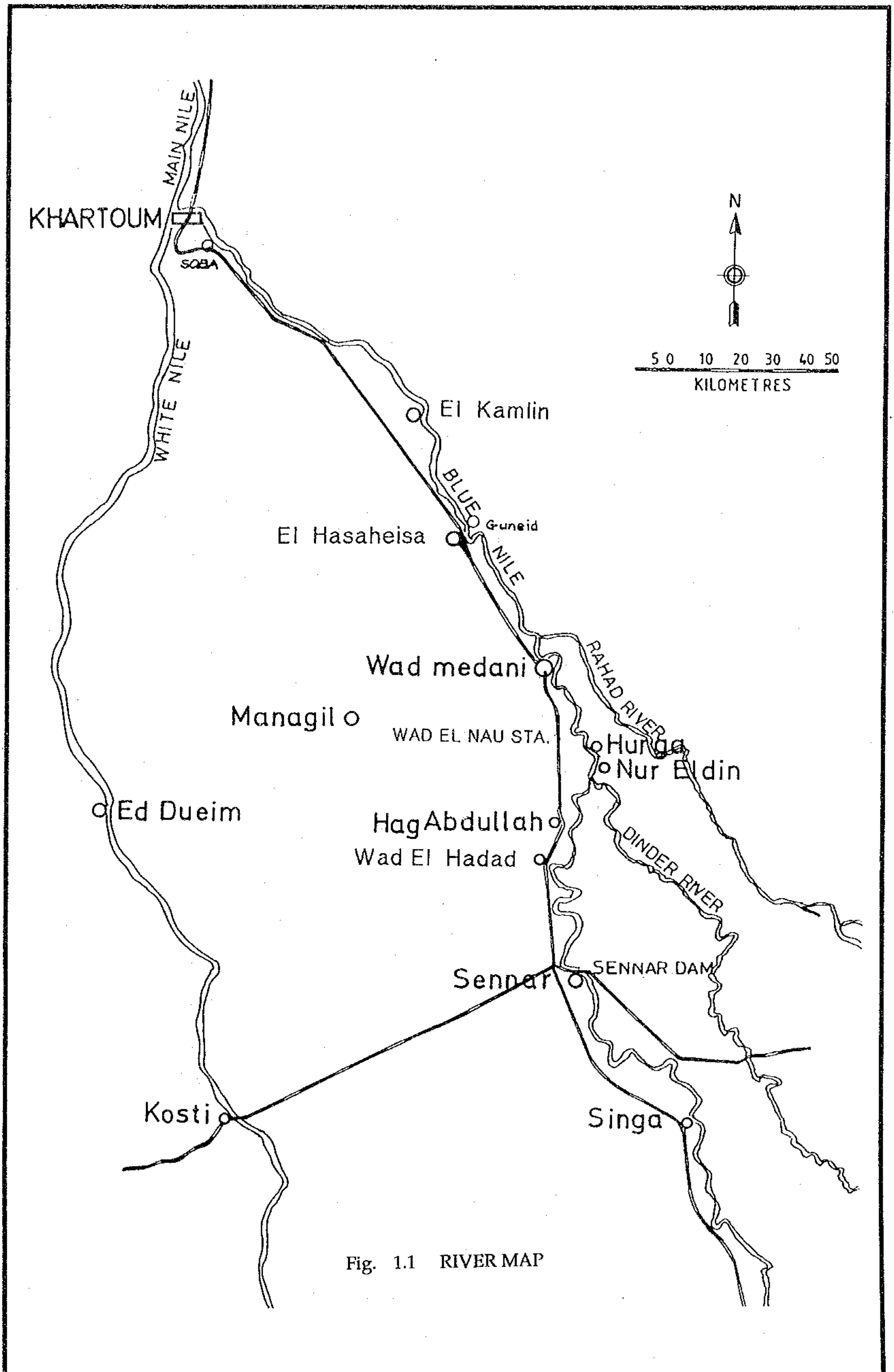
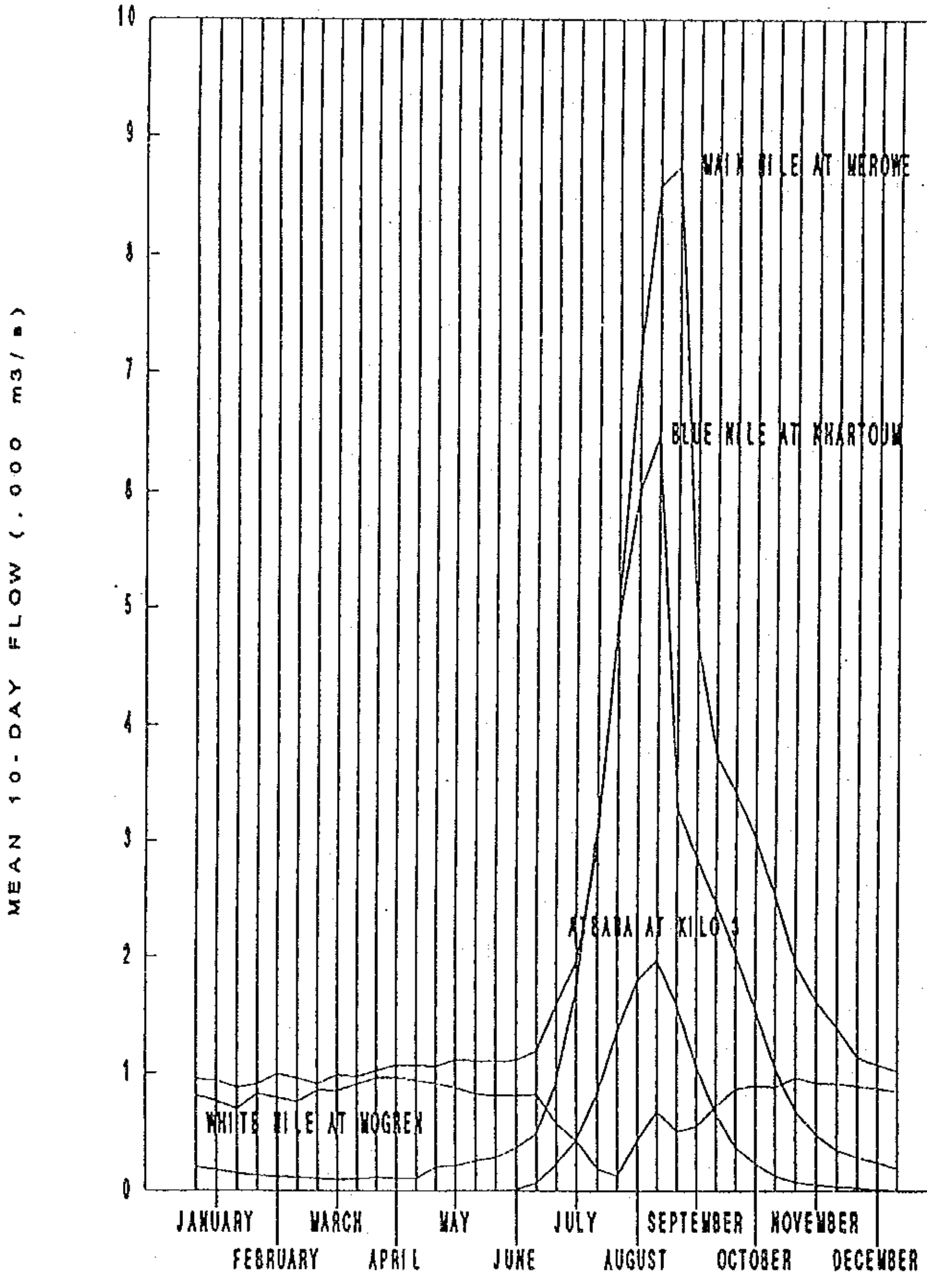
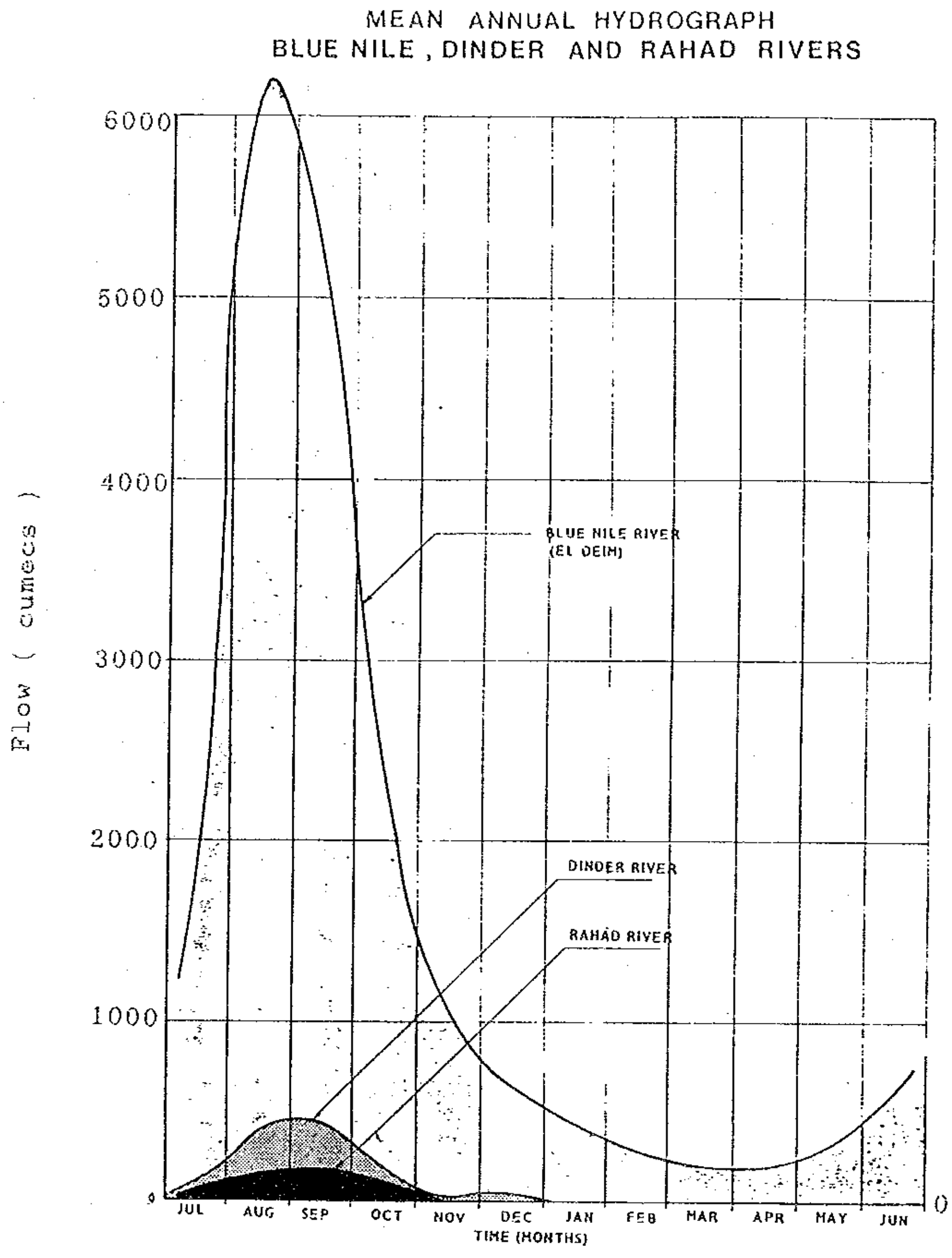


