THE DEMOCRATIC REPUBLIC OF THE SUDAN
MINISTRY OF AGRICULTURE, FOOD
AND NATURAL RESOURCES

FEASIBILITY REPORT ON RICE DEVELOPMENT PROJECT IN ABU GASABA BASIN

ANNEX, VOLUME I

JUNE, 1978

JAPAN INTERNATIONAL COOPERATION AGENCY

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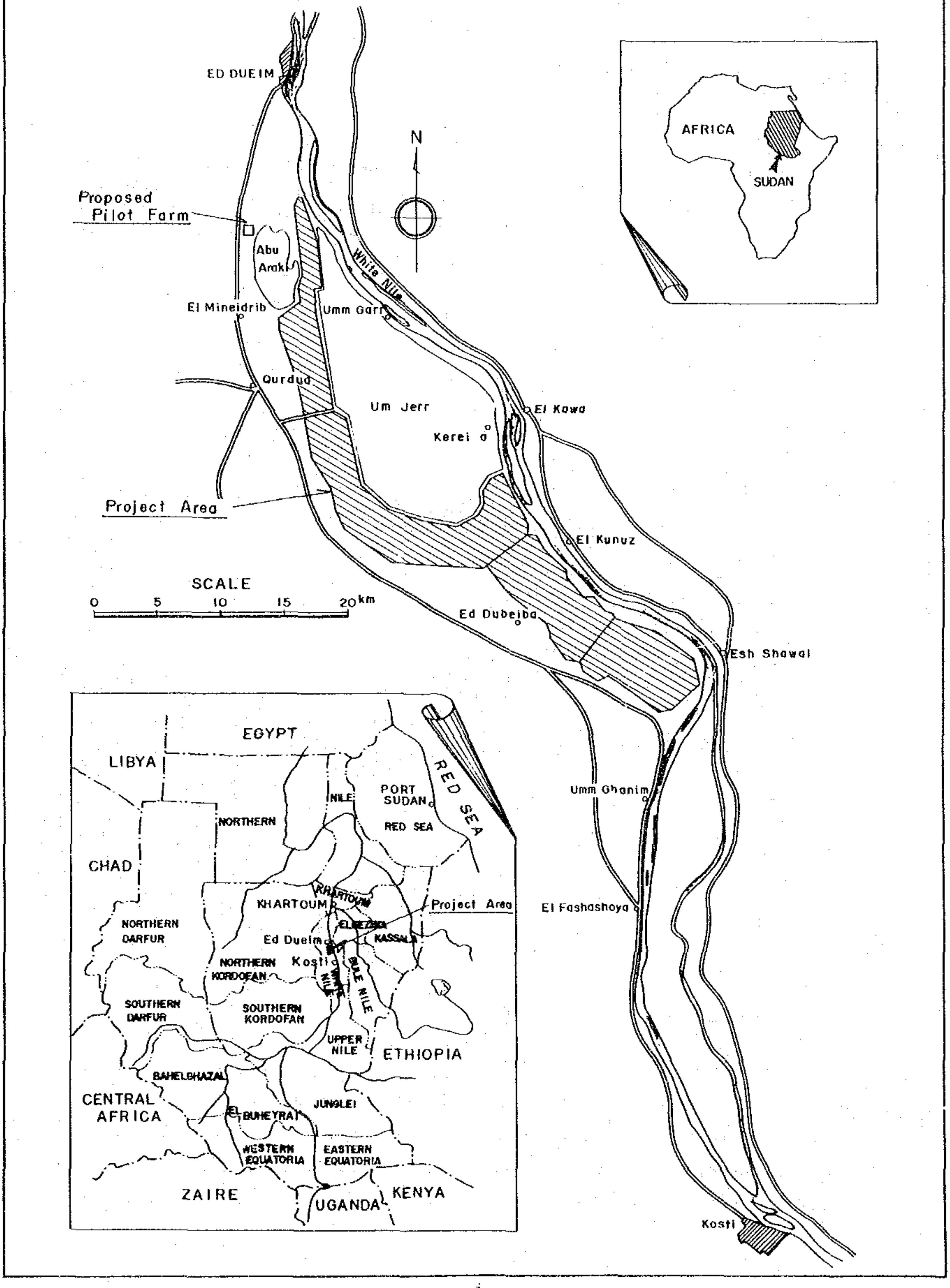
LOCATION MAP



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ABBREVIATION

km	kilometer	m	meter
cm	centimeter	mm	millimeter
t	ton	kg	kilogramme
g	gramme	km^2	square kilometer
m^2	square meter	ha	hectare
fedds	feddans	m^3	cubic meter
kℓ	kiloliter	gal.	gallon
ℓ	liter	m^3/sec	cubic meter per second
m^3/day	cubic meter per day	ℓ/sec	liter per second
ℓ/sec/ha	liter per second per hectare	t/ha	ton per hectare
t/m^2	ton per square meter	ℓ/ha	liter per hectare
kg/ha	kilogramme per hectare	kg/cm^2	kilogramme per square meter
t/hr	ton per hour	m/sec	meter per second
cm/sec	centimeter per second	t/m^3	ton per cubic meter
hr(s)	hour(s)	mm/day	millimeter per day
kW	kilowatt	kVA	kilovolt ampere
pH	potential of Hydrogen	ppm	part per million
^{o}C	degree centigrade	%	percent
o	degree of angle	EL.	Elevation above mean sea level
ft	feet	MSL	Mean Sea Level
PS	horse power	No(s)	Number(s)
L.S.	Lump Sum	US$	U.S. dollar
£s	Sudan pound	Fig.	Figure
IRR	Internal Rate of Return	O & M	Operation and Maintenance
GDP	Gross Domestic Product	GNP	Gross National Product
JICA	Japan International Cooperation Agency		
FAO	Food and Agriculture Organization of the United Nations		
IBRD	International Bank for Reconstruction and Development		
C.I.F.	Cost, Insurance and Freight		
F.O.B.	Free on Board		
H.E.E.	Hydroelectricity and Energy		

CONVERSION TABLE OF MEASURES

1 mile = 1.609 km	1 yard = 0.914 m
1 foot = 0.305 m	1 gallon = 4.546 ℓ
1 feddan = 0.42 ha	

CURRENCY EQUIVALENT

£s 1 = US$ 2.55	US$ 1 = £s 0.39
£s 1 = ¥ 689	US$ 1 = ¥ 270

ANNEX I.

TOPOGRAPHIC SURVEY

ANNEX I

TOPOGRAPHIC SURVEY

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I. TOPOGRAPHIC SURVEY

1.1 Available Data on Topographic Survey

A map of a scale of 1/50,000 prepared by the Egyptian Authorities and aerial-photos of scales of 1/25,000 and 1/50,000 taken recently were provided by the Survey Department, Ministry of Diffence, which cover the entire surveyed area.

The data on the bench marks in and around the surveyed area were furnished by the said Department as well. Each bench mark as shown in Fig. 1.1, was confirmed in the field. The following bench marks were utilized in the topographic survey.

No. of B.M.	Location	Elevation (m) above MSL
B.M. - No. 1	N13° - 45'S E32° - 22'W	377.155
B.M. - No. 2	N13° - 46'S E32° - 28'W	379.753
B.M. - No. 3	N13° - 49'S E32° - 22'W	377.934

Source: Survey Office in Ed-Dueim

1.2 Topographic Survey

1.2.1 Checking the Existing Topographic Map

A topographic survey was carried out to check the existing topographic maps of 1/50,000 in scale with 1-m contour intervals prepared in 1935. Then the topographic maps of 1/50,000 scale with 0.5 m contour intervals were prepared newly which covered the whole Abu Gasaba area of about 20,000 ha. For this purpose the following field surveys were carried out.

- Traverse survey over a distance of about 110 km in total along the boundary of the project area.

- Levelling survey along the above traverse route,

- Levelling survey of cross section with an interval of 100 m along the traverse route.

Arbitrary coordinates of traverse line were established. Accuracy of the levelling was so determined that the difference of surveyed values incurred through repetitions should be kept within $\pm \sqrt{S}$ km (S = distance of levelling in km). At any section where the difference of the values obtained had exceeded this limit, resurvey was carried out to keep the difference within the limit specified.

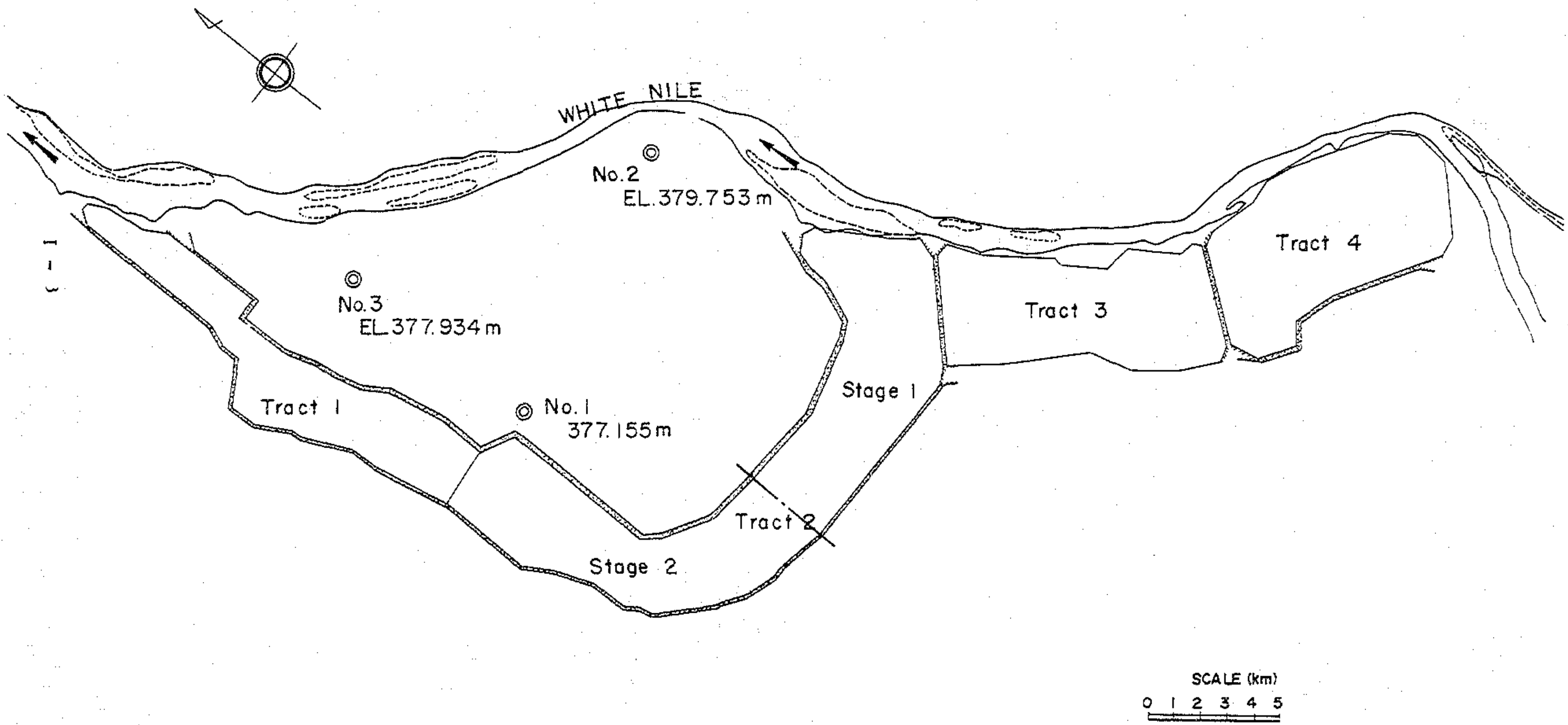
1.2.2 Topographic Maps for Major Structure Sites

The plane survey for the proposed sites for major structures was carried out. Topographic maps on a scale of 1/500 with 0.1-m contour intervals were prepared for design of the related structures for irrigation and drainage system. Total area covered by the maps prepared amounted to about 10 ha.

1.2.3 Surveys for Proposed Pilot Farm Site

The plane survey of the proposed site for the pilot farm was carried out and a topographic map on a scale of 1/5,000 with 0.25-m contour intervals was prepared, covering an area of about 300 ha. In addition, profile and cross section surveys of inlet channel from the White Nile to the proposed pumping site for the pilot farm were carried out.

Fig. 1.1 Location and Elevation of Bench Marks



ANNEX II

METEOROLOGY

ANNEX II

METEOROLOGY

II. METEOROLOGY

2.1 General

The Sudan has a tropical continental climate, except for a narrow fringe along the Red Sea coast where maritime climate generally prevails. The climate is governed mostly by the seasonaly winds, namely, (a) the dry north wind which prevails throughout the year but lacks uniformity, and (b) the moist south wind of maritime origin.

Based on the amount of rainfall which determines the density of vegetation, the country is divided broadly into three major zones/1. (Refer to Table 2.1)

- the northern light-rainfall zone, with an average annual rainfall varying from 0 mm to 400 mm covering about one-third of the country.

- the central savannah zone, which extends from latitude 15°N to 10°N, has an average annual rainfall varying from 400 mm to 750 mm. This zone covers about one half of the country.

- the southern zone of heavy rainfall, with an average annual rainfall varying from 750 mm to 1,500 mm. This zone covers about one-sixth of the country.

The Abu Gasaba area is located in the northern light-rainfall zone. The climate is notable for high temperature and low humidity.

The climate can be broadly divided into three seasons, the dry winter, dry summer and wet summer. The dry winter lasts three months from December to February which is characterized by low temperature and low humidity. The wet summer from July to September on which about 83 % of the annual rainfall is concentrated is characterized by high temperature and high humidity, while the dry summer from March to November (excluding July, August and September) is characterized by high temperature and low himidity.

/1 LAND AND WATER DEVELOPMENT AND USE
Prospective study of agricultural development for the Democratic Republic of the Sudan, F.A.O., ROME, April, 1973.

Meteorological data relevant to the Abu Gasaba area are represented by those recorded at Dueim station (Lat. 13-59'N, Long. 32-20'E, Alt. 380 m) and Kosti station (Lat. 13-10'N, Long. 32-40'E, Alt. 380 m).

2.2 Summary of Relevant Data

The data obtained are the following:

Kosti station (Lat. 13°10'N, Long. 32°40'E, Alt. 380 m)

- Monthly mean air temperature 1941 - 1975 (35 years)
- Monthly mean relative humidity - do.-
- Monthly mean sunshine hours 1941 - 1970 (10 years)
- Monthly mean wind speed - do.-
- Prevailing direction - do.-
- Monthly mean Piche evaporation 1941 - 1975 (35 years)
- Monthly mean rainfall - do.-

Ed-Dueim station (Lat. 13°59IN, Long. 32°20'E, Alt. 380 m)

- Monthly mean air temperature 1941 - 1970 (30 years)
- Monthly mean relative humidity - do.-
- Monthly mean wind speed - do.-
- Prevailing direction 1941 - 1970 (10 years)
- Monthly mean Piche evaporation 1941 - 1970 (30 years)
- Monthly mean rainfall 1902 - 1975 (74 years)
- Daily rainfall - do.-

El-Obeid station (Lat. 13°10'N, Long. 30°14'E, Alt. 570 m)

- Monthly mean air temperature 1941 - 1970 (30 years)
- Monthly mean relative humidity - do.-
- Monthly mean sunshine hours 1941 - 1970 (10 years)
- Monthly mean wind speed - do.-
- Prevailing direction - do.-
- Monthly mean Piche evaporation 1941 - 1970 (30 years)
- Monthly mean rainfall - do.-

Wad-Medani station (Lat. 14°23'N, Long. 33°29'E, Alt. 405 m)

- Monthly mean air temperature	1941 - 1970 (30 years)
- Monthly mean relative himidity	1941 - 1970 (30 years)
- Monthly mean sunshine hours	- do.-
- Monthly mean wind speed	1941 - 1970 (10 years)
- Prevailing direction	- do.-
- Monthly mean Piche evaporation	1941 - 1970 (30 years)
- Monthly mean rainfall	- do.-
- Monthly mean total radiation	1957 - 1976 (19 years)

Shambat (Khartoum) station (Lat. 15°40'N, Long. 32°32'E, Alt. 380 m)

- Monthly mean total radiation	1957 - 1976 (19 years)

Main features of the climate in Ed Dueim and Kosti are shown in Table 2.2 and Table 2.3. Detailed records are tabulated in Annex XXI. Because no daily rainfall records are obtainable at the Kosti station, the rainfall data obtained at the Ed Dueim station are used for the meteorological study in the project area.

2.3 Air Temperature

The general trend of seasonal variation is characterized by its sharp variation in Ed Dueim and in Kosti. There exist two peaks in seasonal variation, one in May and the other in October. The monthly mean temperature is about 29°C on an annual average at the Kosti station. It rises to the highest in May to about 33°C, whereas it falls to the lowest in January to about 25°C. The maximum monthly mean temperature during the summer season ranges from 33°C to 41°C, while the minimum from 20°C to 25°C. During the winter the maximum monthly mean temperature varies from 33°C to 35°C and the minimum from 17°C to 18°C.

2.4 Relative Humidity

As a general trend of seasonal variation in Ed Dueim and in Kosti, the relative himidity rises sharply from May, attains the maximum in August, falls sharply till November and after that drops gradually to the lowest in April. Generally, the relative humidity at the Ed Dueim station is higher than at the Kosti station throughout the year, though the difference is about 2 % or 3 %. The monthly mean relative humidity at the Kosti station ranges from 22 % to 71 % and is about 42 % on an annual average.

2.5 Wind

The wind regime in the project area is characteristically marked by the seasonal cycles. North or Northeast wind, sharply reducing the humidity, dominantly blows during the dry season whereas south or southwest wind, during the rainy season. The monthly mean wind speed ranges from 2.2 m/sec in the rainy season to 2.7 m/sec in the dry season.

2.6 Evaporation

The Piche evaporation is high in the dry season and low in the rainy season. As a trend of seasonal variation, the Piche evaporation increases sharply from August, attains the maximum in April, and decreases sharply till it reaches the minimum in August. The annual average Piche evaporation at the Kosti station is about 12 mm per day ranging from 10-18 mm per day in the dry season to about 6 mm per day in the rainy season. Annual evaporation is assumed to be about 2,590 mm equivalent to 59 % of 4,380 mm of the annual Piche evaporation.

2.7 Rainfall

The rainfall around the project area is characterized by its high intensity resulting from short duration of rainfall, usually 2 to 3 hours. Figures of the annual rainfall observed at the Ed Dueim station over 74 years widely fluctuate between 101.1 mm and 606.0 mm. The average annual rainfall is 296 mm. As general trend of seasonal variation, rainfall increases sharply from June, attains the maximum in August, and declines abruptly in October. The rainy season lasts approximately three months from July to September. About 83 % of the annual rainfall is concentrated in the rainy season, recording 39 % of the annual rainfall in August. The maximum daily rainfall recorded in 73 years at the Ed Dueim station was 101.8 mm on August 3, 1931. There are 26 rainy days a year on the average.

Table 2.1 Monthly Mean Rainfall (mm)

Station	Long.	Lat.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Wadi Halfa	31°E	22°N	-	-	-	-	-	-	2	-	-	1	-	-	3
Merowe	32°E	18°N	-	-	-	-	-	2	7	15	4	2	-	-	30
Khartoum	33°E	16°N	-	-	-	1	5	7	48	72	27	4	-	-	64
Kassala	37°E	16°N	-	-	2	5	14	27	100	124	60	7	2	-	341
EL Fasher	25°E	13°N	-	-	-	1	10	13	89	133	36	5	-	-	287
Kosti	32°E	13°N	-	-	-	4	18	47	111	143	60	22	2	-	407
EL Rosieres	35°E	12°N	-	-	-	15	60	125	183	218	153	30	5	-	789
Raga	26°E	8°N	1	1	15	56	150	165	223	254	192	78	10	1	1,146
Yubo	28°E	5°N	5	23	63	102	187	220	169	212	234	170	51	15	1,451

Source: Sudan Meteorological Service

Table 2.2 Main Features of Climate (1)

Station: ED-DUEIM

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean or (Total)
Monthly Mean Rainfall in mm /1	0	0	0	3	11	24	86	115	46	11	0	0	(296)
Numbers of Rainy Days /1	0	0	0	0	1	3	7	8	5	2	0	0	(26)
Monthly Mean Temperature /2 in °C - Maximum	32.1	33.3	37.3	40.0	41.1	39.6	36.0	34.0	35.9	37.9	35.9	32.7	36.3
Monthly Mean Temperature /2 in °C - Mean	24.3	25.2	28.6	30.9	32.7	32.0	29.7	28.4	29.3	31.6	28.3	25.0	28.7
Monthly Mean Temperature /2 in °C - Minimum	16.4	17.1	19.8	21.7	24.2	24.4	23.4	22.7	22.7	23.2	20.7	17.2	21.1
Monthly Mean Relative Humidity /2 in %	38	34	29	26	32	49	65	73	67	52	39	40	45
Monthly Mean Wind Speed in m/sec /3	1.8	2.7	2.7	2.7	2.7	2.2	2.2	2.2	2.2	1.3	1.8	1.8	2.2
Prevailing Direction /3	NE	NE	NE	NE	NE	SW	SW	SW	SW	NE	NE	NE	-
Monthly Mean Piche Evaporation /2 in mm	14.0	15.7	18.2	19.7	18.8	16.0	10.9	7.7	9.1	12.5	14.9	13.9	14.3

/1 1902 - 1975 (74 years)
/2 1941 - 1970 (29 years)
/3 1941 - 1970 (10 years)

Source: Sudan Meteorological Service

Table 2.3 Main Features of Climate (2)

Station: KOSTI

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean or(Total)
Monthly Mean Rainfall in mm /1	0	0	1	2	16	44	110	140	66	18	1	0	(398)
Numbers of Rainy Days /2	0	0	0	0	3	6	12	14	7	4	0	0	(46)
Monthly Mean Temperature /1 in °C – Maximum	32.8	34.7	37.5	40.7	40.6	38.1	34.5	32.5	34.4	37.3	36.1	33.2	36.0
Monthly Mean Temperature /1 in °C – Mean	24.7	26.1	28.8	31.7	32.8	31.5	28.9	27.5	28.5	30.1	28.5	25.3	28.7
Monthly Mean Temperature /1 in °C – Minimum	16.6	17.5	20.1	22.6	25.0	24.9	23.3	22.5	22.5	22.9	20.9	17.4	21.4
Monthly Mean Relative Humidity /1 in %	36	29	23	22	31	45	60	71	64	47	35	36	42
Monthly Mean Sunshine Hours /3 in hrs	10.3	10.5	10.1	10.3	9.9	8.5	7.2	7.0	8.3	9.6	10.3	10.4	9.4
Monthly Mean Sunshine Hours /3 in %	90	90	84	83	66	66	56	56	68	79	88	92	77
Monthly Mean Wind Speed in m/sec /3	2.7	2.7	2.7	2.2	2.2	2.7	2.7	2.2	2.2	1.8	2.7	2.7	2.7
Prevailing Direction /3	N	N	N	N	N	SSW	SSW	SSW	SSW	N	N	N	–
Monthly Mean Piche Evaporation /1 in mm	12.7	14.6	17.1	18.2	16.0	13.1	7.9	5.0	6.0	9.9	12.8	12.1	12.1

/1 1941 – 1975 (35 years)
/2 1941 – 1970 (30 years)
/3 1941 – 1970 (10 years)

Source: Sudan Meteorological Service

ANNEX III

HYDROLOGY AND WATER RESOURCE

ANNEX III

HYDROLOGY AND WATER RESOURCE

Tables

Figures

III. HYDROLOGY AND WATER RESOURCE

3.1 General Hydrology of the Nile

The general hydrology of the Nile is described in the report of the Sudan Authority./1 The hydrology of the Nile in this report is summarized as follows.

