1.3 Wadi Gauges

(1) Introduction

In order to study the surface water hydrology, wadi gauge were installed in accordance with the three distinct geographical Areas;

- Out valley area of the major mountain in the uppermost reach of wadi (4 sites)
- Junction area between the frontal mountain and the marginal wadi plain (5 sites)
- Coastal strip area (7 sites)

These wadi gauge sites were selected for the purpose of estimating the hydrologic systems and evaluating the ground water recharge system in the Batinah coast.

The 16 wadi gauges of which five sites were selected mean the former gauges, were installed and are shown in Table B-1-6 and Fig. B-1-5. The structure of wadi gauges was designed to withstand flood damage. Three wadi gauges were made of concrete and the other gauges of steel pipes.

A float type water-level recorder was installed at each gauge. The water-level recorder is the same type as the former gauge. A radio current meter with an automatic switch was installed for measuring the surface-velocity of floods at each gauge of the three concrete tower-type wadi gauges. The drawings of those wadi gauges are shown in the Fig. B-1-6(1), (2).

(2) Method of Observation

a. Estimation of the discharge

Estimation of surface water discharge can be calculated with following equation.

$$Q = V.A$$

Where
Q : Discharge of the surface runoff
V : Mean velocity of the flow
A : Cross sectional area of stream

b. Cross sectional area of stream

Cross sectional area of stream was found by the cross-section survey at the each site.

c. Mean velocity of the stream

Mean velocity of the stream was obtained using Manning's equation as follows:

$$V = 1/n \, R^{2/3} \, I^{1/2}$$

Where
V : Mean velocity of the stream (m/s)
n : Roughness coefficient
R : Hydraulic radius (m)
I : Gradient of Wadi-bed

Roughness coefficients were estimated by Gibb and also PAWR from the observed data. On Feb. 9, 1975, Gibb observed the flood at Wadi Al Khowdh and at that time they obtained the intersecting relation between the roughness coefficient and water level. As a result they suggested 0.035 as a mean roughness coefficient for the wadi. On the other hand PAWR suggested the general range of the roughness for this study area as 0.035 - 0.045. Generally, at the natural river or wadi, the identification of the roughness coefficient would come from comparison of direct observation and the relation with Manning's equation. However, in this project, we installed a current meter since we were expecting a flood during this study. Based on our estimation of the flood discharge, we used the value of 0.040 for the calculation because the all floods occured in the mountain area.

The ground surveys such as longitudinal profile and cross-section leveling surveys were executed at all the gauge sites during the survey period. The results of survey are summarized in Table B-1-7 and Fig. B-1-7 (1) (5).

Table B-1-6 Wadi Gauge Sites of JICA

Wadi Basin	Location		Code number	*1) Type	Height (m)	*2) Equip-ment	Catch-ment Area (km^2)	Starting date of Observa-tion
	Site Name	UTM-Grid						
W. Ahin	Al-Hail	40R DB 560-597	WA1	S	12	L	768.3	Mar. 14, 1984
	Saham	40R DB 858-760	WA2(A)	S	6	L	842.2	Dec. 26, 1983
	Saham	40R DB 856-764	WA2(B)	S	6	L	222.8	Jan. 20, 1984
W. Banj Ghafir	Al-Houqain	40Q EB 345-044	WG1	C	12	L & F	591.1	Sep. 7, 1983
	Al-Suwaiq	40Q EB 414-370	WG2	S	6	L	951.9	Nov. 21, 1983
W. Al-Fara'	Al-Mazahit	40Q EA 458-954	WF1	C	12	L & F	698.2	Sep. 11, 1983
	Al-Tarif	40Q EB 626-279	WF2	S	6	L	1014.5	Nov. 21, 1983
	Al-Musana'ah	40Q EB 660-273	WF3	S	6	L	93.8	Jan. 7, 1984
	Al-Tabaqah	40Q EA 315-856	WF4	S	13	L	165.3	Jan. 22, 1984
	Fara'	40Q EA 498-789	WF5	S	10	L	170.2	Jan. 22, 1984
W. Bani Kharus	Al-Abiyad	40Q EA 928-676	WK1	C	12	L & F	750.6	Jan. 19, 1984
	Abu-Abali	40Q EB 729-259	WK2	S	6	L	1292.3	Jan. 21, 1984
	Al-Awabi	40Q EA 540-760	WK3	S	10	L	253.6	Jan. 22, 1984
	Al-Ghubrah	40Q EA 706-792	WK4	S	10	L	201.5	Jan. 22, 1984
W. Al-Ma'awil	Barka'	40Q EB 840-222	WM1	S	6	L	1029.8	Dec. 21, 1983
	Afi	40Q EA 849-850	WM2	S	8	L	319.1	Jan. 4, 1984