Fig. 1.1 RIVER MAP



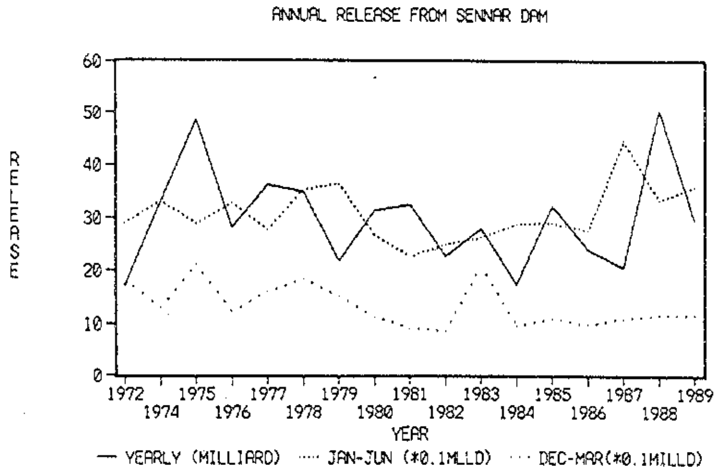
Source : Ministry of Irrigation

Fig. 3.1 FLOW DATABASE HYDROGRAPHS



Source : Blue Nile Waters Study, 1978

Fig. 3.2 MEAN ANNUAL HYDROGRAPH (BLUE NILE, DINDER AND RAHAD RIVER)