The Nile is one of the most remarkable rivers and is the second longest river in the world. The length of its course from the source to the sea is about 6,440 km. The Nile has an average annual flow of 84 milliard m^3, measured at Aswan. This flow constitutes only 6% of the total amount of rainfall in the Nile basin. The percentage contribution of the main tributaries of the Nile is as follows:-

			Run-off (milliard m^3)
Blue Nile	59%		50
River Atbara	13%		10
White Nile	28%		24
- Sobat		14%	12
- Bahr EL Jebel		14%	12

During flood time, the percentage contribution of the tributaries is as follows:-

Blue Nile	68%	
River Atbara	22%	
White Nile	10%	
- Sobat		5%
- Bahr EL Jebel		5%

The White Nile is characterised by its relatively uniform flow as compared with the Blue Nile and River Atbara. Its seasonal variation at Malakal, about 600 km upstream from ED-DUEIM, for the period of 1912-1962 ranges from 525 m^3/sec to 1,215 m^3/sec, while the average variation of the Blue Nile at Roseires for the same period ranges from 125 m^3/sec to 6,200 m^3/sec.

/1 Control and Use of the Nile Waters in the Sudan, Ministry of Irrigation & H.E.E., Khartoum, June, 1975.

The silt carried annually by the Nile is about 110 million tons as measured in Egypt. The rivers flowing from the Ethiopian Plateau, especially the Blue Nile and River Atbara, are the main source of silt in the Nile. The White Nile carries relatively less silt. This is due to the fact that most of its silt is deposited, on its way, at the lakes, swamps, and marshes through which the White Nile flows. The annual sedimentation loads at each month of the Blue Nile and River Atbara are shown below.

River	Annual Sedimentation Load	Mechanical Analysis
Blue Nile	140 million tons	Sand 45%, Silt 15%, Clay 40%
River Atbara	8 million tons	Sand 52%, Silt 15%, Clay 18%

The data on soluble salts are available at several places as shown belows:-

Lake Victoria	80 p.p.m
Victoria Nile	100
Lake Edward	670
Lake Albert	590
Lake Tana	170
Albert Nile	160
Blue Nile at Khartoum	130
White Nile at Khartoum	140
Nile at Cairo	170

The quality of water of the Blue Nile and the White Nile varies from class C1S1 /1 during the flood to C2S1 /1 after recession of the flood. The Blue Nile water is slightly saline during most of the months of the year except in May and June when the salinity rises to a medium level. The White Nile water is also slightly saline except in April, May and June. In general, data available on the chemical composition of the Nile water show a low soluble content, a high Ca/Na ratio and a low percentage of sodium. (Refer to Table 3.4)

3.2 Hydrology of the White Nile

3.2.1 River and Basin

The White Nile, the water source of the Project is originated from the Equatorial lakes on the lake plateau, flows through rocky rapids

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/1: the classification by the U.S. Salinity Laboratory extending over a length of 170 km and thereafter through the swampy Sudd region. After it emerges from the swamps, it is joined by Bahr EL Ghazal on the west and by Sobat on the east. At Kahrtoum the White Nile joins the Blue Nile which originates from the Ethiopian plateau. On the way it is joined by River Atbara and pours into the Main Nile. (Refer to Fig.3.1)

Before the construction of the Jebel Aulia Dam located at about 50 km upstream from the confluence of the White Nile and the Blue Nile, the flood of the Blue Nile used to create high rise of water forming a natural reservoir on the reaches of the White Nile. During the period of flooding season, the backflow of the White Nile reached as far as Kosti located at about 250 km upstream from the Jebel Aulia Dam, and the high water level normally ranged from 374.50 m to 376.00 m above MSL. The maximum water level at Mogren (Khartoum) was recorded at 376.56 m above MSL in 1917. Fig. 3.2 shows the water level at each gauging station in both the rising stage and the falling stage on the White Nile. The effect of backwater evidently reached Kosti. The reaches of the White Nile from Sobat mouth to Kosti are governed by the run-off from Sobat and Bahr El Jebel. The reaches from Renk to Mogren were subject to the behavior of the Blue Nile.

Eversince the completion of the Jebel Aulia Dam in 1937, the hydrologic regime in the White Nile was substantially changed as shown in Fig. 3.3; lower reaches of the White Nile was converted into an artifical reservoir. Normally, the filling is conducted in two phases, based on the dam operation criteria. The first filling to 376.50 m above MSL is commenced in mid-July; the second filling to 377.20 m above MSL starts in mid-September. The water level of 377.20 m above MSL is continuously maintained until mid-February. The stored water in the reservoir is gradually released from mid-February until the reservoir is completely emptied in the end of May. (Refer to Fig. 3.3)

The backwater of the reservoir reaches as far as Renk. The water levels of the White Nile at Dueim are summarized as follows.

Month	Before Dam Constructed (1906-1936)	After Dam Constructed (1944-1976)	Water Level - Maximum - (1966-1976)	WaterLevel - Minimum - (1966-1976)
Jan.	373.40	377.46	377.72	377.22
Feb.	372.79	377.35	377.74	377.32
Mar.	372.39	376.92	377.66	376.88
Apr.	372.21	375.63	377.48	374.92
May	372.21	373.82	376.26	372.72
Jun.	372.45	372.90	373.78	372.56
Jul.	373.12	373.66	375.94	372.78
Aug.	374.92	376.26	377.34	374.66
Sep.	375.37	377.06	377.64	376.70
Oct.	374.74	377.40	377.65	377.32
Nov.	373.98	377.41	377.62	377.32
Dec.	373.74	377.43	377.62	377.24

Source: Ministry of Irrigation & H.E.E.

The relevant data are shown in from Table 3.1 to Table 3.3.

The features of the Jubel Aulia reservoir are summarized as follows:-

- Full water level — 377.20 m above MSL
- 1st filling level — 376.50 above MSL
- Length of reservoir — 314 km
- Mean width of reservoir — 4.2 km
- Area of reservoir — 580,000 fedds (2,436 km^2)
- Capacity of reservoir — 3.1 milliard m^3

3.2.2 Water Loss from the River Reaches

According to the results of the study/1 by the Sudan Government, the discharges at Malakal and Renk are as shown below.

Discharge (1928 - 1946)

(Unit: Milliard m^3)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Malakal	1.98	1.37	1.40	1.32	1.55	1.95	2.42	2.76	2.94	3.22	3.12	2.91	26.94
Renk	2.29	1.51	1.43	1.32	1.49	1.80	2.26	2.64	2.94	3.19	3.03	2.89	26.79

/1 Nile Water Jebel Aulia Reservoir Preliminary Investigations Report No.1, Ministry of Irrigation & H.E.P., Jan., 1968, Khartoum

Over the whole period for which the records are available, there is no significant difference between the two. Therefore, there is no significant loss on the reaches from Malakal to Renk.

Data on the discharges at Malakal and Mogren before the construction of the Jebel Aulia Dam are as shown below.

Discharge (1912 - 1937)

	Nov. - May (milliard m^3)	Jun. - Oct. (milliard m^3)	Total (milliard m^3)
Malakal	14.3	13.5	27.8
Mogren	14.3	11.5	25.8
Loss	-	2.0	2.0

It is evident that water loss takes place during the period of high water from June to October which is estimated at 2.0 milliard m^3 and is constituting the natural loss in the Jebel Aulia Basin.

The results of the study carried out by the Egyptian Authorities to assess the total loss after the construction of the Jebel Aulia Dam are as shown below.

(Unit: milliard m^3)

Period	Inflow at Renk	Outflow at Dam	Diff	Storage Capacity Start	Storage Capacity End	Amount of Storage	Loss
Filling Jul.17 to Sep. 30	6.30	2.53	3.77	0.44	3.83	3.39	0.38
Standing Oct.1 to Jan. 31	10.78	8.99	1.79	3.83	3.79	-0.04	1.83
Emptying Feb.1 to May 5	4.80	7.34	-2.54	3.79	0.13	-3.66	1.12
Total	21.88	18.86	3.02	-	-	-0.31	3.33

From the 5th May to 17th July the river flows naturally and the natural loss during this period is estimated at 6 mm/day (0.21 milliard m^3 = 6 mm x 73 days x 48,000 ha) which has to be added to the figure of 3.33 milliard m^3.

Water loss on the reaches between Malakal and Mogren is summarized below.

- total loss with full operation of the Dam = 3.54 milliard m^3
- natural loss before the construction of the Dam = 2.00 milliard m^3
- additional loss by the creation of the reservoir = 1.54 milliard m^3

3.2.3 Water Quality

Two water samples of the White Nile at Ed Dueim were taken and analyzed at the laboratory in Japan. The results are shown in Table 3.4. From its low electric conductivity and low sodium content, it is evident that the water of the White Nile is suitable for paddy irrigation, though PH values are rather high.

3.3 Water Resources

3.3.1 Present Condition of Water Resources

The Sudan's water resources share of the Nile system according to the 1959 water agreement between the Sudan and Egypt is 18.5 milliard m^3 at Aswan or 20.35 milliard m^3 at Sennar, while that of Egypt is 55.5 milliard m^3. The present water consumption in the Sudan from the Nile system including consumption by the project under construction is 18.259 milliard m^3 as shown below./1

River System	Irrigated Area (ha)	Annual Consumption (milliard m^3)
Blue Nile System	1,246,535	11.977
White Nile System	260,395	2.840
Atbara System	156,237	1.839
Main Nile System	176,396	1.603
Total	1,839,563	18.259

From the above table, the remaining share, of the Sudan is about 2.1 milliard m^3. This amount however is not sufficient to meet the water demand for irrigation development proposed in the short and medium term plans in the country as shown below./1

/1: WATER RESOURCES OF THE SUDAN

A Report of the Sudan National Preparatory Committee for the United Nations Water Conference, 1977.

River System	Proposed Irrigation area (ha)	Required Annual Consumption (milliard m^3)
Atbara (Upper Otbara & Setit)	260,815	2.190
Blue Nile (Kenana, South of Khartoum, Rahad II)	596,388	4.800
White Nile	117,597	2.300
Total	974,800	9.290

Thus, it is evident from the prospective plans that extra Nile water required for the short and medium term plans is 9.3 - 2.1 = 7.2 milliard m^3. In addition there are 630,000 ha of cultivable areas to be irrigated by the Blue Nile in the long term plans, requiring another 5 milliard m^3.

3.3.2 Water Resource Development Projects

In order to meet the anticipated demand for the prospective project, a number of water resources development projects has been framed out.

- The first phase of Jonglei diversion canal project to provide an extra annual yield of 4.7 milliard m^3, and the second phase of the project to provide 4.3 milliard m^3.

- An annual storage on the River Baro together with the training and banking of 23 km of this river course to equalize its flow and provide an extra annual yield of 4 milliard m^3 presently lost by spillage in the swamps.

- The diversion project to provide 4 milliard m^3 now lost in the Machar Marshes through a canal from Machar, Adar to Melut on the White Nile.

- The construction of storage reservoirs and diversion canals to conserve about 7 milliard m^3 out of 14 milliard m^3 currently being lost in the swamps of Behr El Ghazal basin.

- The project to provide an extra storage capacity of about 4 milliard m^3 by heightening the Roseires Dam on the Blue Nile.

When these water resource development projects would be launched, it is evident that considerable amount of water resources can be developed and the stable water supply for the agricultural sector can be secured.

Table 3.1 Water Level before Jebel Aulia Dam Constructed

Station: ED DUEIM

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1906					10.18	10.47	11.26	13.08	13.86	12.90	12.12	11.84
07	11.53	10.75	10.47	10.35	10.33	10.37	10.99	12.07	12.90	12.25	11.84	11.62
08	11.06	10.56	10.21	10.02	10.01	10.08	10.67	13.42	14.10	13.32	12.28	11.94
09	11.80	11.24	10.49	10.35	10.50	10.80	11.49	13.45	14.12	13.49	12.56	12.25
10	12.11	11.80	10.82	10.21	10.03	10.44	10.99	12.86	13.68	13.34	12.36	11.86
11	11.76	11.14	10.44	10.21	10.10	10.41	10.09	12.78	13.67	12.62	11.89	11.68
12	11.05	10.46	10.24	10.21	10.19	10.18	10.87	12.97	13.04	12.20	11.87	11.64
13	11.08	10.39	10.20	9.95	10.08	10.39	10.55	11.43	12.14	11.51	11.27	10.55
14	10.12	9.94	9.88	9.86	9.79	9.87	10.66	13.14	13.21	13.00	12.33	11.86
15	11.69	11.03	10.29	10.09	10.07	10.24	10.79	12.02	12.68	12.65	11.82	11.57
16	11.25	10.43	10.08	9.94	9.99	10.24	11.14	13.35	13.96	13.71	12.60	12.12
17	12.01	11.94	11.39	10.48	10.39	10.58	11.39	13.25	14.39	13.85	12.50	12.21
18	12.21	12.29	12.37	12.35	11.75	11.24	11.57	12.58	13.11	12.34	11.96	11.74
19	11.06	10.68	10.51	10.32	10.18	10.49	11.14	12.92	11.49	12.28	11.83	11.71
20	11.06	10.47	10.24	10.06	10.07	10.48	11.28	12.85	12.86	12.59	11.97	11.68
21	11.23	10.51	10.21	9.96	9.99	10.28	10.83	12.60	13.19	12.52	11.74	11.58
22	11.04	10.16	9.80	9.38	9.37	10.01	10.84	12.94	13.45	12.76	11.84	11.57
23	11.25	10.27	9.89	9.95	10.01	10.49	11.22	13.21	13.46	12.74	11.83	11.72
24	11.39	10.56	10.08	10.09	10.24	10.26	11.00	12.77	13.44	12.41	11.86	11.62
25	11.40	10.49	10.11	10.05	10.17	10.40	11.06	12.47	12.77	12.31	11.75	11.66
26	11.12	10.34	10.09	10.06	10.07	10.50	11.07	13.16	13.39	12.61	11.90	11.78
27	11.67	11.00	10.27	10.13	10.07	10.17	10.95	12.67	12.90	12.30	11.46	11.14
28	10.35	10.05	9.92	9.91	10.25	10.66	11.50	13.04	13.23	12.22	11.76	11.66
29	11.38	10.54	10.25	11.04	10.30	10.90	11.86	13.48	13.89	13.14	11.99	11.72
30	11.55	10.80	10.30	10.10	10.16	10.29	11.14	12.87	12.93	11.99	11.46	11.17
31	10.53	10.12	9.93	9.87	9.89	10.10	10.76	12.63	13.30	12.57	11.84	11.65
32	11.15	10.31	10.10	10.03	10.06	10.47	11.11	13.04	13.47	12.57	12.01	11.95
33	12.03	11.68	10.68	10.37	10.25	10.41	10.81	12.48	13.51	12.78	12.15	12.00
34	11.75	10.90	10.41	10.18	10.26	10.45	11.38	13.14	13.65	12.76	11.96	11.85
35	11.76	10.95	10.43	10.33	10.35	10.70	11.71	13.47	13.69	12.98	11.97	11.79
36	11.50	10.76	10.49	10.19	10.22	10.49	11.38	13.04	13.77	12.65	11.71	11.54
Average	11.36	10.75	10.35	10.17	10.17	10.41	11.08	12.88	13.33	12.70	11.94	11.70
EL.	373.40		372.39		372.21		373.12		375.37		373.98	
(1906 – 1936)		372.79		372.21		372.45		374.92		374.74		373.74

Source: Ministry of Irrigation & H.E.E.

Table 3.2 Water level after Jebel Aulia Dam Constructed

Station: ED DUEIM

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1937	10.98	10.36	10.19	10.05	10.02	10.47	11.25	13.28	13.58	12.86	12.90	12.89
38	12.82	12.22	10.61	10.12	10.15	10.40	11.80	13.70	14.14	13.55	13.37	13.39
39	13.37	13.35	13.23	12.23	10.61	11.06	12.36	14.22	13.99	13.76	13.87	13.90
40	13.82	13.34	11.68	10.14	10.08	10.24	10.82	13.64	14.69	14.32	14.38	14.36
41	14.25	13.46	12.02	10.12	9.94	10.39	11.80	14.17	14.77	14.79	14.60	14.63
42	14.68	14.35	13.27	11.43	9.94	10.45	11.88	14.28	14.92	14.98	14.93	14.93
43	14.83	14.47	13.28	11.13	10.07	10.22	10.90	13.71	14.91	15.21	15.26	15.30
44	15.29	14.94	13.78	11.56	10.16	10.53	11.51	14.11	14.92	15.20	15.23	15.25
45	15.33	14.89	13.70	11.23	9.71	10.35	10.84	13.61	14.90	15.23	15.24	15.23
46	15.28	15.22	14.39	12.73	10.16	10.11	11.80	14.19	14.97	15.27	15.24	15.18
47	15.26	15.33	15.22	14.50	13.31	11.00	11.43	14.14	14.78	15.21	15.26	15.28
48	15.29	15.13	14.44	13.05	10.52	10.40	12.30	14.16	14.81	15.25	15.19	15.17
49	15.22	15.18	14.75	13.47	11.19	10.31	11.21	14.02	14.70	15.23	15.16	15.13
50	15.21	15.20	14.65	13.27	11.08	10.49	11.39	14.09	14.86	15.19	15.20	15.16
51	15.21	15.16	14.35	12.58	10.02	10.16	10.84	13.63	14.84	15.13	15.14	15.13
52	15.25	14.75	13.34	11.04	10.04	10.31	11.07	13.89	14.75	15.16	15.23	15.25
53	15.21	14.79	13.65	10.98	10.08	10.35	11.10	13.90	15.02	15.27	15.23	15.19
54	15.34	15.04	13.90	11.62	10.06	10.31	11.47	14.29	14.86	15.27	15.32	15.39
55	15.37	15.38	15.00	14.19	11.90	10.47	11.47	14.12	14.88	15.39	15.41	15.38
56	15.40	15.44	15.09	14.04	12.58	10.91	12.54	14.52	14.84	15.42	15.41	15.39
57	15.42	15.36	15.11	14.68	13.85	11.74	11.37	14.00	14.86	15.33	15.41	15.42
58	15.34	14.88	14.11	11.76	10.21	10.31	11.37	14.04	14.83	15.37	15.45	15.37
59	15.43	15.22	14.56	12.99	10.52	10.43	11.02	13.98	14.66	15.33	15.36	15.44
60	15.50	15.41	14.76	13.35	10.98	10.44	11.23	14.03	15.15	15.53	15.52	15.55
61	15.56	15.24	14.28	11.86	10.41	10.25	11.67	14.32	14.67	15.38	15.50	15.63
62	15.74	15.79	15.77	15.20	13.98	11.93	11.49	14.30	15.09	15.62	15.73	15.70
63	15.72	15.75	15.75	15.15	14.25	13.67	12.69	14.38	14.88	15.37	15.73	15.82
64	15.78	15.84	15.85	15.57	14.45	12.11	11.87	14.60	15.02	15.48	15.49	15.55
65	15.58	15.56	15.60	15.61	14.94	12.46	11.64	13.53	15.39	15.52	15.48	15.59
66	15.61	15.47	15.27	14.19	11.65	11.04	11.64	14.16	15.31	15.44	15.48	15.47
67	15.51	15.48	15.51	14.81	13.24	10.79	11.48	14.80	15.09	15.52	15.48	15.50

- to be continued -

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1968	15.53	15.52	15.49	14.73	13.19	10.89	12.02	14.55	15.35	15.39	15.38	15.36
69	15.37	15.45	15.41	14.34	11.77	10.82	12.11	14.62	15.32	15.43	15.35	15.44
70	15.50	15.49	15.44	14.22	11.87	10.79	11.46	14.28	15.16	15.41	15.33	15.32
71	15.43	15.34	15.39	14.36	12.07	10.78	11.85	14.65	15.29	15.41	15.39	15.40
72	15.43	15.39	15.31	14.06	11.78	10.70	11.61	14.51	15.26	15.37	15.33	15.42
73	15.39	15.37	15.20	14.19	12.02	10.87	11.73	14.36	15.10	15.43	15.38	15.50
74	15.53	15.41	15.20	14.11	11.85	10.90	11.94	14.40	15.28	15.43	15.32	15.45
75	15.40	15.39	15.36	14.36	12.02	10.81	12.17	14.56	15.51	15.54	15.45	15.34
76	15.34	15.46	15.34	14.79	12.79	11.04	12.19	14.52	15.28	15.41	15.40	15.35
Average	15.42	15.31	14.88	13.59	11.78	10.86	11.62	14.22	15.02	15.36	15.37	15.39
EL. (1944 ~ 1976)	377.46	377.35	376.92	375.63	373.82	372.90	373.66	376.26	377.06	377.40	377.41	377.43

Source: Ministry of Irrigation & H.E.E.

Table 3.3 Discharge at Malakal

(Unit: m^3/sec)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1967	1,290	-	799	742	714	863	995	1,212	1,303	1,567	1,583	1,543
1968	1,380	1,081	856	707	698	935	1,043	1,176	1,279	1,386	1,438	1,194
1969	940	853	833	798	798	986	1,143	1,242	1,344	1,383	1,492	1,433
1970	1,049	903	828	742	727	948	1,064	1,232	1,235	1,512	1,555	1,512
1971	1,334	990	879	782	723	834	1,038	1,200	1,377	1,477	1,517	1,512
1972	1,176	888	777	699	873	941	1,129	1,235	1,241	-	1,111	934
1973	760	649	634	631	732	864	1,022	1,108	1,245	1,258	1,312	-
1974	870	702	648	614	692	923	1,067	1,225	-	1,464	1,454	1,371
1975	989	736	702	667	670	842	1,012	1,149	1,293	1,464	1,533	1,462
1976	1,349	918	761	712	739	904	1,046	1,122	1,190	1,289	1,333	1,228
1977	826	789	703	681	637	-	-	-	-	-	-	-
Ave.	1,088	851	765	707	728	904	1,056	1,190	1,279	1,422	1,433	1,354

Source: Ministry of Irrigation & H.E.E.