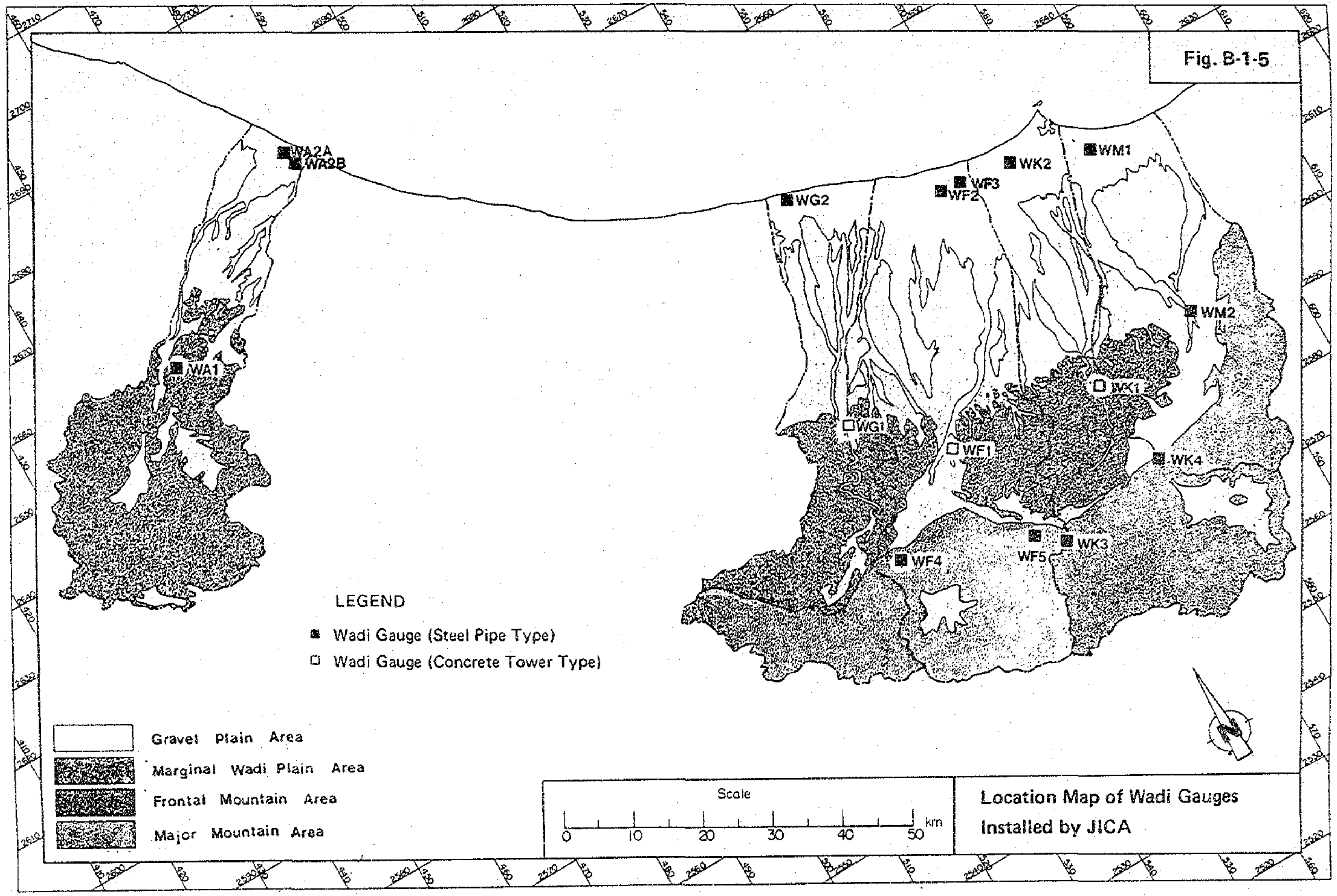
*1) Type : C: Concrete tower type
S: Steel pipe type