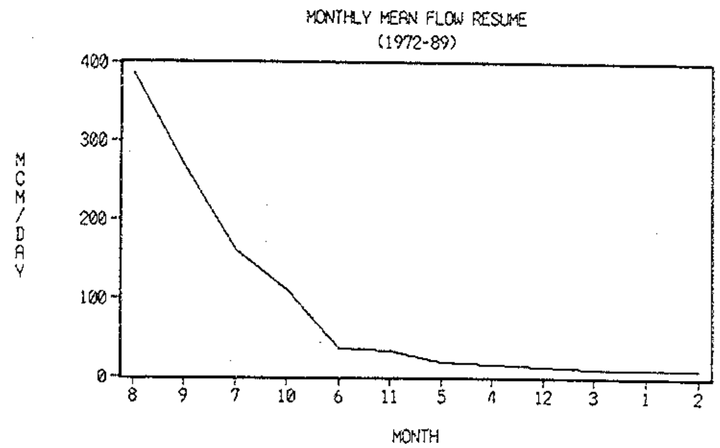
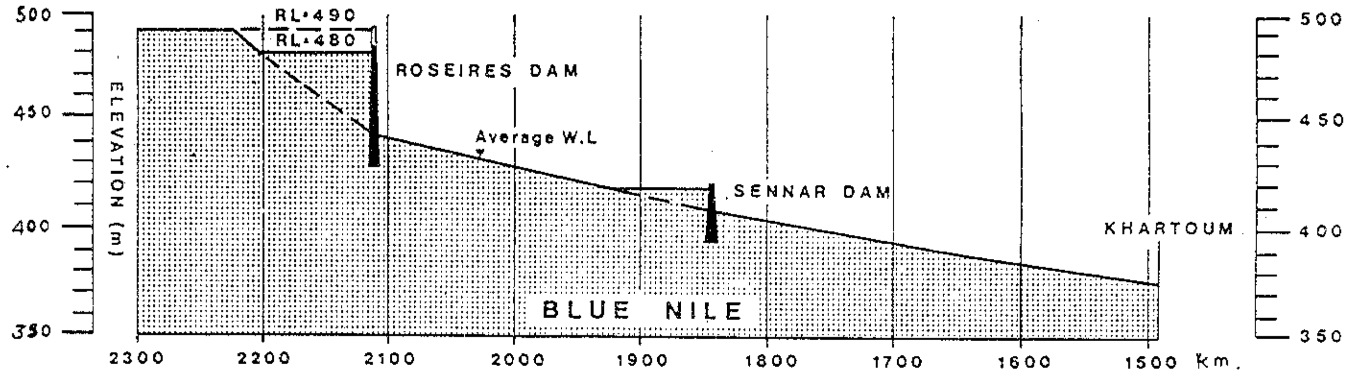


Fig. 3.3 MEAN MONTHLY DISCHARGE AT SENNAR DAM (MCM /DAY)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEARLY TOTAL MD	JAN-JUN TOTAL 0.1MD	DEC-MAR TOTAL 0.1MD
1972	24.28	14.67	11.78	14.17	9.81	20.55	107.31	263.59	99.86	55.82	14.79	9.39	17.0	28.7	18.2
1974	14.73	7.38	10.13	10.63	16.49	50.16	198.26	410.75	304.21	113.85	37.05	9.87	33.0	33.1	12.8
1975	9.99	13.80	21.74	14.98	12.34	22.24	205.64	534.30	604.59	155.91	64.13	23.79	48.6	28.7	21.1
1976	10.18	7.62	9.27	13.84	22.88	44.40	150.94	381.55	223.85	93.28	51.60	13.07	28.1	32.7	12.2
1977	7.51	9.61	10.44	14.82	12.78	37.02	219.50	438.61	273.51	139.57	87.42	24.61	36.3	27.8	15.9
1978	16.19	13.97	10.23	18.70	20.85	37.27	193.84	405.00	300.80	172.52	48.43	20.45	35.1	35.4	18.4
1979	15.32	13.29	10.61	16.00	28.48	37.10	127.13	261.40	193.33	88.13	22.00	10.32	21.6	36.5	15.0
1980	9.58	8.94	10.39	16.33	20.23	22.37	198.69	472.28	237.37	81.58	21.44	8.19	31.4	26.6	11.2
1981	7.00	8.00	7.74	13.33	18.97	20.00	140.61	462.42	330.33	95.32	23.00	7.65	32.5	22.7	9.2
1982	6.65	6.36	6.00	20.33	18.97	23.67	104.71	315.23	153.33	132.04	20.67	9.61	22.7	24.8	8.7
1983	7.00	7.36	8.35	16.67	22.39	24.67	82.94	375.48	250.33	120.39	31.00	44.90	27.8	26.2	20.7
1984	7.00	7.00	11.65	15.00	14.65	40.33	154.74	227.84	125.00	45.06	5.51	5.46	17.4	28.9	9.4
1985	6.75	12.07	9.11	10.93	22.33	34.68	143.24	431.90	385.12	66.71	20.46	8.28	32.4	28.9	10.9
1986	8.35	8.88	9.63	16.26	16.63	30.99	175.04	307.53	198.14	76.57	11.10	5.53	23.8	27.4	9.8
1987	9.35	10.94	9.37	13.19	19.96	85.40	112.51	302.85	121.54	89.88	28.00	6.59	20.4	44.6	10.9
1988	5.46	6.53	11.20	19.74	19.21	48.48	231.80	615.39	496.29	231.54	61.22	14.43	50.6	33.4	11.5
1989	7.33	6.72	11.85	21.66	29.74	41.28	170.22	357.35	268.25	123.16	28.80	11.97	29.5	35.9	11.5
AVERAGE	10.16	9.60	10.56	15.68	19.22	36.51	159.83	386.09	268.58	110.67	33.92	13.77	29.9	30.7	13.4

(MD:Milliard/year)