Table 3.4 Water Quality of The White Nile

Item	Unit	No. 1 Point /1	No.2 Point /2
pH	-	8.0	8.0
Electrical Conductivity	10^{-4} mho/cm	2.23×10^2	2.20×10^2
Na^+	me/ℓ	0.97	0.97
	mg/ℓ	22.4	22.4
K^+	me/ℓ	0.12	0.12
	mg/ℓ	4.54	4.64
Ca^{2+}	me/ℓ	0.52	0.52
	mg/ℓ	10.42	10.42
Mg^{2+}	me/ℓ	0.62	0.62
	mg/ℓ	7.5	7.5
Total Cation	me/ℓ	2.23	2.23
Cl^-	me/ℓ	0.64	0.63
	mg/ℓ	22.61	22.27
SO_4^{2-}	me/ℓ	0.29	0.28
	mg/ℓ	13.68	13.33
Alkalinity	me/ℓ	1.72	1.70
Total Anion	me/ℓ	2.64	2.61
Mn	mg/ℓ	0.03	0.03
SiO_2	mg/ℓ	25.31	25.31
PO_4^{3-}	ppm	0.02	0.02
COD	O_2 mg/ℓ	6.46	6.38
NO_3	mg/ℓ	0.43	0.49

/1 Water was sampled at El Goli, 65 km upstream from Ed Dueim, June, 1977

/2 Water was sampled at Um Jerr, 15 km upstream from Ed Dueim, June, 1977

Fig. 3.1 The Nile Basin

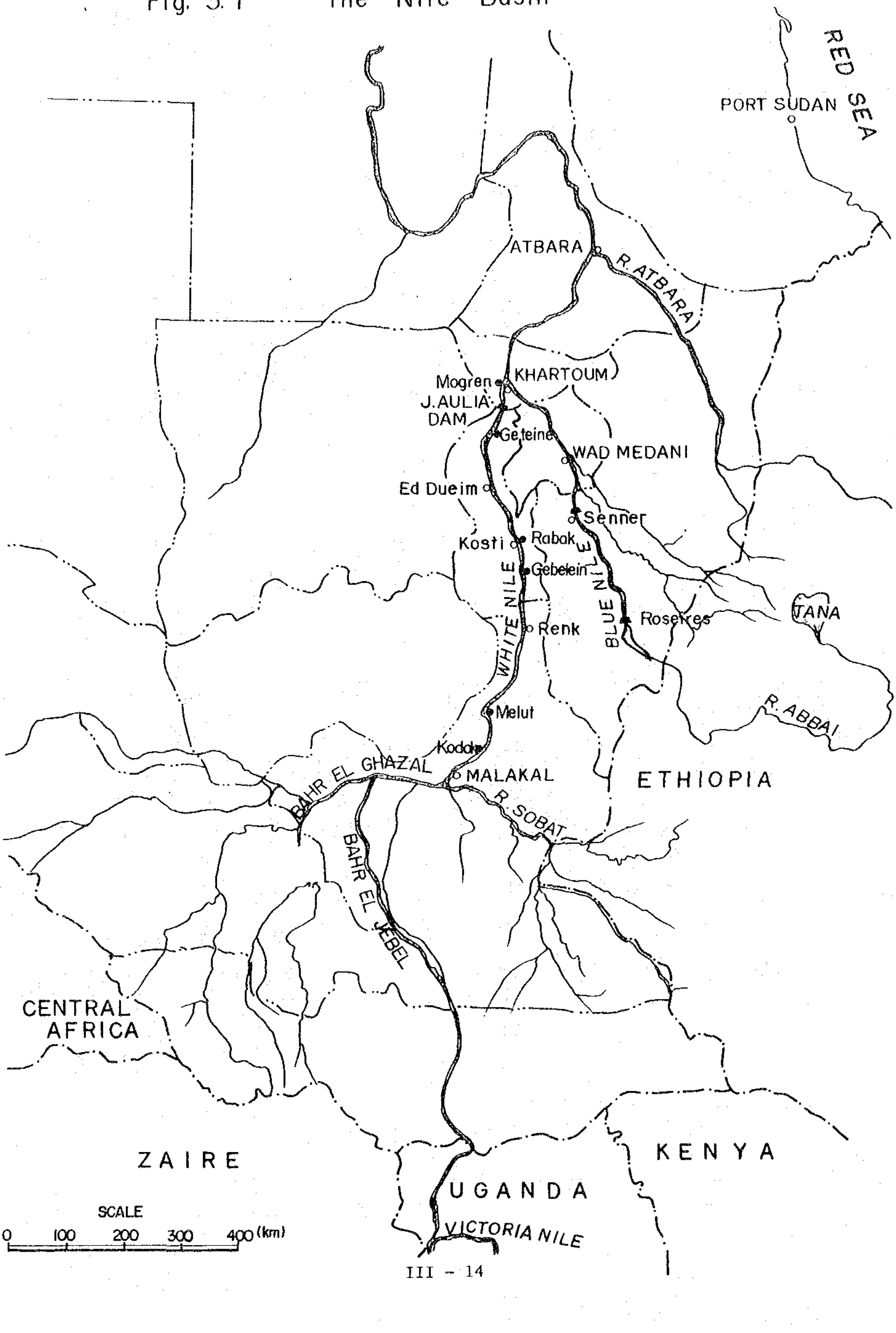
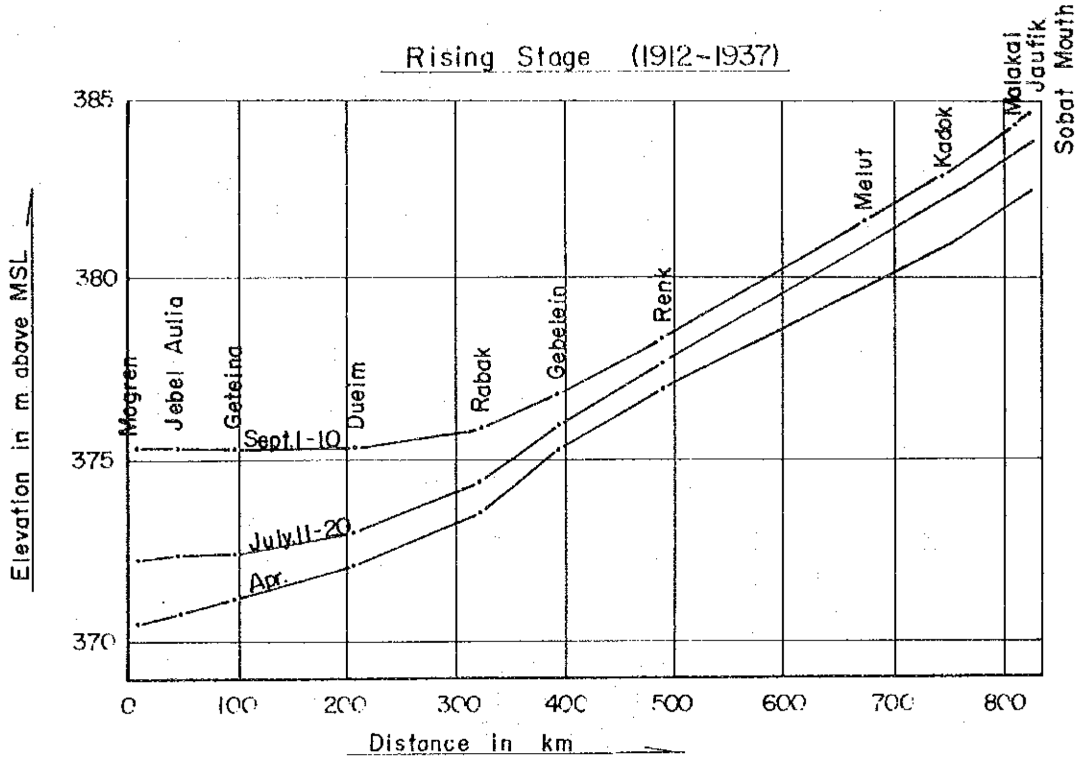


Fig. 3. 2 Normal Profile of the White Nile



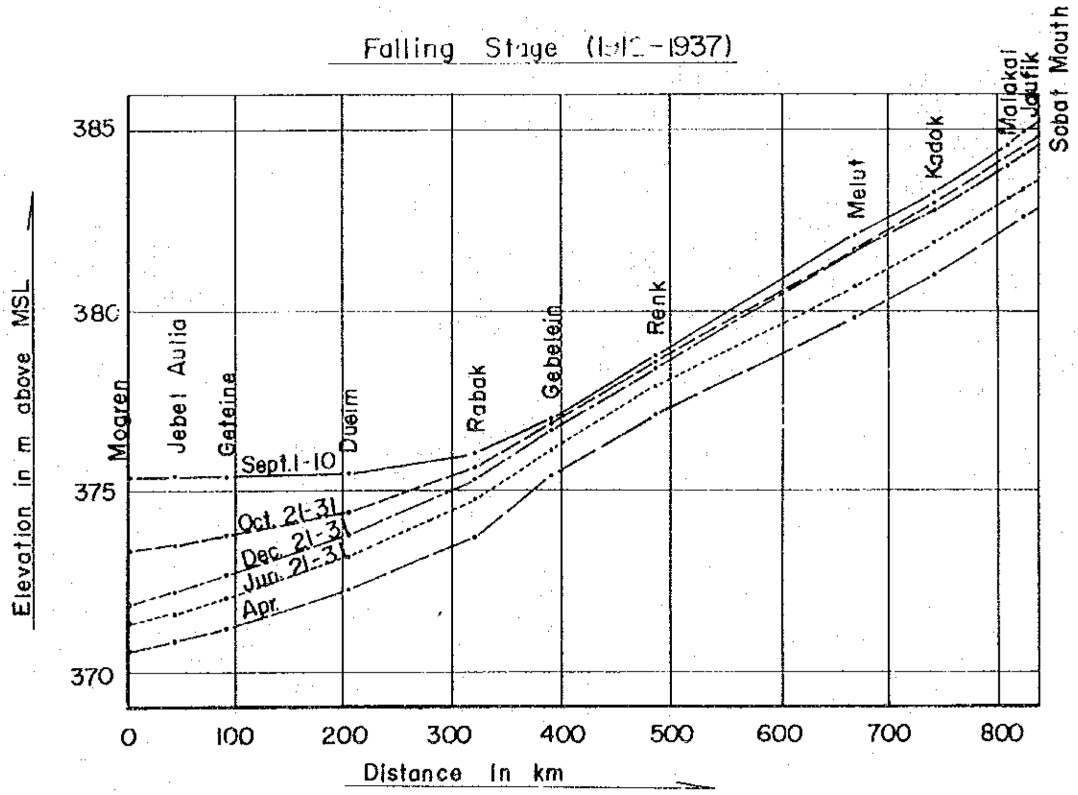
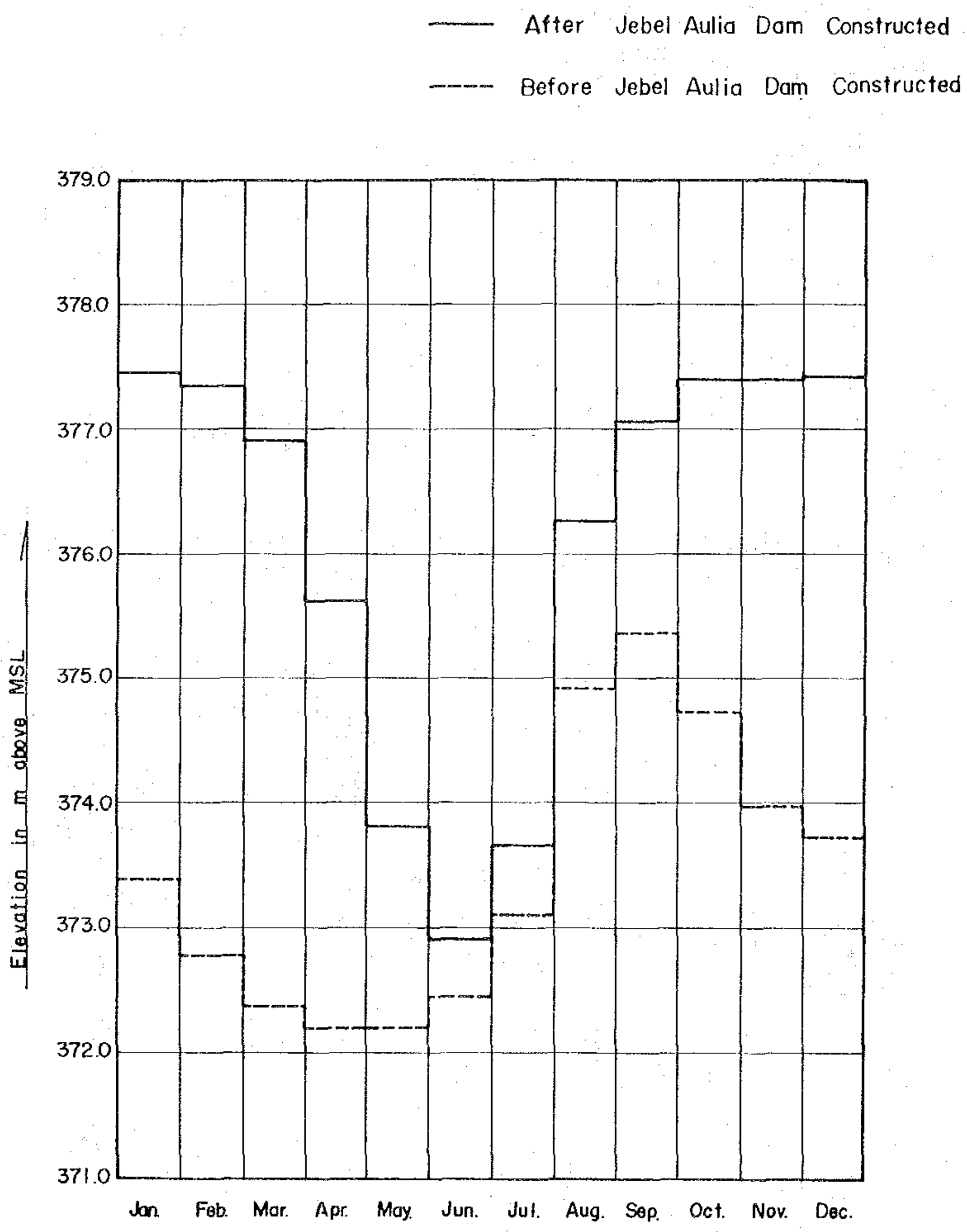


Fig. 3.3 Water Level of the White Nile
Station : Ed Dueim



ANNEX IV

GEOLOGY AND SOIL MECHANICS

ANNEX IV

GEOLOGY AND SOIL MECHANICS

Tables

Figures

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IV. GEOLOGY AND SOIL MECHANICS

4.1 Geology

The primary formation of landscape in the Abu Gasaba Area has been arisen from the Quaternary period with the fluvial sedimentation by the White Nile.

Soil layers in the project area are classified into four layers, namely, clay layer with water content remakably dried (hereinafter named as "dry clay" layer), clay layer with water content below its plastic limit (hereinafter named as "semi-dry clay" layer), clay layer with water content above its plastic limit (hereinafter named as "plastic clay" layer) and sand layer.

The "dry clay" layer, gray in colour, occupies the uppermost part of soil profiles all over the project area. The layer is 0.8 m to 1.4 m or more thick beneath the upland between Abu Araki and El. Sher. This layer seems just like a soft rock with plenty of cracks on its surface and to be transformed into a soft clay with less trafficability in the case inundated with water.

The "semi-dry clay" layer, gray in colour, was limitedly at the point of 1.5 km south from EL Mineidrib. The layer seems to be transitional layer from the "dry clay" layer to the "plastic clay" layer which lies along the shore of the White Nile.

The sand layer underlies the clay layers all over the project area. A part of this layer, the depth of 7.0 m to 8.5 m or 372 m to 368 m above MSL in elevation, seems to be compact sand (hereinafter named as "compact sand" layer). Though the thickness of this "compact sand" layer couldn't be cleared in this field survey, it seemes to be considerably thick, because this layer extends continuously under the clay layer.

The location map of soil mechanic survey and the profile of soil are shown in Fig. 4.1 and Fig. 4.2, respectively. Groundwater level of each survey point is also shown in Fig. 4.3. Soil mechanic properties of layers are shown in Table 4.1.

So as to examine the trafficability of agricultural equipments in the project area, the cone test was carried out on the margins of the surrounding small ponds, where the ground surfaces seem just like remoulded clay. The cone resistance are 0 to 1 kg/cm^2 in depth of 0 to 0.5 m and 7 kg/cm^2 or more in depth of 0.5 to 1.0 m as shown in Fig. 4.4.

4.2 Soil Mechanic Properties of Polder Dike Materials

4.2.1 Classification of Polder Dike Materials

The clays of the three clay layers resemble closely on their physical property, as shown in Fig. 4.5 to Fig. 4.6. Therefore, all clays in the project area are treated as a same material, that is to say a clay, in this report. From this standpoint, the materials of the polder dike are broadly classified into a clay and a sand.

4.2.2 Property of Clay

Soil mechanic test of the clay in the "dry clay" layer and the "plastic clay" layer was carried out at the laboratory in Japan. The results are shown in Fig. 4.7 and Fig. 4.8. The clay in the "semi-dry clay" layer is supposed to show intermediate properties between the said both clays. All clays belong the same class on their physical property classifications, CH in unified soil classification system.

Properties of the clay compacted by the Proctor's standard energy are mentioned below:-

- Cone resistance of the clay is greater than 4 kg/cm^2 at water content of less than 40 %;
- Permeability of the clay is estimated to be within the order of 10^{-7} in cm/sec;
- Consolidation test data made on the clay compacted at water content of 36 % is available which shows roughly the property of consolidation of the clay at relatively wet side;
- While, the property of consolidation of the clay at relatively dry side is considered to show less consolidation settlement and faster rate of consolidation than those of the test data, because it shows larger dry density and permeability than the test data;
- Parameters of minimum shearing strength under saturated, unconsolidated and undrained condition, are estimated as cohesion of 1.1 t/m^2 and angle of friction of 0^o; and

- Saturated density of the clay ranges from 1.70 t/m^3 to 1.93 t/m^3.

4.2.3 Property of Sand

From results of soil mechanic test as shown in Fig. 4.9 to Fig. 4.10, properties of the sand compacted by the Proctor's standard energy, are mentioned follows:-

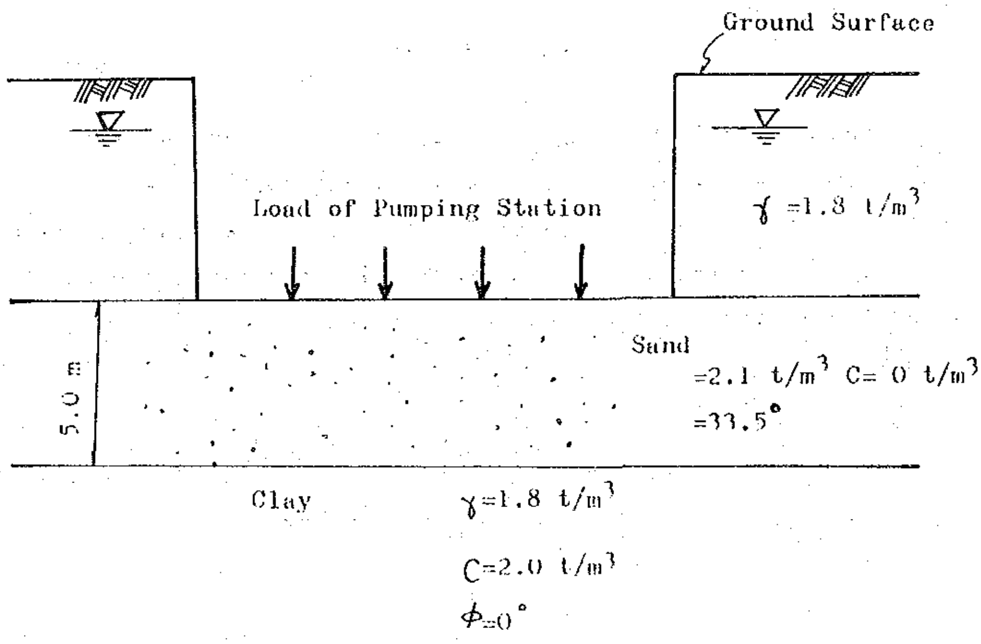
- The sand belongs to SC on S-C in unified soil classification;
- The sand shows a cone resistance of 8 km/cm^2 at water content of 9.5 %, and decreases it down to 4 km/cm^2 at water content of 18 %;
- Permeability by laboratory test is estimated at 6×10^{-4} cm/sec at water content of 9.5 % and 3×10^{-6} at content of 15.7 %, nearly optimum water content;
- Parameters of shearing strength at water content of 10.4 % and 17.1 % is almost same and is estimated as cohesion of 1.0 t/m^2 and angle of friction of 30^o under saturated, consolidated and drained condition; and
- Saturated density of the sand ranges from 2.06 t/m^3 to 2.09 t/m^3.

4.3 Soil Mechanics for Planning of Pumping Station

4.3.1 Bearing Capacity at Pumping Station

The base of the pumping station is placed at elevation of about 368 m above MSL, depth of 6 m to 9 m beneath ground surface. Level of the base, therefore, will be located in the "compact sand" layer.

As the basic condition for analysis on bearing capacity, the thickness of the "compact sand" layer is estimated at 5 m as shown in the following figure. This condition is considered to be the most dangerous for the design of the pumping station.



Long term allowable bearing capacities of the sand and the clay (qa_1 & qa_2) are generally calculated by the following formulas, respectively.

$$qa_1 = \frac{1}{3}\left\{\alpha \cdot C \cdot Nc + \beta \cdot \gamma_1 \cdot B \cdot N_\gamma + \gamma_2 \cdot Df \cdot (Nq + 2)\right\}$$

$$qa_2 = \frac{1}{3}\left(1 + \frac{H-Df}{B}\right)\left(1 + \frac{H-Df}{L}\right)(5.3\,\alpha \cdot C + 3.0\,\gamma_2 \cdot Df)$$

where,

H : depth to the boundary between sand and clay

Df : depth to the base of pumping station

B&L : each side length of a rectangular base ($B \leqq L$), $B=15^m$ & $L=35^m$

γ_1 & γ_2: densities of soil below or above the depth of the base, submerged unit weight is used for the soil under ground water

α : $1.0 + 0.3 \frac{B}{L}$

β : $0.5 - 0.1 \frac{B}{L}$

C : cohesion

Nc, N_γ, & Nq: bearing capacity factors which are functions of internal friction angle,
Nc = 25 N_γ = 15 Nq = 20

Results are as below,

$qa_1 = 91.1\ t/m^2$ $qa_2 = 15.3\ t/m^2$

Long term allowable bearing capacity of the pumping station is $15.3\ t/m^2$ because allowable bearing capacity is adopted low value between ones of the upper sand layer and the lower clay layer. From the result of this calculation, long term allowable bearing capacity of the pumping station is expected to be at least $15\ t/m^2$.