*2) Equipment: L: Water level recorder
F: Radio flow meter

Table B-1-7 Summary of Ground Surveys of Wadi Gauge Sites

Name of Wadi Basin	Name of Place	Name of Wadi Gauge	Executed date of Survey	Longitudinal/Cross sectional Profiles			Longitudinal Slope
				Length	Distance between Two Stations	Number of Cross Sections	
WADI'AHIN	AL-HEIL	WA 1	Feb.22'83	1,200m	200m	7	1/156
	SAHAM	WA 2(A)	Feb.23'83	1,800m	200m	11	1/350
	SAHAM	WA 2(B)	Feb.23'83	1,800m	200m	11	1/381
WADI BANY GHAFIR	AL-HOUQAIN	WG 1	Jan,22'84	1,200m	200m	7	1/205
	AL-SUWEIQ	WG 2	Feb. 9'83	1,200m	200m	8	1/289
WADI AL-FARA	MAZAHIT	WF 1	Dec.27'83	1,200m	200m	7	1/177
	TARIF	WF 2	Jan.27'83	1,400m	200m	8	1/776
	AL-MUSANA'AH	WF 3	Jan.29'83	1,200m	200m	7	1/517
	TABAQAH	WF 4	Feb. 2'83	1,200m	200m	7	1/65
	FARA'	WF 5	Feb. 3'83	1,200m	200m	7	1/130
WADI BANI KHARUS	AL-ABIYAD	WK 1	Feb. 6'83	1,200m	200m	7	1/144
	BU-ABALI	WK 2	Feb. 1'83	1,200m	200m	7	1/797
	AL-AWABI	WK 3	Feb.15'83	1,200m	200m	7	1/95
	AL-GHUBRAH	WK 4	Feb.14'83	1,200m	200m	7	1/76
WADI AL-MA'AWIL	BARKA	WM 1	Feb. 5'83	1,200m	200m	7	1/591
	AFI	WM 2	Feb.10'83	1'200m	200m	7	1/140