Source : Blue Nile Waters Study, 1978

Fig. 3.4 RIVER PROFILE SECTION OF BLUE NILE

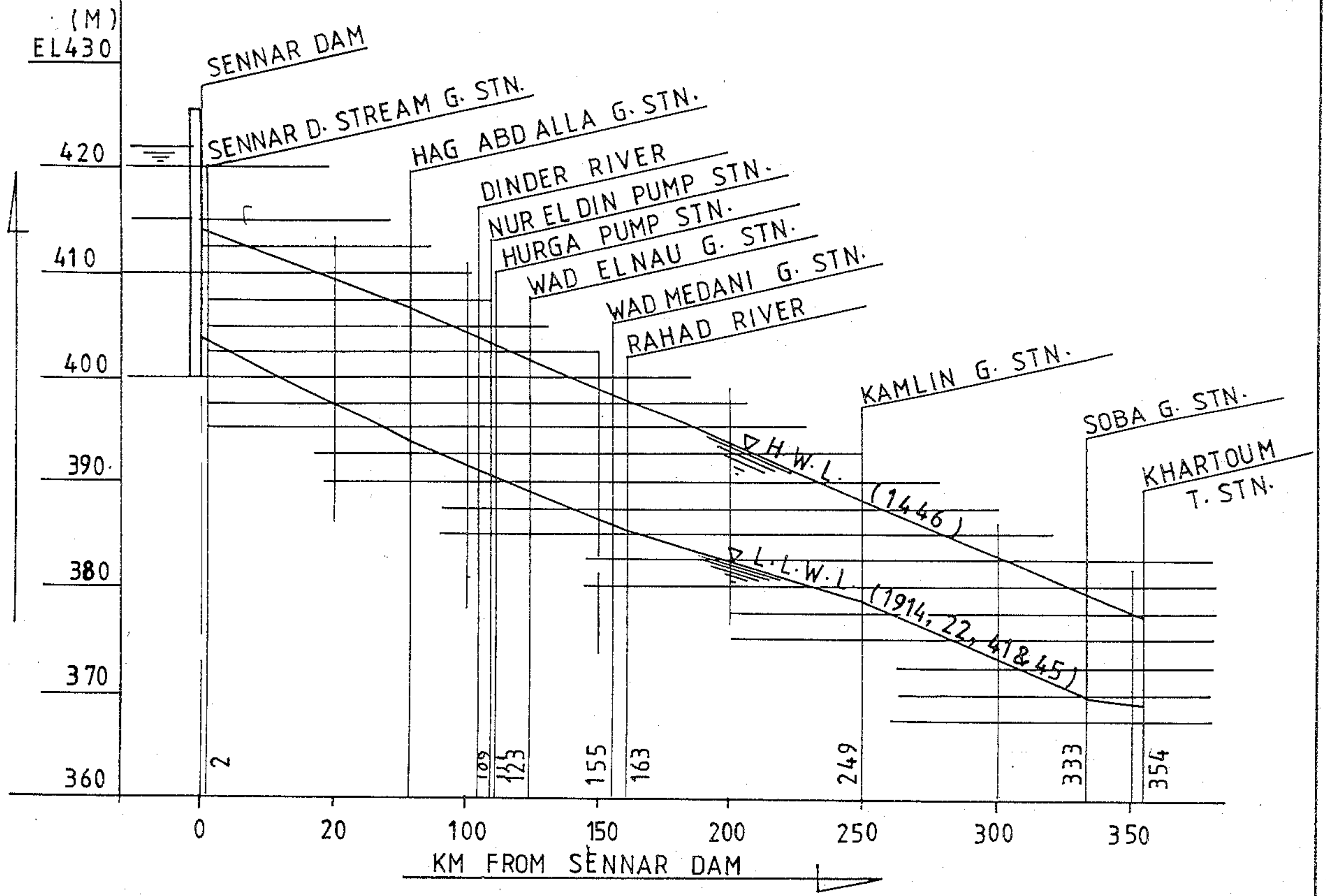
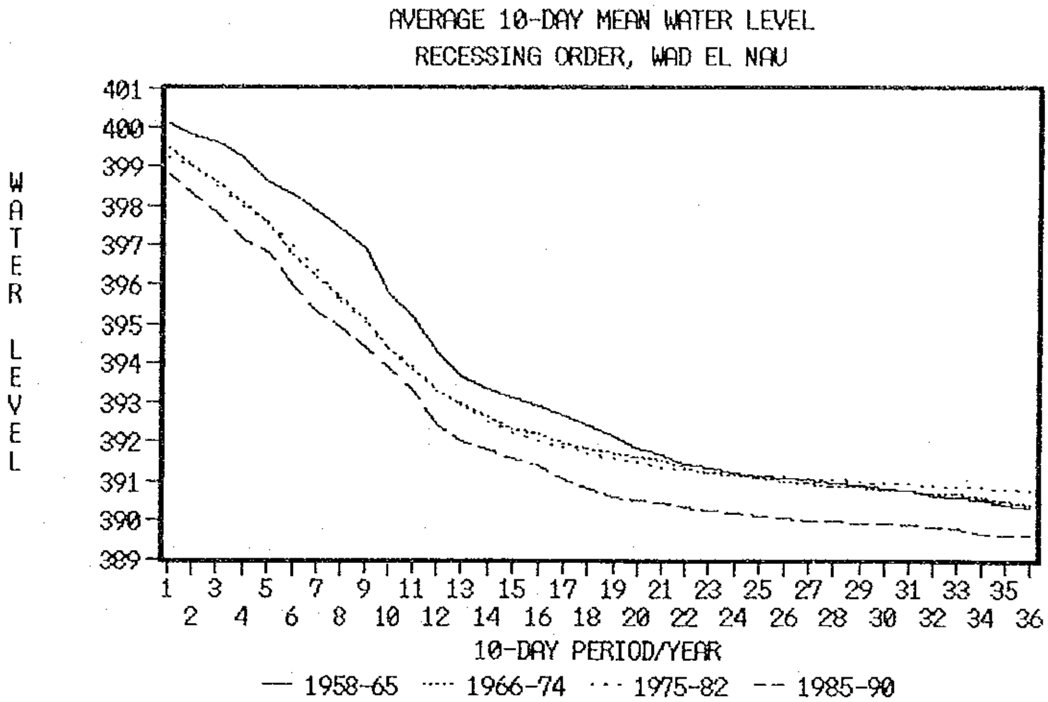


Fig. 3.5 MAXIMUM AND MINIMUM WATER LEVEL

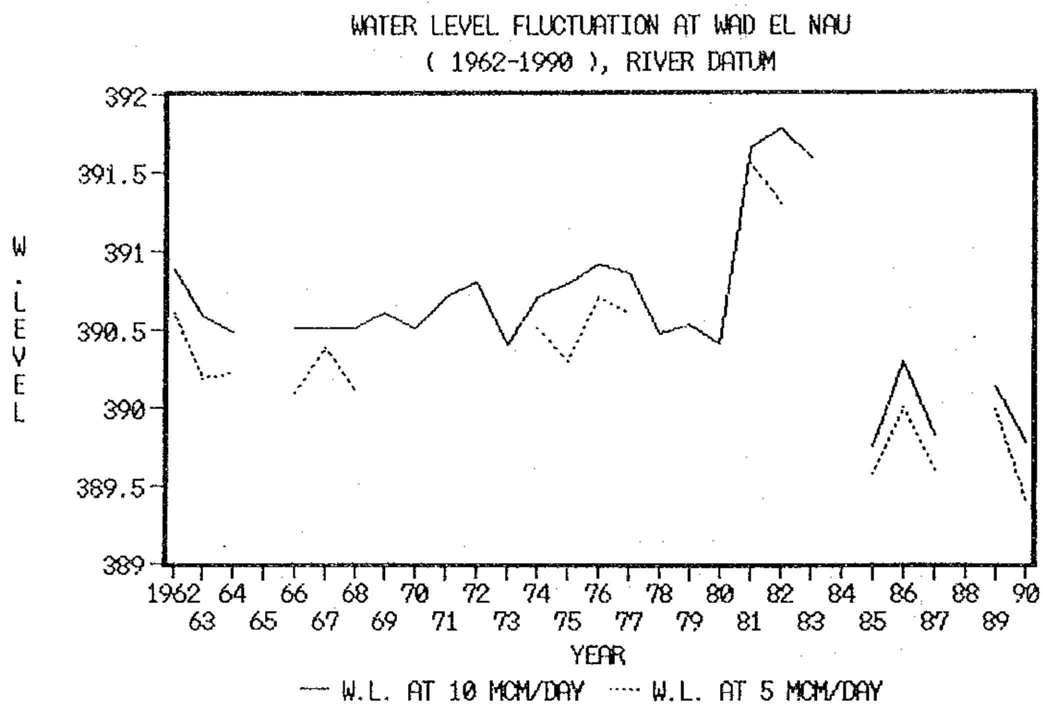


AVERAGE 10-DAY MEAN WATER LEVEL
RIVER DATUM (RECESSING ORDER)