4.3.2 Settlement of Pumping Station

When the "plastic clay" layer extends under the sand layer, settlement of the sand layer will increase corresponding to the thickness of the sand layer. It is necessary to carry out more detailed survey by boring in the stage of the detail design. According to the assumption that the "plastic clay" layer of 5 m thick will extend under the sand layer of 5 m thick at the pumping station, the consolidation settlement of the "plastic clay" layer will be assumed to be about 5 cm. Total settlement will be assumed to be less than 10 cm in addition to initial settlement of both layers.

On the other hand, differential settlement of the pumping station might be occured, though settlement of each parts might be small in the case that the "plastic clay" layer is not so thick.

4.4 Stability, Settlement, Erosion and Seepage of Polder Dike

4.4.1 Stability of Polder Dike

It is the most unstable against the sliding that the polder dike of the clay materials will be constructed on the foundation which is occupied by the thick "plastic clay" layer. As mentioned in the later subsection, it has been found that consolidation of the dike or foundation of the clay materials will be progress very slowly. From this viewpoint, the effective increase of the shearing strength by consolidation will achieved in the long term more than 20 years. Initial shearing strength, therefore, must be taken in the analysis of stability. The stability analysis against failure along slip circles is carried out using the shearing strength parameters of $C = 1.1$ t/m^2 and $\phi = 0^{\circ}$C. From the result of stability analysis, the cross section of the polder dike with the safety factor of 1.2 on its sliding has been designed as shown in Fig. 4.11.

In general, when a dike is built by sand materials with non-cohesion and constant flow is oozing out from a dike slope, a local failure sometimes occurs around the oozing point and develops into piping. However, this failure never occurs on the dike in the project area because the sand material is expected to have the cohesion of 1.0 t/m^2. Therefore, the failure pattern of the dike constructed by the sand material is a general failure that the stability analysis against failure along slip circle can be applied. The dike of the sand material which has the same dimension mentioned above is much more stable because it has the shearing strength parameters of $C = 1.0$ t/m^2 and $\phi = 30^{\circ}$.

4.4.2 Settlement of Polder Dike

Since initial settlement of dike will finish by the end of construction, correctional embankment for settlement can be made during under construction. Only settlement due to consolidation, therefore, is analyzed in this report.

Settlement due to consolidation (Sc) and the relation between time (t) and degree of consolidation are calculated by the following formula.

$$Sc = \sum \frac{e_o - e}{1 + e_o} \cdot h$$

$$t = \frac{D^2}{Cv} \cdot T$$

where;

e_o & e = void ratio corresponding to vertical stress on soil before and after loading

D = drainage path

Cv = coefficient of consolidation

T = time factor which is a function of degree of consolidation

Value of e_o, e and Cv are referred to data sheets of consolidation test in the appended soil test data.

The result of calculation is summarised as follows;

- the dike which has the height of 4.5 m and the foundation occupied by the "plastic clay" layer in 6.5 m thick:-

  The settlement of the dike and the total settlement of the dike and its foundation is estimated at 12 cm and 45 cm, respectively. The progress of the settlement is very slow, that is to say, it takes more than 20 years after construction of the dike for settlement to reach to 30 % of the final settlement.

- the dike which has the height of 2.5 m and the foundation occupied by the "plastic clay" layer in only 1.5 m thick:-

  The total settlement of the dike and its foundation is estimated at 10 cm and it takes 0.8 years by 30 % of the final settlement.

4.4.3 Erosion of Polder Dike

The dike in the Project area is supposed to be eroded by wave of the White Nile and wind. Though some protection materials are available for the dike, for example, rock, bag filled with soil, concrete, etc., one of the most economical protection methods for erosion may be to enlarge the width of the dike.

The crest width of the proposed polder dike will be enlarged 1m longer toward the river for the protection against the erosion by wave. An effective width against erosion will become clear by the survey on erosion of dike constructed first.

4.4.4 Seepage From Polder Dike

The maximum coefficient of permeability of the dike made of the sand material, is expected around 1×10^{-3} cm/sec. From the following assumptions, the maximum seepage flow discharge was estimated at about 2,000 m^3/day,

- The seepage flow is constant because the water level of the White Nile is kept at the high water during half a year.

- The phreatic surface is shown in Fig. 4.12.

- The length of the polder dike of the sand material on the tract is about 2.5 km.

This seepage water is again used for irrigation with the surplus water for irrigation.

4.4.5 Embankment of Polder Dike

For dikes such as those constructed in the project area, a bulldozer is generally used for compaction. From the condition that cone resistances of soils in the Project area are estimated at more than 4 kg/cm^2 except for the swamps, a bulldozer with the weight of 15 t to 20 t can run on the ground. The usual compaction by a bulldozer that is a weight of 15 to 20 t, the lift of 30 cm and compaction times of 4 to 6 is recommended. It is desirable that the exact compaction energy required for embankment construction which corresponds to the Proctor's standard energy is judged in a test run embankment to be done at the earliest stage of the first construction phase.

Table 4.1 Summary of Soil Mechanic Properties of Soil Layers

Soil layer	dry clay	semi-dry clay	plastic clay	sand
fine (ø 0.074 mm) fraction (%)	90	90	85 - 93	14 - 22
liquid limit (%)	61	103	66 - 94	20 - 29
plastic limit (%)	25	28	22 - 30	12 - 13
Japan unified soil classification	CH	CH	CH	SC - SC
natural water content (%)	13	22	26 - 39	10 - 18
wet density * (t/m^3)	1.6	1.8	1.8	1.8-2.0
saturated density /1 (t/m^3)	1.9	1.9	1.8	2.1
shear strength /2 (t/m^2)	7 - 50	5 - 10	1 - 5	-
coefficient of permeability (cm/sec)	1×10^{-6}	1×10^{-6}	1×10^{-6}	$10^{-3} - 10^{-6}$
cone resistance (kg/cm^2)	15	7	4	8
angle of internal friction (°)	-	-	-	33.5 - 35

/1 Values assumed in reference to densities of compacted materials.

/2 These correspond to the cohesion in undrained condition.

Fig. 4.1 Location Map of Soil Mechanic Survey

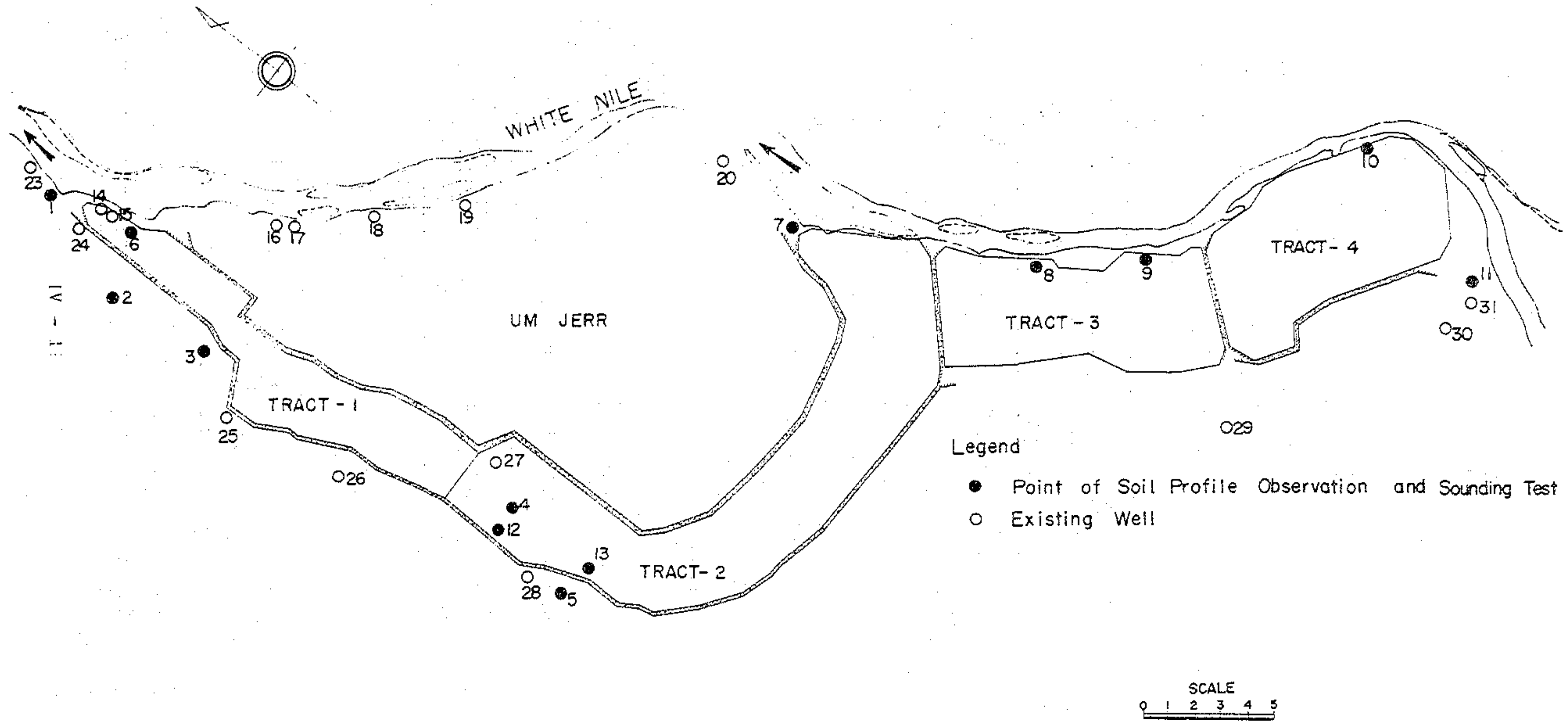
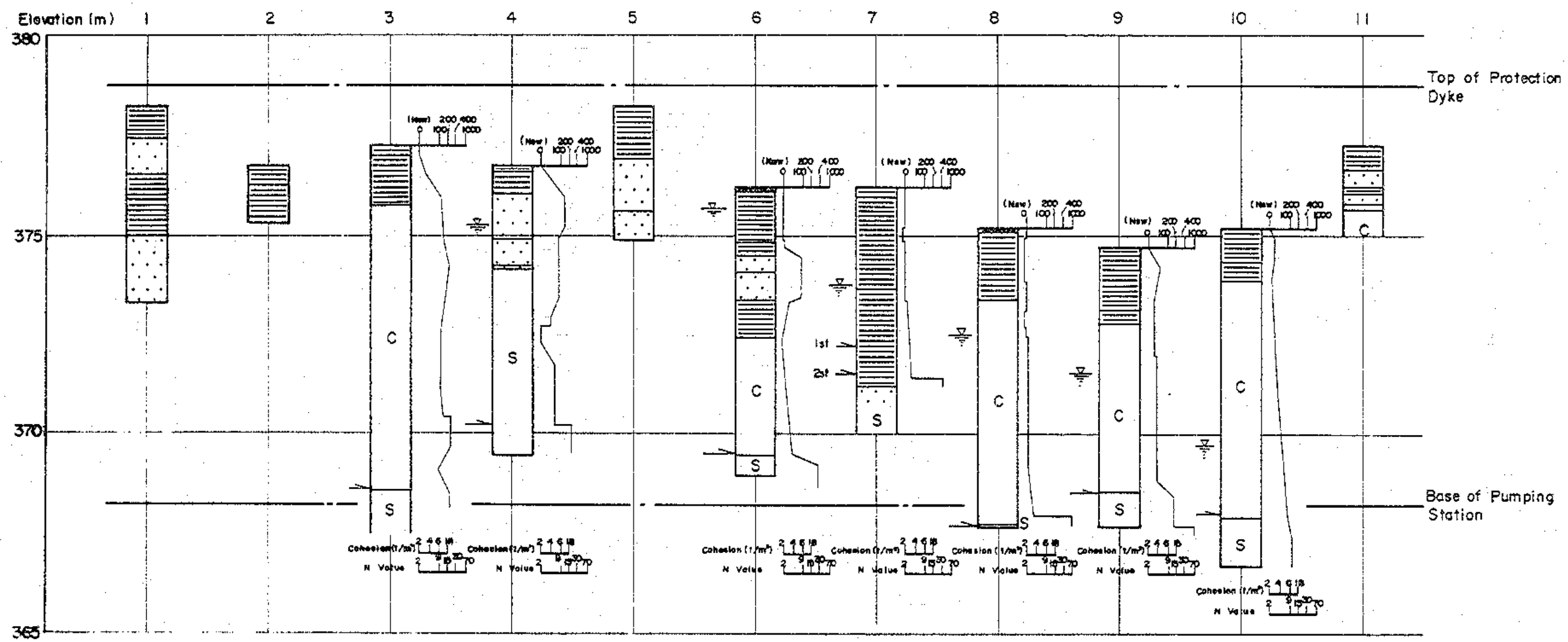


Fig. 4. 2 Profile of Soil



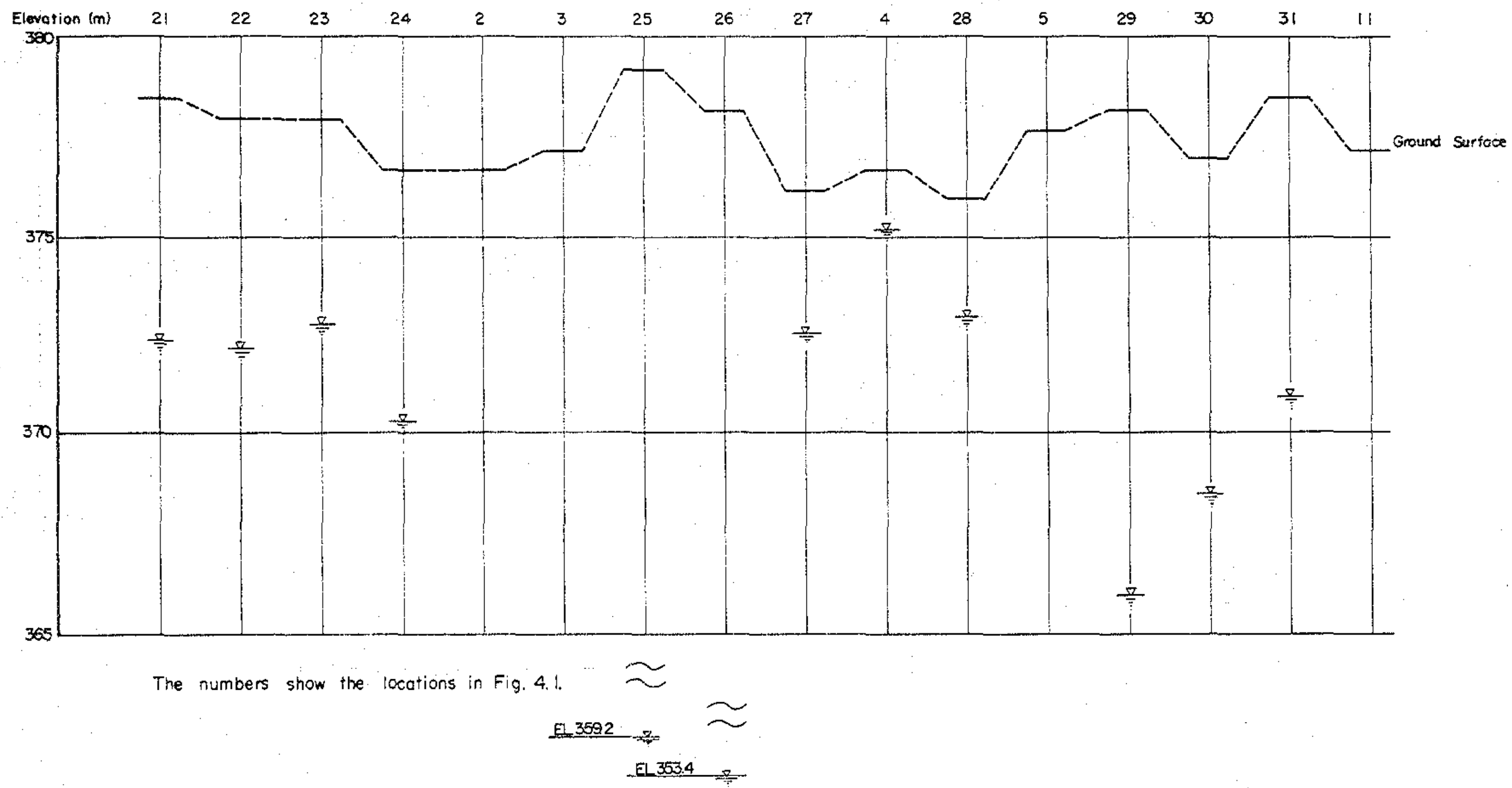
The numbers show the locations in Fig. 4.1.

Symbol C or S show cray or sand supposed from a swedish sounding test.

Nsw means No. of half rotation per meter in a swedish sounding test

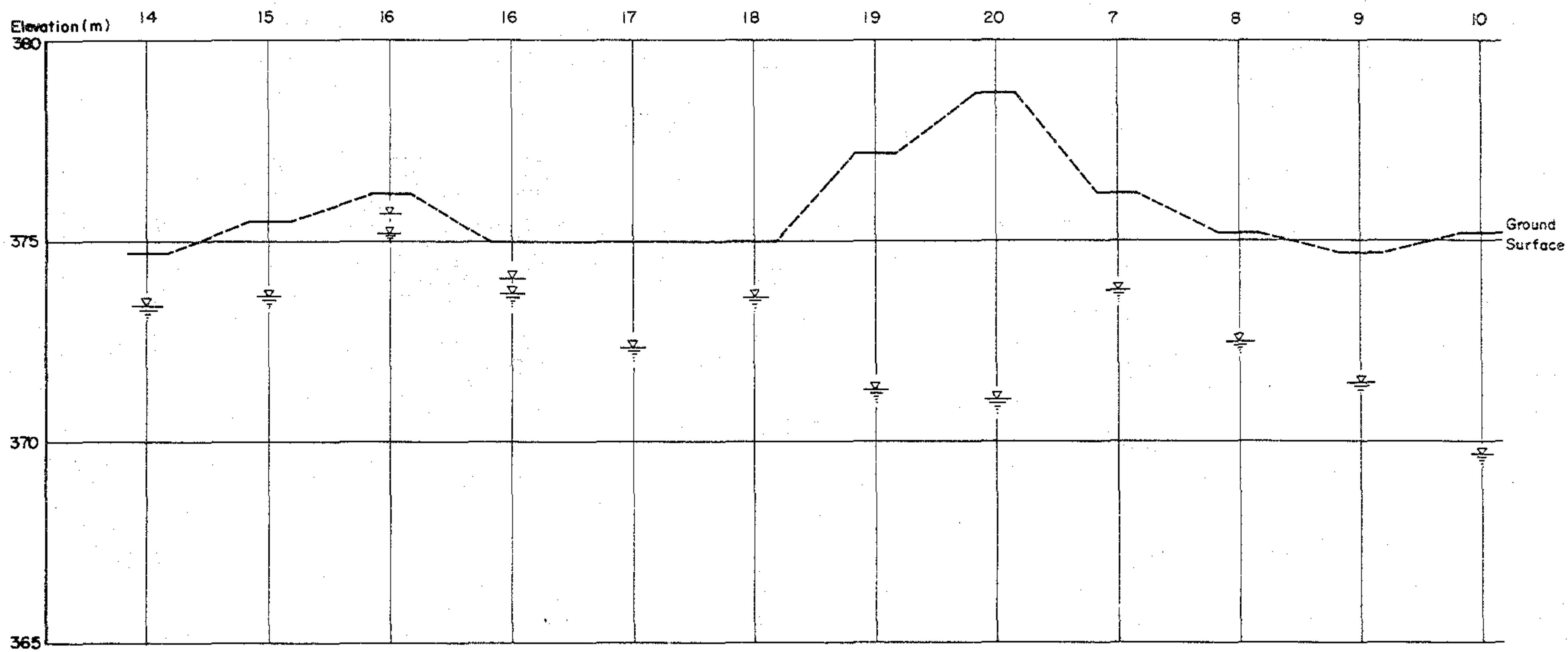
Cohesion or N value are estimated from a swedish sounding test on clay or sand.

Fig. 4. 3 (1)   Ground Water Level



The numbers show the locations in Fig. 4.1.

Fig. 4. 3 (2)   Ground   Water   Level



The numbers show the locations in Fig. 4.1.

Fig. 4.4 Cone Resistence of Ground.