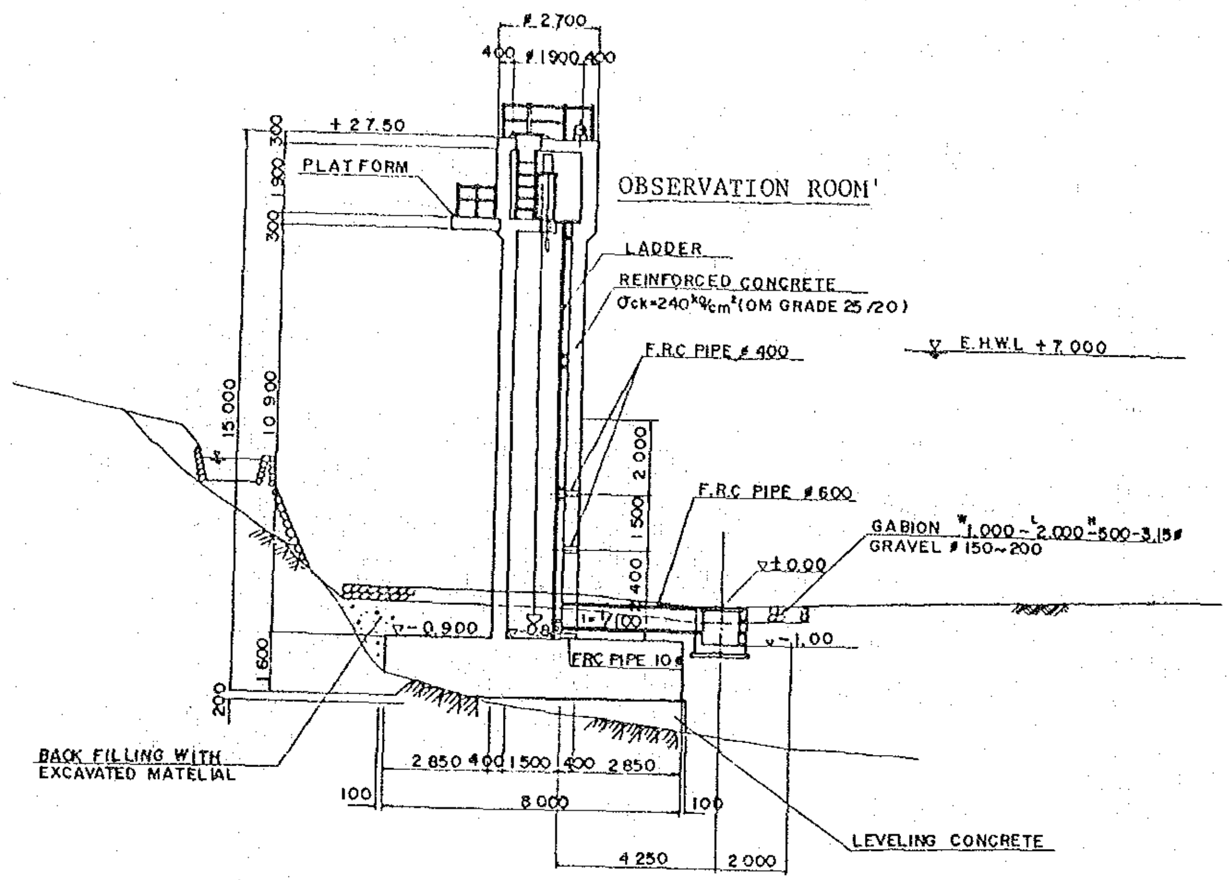
Fig. B-1-5

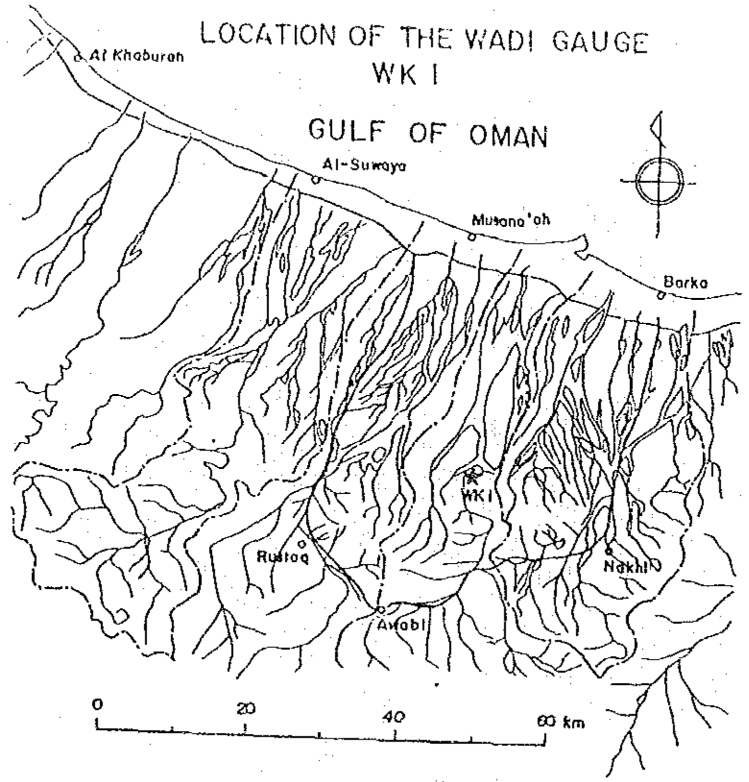


Location Map of Wadi Gauges Installed by JICA