10-DAY	1958-65	66-74	75-82	85-90	10-DAY	1958-65	66-74	75-82	85-90
1	400.06	399.45	399.23	398.77	20	391.83	391.60	391.47	390.51
2	399.82	399.03	399.00	398.30	21	391.64	391.50	391.37	390.45
3	399.64	398.62	398.52	397.80	22	391.45	391.36	391.29	390.35
4	399.22	398.07	398.00	397.14	23	391.34	391.22	391.23	390.23
5	398.61	397.55	397.58	396.82	24	391.20	391.16	391.18	390.20
6	398.31	396.76	396.97	395.96	25	391.11	391.07	391.14	390.11
7	397.85	396.19	396.36	395.27	26	391.08	390.99	391.12	390.05
8	397.39	395.65	395.57	394.88	27	391.03	390.93	391.10	389.99
9	396.90	395.11	395.03	394.42	28	390.97	390.87	391.02	389.97
10	395.79	394.36	394.35	393.86	29	390.92	390.85	390.99	389.95
11	395.14	393.81	393.94	393.32	30	390.84	390.79	390.95	389.92
12	394.28	393.29	393.31	392.41	31	390.76	390.76	390.93	389.90
13	393.66	392.93	392.96	392.00	32	390.65	390.70	390.89	389.86
14	393.34	392.62	392.52	391.80	33	390.61	390.67	390.86	389.82
15	393.12	392.34	392.24	391.58	34	390.54	390.61	390.84	389.65
16	392.88	392.21	392.03	391.37	35	390.44	390.51	390.80	389.61
17	392.66	391.95	391.89	391.03	36	390.34	390.40	390.78	389.61
18	392.42	391.84	391.71	390.81					
19	392.16	391.70	391.58	390.59	AVERAGE	393.61	393.04	393.08	392.18

Note: Based on Irrigation Datum

Fig. 3.6 AVERAGE 10-DAY MEAN WATER LEVEL AT WAD EL NAU



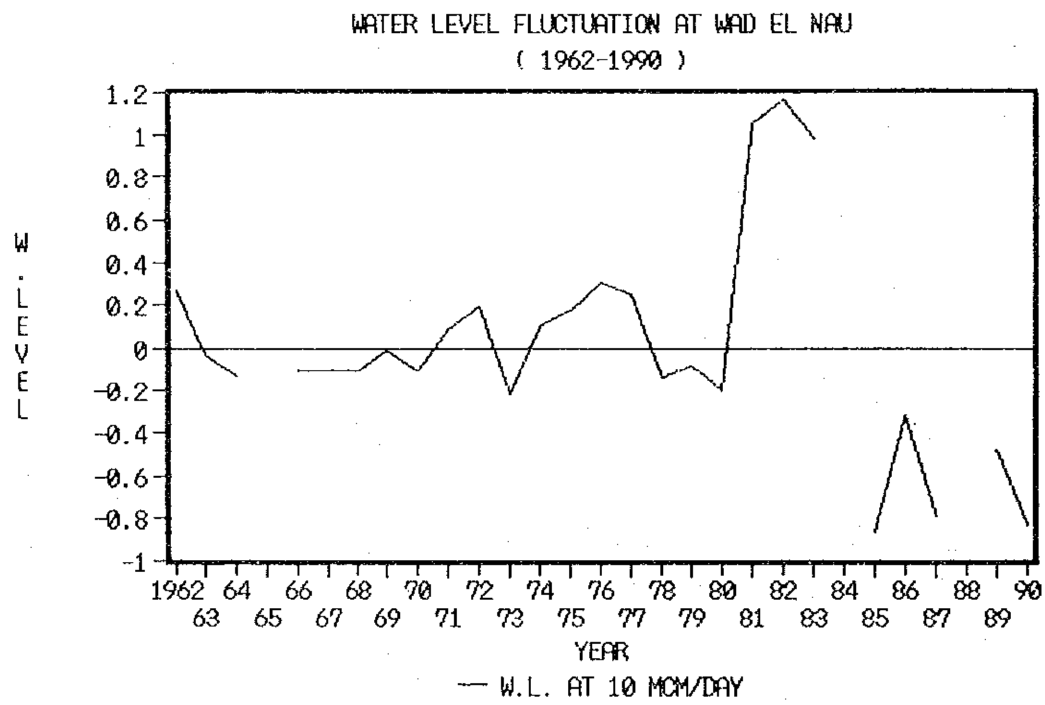
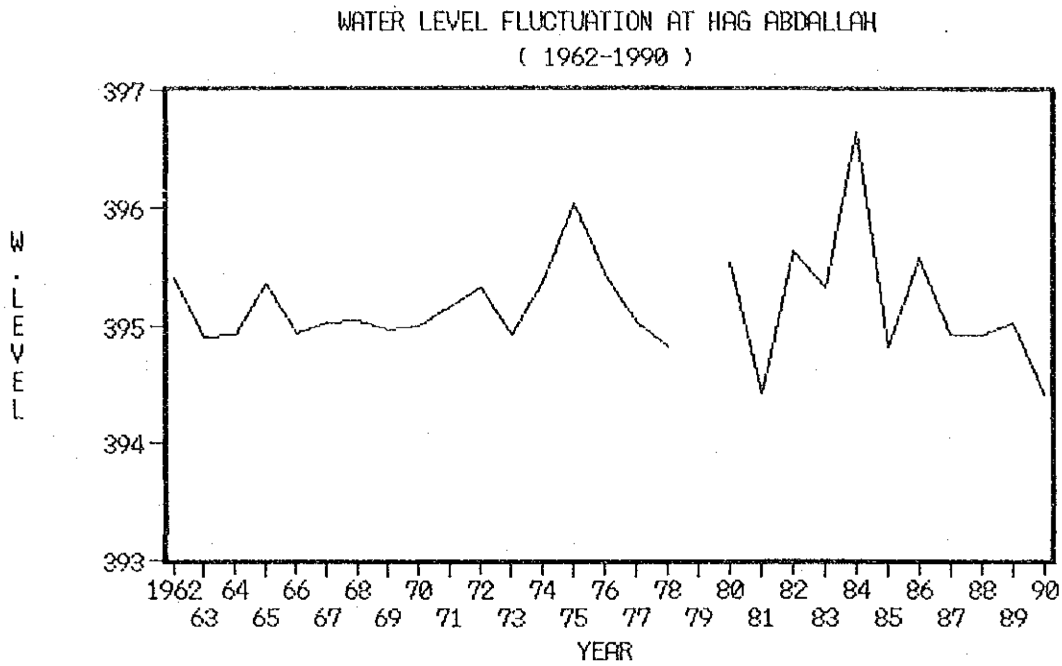