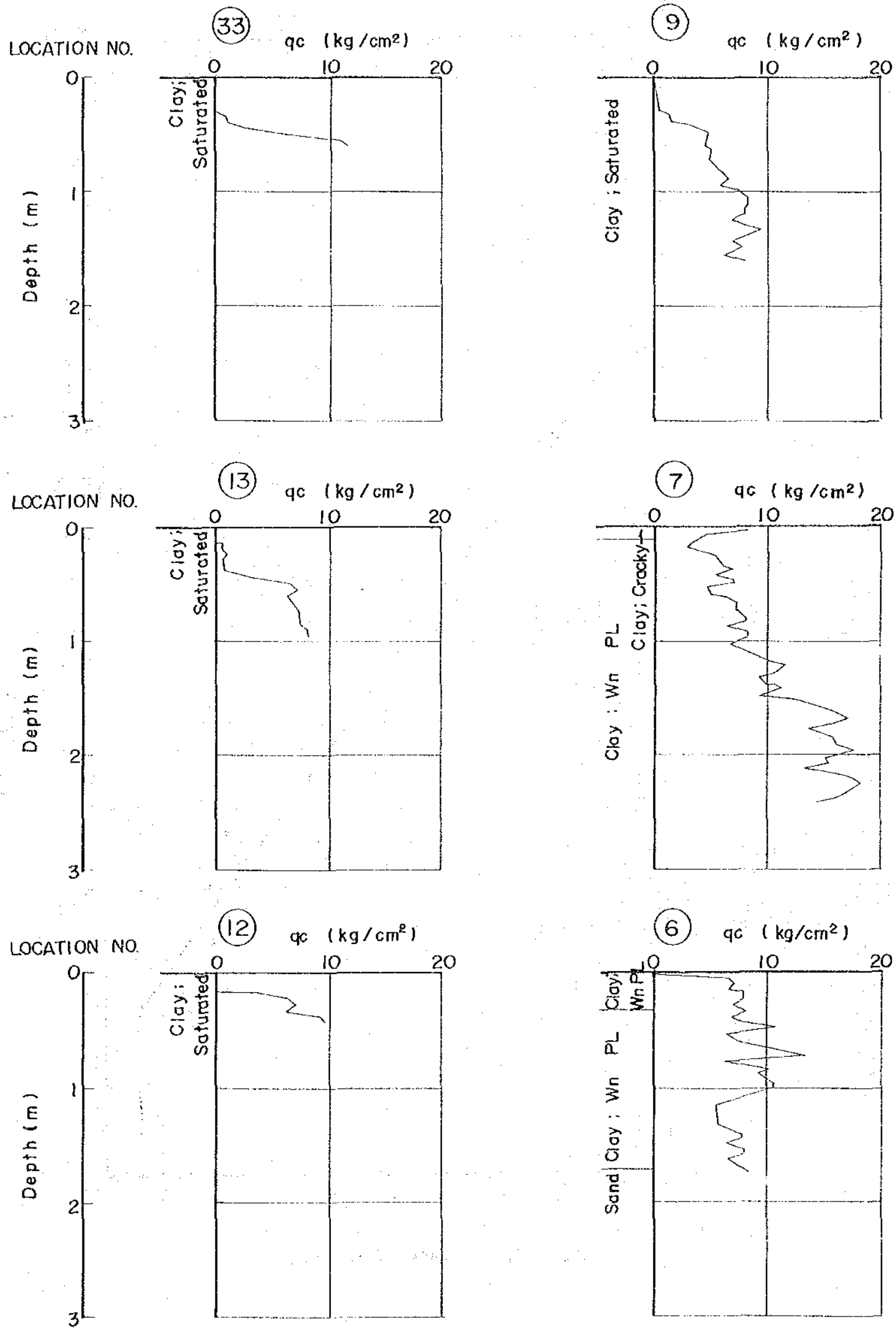


Fig.4.5, Plasticity Chart of the Clay

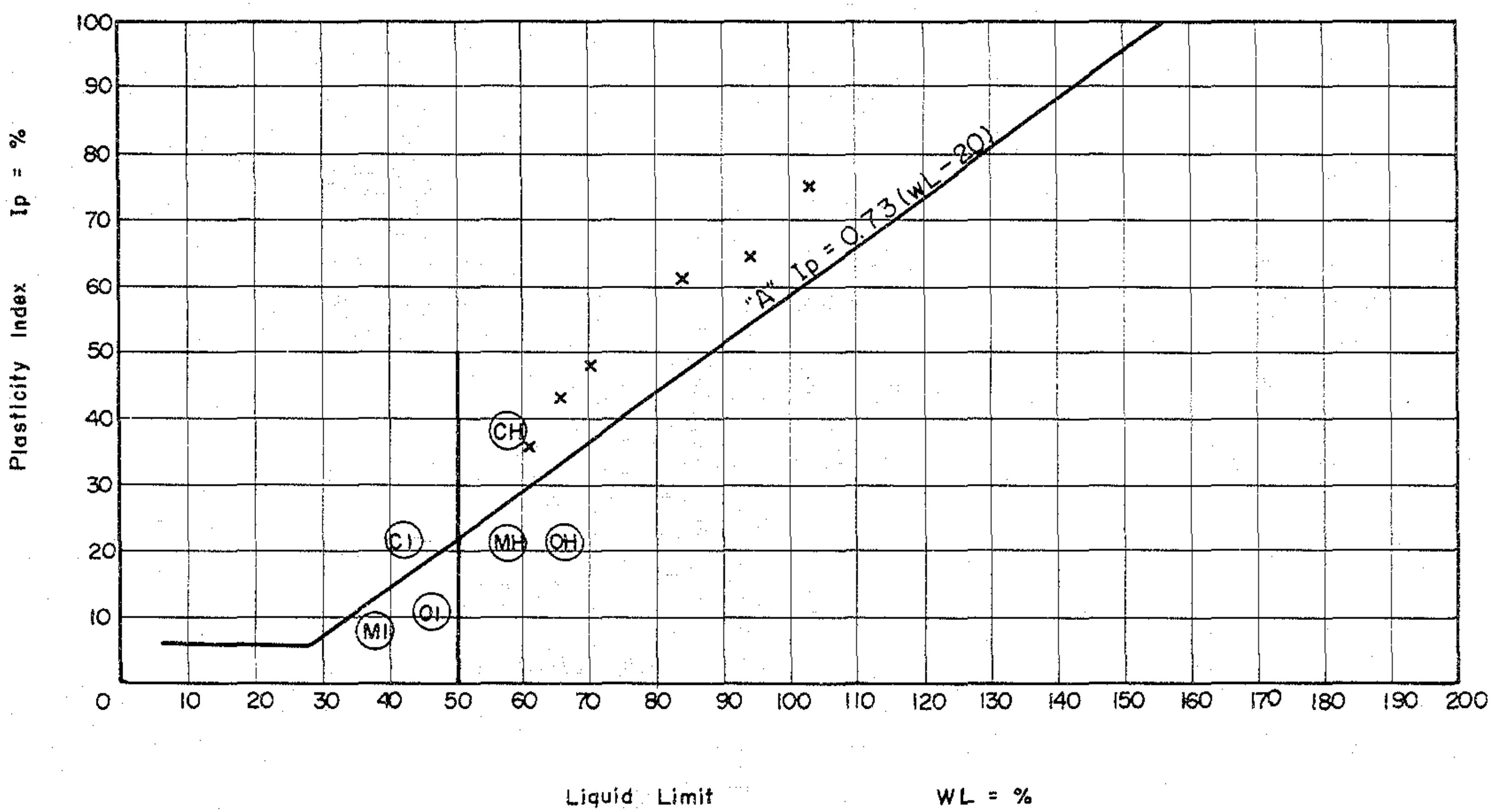


Fig.4.6. Summary of Gradation Analysis of the Clay

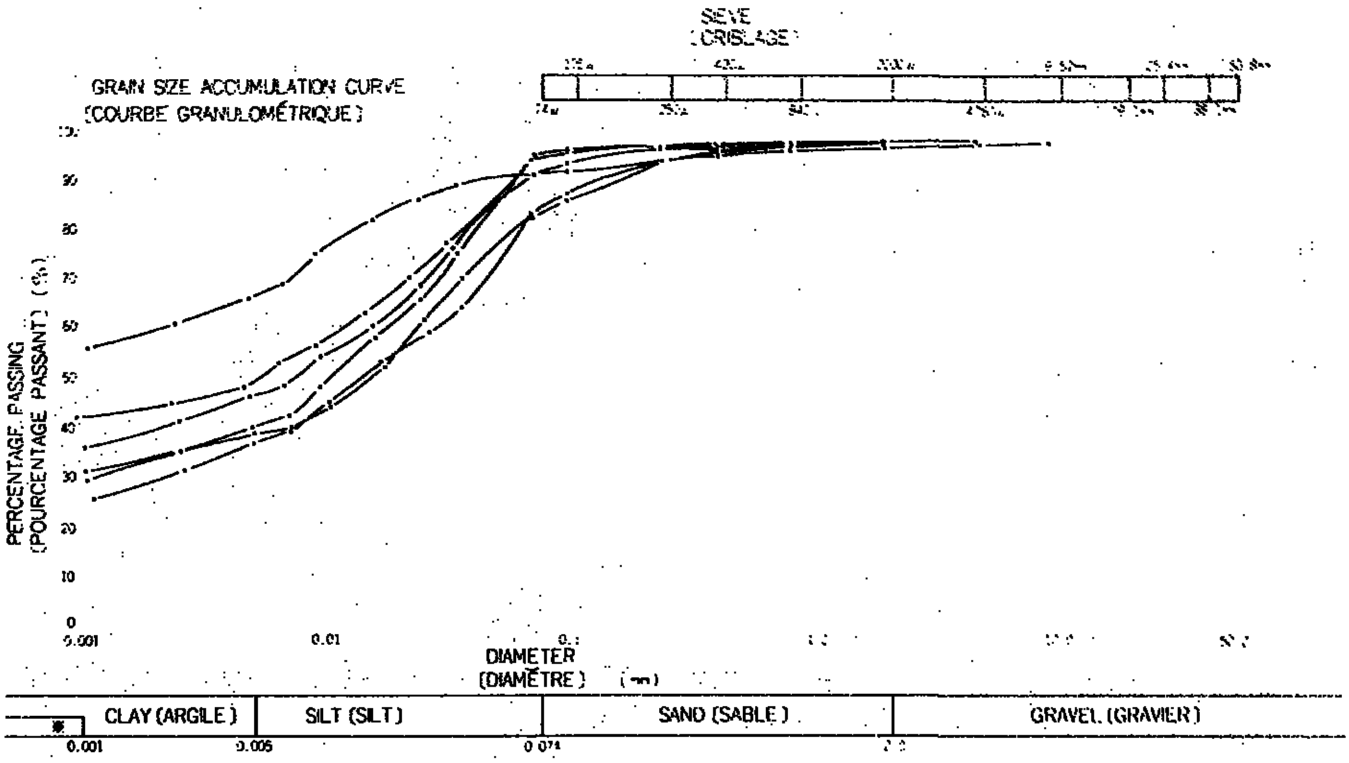
FOR REPORTING
(POUR LE RAPPORT)

NAME OF SURVEY & LOCALITY (DÉNOMINATION DE L'ENQUÊTE ET LOCALITÉ)		DATE (DATE)	
SAMPLE NO. & DEPTH (N° DE L'ÉCHANTILLON ET PROFONDEUR)		TESTED BY (ESSAI PAR)	

PARTICLE SIZE & WEIGHT PERCENTAGE OF PARTICLES UNDER THE SIZE
(DIMENSION DES PARTICULES ET POURCENTAGE DE POIDS DES PARTICULES DE DIMENSION INFÉRIEURE AUX PRÉCÉDENTES)

SPECIFIC GRAVITY
(POIDS SPÉCIFIQUE) Gs

SIEVE (CRIBLAGE)	GRAIN SIZE (mm) (GRANULOMÉTRIE)	50.8	38.1	25.4	19.1	9.52	4.76	2.00	0.84	0.42	0.25	0.105	0.074
	TOTAL PASSING (%) (TOTAL PASSANT)												
HYDROMETER (ARÉOMÉTRIE)	GRAIN SIZE (mm) (GRANULOMÉTRIE)												
	TOTAL PASSING (%) (TOTAL PASSANT)												



✱ COLLOID
(COLLOÏDE)

PROPORTION (PROPORTION)				
	4.76mm <	%	MAXMUM DIAMETER (DIAMÈTRE MAXIMUM)	mm
	4.76 ~ 2.00mm	%	60% DIAMETER (DIAMÈTRE 60%)	mm
	2.00 ~ 0.42mm	%	30% DIAMETER (DIAMÈTRE 30%)	mm
	0.42 ~ 0.074mm	%	10% DIAMETER (DIAMÈTRE 10%)	mm
	0.074 ~ 0.005mm	%	COEFFICIENT OF UNIFORMITY (COEFFICIENT D'UNIFORMITÉ)	
	0.005mm >	%	COEFFICIENT OF CURVATURE (COEFFICIENT DE COURBURE)	

Fig. 4.7. Cone Resistance of the Clay Compacted under Proctor's Standard Energy

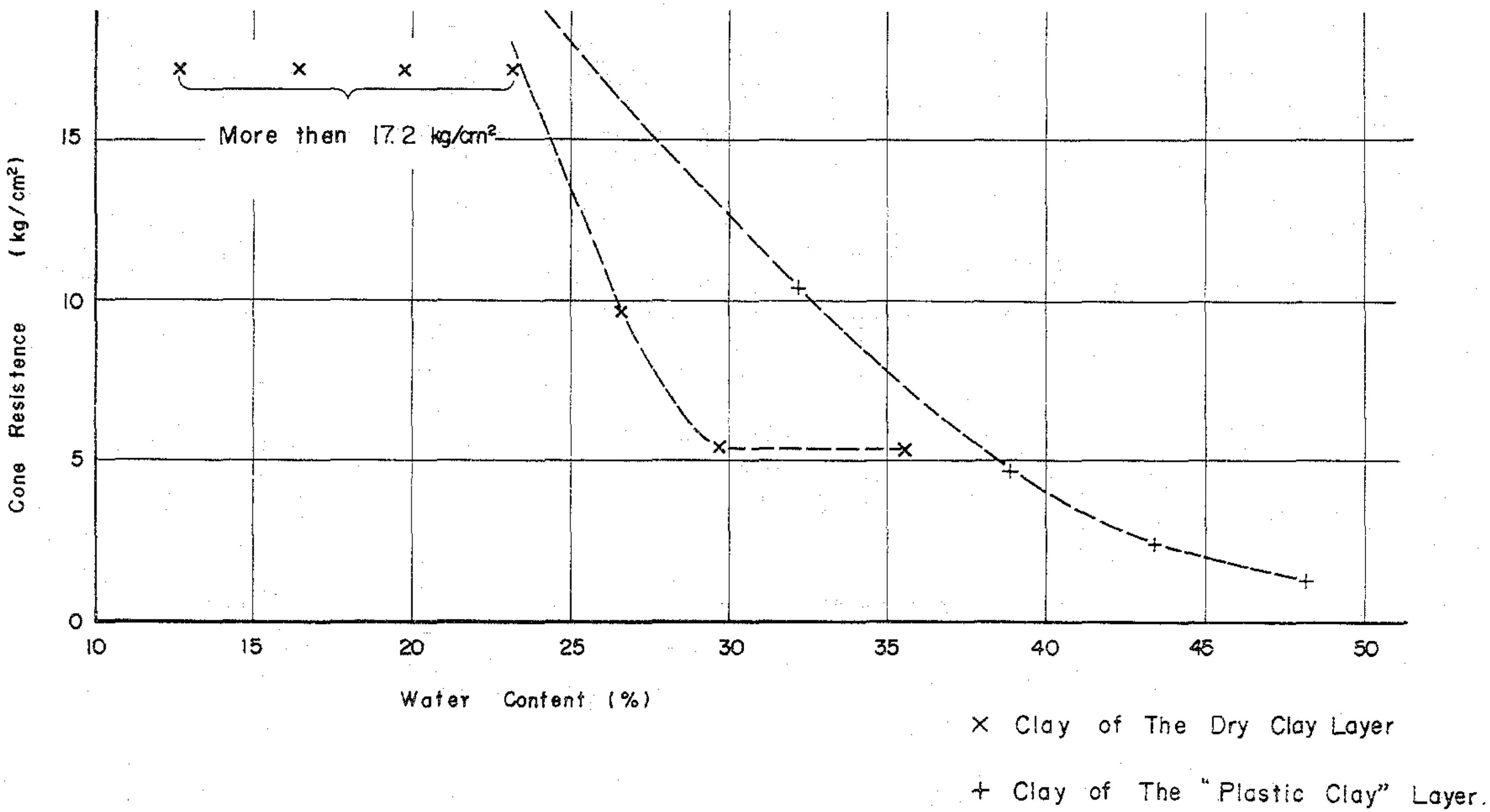


Fig. 4.8. Properties of the Clay Compacted under Proctor's Standard Energy

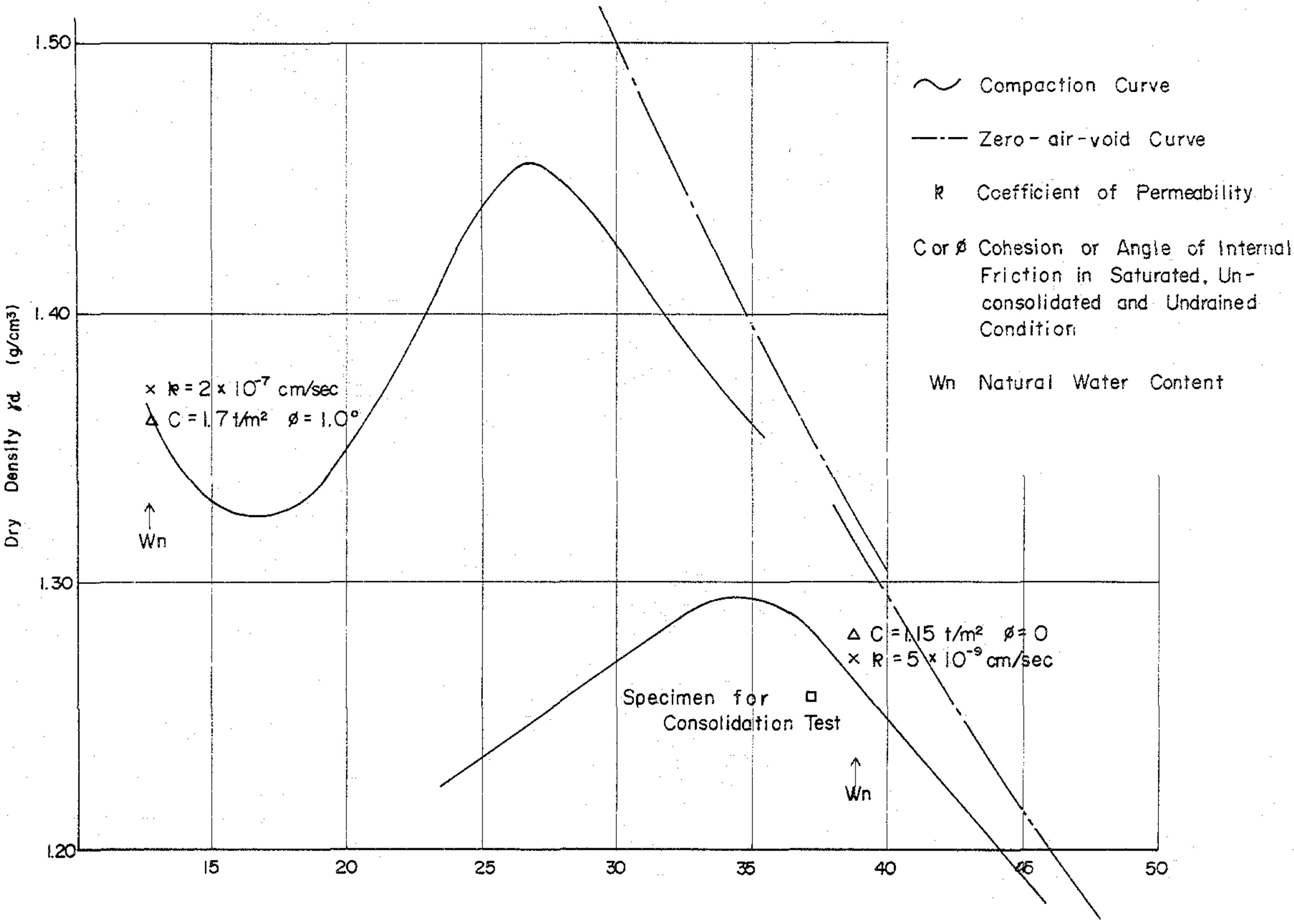


Fig.4.9. Summury of Gradation Analysis of the Sand

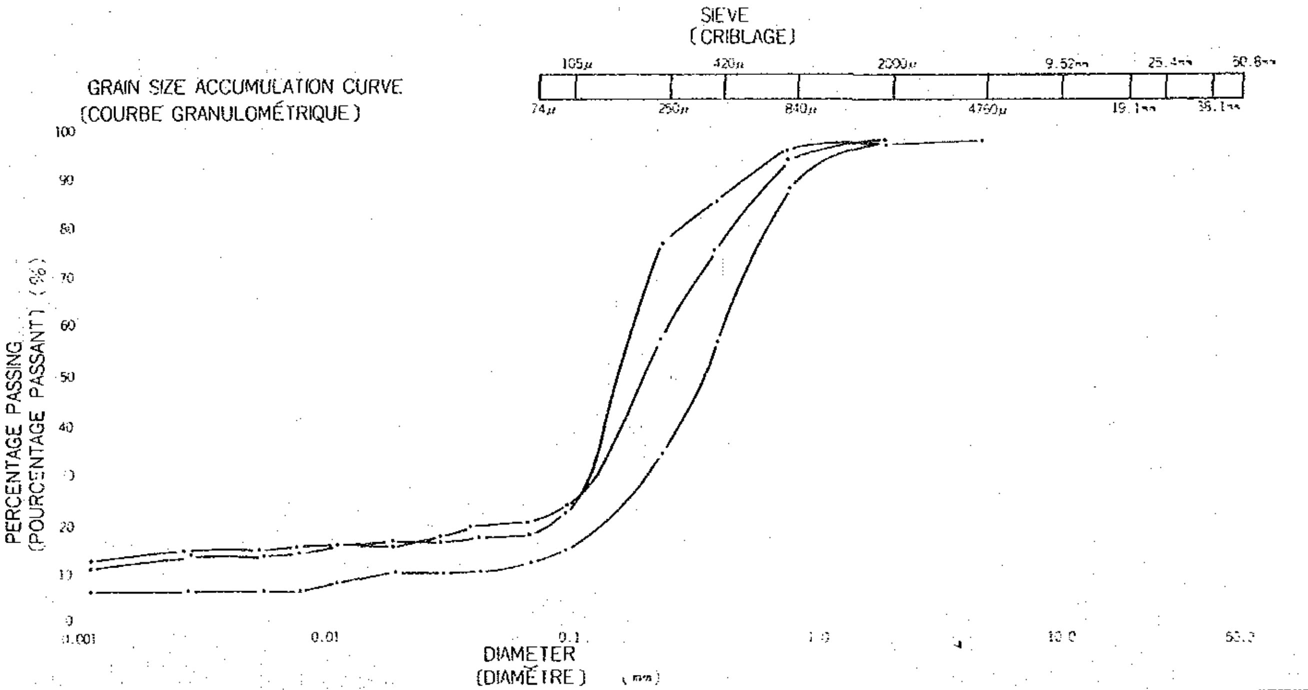
FOR REPORTING
(POUR LE RAPPORT)

NAME OF SURVEY & LOCALITY (DÉNOMINATION DE L'ENQUÊTE ET LOCALITÉ)		DATE (DATE)	
SAMPLE NO. & DEPTH (N° DE L'ÉCHANTILLON ET PROFONDEUR)	(m ~ m)	TESTED BY (ESSAI PAR)	

PARTICLE SIZE & WEIGHT PERCENTAGE OF PARTICLES UNDER THE SIZE
(DIMENSION DES PARTICULES ET POURCENTAGE DE POIDS DES PARTICULES DE DIMENSION INFÉRIEURE AUX PRÉCÉDENTES)

SPECIFIC GRAVITY
(POIDS SPÉCIFIQUE) Gs ____________

SIEVE (CRIBLAGE)	GRAIN SIZE (mm) (GRANUROMÉTRIE)	50.8	38.1	25.4	19.1	9.52	4.76	2.00	0.84	0.42	0.25	0.105	0.074
	TOTAL PASSING (%) (TOTAL PASSANT)												
HYDROMETER (ARÉOMÉTRIE)	GRAIN SIZE (mm) (GRANULOMÉTRIE)												
	TOTAL PASSING (%) (TOTAL PASSANT)												