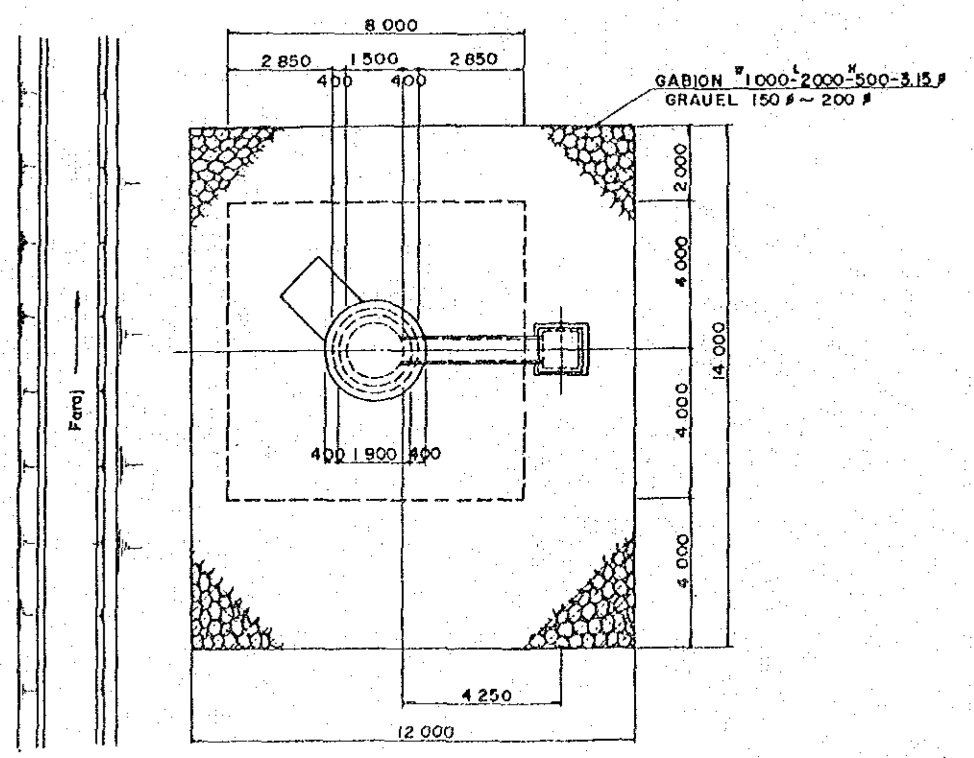
Fig. B-1-6(1) Structural Drawing of Concrete Tower Type Wadi Gauge