Fig. 3.7 WATER LEVEL FLUCTUATION AT WAD EL NAU



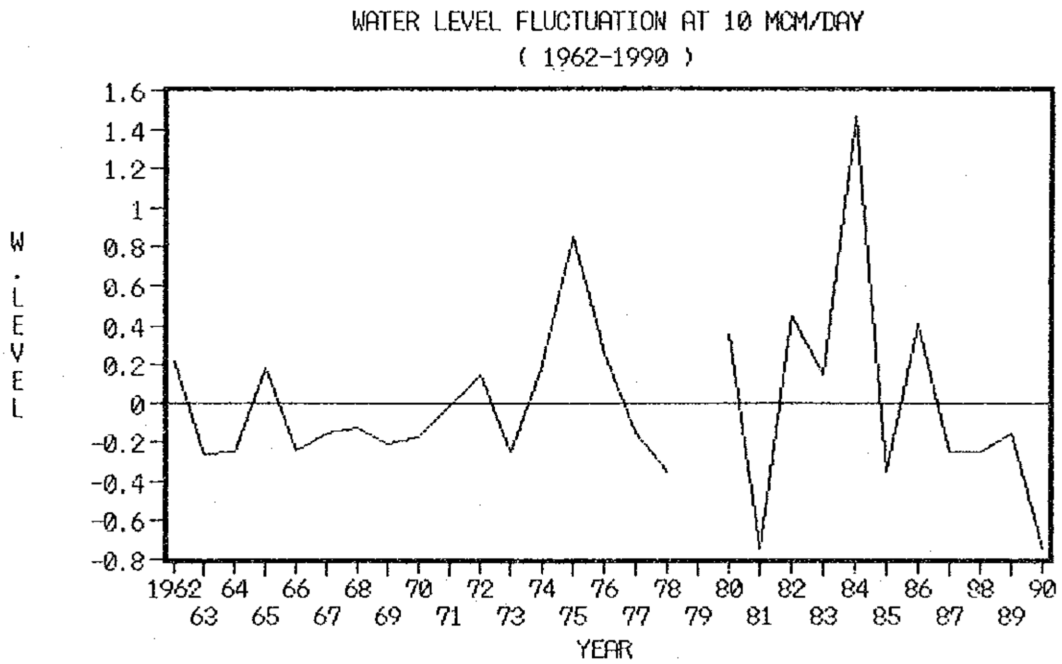
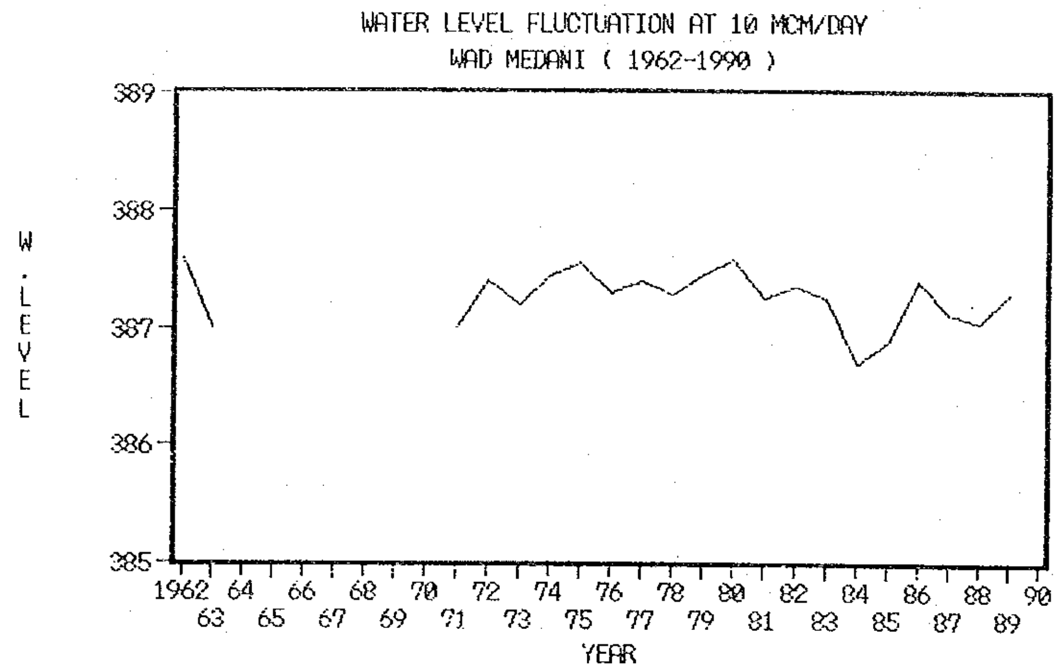