※	CLAY (ARGILE)	SILT (SILT)	SAND (SABLE)	GRAVEL (GRAVIER)

0.001 0.005 0.074 2.0

※ COLLOID
(COLLOÏDE)

PROPORTION (PROPORTION)	4.76mm <	%	MAXMUM DIAMETER (DIAMÈTRE MAXIMUM)	mm
	4.76~2.00mm	%	60% DIAMETER (DIAMÈTRE 60%)	mm
	2.00~0.42mm	%	30% DIAMETER (DIAMÈTRE 30%)	mm
	0.42~0.074mm	%	10% DIAMETER (DIAMÈTRE 10%)	mm
	0.074~0.005mm	%	COEFFICIENT OF UNIFORMITY (COEFFICIENT D'UNIFORMITÉ)	
	0.005mm >	%	COEFFICIENT OF CURVATURE (COEFFICIENT DE COURBURE)	

N. K FORM NO. 002 (1975)

Fig. 4. 10. Properties of the Sand Compacted Under Proctor's Standard Energy

調査名・調査地点 NAME OF SURVEY & LOCALITY		期日 DATE	
試料番号・深さ SAMPLE NO. & DEPTH		試験者 TESTED BY	

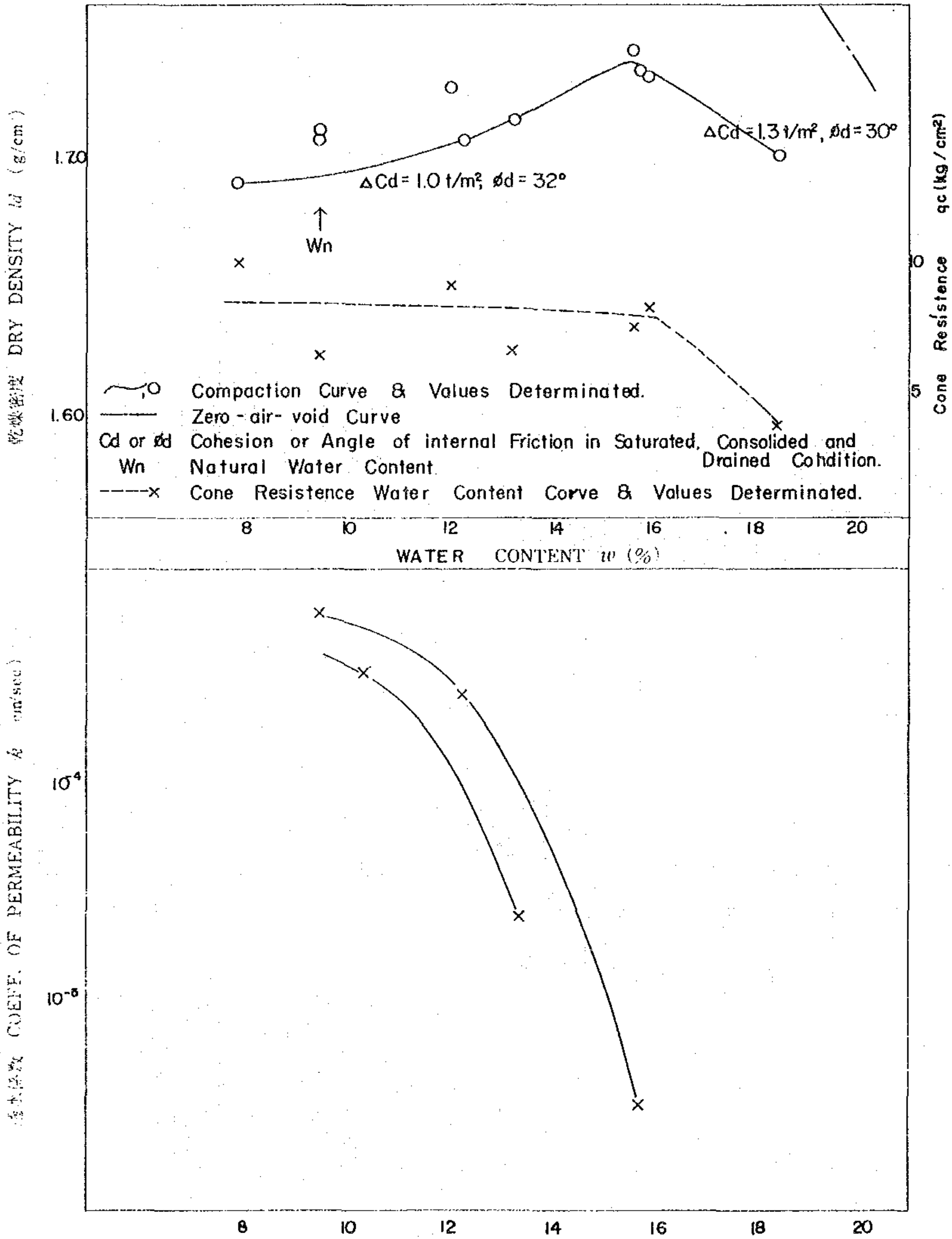


Fig.4.11. Stability Analysis of Protection Dike

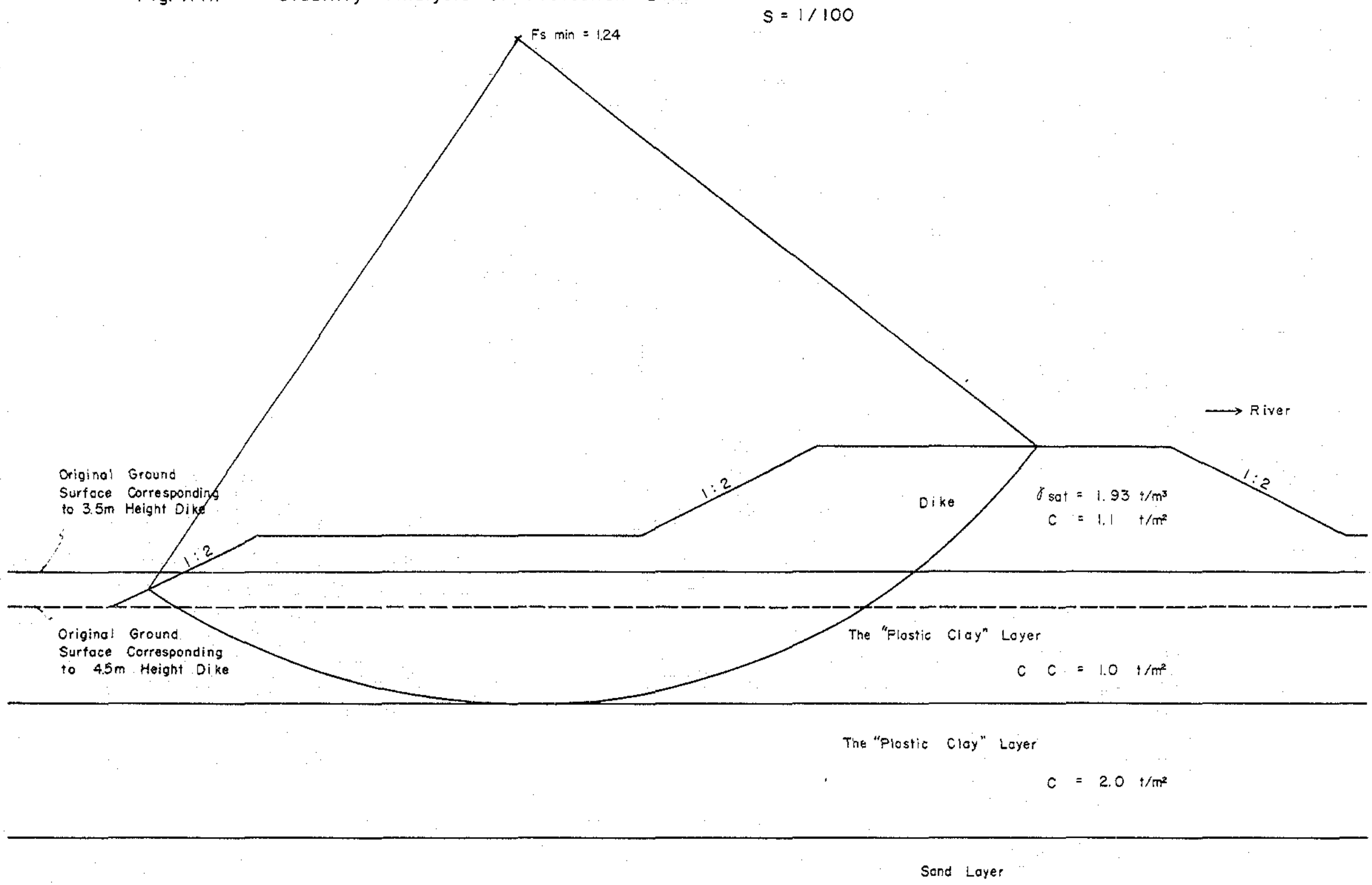
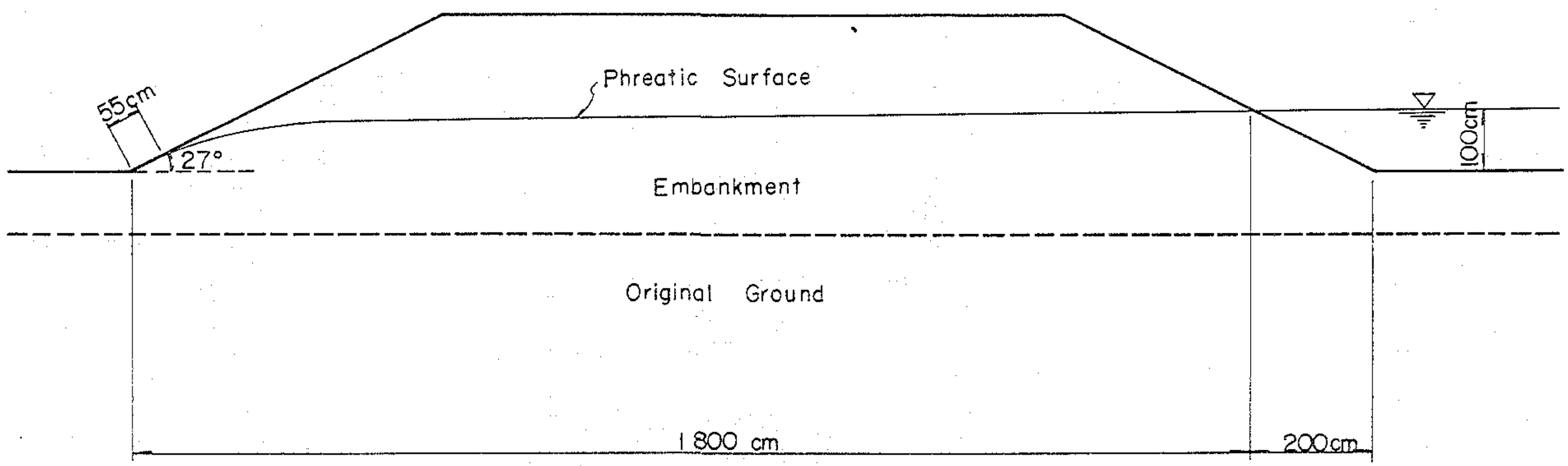


Fig. 4.12. Phreatic Surface



ANNEX V

SOIL AND CLASSIFICATION

ANNEX V

SOIL AND LAND CLASSIFICATION

Tables

V. SOIL AND LAND CLASSIFICATION

5.1 Procedure of Works and Work Progress

5.1.1 Field Survey

The field works were carried out by the use of the contour map on a scale of 1/50,000 along with the aerial photographs on scales of 1/25,000 and 1/50,000 provided by the Government.

The exploratory pits were set up at 120 locations in total as the representative sites of the major soil groups in the project area. The pits were dug to a depth of two meters. Soil profiles deeper than two meters were checked by hand augering at the major locations. Besides, hand augering tests at 66 locations were additionally carried out to confirm the extent of the soils.

The profile descriptions were basically in accordance with the procedure defined by U.S.D.A., Soil Conservation Service, 1973.

In the course of profile examination, about 150 soil samples were taken from the major horizon or layers in various soil groups and then their pH and EC were measured at the site. Besides, the intake rate and permeability of soils were measured on evaluating the irrigability and drainability of the soils. The measurement was made by means of dry auger-hole method under uncompressed and undrained conditions.

The procedures of field works are listed in Table 5.1.

5.1.2 Laboratory Works

On the basis of the results of the profile examination and pH and EC measurements, some 80 representative soil samples (30 locations) were selected and sent to Tokyo for the chemical and physical analyses. In the laboratory, the items in Table 5.2 were examined in accordance with the methods approved in general.

5.1.3 Procedure of Soil and Land Capability Classification

As requested by the Soil Survey Department in Wad Medani Research Cooperation, Ministry of Agriculture, Food and National Resource, Sudan, the soils were grouped in accordance with the Soil Taxonomy compiled by U.S.D.A., Soil Conservation Service, 1973.

In reference to the Soil Taxonomy, the following terms of soil features were used for the soil classification in the Gasaba plain.

1) Parent materials or lithological materials;

   a) Recent alluvial depositions, having more than 60 % of clay matrix and a few percent of fresh organic matters or humus.

   b) Old alluvium, having more than 60 % of clay matrix and a small percentage of organic carbon.

2) Climatic regime particularly on the earth temperature, such as Thermic, Hyperthermic, etc.

3) Diagnostic profile features;

   a) Surface horizon.

      - Soils in each group have different soil colour, humus contents and structures.

   b) Sub-surface horizon, lying within 150 cm below the ground surface.

      - Cracking in the profile which mainly depends on the moisture regime, co-relating with the terms of shrinkage and swelling characteristics of soils.
      - Gleyic horizon affected by the surface water stagnation.
      - Gleyic horizon affected by the groundwater fluctuation.

   c) Topographic conditions, particularly on the micro-relief characterized by the Gilgai formation.

As for the land suitability classification, "Manual for Land Suitability Classification for the Agriculture, Part II, Guidelines for Soil Survey Party Chiefs, Wad Medani, 1976" was applied in order to contribute to the national programme of Sudan on the land classification for agricultural development which has been now undertaken by the Government.

In this land classification, rice is selected as the specific crop, and full mechanization and irrigation operation are foreseen in the future development conditions in accordance with the project objectives requested by the Government of Sudan. With the realization of the above conditions, the land features were evaluated by the present soil and land conditions, and thereafter, degrees of land potential for the rice production were formulated in the Land Suitability Classification Map.

In the project area, the following soil features and land categories are essential factors on evaluating the land suitability for rice production.

(1) Heavy soil textural quality
(2) Slightly to moderately strong alkalinity
(3) Very low permeability and low intake rate
(4) Relativety deep groundwater
(5) Deficiency of organic matters and nitrogen
(6) Free from salinity problem and soil toxicity
(7) Very gentle undulation and/or nearly flat topography
(8) Gilgai micro-relief in certain extent
(9) Free from dense vegetation and other land covers

5.2 General Conditions of Soils

The soils in the Gasaba plain are derived from the old clayey alluvium deeply deposited by the White Nile. The clayey alluvium generally including clay fractions of more than 60 % of soil and a few percent of humus throughout the profile and such conditions uniformly extend all over the plain.

According to the information obtained from the local inhabitants, almost all the lands in the Gasaba plain had been extensively cultivated by the local inhabitant without serious problem of flooding of the White Nile and its tributaries.

Eversince the completion of the Jebel Aulia Dam in 1937, however, all the lands in the plain have been submerged seasonally from August to the end of March. Under such circumstances, most soils in the

Gasaba plain are grouped in the Vertisols under the arid climates[/1] except some narrowly developed lands covered by the Entisols along the rivers. A greater part of these Vertisols has been put under the process of the hydromorphic weathering caused by the waterlogging and rising groundwater.

According to the soil taxomony system by U.S. Department of Agriculture, the 4 soil groups in the Gasaba plain are identified as in the followings.

The soils of group I and II are correlated with the Vertisols in Order, the Torrerts in Suborder, the Typic Torrerts in Great Soil Group, the Peleustollic Torrerts in Subgroup, and then the former soils are correlated with the Very fine clayey-Mixed-Deeply cracked-Hyperthermic-Peleustollic Torrerts and the latter soils are correlated with the Very fine clayey-Mixed-Shallowly cracked-Thermic-Peleustollic Torrerts in Family at the lower category of soil classification.

While, the both soils of group III and IV are correlated with the Entisols in Order. Then, the soils of group III are correlated with the Aquents in Suborder, the Fluvaquents in Great Soil Group, the Vertic Fluvaquents in Subgroup, and the Very fine clayey-Mixed-Thermic-Vertic Fluvaquents in Family, and the soils of group IV are correlated with the Fluvents in Suborder, the Udifluvents in Great Soil Group, the Vertic Udifluvents in Subgroup, and the Fine clayey-Mixed-Thermic-Vertic Udifluvents in Family.

The development of these identified soil groups is shown in Table 5.4 and 5.5.

To speak in general, the soils of the Gasaba plain are very fine clay in texture, mild to moderate in alkalinity, relatively poor in humus, rich in mineral elements, free from salinity and chemical toxicity, high water holding capacity and very low permeability.

/1: The Gasaba plain is characterized by the "Arid climate", having summer rain and warm winter (Al.1), according to the schematic classification on the zonal climate in Sudan which is defined in Land Suitability Classification for Agriculture, Part II, Wad Medani, 1976.

It is noteworthy that the most Vertisols have common specific characteristics of making cracking and gilgai micro-relief on the surface where the lands are dried up.

5.3 Soil Classifications

5.3.1 Soil classification

On the basis of the remarkable soil features the soils in the Gasaba plain are broadly classified into four soil groups. (The diagnostic characteristics and profile features of each soil group are shown in Table 5.3.)

5.3.2 Main Soil Features of Each Soil

(1) Soils of group I and II

Both the soils of group I and II are identified with the Peleustollic Torrerts in Subgroup. These soils are the Vertisols generally developed under arid and/or semi-arid climatic conditions. They are derived from old alluvium of the White Nile and have soil matrix colour ranging between 10 YR 3/1 (brownish black) and 2.5Y 4/2 (black grayish yellow) throughout the upper profile of 100 cm deep; 60% or more clay are contained in soils of all horizons or layers to a depth of 150 cm or more; intersecting slickensides are shown on parallel-piped structural aggregates of profile; gilgai micro-relief is formed on the surface of land.

Soil crackings as the most remarkable characteristics of the Vertisols develop densely in the profile. The depth of cracks varies from 30 cm to 100 cm or more, depending on the soil moisture contents.

Earth thermal regime of soils might be directly influenced by water standing and its long duration. According to the meteological data obtained from the Kosti Meteological station, the earth thermal regime in these soils is categorized into Thermic (annual soil temperature at a depth of 50 cm is ranged between $15^{o}C$ and $22^{o}C$) and Hyperthermic ($22^{o}C$ or more).

Based upon their general features, the soils of group I and II are identified with the following Families at the lower category of classification.

(1)-A. Group I ... Very fine clayer-Mixed-Deeply cracked-Hyperthermic Peleustollic Torrerts.

(1)-B. Group II ... Very fine clayey-Mixed-Shallowly cracked, Thermic-Peleustollic Torrerts.

(1)-A. Group I ... Very fine clayer-Mixed-Deeply cracked-Hyperthermic-Peleustollic Torrerts.

The soils of this group develop over the lands in the vicinity of Abu Araki and Um Jerr islands. In the Gasaba plain, the soils are only found spottily on the old remnant levees with elevation of 376.7 m or some more. Most lands are sparsely covered by acacia scrub with some cover grasses. The lands are mostly free from the flooding or very shallowly submerged in a short period when the White Nile is high in flood.

The horizon sequence is A11/A12/A13 or A2 with diffuse and/or unclear boundaries in common. The surface soils (A11) are brownish black to brownish gray in colour, very fine clay in texture, coarse sub-angular blocky in structure. They gradually change to the A12 horizon which is heavy clay in texture with few and fine lime concretions and very coarse blocky in structures. The soil colour, when moistened, is mostly similar to or slightly darker than that of the A11 horizon in general. The A13 or A2 horizon occurs at the depth of 120 to 150 cm and its thickness is more than 100 cm common. The soils of the A13 and/or A2 horizon are brownish gray (10 YR 5/1) to dark greyish yellow (2.5 YR 4/2) in colour; heavy clay in texture and massive in structure. Below the A13 and/or A2 horizon, a very compact sandy layer underlies in general.

Generally speaking, the soils of this group are very compact and firmly consolidated throughout the solum except thin top soil with rather friable consistence due to self-churning and self-mulching specific to the Vertisols. They have very hard to extremely hard when dry, while friable and soft when wet. They have very high water holding capacity, while their permeability is very low ranging 1.5×10^{-5} cm/sec to 7.1×10^{-6} cm/sec and their basic intake rate is very low.

As for the chemical properties, the soils are slightly alkaline with pH values ranging between 7.8 and 8.4 throughout the profile. Total organic carbon is 1.0 % or less in the A11 and A12 horizons and 0.5 % or less in the lower horizons. EC values are mostly less than 1.0 m. mho/cm/25°C throughout the profile. Cation exchange capacity ranges between 35 and 50 m.eq. and its capacity is mostly saturated by the bases, in which calcium is dominant.

(1)-B. Group II ... Very fine clay-Mixed-Shallowly cracked-Thermic-Peleustollic Torrerts

The soils of this group extend over the land where the elevation ranges between 376.2 m and 376.7 m. The lands are, more or less, submerged with stagnant flood water from August to the end of March. Since the soils mostly hold favorable moisture level for vegetation during the dry period, all the lands of this soil group are densely covered by short wild grasses.

They have A11/A12/A2g horizon sequence, in general. In both the A11 and A12 horizons with a depth of about 60 cm, the soils have brownish black to grayish yellow colour when wet; weakly subangular blocky structures. Their texture is heavily fine and they are firmly compacted and consolidated. Cracking is generally shallower than 60 cm in depth. The A2g horizon to a depth of 200 cm or more is a gleyic horizon influenced by a seasonal fluctuation of groundwater table and includes many distinct ferruginous mottles (10YR 5/6 to 5Y 6/6) and some fine manganese concretions.

Regarding the chemical properties, the soils are moderately alkaline ranging between 8.0 and 8.5 in pH values throughout the profile, while their EC values are mostly less than 1.0 m.mho/cm/25°C, indicating they have no serious salinity problems at present. Total organic carbon is estimated at 3.5 % in their surface soils, while less than 0.5 % in sub-soils. Cation exchange capacity is about 40-45 m.eq. which is mostly saturated with bases. Nitrogen is deficient in these soils. As for the hydrodynamic features, the soils of this group have a high water holding capacity, but very low permeability of 1.8×10^{-6} cm/sec to 2.4×10^{-6} cm/sec and low basic intake rate.

In the light of soil features, both the soils of group I and II correlated with the Peletollic Torrerts are usable for the irrigated rice cultivation providing proper irrigation farming practices could be applied satisfactorily. The other common tropical and/or semi-tropical crops can be also grown on these soils by applying adequate farming practices.

(2) Group III ... Very fine clay-Mixed-Thermic-Vertic Fluvaquents

The soils of this group are primarily wet soils which mainly extend over the low lying area where the water deeply stands for 8 months from August to March. The terrain of the land is nearly level with partial depression. At present, most of the land is covered with swampy grasses, such as reed (Phragmites communis TRINIUS), reed-mace (Typha L.) sedge (Cyperus rotundes L.) etc. and water hyacinth (Eichhornia KUNTH) in the depressed land.

They are also originated from the old alluvium of the White Nile. The soils are wet or moist all the time, and then, gleization is proceeding throughout the profile due to high groundwater level. Their horizon sequence is A1/A2g/A3g in common. The A1 horizon is usually less than 5 cm in thickness. The soils in this horizon are somewhat dried and very shallowly cracked in the dry season. The A2g horizon is also thin, 5 to 10 cm in thickness. The soils is generally put under strong reductive conditions, and then, shows greenish gray (5G 5/1) colour. The A3g horizon is usually deeper than 200 cm. The soil is olive (5Y 5/4) to grayish olive (7.5Y 5/2) mixed with gray (5Y 5/1) in colour when wet. Ferruginous mottlings are found very rarely in this horizon.

Throughout the profile, the soils consist of very clayey compacted matrix. The consistence of the soils is relatively friable when wet, while very hard when dry. Their permeability is as low as from 1.3×10^{-6} cm/sec to 7.3×10^{-7} cm/sec in common.

As for the chemical features, the soils are slightly to moderately alkaline ranging from 7.7 to 8.5 in pH value and have no serious salinity problems at present. Organic matters or humus content in the surface soil is about 5.4 % (2.3 % of organic carbon) on an average, but the content abruptly decrease to 1.0 % or less in the sub-soils. Cation exchange capacity is ranged from 40 to 46 m.eq. per 100 gr of soil, and most of the soils are fully saturated by bases in which calcium accounts for more than 50 % of the total.

The poor natural drainage condition is the biggest constraint upon the crop production in this area. In effect, however, the cultivation of rice can be done profitably provided that flood control and drainage systems would be well facilitated and adapted irrigation farming practices could be properly performed.

(3) Group IV ... Fine clayey-Mixed-Thermic-Vertic Udifluvents

The soils of this group are the recent alluvial soils which have no diagnostic characteristics except heavy clayey texture and a very small content of fresh organic matters in the surface soil on profile. These soils are mainly developed narrowly along the White Nile. The land of these soils is usually flooded deeply for about 9.5 months from August to the next mid-April. For only about a short period of 2.5 months, the land is covered by velvet grasses.

In usual, the surface soils have dark brownish colour (10YR 3/4) which gradually changes to yellowish gray (2.5 Y 5/1) with the depth. The soils have mild to moderate alkalinity ranging from 7.8 to 8.5 in pH value; no serious salinity problem at present (EC values is less than 0.5 m. mho/cm/25^{o}C). Total organic matter is estimated at a few percent of the soil.

In the terms of the earth temperature, the soil is in the thermic regime. Their permeability is very low ranging from 1.3 x 10^{-6} cm/sec to 1.9 x 10^{-6} cm/sec. The moisture retaining capacity is generally high throughout the profile.

5.4 Land Classification

5.4.1 Specification of Land Classification

The degree of land suitability of the project area is examined in accordance with the "Manual for Land Classification for Agriculture, Part II, Guide Line for Soil Survey Party, Wad Medani, 1976." In this examination, the lands are graded with emphasis on their capability for machanized and irrigated farming under the condition of project implementation.

Of all the specification of land evaluation defined in the above Manual, the following factors are taken up as the essentials on evaluating the land suitability in the project area.

1) inundation (i); limitation caused by seasonal flooding

2) topography (t); limitation mainly by the unsuitable land elevation for the economical gravity irrigation.

3) alkalinity (a); limitation due to alkaline reaction of soil. No sodic constraint exists in the project area.

4) fertility (f); limitation due to deficiency of nitrogen and organic matters in soils.

5) Vertisolic feature (v); limitation due to high contents of clay in soil matrix which have large swelling characteristics and friable, very plastic and very sticky consistence when wet, while shrinking characteristics and very hard and very firm consistence when dry.

Among the five conditions in the above, inundation (i) is the biggest limiting factor on the agricultural development in the project area. In order to successfully develop the objective area, high capital investment will be required for the flood protection.

Topographic constraint is the land elevation of more than 376.7 m where is unsuitable for the economical gravity irrigation. It is considered that the gilgai micro-relief in the area is not so serious problem for the preparation and arrangement of rice field.

As for the chemical constraints (a) and (f) of soils, it is considered that the defficiency of the fresh organic matters and nitrogen can be supplemented by the application of manure and chemical fertilizers. However, it is noticed that those fertilizing efficiency, especially of nitrogen, will be reduced owing to the diammonification proceeded with alkaline reaction of soils.

Vertisolic (v) conditions are generally accepted to the usable for rice cultivation. However, the farm mechanization will be restricted, to some remarkable extent, due to specific unfavourable characteristics of soils.

Some agronomic constraints such as climate of low humidity (c), and successive wetness or low permeability are found in the project area. As far as the rice cultivation is concerned, however, these conditions will be negligible for this land classification because these conditions would be improved by the proper application of adapted farming technics practically. Conditions of such erosion hazard (e), salinity problem (s), surface gravel and stoniness (g), limitation of effective soil depth and stoniness in sub-soil layer (d) are absent or negligible in the area.

Taking into account the soil and land conditions mentioned in the above and also into consideration the plant physiological characteristics of rice, the terms of land classification and their specific degree corresponding to the land suitability classes are established and summarized in the following Table 5.6.

5.4.2 Land Classification

On the basis of the above specification of land suitability, the lands of each soil group are evaluated as shown in Table from 5-9 to 5-12.

In this land evaluation, all the lands in the objective area estimated into highly (S_1) to moderately suitable (S_2) for irrigated rice cultivation, in the light of the soil chemical and physical characteristics. While, in view of their usability for farm mechanization, their land grades might be down into moderately (S_2) to marginally suitable (S_3) in land grade due to limitation caused by the soil having very hard consistence when dry, and very plastic and very sticky consistence when wet. Besides, from the irrigation engineering point of view, the land having elevation at more than 376.7 m is estimated into economically unsuitable (N_1) for gravity irrigation. In the low lying area, the land which is expected to also be marginally suitable (S_3) in grade because of high capital investiment required for flood protection and/or rather expensive management cost for surface drainage during the cropping season.

With the comparative land evaluation in the above, the lands in the objective area are classified into four land suitability classes as shown in Table 5.7 and 5.8.

There is no Class S_1: Highly suitable land in the objective area.

Class S_2; Moderately suitable land is the land which is expected to be sufficiently high productivity and profitability.
There are moderate limitations mainly caused by alkaline-reaction and vertisolic characteristics of soils. Both factors are likely to reduce crop yield and to increase recurrent cost for production and conservation of soil and land.

Class S_3: Marginally suitable land is the land which can be also expected to have sufficient productivity for the defined rice cultivation, although there are limitations which in aggregate considerably reduce the crop yield and/or increase recurrent cost for production and soil conservation. Seasonal inundation (i) inclusive of inland flooding due to low lying topography is the biggest constraint in this land class.

Class Sc: Conditionally suitable land is the land which is also expected to obtain sufficient crop yield in the defined land use, if the flood control is properly made by diking. In reality, however, it would require a large capital investiment for this purpose.

Class N_1: Currently unsuitable land is the land in which the land productivity is also expected rather high to be similar to the land in Class S_2. However, topographic condition is unsuitable for the gravity irrigation system specified in this development plan. Thus, the land graded in this class is precluded from the arable land.

Table 5.1 Field Works

	Work items	Work quantity	Procedure of works
1.	Profile Survey		
	- by pit	- 120 locations	- Digging pit to a depth of about 2 m
	- by auger-hole	- 66 locations	- Augering to a depth of about 1.5 m
2.	Samplings	- 151 samples	- Samples were taken from 57 locations
3.	pH Measurement	- 151 samples	- Glass electrode meter method with 1:2.5 soil-water suspension
4.	EC Measurement	- 151 samples	- Electrode meter method with 1:5 soil-water extraction
5.	Permeability Measurement	- 20 locations	- Dry auger - hole method using 1.0 m deep and 15 cm diameter borehole

Table 5.2 Laboratory Works

	Test items	Work quantity	Test method
1.	Electric Conductivity (EC_1)	80 samples	- Electrode meter method with 1:1 soil-water extraction
2.	Exchangeable Na^+ and K^+	80 samples	- Atomic absorption spectro-photo-meter method with leaching extraction by 1N - ammonium acetate
3.	Exchangeable Ca^{++} and Mg^{++}	80 samples	- Atomic absorption spectro-meter method with leaching extraction by 1N - sodium chloride
4.	Cation Exchange Capacity	80 samples	- Centrifugal method with leaching extraction by 1N - ammonium and sodium acetate
5.	Total Carbon or Humus	80 samples	- Tyurin's chromic acid oxidation method
6.	Total Nitrogen	80 samples	- Micro Kjeldahl's method
7.	Available Phosphate	80 samples	- Truog's method with 1:100 soil - 0.025N sulfuric acid extraction
8.	Specific Gravity	10 samples	- Picno meter method
9.	Particle Size Analysis	10 samples	- Pipet method
10.	Permanent Wilting Point (pF = 4.2)	10 samples	- Centrifugal method

Table 5.3 Soil Features of Each Soil Group

Soil features		Soil Groups			
		Group I	Group II	Group III	Group IV
1.	Lithological Materials	Old alluvium	Old alluvium	Old alluvium	Recent alluvium
2.	Texture	Heavy clay	Heavy clay	Heavy clay	Heavy clay
3.	Soil Colour	Brownish gray (1.5 % of humus)	Brownish black (6.5 % of humus)	Gray (5.4 % of humus)	Yellowish gray (1.9 % of humus)
4.	Crackings	Wide & deep	Wide & rather deep	Narrow & shallow	Narrow & very shallow
5.	Moisture Regime	Dry	Dry	Wet	Wet
6.	Special Soil Formation	Ca^{++} accumulation	Ca^{++} accumulation	Gleization	-
7.	Micro-relief	Gilgai	Gilgai	-	-
8.	Earth Thermal Regime	Very high (22°C or more)	high (15°C-22°C)	high (15°C-22°C)	high (15°C-22°C)
9.	Permeability	very low	very low	very low	very low

Table 5.4 Soil Groups in Higher Categories

(GROUP)	ORDER	SUB-ORDER	GREAT SOIL GROUP	SUB-GROUP
I	Vertisols	Torrerts 1)	Typic Torrerts	Peleustollic-Torrerts
II	Do	Do	Do	Do
III	Entisols	Aquents 2)	Fluvaquents	Vertic-Fluvaquents
IV	Do	Fluvents 3)	Udifluvents	Vertic-Udifluvents

Note: 1) Torrerts are the Vertisols which develop under the arid and/or semi-arid climatic conditions. They are classified into Grumusols defined by the U.S.D.A. standard in 1938 and modified in 1951.

2) Aquents are the wet Entisols. They are considered Low Humic Gley soils in the 1938 U.S.D.A. classification and modified in 1949.

3) Fluvents are the Entisols formed in recent waterdeposited sediments. They were called Alluvial soils in the 1938 classification defined by U.S.D.A.

Table 5.5 Soil Groups in Lower Categories

(GROUP)	SUB GROUP	SOIL FAMILY	EXTENT AREA (ha)
I	Peleustollic Torrerts	- Very fine clayey, mixed, hyperthermic, deeply cracked soils	5,240 (26.2%)
II	Do	- Very fine clayey, mixed, thermic, shallowly cracked soils	9,640 (48.2%)
III	Vertic Fluvaquents	- Very fine clayey, mixed, thermic soils	3,920 (19.6%)
IV	Vertic Udifluvents	- Very fine clayey, mixed, thermic soils	1,200 (6.0%)
		TOTAL	20,000 (100 %)

Note: 1) Cracking conditions are tentatively classified into (a) deeply cracked - cracking depth deeper than 60 cm and (b) shallowly cracked - cracking depth shallower than 60 cm.

2) Earth temperature regime is assumed on the basis of the air temperature at Kosti Station, 50 km far from the Gasaba plain.

Table 5.6 Terms of Land Classification and Their Specific Degree

ORDER	SUITABLE			UNSUITABLE
SUITABILITY CLASS	HIGHLY SUITABLE (S1)	MODERATELY SUITABLE (S2)	MARGINALLY SUITABLE (S3)	CURRENTLY (N1) & PERMANENT (N2)
LAND QUALITY				
1. Soil Fertility				
- Organic carbon (%)	more than 0.75	0.15 - 0.75	less than 0.15	less than 0.15
- Total nitrogen (%)	more than 0.05	0.01 - 0.05	less than 0.01	less than 0.01
- Available phosphate	moderate - high	low	very low	very low
- Cation exchange Cap. (m.e)	more than 10	3 - 10	less than 3	less than 10
- Potassium (m.e)	more than 0.2	0.1 - 0.2	less than 0.1	less than 0.1
- Base saturation degree (%)	more than 40	10 - 40	less than 10	less than 10
2. Conditions for Seedling Establishment				
- Soil structure & consistence	granular/friable	subangular/firm	blocky/very firm	massive/extremely firm
- Susceptibility to surface sealing	more - slight	moderate	strong	strong
3. Workability				
- Consistence when wet	slightly sticky and plastic	sticky and plastic	very sticky and plastic	very sticky and plastic
- Consistence when dry	loose to moderate	hard	very hard	extremely hard
4. Possibility for Mechanization				
- Micro-relief (± cm)	less than 10	10 - 25	25 - 40	more than 40
- Land form & slope (%)	flat-undulating (0 - 8)	rolling (8 - 16)	hilly (16 - 30)	steeply dissected more than 30
- Cone penetration (kg/cm^2)	more than 4	3 - 4	less than 3	less than 3
5. Alkalinity & Sodicity				
- PH	less than 8.0	8.0 - 8.5	8.5 - 9.0	more than 9.0
- Exchangeable sodium %	less than 10	10 - 20	20 - 35	more than 35
- Sodium absorption ratio	less than 8	8 - 18	18 - 38	more than 38
6. Capability for Maintaining Surface Water				
- Permeability	less than 1.4×10^{-4} cm/sec	$5.5x10^{-4}$-$1.3x10^{-4}$ cm/sec	$1.6x10^{-3}$-$5.5x10^{-4}$ cm/sec	more than $1.6x10^{-3}$ cm/sec
- Drainability	impertect - poor	poor	moderately good	good

Table 5.7 Land Suitability Classification

Soils	Order	Class	Sub-class	Unit
Peleustollic Torrerts (1)	Unsuitable (N)	Currently unsuitable (N_1)	N_1 tav	t (4)
Peleustollic Torrerts (2)	Suitable (S)	Moderately suitable (S_2)	S_2av	a(2)v(3)
Vertic Fluvaquents	Suitable (S)	Marginally suitable (S_3)	S_3wiav	W(3)i(3)a(2)v(3)
Vertic Udifluvents	Suitabld (S)	Conditionally suitable (Sc)	Scwiav	W(3)i(4)a(2)v(3)

Note: Greater part of the Peleustollic Torrerts (1) will be included into the Class S_2.

Table 5.8 Land Classes and Their Proportional Extent

	Area (ha)	Proportional extent (%)
Class S2: Moderately suitable land	13,180	65.9
Class S3: Marginally suitable land	3,920	19.6
Class Sc: Conditionally suitable land	1,200	6.0
Class N_1: Currently unsuitable land	1,700	8.5
Total	20,000	100.0

Table 5.9 Estimation of Land Class for Irrigated Agriculture

ORDER	SUITABLE												UNSUITABLE			
SUITABILITY CLASS	HIGHLY SUITABLE (S1)				MODERATELY SUITABLE (S2)				MARGINALLY SUITABLE (S3)				(N1 or N2)/2			
LAND QUALITY / LAND USE TYPE/1	I1	I2	I3	I5	I1	I2	I3	I5	I1	I2	I3	I5	I1	I2	I3	I5
Chemical Soil Fertility	1-2	1	(1-2)	1-2	3	2	3	3	4	3	4	4	4	4	4	4
Conditions for See ling Establishment	1-2	1-2	1-2	1-3	3	3	3	4	4	4	(4)	4	4	4	4	4
Workability	-	1	1-2	-	-	2	3	-	-	3	(4)	-	-	4	4	-
Possibility for Mechanization	1	-	1	-	2	-	2	-	3	-	(3)	-	4	-	4	-
Salinity	1	1	(1)	1	2	2	2	2	3	3	3	3	4	4	4	4
Alkalinity and/or Sodicity	1	1	1	1	2	2	(2)	2	3	3	3	3	4	4	4	4
Capacity for Maintaining Surface Water	-	-	(1)	-	-	-	2	-	-	-	3	-	-	-	4	-
Topography for Gravity Irrigation	1	1	1	1	2	2	2	2	3	3	3	3	4	4	(4)	4
Soil Drainability (surface)	1	1	(1)	1	2	2	2	2	3	3	3	3	4	4	4	4

Note; /1 I = irrigated agriculture; I1 = high capital intensity; I2 = Low capital intensity I3 = paddy rice I5 = tree crop

/2 Class N1; currently unsuitable; class N2 = permanently unsuitable in class. The land of N2 is generally reserved for miscellaneous land types and other land with very severe, incurring limitations for agricultural use.

Soil Group

Vertisols in order, Torrerts in sub-order, Peleustollic torrerts in sub-group, Very fine clayer, mixed, hyperthermic, deeply cracked Soils in soil family.

Topography

Very gently undulating (more than 367.2 m in elevation)

Vegetation

Acacia scrub and trees

Table 5.10 Estimation of Land Class for Irrigated Agriculture

ORDER	SUITABLE												UNSUITABLE			
SUITABILITY CLASS	HIGHLY SUITABLE (S1)				MODERATELY SUITABLE (S2)				MARGINALLY SUITABLE (S3)				(N1 or N2)/2			
LAND QUALITY / LAND USE TYPE/1	I1	I2	I3	I5	I1	I2	I3	I5	I1	I2	I3	I5	I1	I2	I3	I5
Chemical Soil Fertility	1-2	1	(1-2)	1-2	3	2	3	3	4	3	4	4	4	4	4	4
Conditions for Seedling Establishment	1-2	1-2	1-2	1-3	3	3	3	4	4	4	(4)	4	4	4	4	4
Workability	-	1	1-2	-	-	2	3	-	-	3	(4)	-	-	4	4	-
Possibility for Mechanization	1	-	1	-	2	-	2	-	3	-	(3)	-	4	-	4	-
Salinity	1	1	(1)	1	2	2	2	2	3	3	3	3	4	4	4	4
Alkalinity and or Sodicity	1	1	1	1	2	2	(2)	2	3	3	3	3	4	4	4	4
Capacity for Maintaining Surface Water	-	-	(1)	-	-	-	2	-	-	-	3	-	-	-	4	-
Topography for Gravity Irrigation	1	1	(1)	1	2	2	2	2	3	3	3	3	4	4	4	4
Soil Drainability (surface)	1	1	(1)	1	2	2	2	2	3	3	3	3	4	4	4	4

Soil Group

Vertisols in order,
Torrert in sub-order
Peleustollic torrerts in sub-group
Very fine clayey, mixed, hydrothermic, shallowly cracked soils in soil family.

Topography

Very gently undulating
(376.2 m - 377.2 m in elevation)

Vegetation

Dense shoot grass

Note: /1 I = irrigated agriculture; I1 = high capital intensity; I2 = Low capital intensity I3 = paddy rice I5 = tree crop

/2 Class N1; currently unsuitable; class N2 = permanently unsuitable in class.
The land of N2 is generally reserved for miscellaneous land types and other land with very severe, incurring limitations for agricultural use.

Table 5.11 Estimation of Land Class for Irrigated Agriculture

ORDER	SUITABLE												UNSUITABLE			
SUITABILITY CLASS	HIGHLY SUITABLE (S1)				MODERATELY SUITABLE (S2)				MARGINALLY SUITABLE (S3)				(N1 or N2)/2			
LAND QUALITY / LAND USE TYPE/1	I1	I2	I3	I5	I1	I2	I3	I5	I1	I2	I3	I5	I1	I2	I3	I5
Chemical Soil Fertility	1-2	1	(1-2)	1-2	3	2	3	3	4	3	4	4	4	4	4	4
Conditions for Seedling Establishment	1-2	1-2	1-2	1-3	3	3	3	4	4	4	(4)	4	4	4	4	4
Workability	-	1	1-2	-	-	2	3	-	-	3	(4)	-	-	4	4	-
Possibility of Mechanization	1	-	1	-	2	-	2	-	3	-	(3)	-	4	-	4	-
Salinity	1	1	(1)	1	2	2	2	2	3	3	3	3	4	4	4	4
Alkalinity and/or Sodicity	1	1	1	1	2	2	(2)	2	3	3	3	3	4	4	4	4
Capacity for Maintaining Surface Water	-	-	(1)	-	-	-	2	-	-	-	3	-	-	-	4	-
Topography for Gravity Irrigation	1	1	(1)	1	2	2	2	2	3	3	3	3	4	4	4	4
Soil Drainability (surface)	1	1	1	1	2	2	2	2	3	3	(3)	3	4	4	4	4

Soil Group

Entisol in order
Aquents in sub-roder
Fluvaquents in great soil group
Vertic fluvaquents in sub-group
Very file clayey, mixed, thermic, in soil family.

Topography

Low laying land
(376.2 - 375.7 m in elevation)

Vegetation

Swampy grasses

Note; /1 I = irrigated agriculture; I1 = high capital intensity; I2 = Low capital intensity I3 = paddy rice I5 = tree crop

/2 Class N1; currently unsuitable; class N2; permanently unsuitable in class.
The land of N2 is generally reserved for miscellaneous land types and other land with very severe, incurring limitations for agricultural use.