Fig. 3.8 WATER LEVEL FLUCTUATION AT HAG ABDALLAH



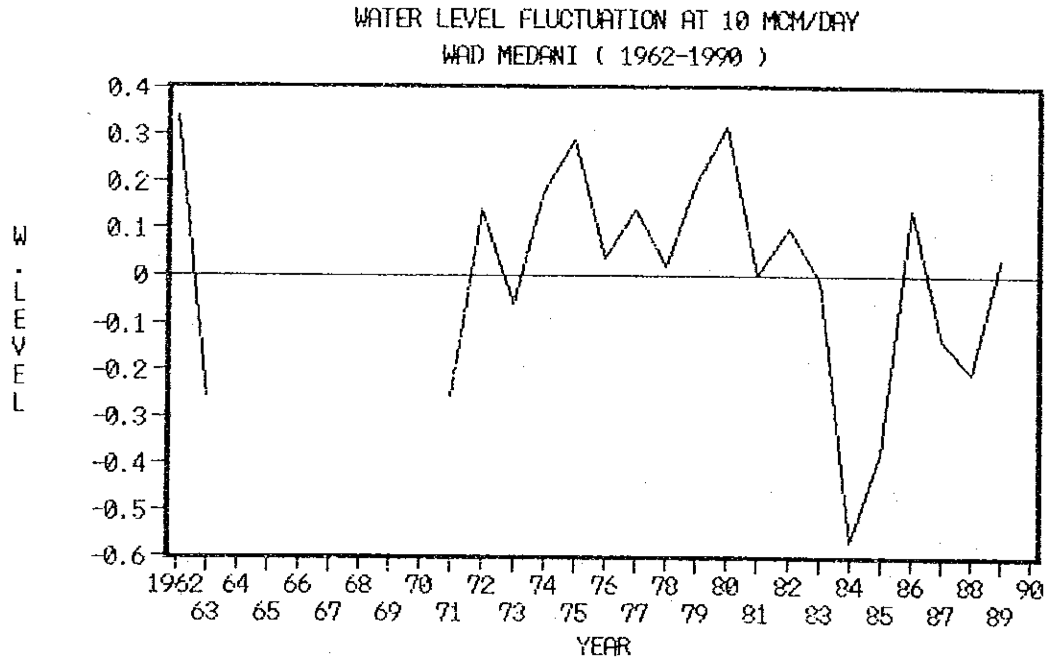


Fig. 3.9 WATER LEVEL FLUCTUATION AT WAD MEDANI

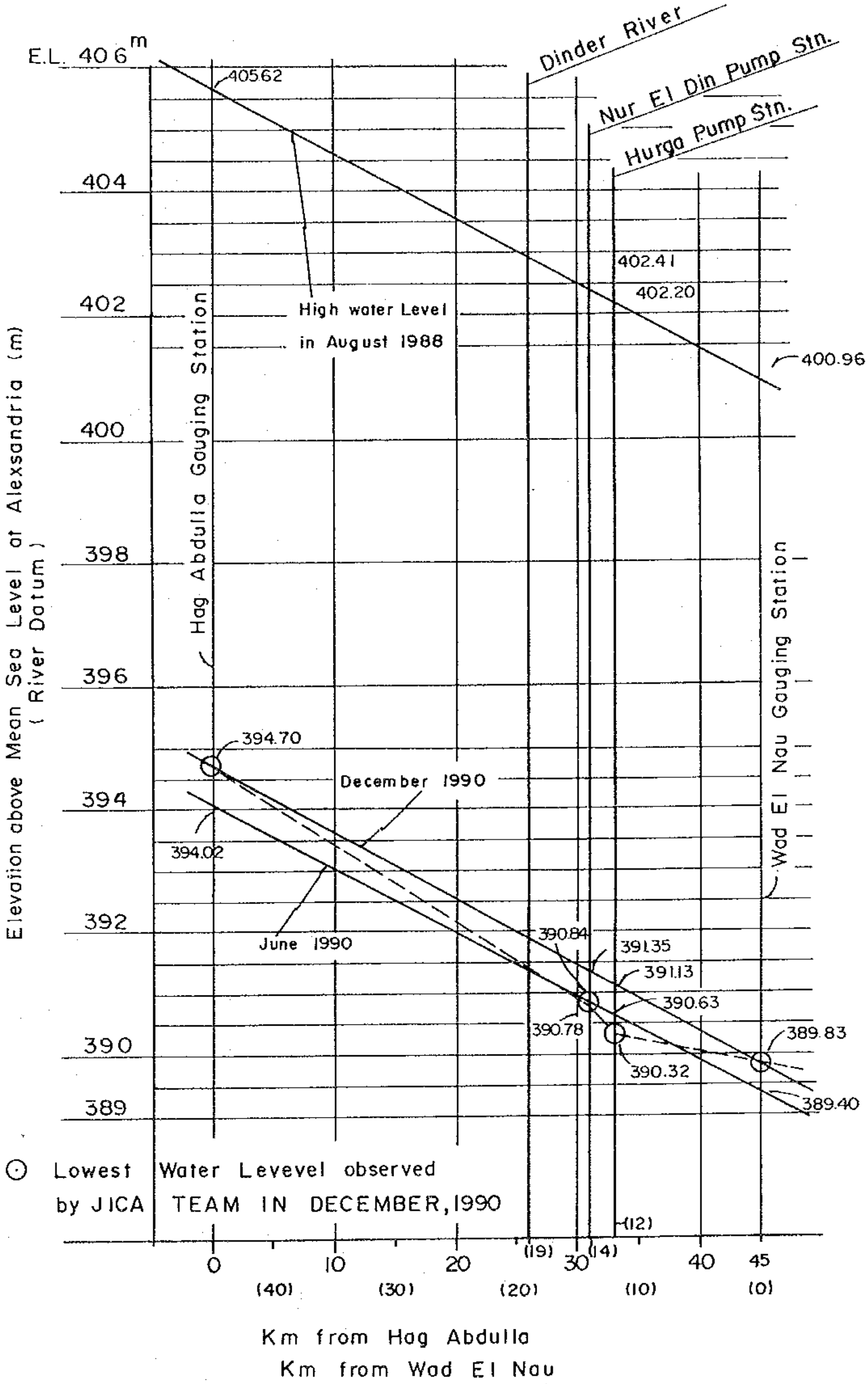
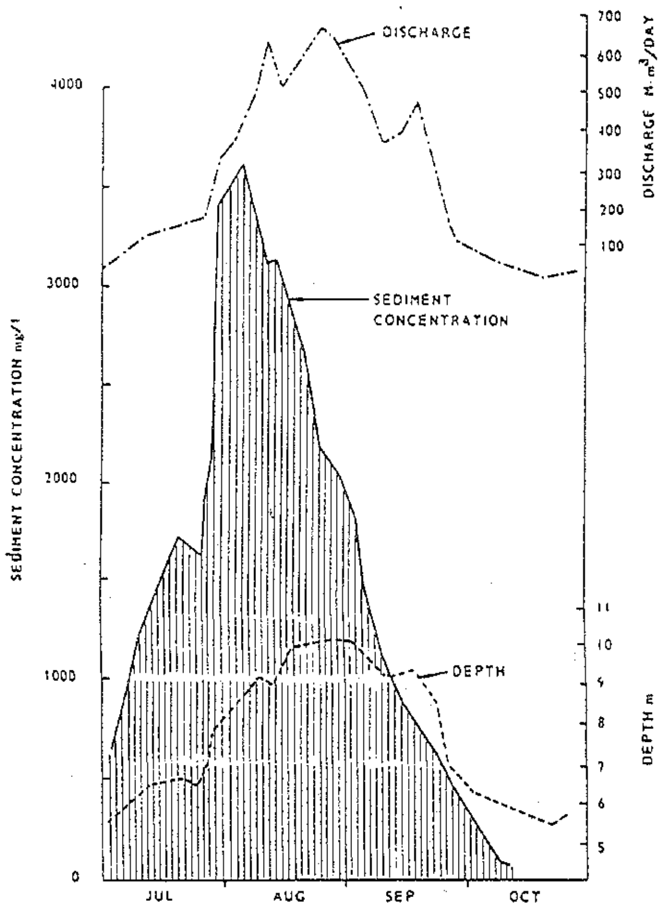
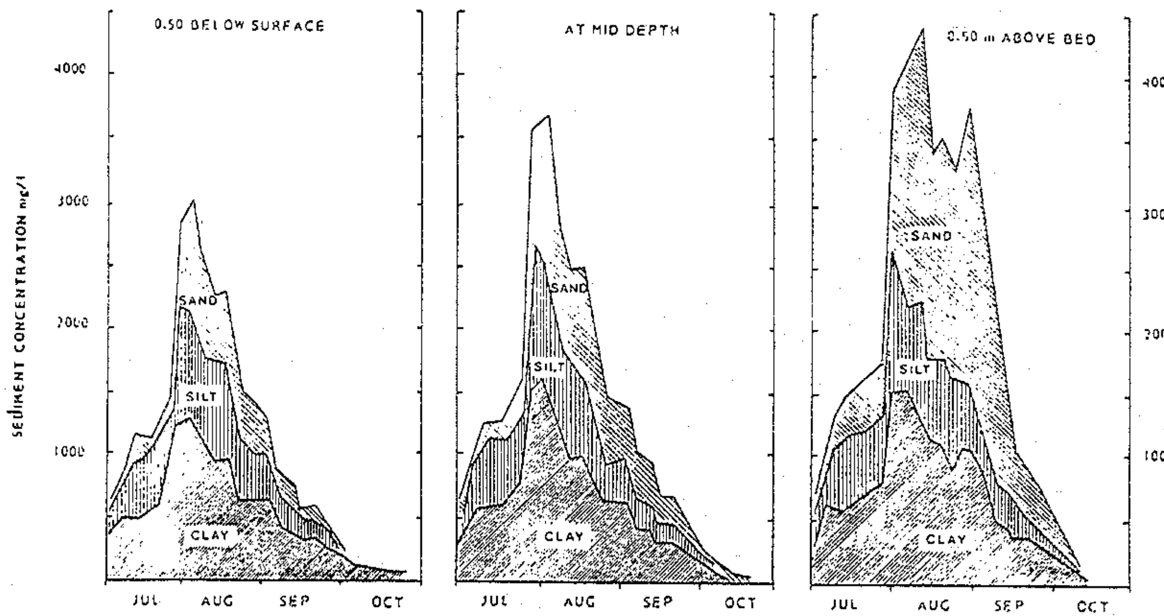