Table 5.12 Estimation of Land Class for Irrigated Agriculture

ORDER	SUITABLE												UNSUITABLE			
SUITABILITY CLASS	HIGHLY SUITABLE (S1)				MODERATELY SUITABLE (S2)				MARGINALLY SUITABLE (S3)				(N1 or N2) /2			
LAND QUALITY / LAND USE TYPE /1	I1	I2	I3	I5	I1	I2	I3	I5	I1	I2	I3	I5	I1	I2	I3	I5
Chemical Soil Fertility	1-2	1	(1-2)	1-2	3	2	3	3	4	3	4	4	4	4	4	4
Conditions for Seedling Establishment	1-2	1-2	1-2	1-2	3	3	(3)	4	4	4	4	4	4	4	4	4
Workability	-	1	1-2	-	-	2	3	-	-	3	(4)	-	-	4	4	-
Possibility for Mechanization	1	-	1	-	2	-	(2)	-	3	-	3	-	4	-	4	-
Salinity	1	1	(1)	1	2	2	2	2	3	3	3	3	4	4	4	4
Alkalinity and/or Sodicity	1	1	1	1	2	2	(2)	2	3	3	3	3	4	4	4	4
Capacity for Maintaining Surface Water	-	-	(1)	-	-	-	2	-	-	-	3	-	-	-	4	-
Topography for Gravity Irrigation	1	1	(1)	1	2	2	2	2	3	3	3	3	4	4	4	4
Solid Drainability (surface)	1	1	1	1	2	2	2	2	3	3	(3)	3	4	4	4	4

Soil Group

Entisols in order
Fluvents in sub-roder
Udifluvents in great soil group
Vertic Udifluvents in sub-group
Very fine clayey, mixed, thermic in soil family.

Topography

Low laying land (less than 375.7 m in elevation)

Vegation

Velvet grass in some area

Note; /1 I = irrigated agriculture; I1 = high capital intensity; I2 = Low capital intensity I3 = paddy rice I5 = tree crop

/2 Class N1; currently unsuitable; class N2 = permanently unsuitalbe in class.
The land of N2 is generally reserved for miscellaneous land types and other land with very severe, incurring limitations for agricultural use.

Table 5.13 Test Results on Soil Physical Properties

Pit No. & Horizon	Particle Size Distribution coarse sand (%)	fine sand (%)	silt (%)	clay (%)	Texture /1	Specific gravity
6-1	5.2	20.7	11.3	62.8	Swt	2.54
2	2.8	21.5	12.6	63.1	Swt	2.54
3	3.3	19.8	14.5	62.7	Swt	2.65
4	4.1	20.3	19.9	62.7	Swt	2.71
13-1	4.7	19.5	10.5	65.3	Swt	2.65
2	2.6	20.7	11.3	65.4	Swt	2.71
3	3.3	21.1	10.6	65.0	Swt	2.69
18-1	3.7	23.3	9.6	63.4	Swt	2.71
2	2.5	20.9	10.4	66.2	Swt	2.68
27-1	4.1	21.5	14.3	60.1	Swt	2.64
2	3.1	20.1	13.9	62.9	Swt	2.73
3	4.0	22.0	12.9	61.1	Swt	2.71
53-1	4.8	24.4	11.7	59.1	Swt	2.65
2	4.0	17.9	11.2	66.9	Swt	2.73
3	3.0	22.6	12.8	61.6	Swt	2.81
55-1	5.4	23.6	10.6	60.4	Swt	2.53
2	3.2	20.5	10.5	65.8	Swt	2.71
3	4.2	22.7	11.3	61.8	Swt	2.65
63-1	2.8	21.4	17.7	58.1	Swt	2.76
2	2.9	18.9	29.1	49.1	Swt	2.80
67-1	4.8	21.3	13.5	60.4	Swt	2.63
2	3.5	20.7	12.1	63.7	Swt	2.71
72-1	5.6	22.4	10.6	61.4	Swt	2.73
2	3.1	20.7	9.5	66.7	Swt	2.75
3	3.7	24.5	15.7	56.1	Swt	2.59
82-1	3.6	24.2	13.4	58.8	Swt	2.62
2	2.7	21.7	14.1	61.5	Swt	2.73
3	2.5	20.6	12.9	64.0	Swt	2.75

Note; /1 Classification specified by International Soil Science Association (Tommerup method)

Table 5.18 Test on Moisture Equivalent

Pit No. & Horizon	Bulk density	Field capacity (pF=2.0)	Moisture equivalent (pF=3.0)	Wilting point (pF=4.2)	Air-dried condition (pF=6.0)
16-1	1.14	61.7	47.2	33.8	7.1
2	1.17	65.9	49.8	38.0	8.0
3	1.12	64.5	48.4	36.9	6.6
4	1.0	64.3	45.8	38.8	11.9
30-1	0.97	60.1	49.3	46.0	7.6
2	1.17	75.5	52.9	38.0	8.1
3	1.17	67.2	64.7	40.8	8.4
63-1	1.14	72.1	36.9	31.6	6.3
2	1.18	55.3	45.5	34.0	6.9

Note: Figures in moisture content are weighted percent

Table 5.15 Test Results on Intake Rate and Permeability

Soil Group & Pit No.	Intake Rate (cm/hr)	Permeability (cm/sec)
Group I: Peleustollic Torrerts, Very fine clayey-Mixed-Hyperthermic-Deeply cracked soils		
27	5.29	1.561×10^{-5}
53	3.50	8.735×10^{-6}
67	2.60	1.022×10^{-5}
82	2.10	1.004×10^{-5}
83	1.80	7.126×10^{-6}
Group II: Peleustollic Torrerts, Very fine clayey-Mixed-Thermic-Shallowly cracked soils		
13	24.4	2.471×10^{-6}
18	21.9	2.216×10^{-6}
72	24.4	2.471×10^{-6}
81	19.4	1.965×10^{-6}
89	17.8	1.805×10^{-6}
Group III: Vertic Fluvaquents, very fine clayey-Mixed-Thermic soils		
6	12.8	1.301×10^{-6}
63	10.1	1.026×10^{-6}
66	7.2	7.276×10^{-7}
79	12.9	1.309×10^{-6}
80	12.9	1.311×10^{-6}
Group IV: Vertic Udifluvents, very fine clayey-Mixed-Thermic soils		
36	13.6	1.382×10^{-6}
55	12.8	1.306×10^{-6}
86	17.8	1.805×10^{-6}
118	19.2	1.947×10^{-6}
119	18.7	1.901×10^{-6}

Table Averaged Soil Chemical Properties

Soil Group & Horizon	T-C	T-N	C/N	Humus	PH	C.E.C.	Exchangeable Bases Ca	Mg	K	Na	B.S.D.	Av.P2 05
	(%)	(%)		(%)	(H20)	(m.e)	(me/100 gr)				(%)	(mg/100g)
Group I: Very fine clayey-Mixed-Hyperthermic-Deeply cracked soils, Pelustollic Torrerts, Typic-Torrerts, Torrerts, Vertisols:												
I	0.97	0.08	12.1	1.55	8.1	35.7	24.3	12.1	1.6	1.7	111.2	14.0
II	0.44	0.03	14.7	0.73	8.3	42.8	27.1	11.9	1.1	4.8	104.8	17.8
III	-	-	-		8.3	43.7	24.9	8.5	0.7	5.3	90.2	9.8
IV	-	-	-		8.0	49.4	38.4	10.3	1.0	8.4	117.6	11.1
Group II: Very fine clayey-Mixed-Thermic-Shallowly cracked soils, Pelustollic Torrerts, Typic Torrerts, Torrerts, Vertisols:												
I	3.85	0.32	12.0	6.65	7.7	43.5	27.5	14.4	2.1	2.1	105.9	13.3
II	0.28	0.02	14.0	0.58	8.5	43.1	27.3	14.6	1.5	3.7	109.3	19.6
III	-	-	-		8.4	40.7	19.8	12.1	1.1	6.8	97.7	21.3
IV	-	-	-		8.3	36.8	8.2	8.2	0.6	5.3	60.6	23.0
Group III: Very fine clayey-Mixed-Thermic soils, Vertic Fluvaquents, Fluvaquents, Aquents, Entisols												
I	2.33	0.22	10.6	5.44	7.4	46.0	25.2	16.5	2.1	1.7	98.9	12.3
II	0.58	0.05	11.6	1.12	8.2	42.6	25.7	15.3	1.5	4.0	109.1	28.1
III	-	-			8.5	45.5	27.7	15.4	1.5	4.9	108.9	22.5
IV	-	-			7.9	39.9	23.6	10.3	0.5	5.5	99.9	18.3
Group IV: Very fine clayey-Mixed-Thermic soils, Vertic Udifluvents, Udifluvents, Fluvents, Entisols												
I	1.08	0.09	12.0	1.9	7.4	32.9	18.6	14.9	1.4	0.9	109.1	15.1
II	0.68	0.04	17.0	1.2	7.9	40.5	22.8	15.1	1.2	2.5	102.7	26.2
III	0.56	0.04	14.0	1.0	7.4	36.4	20.1	16.3	1.4	3.0	112.0	14.4

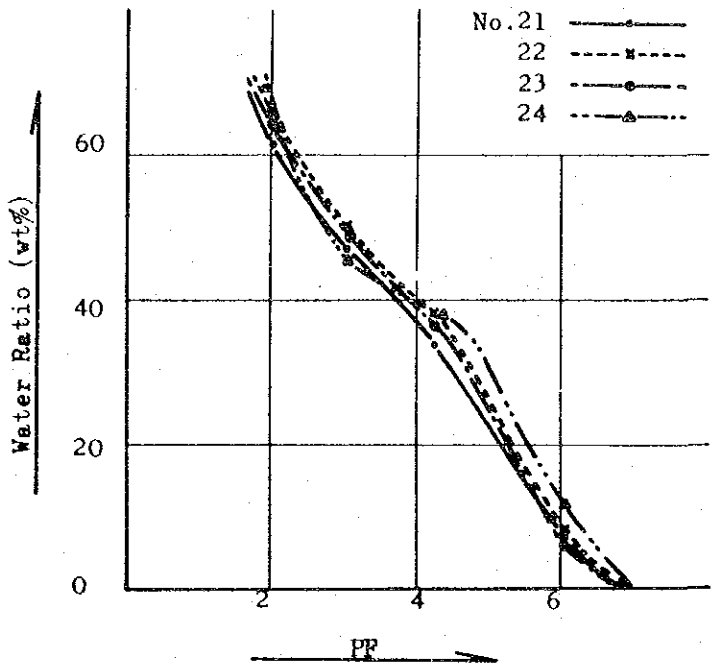
Table 5.17 **Results of Soil Chemical Analyses**

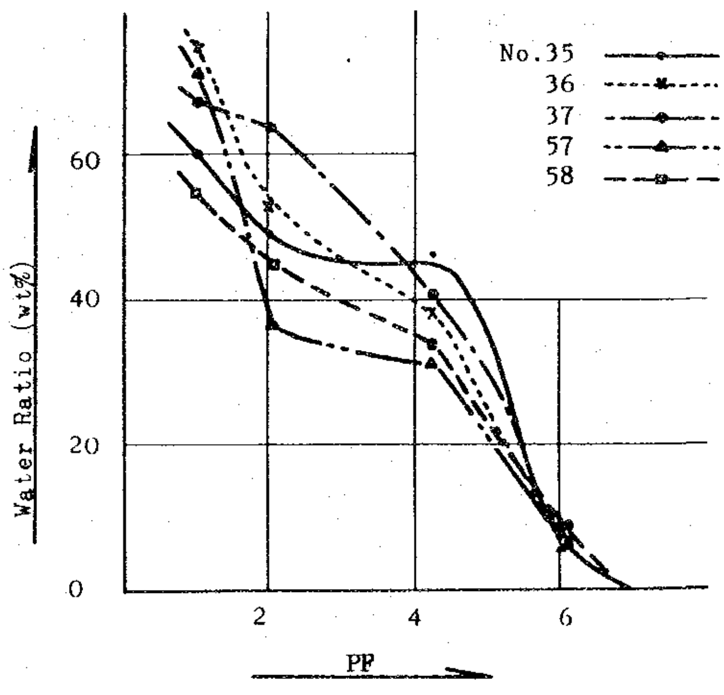
Pit No. & Horizon	T-C	T-N	C/N	Humus	PH	CEC	Exchangeable Bases (me/100g) Ca	Mg	K	Na	Total	B.S.D.	EC	Av. P2 O5
	(%)	(%)		(%)	(H20)	(me/100g)						(%)	(m.mhos/cm)	(mg/100g)
1-1	9.27	0.76	12.2	16.0	7.9	57.0	43.4	20.1	3.26	4.11	70.9	124	1.75	6.4
2	0.20	0.20	10.0	0.3	8.9	44.3	25.5	16.1	1.63	4.51	47.7	108	0.45	24.5
3	tr	tr			8.8	41.8	25.3	9.38	1.17	7.73	43.6	104	0.80	38.0
4	tr	tr			8.3	36.8	23.8	8.19	0.59	5.32	37.9	103	1.51	45.2
5-1	0.93	0.09	10.3	1.6	7.6	39.9	23.8	14.1	2.02	1.37	41.3	104	1.05	4.8
2	0.32	0.02	16.0	0.6	8.7	41.2	25.8	12.6	0.85	3.54	42.8	104	0.41	11.9
3	tr	tr			8.6	39.2	24.6	10.5	0.58	5.80	41.5	106	0.76	23.9
4	tr	tr			7.9	39.9	23.6	10.3	0.50	5.48	39.9	100	2.18	18.3
7-1	0.59	0.04	14.8	1.0	8.6	24.7	19.8	6.45	1.63	0.81	28.7	116	0.67	15.6
2	tr	tr			8.9	26.9	21.1	5.26	0.26	2.90	29.5	110	0.65	24.6
3	tr	tr			9.2	7.4	4.78	2.04	0.20	1.37	8.4	114	0.35	42.4
8-1	1.58	0.15	10.5	2.7	7.0	41.2	23.6	13.3	1.96	0.81	39.7	96	0.58	2.2
2	0.70	0.05	14.0	1.2	7.3	39.9	25.3	12.9	0.13	1.29	39.6	100	0.94	5.7
3	tr	tr			8.4	41.8	27.3	12.0	0.91	2.42	42.6	102	0.56	9.1
13-1	1.17	0.08	14.6	2.0	8.1	49.4	31.5	17.4	2.28	1.93	53.1	107	0.88	5.1
2	0.20	0.02	10.0	0.3	8.4	48.1	30.3	17.4	1.50	3.14	52.3	109	0.93	7.2
3	tr	tr			8.5	46.7	30.5	16.3	1.43	3.22	51.5	110	1.17	7.7
14-1	1.42	0.11	12.9	2.4	8.0	46.9	32.2	16.8	2.80	3.92	55.7	119	1.61	13.2
2	tr	tr			8.3	55.7	35.7	18.9	1.96	3.62	60.2	108	0.86	5.9
3	tr	tr			8.6	54.5	34.0	17.9	1.50	5.16	58.6	108	0.75	9.3
16-1	1.51	0.12	12.6	2.6	8.3	43.1	32.5	13.3	1.63	1.93	49.4	115	1.05	15.4
2	0.49	0.03	16.3	0.8	8.7	46.2	31.0	11.7	1.43	3.87	48.0	104	0.83	12.6
3	0.44	0.03	14.8	0.8	8.6	45.6	32.2	10.8	1.17	5.64	49.8	109	1.45	12.6
4	0.44	0.03	14.8	0.8	8.0	49.4	38.4	10.3	1.00	8.38	58.1	118	4.10	11.1
18-1	0.96	0.09	10.7	1.7	8.1	46.9	37.4	16.7	2.67	1.29	58.1	124	0.77	11.1
2	0.55	0.04	13.8	0.9	8.7	53.1	33.7	16.3	1.50	9.57	61.1	115	1.37	12.1
21-1	3.25	0.35	9.3	5.6	7.0	54.8	27.3	20.2	1.96	2.26	51.7	94	3.80	12.6
2	1.42	0.11	12.9	2.4	7.7	42.4	25.5	15.2	2.15	2.09	44.9	106	1.95	10.1
3	tr	tr			8.7	51.3	28.3	18.0	1.76	7.25	55.3	108	1.04	20.1
23-1	3.80	0.30	12.7	6.5	7.6	47.5	29.8	14.9	2.09	1.29	48.1	101	0.66	26.7
[illegible]	0.40	0.03	13.3	0.7	8.4	49.4	32.0	16.7	2.22	1.77	52.7	107	0.61	8.4
27-1	3.92	0.33	11.8	6.8	7.4	44.3	27.5	13.0	2.61	1.77	45.5	103	1.30	25.1
2	0.51	0.03	17.0	0.9	8.5	40.5	25.3	14.9	1.96	2.26	44.4	110	0.95	22.2
[illegible]	0.41	0.03	13.7	0.7	8.5	41.2	25.8	13.0	1.56	5.80	46.2	112	1.98	26.0
30-1	3.99	0.34	11.7	6.9	7.1	47.5	27.3	16.1	1.96	1.77	47.1	99	1.22	7.5
2	0.30	0.02	15.0	0.5	8.6	46.2	28.5	16.4	1.63	3.54	50.1	108	0.93	13.1
3	tr	tr			8.5	48.1	29.8	16.4	1.43	6.28	53.9	112	1.15	15.2
33-1	5.63	0.50	11.3	9.7	6.9	44.3	27.0	14.6	1.96	1.37	44.9	102	1.70	11.0
2	0.47	0.03	15.7	0.8	8.7	41.8	26.0	15.2	1.76	5.08	48.0	115	1.58	21.3
47-1	1.08	0.09	13.0	1.9	7.4	32.9	18.6	14.9	1.43	0.97	35.9	109	0.50	15.1
2	0.68	0.04	17.0	1.2	7.9	40.5	22.8	15.1	1.24	2.47	41.6	103	0.96	26.2
3	0.56	0.04	14.0	1.0	7.4	36.4	20.1	16.3	1.37	3.06	40.8	112	0.75	14.4
53-1	1.39	0.13	10.7	2.4	8.6	40.5	27.3	14.5	1.63	2.01	45.4	112	0.66	6.1
2	0.43	0.03	14.3	0.7	8.0	46.9	34.7	10.3	0.78	5.08	50.9	108	3.97	13.6
3	tr	tr			7.5	46.9	45.6	11.7	0.64	14.5	72.4	155	9.90	9.1
54-1	1.27	0.08	15.8	2.2	8.0	46.9	29.0	16.8	2.02	1.85	49.7	106	0.67	4.6
2	1.35	0.02	17.5	0.6	8.5	40.5	23.6	15.2	1.56	4.91	45.3	112	1.95	42.0
3	tr	tr			8.5	51.0	31.7	15.4	1.17	5.96	54.2	106	1.65	8.8

- to be continued -

Pit No. & Horizon	T-C	T-N	C/N	Humus	PH	CEC	Exchangeable Bases (me/100g) Ca	Mg	K	Na	Total	B.S.D.	EC	Av. P2 O5
	(%)	(%)		(%)	(H2O)	(me/100g)						(%)	(m.mhos/cm)	(mg/100g)
55-1	1.36	0.13	10.5	2.3	7.4	46.2	20.6	16.7	1.30	1.05	39.7	86	0.61	16.2
2	1.01	0.09	11.2	1.7	7.8	46.6	24.8	17.3	1.30	1.69	45.1	97	0.95	45.3
3	tr	tr			8.5	44.3	28.3	17.1	2.09	3.14	50.6	114	1.06	42.0
56-1	0.53	0.04	13.3	0.9	8.9	33.6	19.6	12.4	1.43	2.74	36.2	107	0.74	19.8
2	0.33	0.02	16.5	0.6	8.4	39.9	22.6	12.4	1.17	8.06	44.2	111	2.76	21.3
58-1	0.80	0.08	10.0	1.4	7.7	15.8	9.18	5.86	0.91	1.13	17.1	109	1.32	3.2
2	0.22	0.02	11.0	0.4	8.3	46.2	29.8	14.8	1.34	2.09	48.0	104	0.60	8.6
3	tr	tr			7.4	5.5	2.98	1.74	0.14	0.29	5.20	95	0.13	2.7
63-1	2.16	0.21	10.3	3.7	7.4	39.3	22.3	14.5	1.76	1.45	40.0	102	0.95	13.0
2	0.45	0.03	15.0	0.8	8.0	42.4	25.5	12.6	0.85	7.73	46.7	110	4.63	23.3
65-1	1.28	0.13	9.8	2.2	7.7	32.1	19.3	10.8	1.04	1.93	33.1	103	0.57	9.3
2	0.37	0.02	18.5	0.6	8.5	35.5	22.1	9.67	0.72	5.08	37.6	106	1.13	22.9
3	0.49	0.03	16.3	0.8	7.0	41.2	26.8	10.4	0.46	15.3	53.0	129	9.00	9.4
66-1	2.94	0.26	11.3	5.1	7.6	44.3	25.5	15.8	1.70	1.98	45.0	102	1.23	14.9
2	0.33	0.02	16.5	0.6	8.5	50.7	26.3	17.6	1.86	5.32	51.1	101	0.95	22.8
3	0.91	0.07	13.0	1.6	8.2	46.2	26.8	15.2	1.83	5.16	49.0	106	1.67	18.8
67-1	0.68	0.06	11.3	1.2	7.8	28.5	17.6	9.51	1.89	1.21	30.2	106	0.93	36.8
2	tr	tr			8.6	29.1	18.4	8.36	0.81	3.87	31.4	108	1.56	53.5
68-1	6.55	0.61	10.7	11.3	6.7	42.4	21.3	13.8	1.96	1.77	38.8	92	1.39	13.6
2	0.36	0.02	18.0	0.6	8.4	50.7	33.0	17.9	1.43	3.38	55.7	110	0.79	11.8
70-1	4.51	0.40	11.2	7.8	7.0	42.4	23.6	14.6	1.96	1.85	42.0	99	1.16	13.2
2	0.33	0.03	11.0	0.6	8.6	33.6	19.8	12.7	1.43	3.38	37.3	111	1.05	61.4
72-1	1.28	0.12	10.7	2.2	8.4	36.7	23.1	9.67	1.14	3.06	37.0	101	1.08	8.2
2	tr	tr			8.8	34.5	23.1	7.90	0.55	5.80	37.4	108	1.06	10.0
3	tr	tr			9.2	22.8	18.1	4.84	0.33	3.38	26.7	117	0.73	19.8
75-1	7.85	0.67	11.7	13.5	6.2	51.9	27.0	18.8	3.91	1.93	51.6	99	2.20	18.5
2	0.41	0.03	13.7	0.7	8.4	44.3	28.3	16.1	1.76	5.31	51.5	116	1.28	43.0
82-1	0.40	0.04	10.0	0.7	8.1	35.8	22.8	11.1	1.63	1.37	36.9	103	0.67	30.8
2	0.39	0.02	19.5	0.7	8.5	36.1	22.8	10.5	1.86	2.34	37.5	104	0.67	36.6
3	0.29	0.02	14.5	0.5	8.7	38.3	23.1	10.3	1.24	5.56	40.2	105	1.03	36.0
84-1	0.52	0.04	13.0	0.9	8.0	47.1	30.5	14.5	1.08	1.53	47.6	101	0.53	6.4
2	tr	tr			8.1	50.0	29.8	13.8	1.08	6.28	51.0	102	0.65	9.9

Table 5.18 PF Curve





ANNEX VI

ECONOMY

ANNEX VI

ECONOMY

Tables