Fig. 3.10 HIGH WATER LEVEL AND LOW WATER LEVEL

BLUE NILE AT KHARTOUM 1969 FLOOD



PARTICLE SIZE DISTRIBUTION OF SEDIMENT BLUE NILE AT KHARTOUM 1969 FLOOD



PARTICLE SIZE RANGE

SAND	0.07	TO	0.2 mm
SILT	0.002	TO	0.02 mm
CLAY	LESS THAN 0.002 mm		

Source: Sediment,Transport and Deposition in the Blue Nile at Khartoum
Omer El Bedri Ali
Ph.D thesis,University of Khartoum ,1972

Fig. 5.1 BLUE NILE SEDIMENT CONCENTRATION

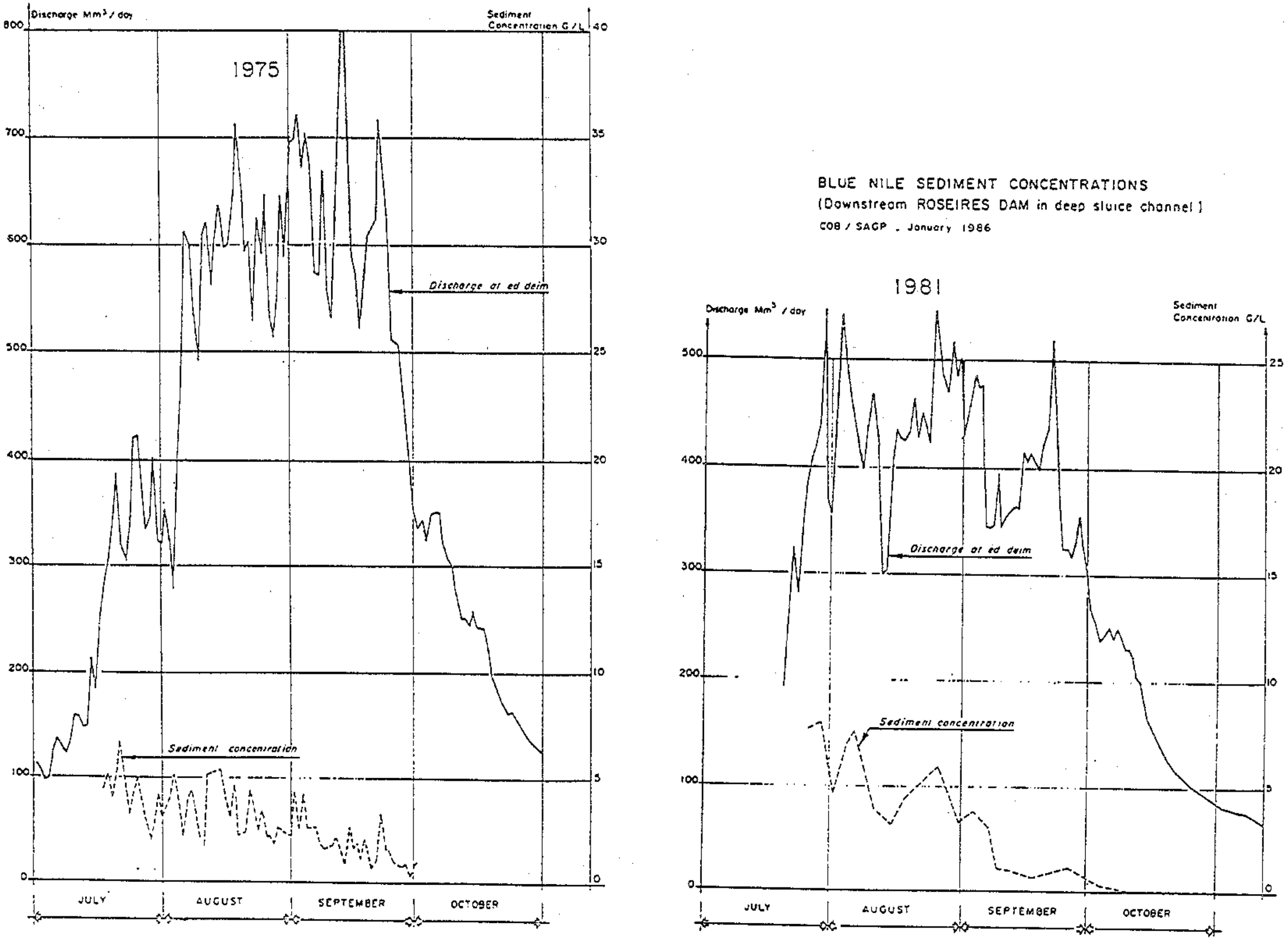


Fig. 5.2 BLUE NILE SEDIMENT CONCENTRATION