LONGITUDINAL SECTION Unit=mm





PLAN Unit=mm



OBSERVATION ROOM FLOOR Unit=mm

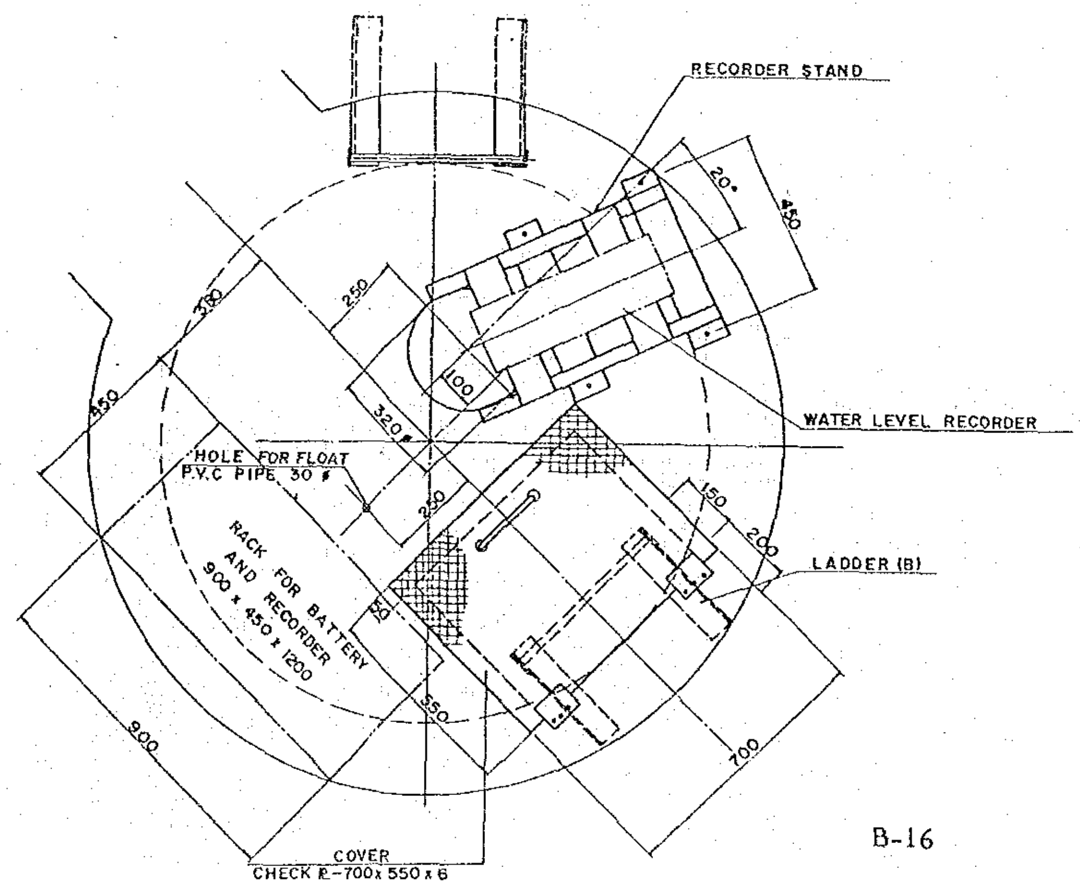
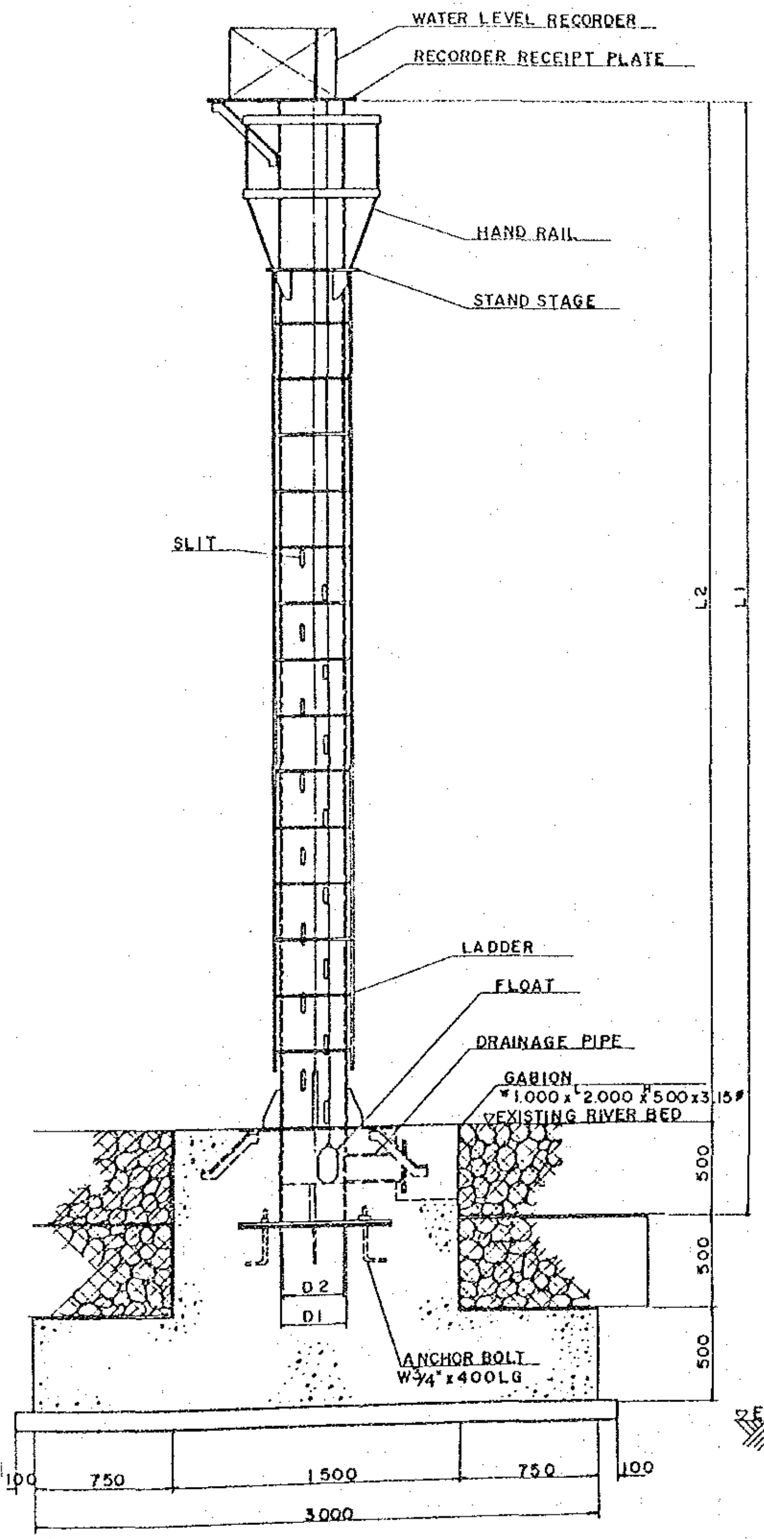
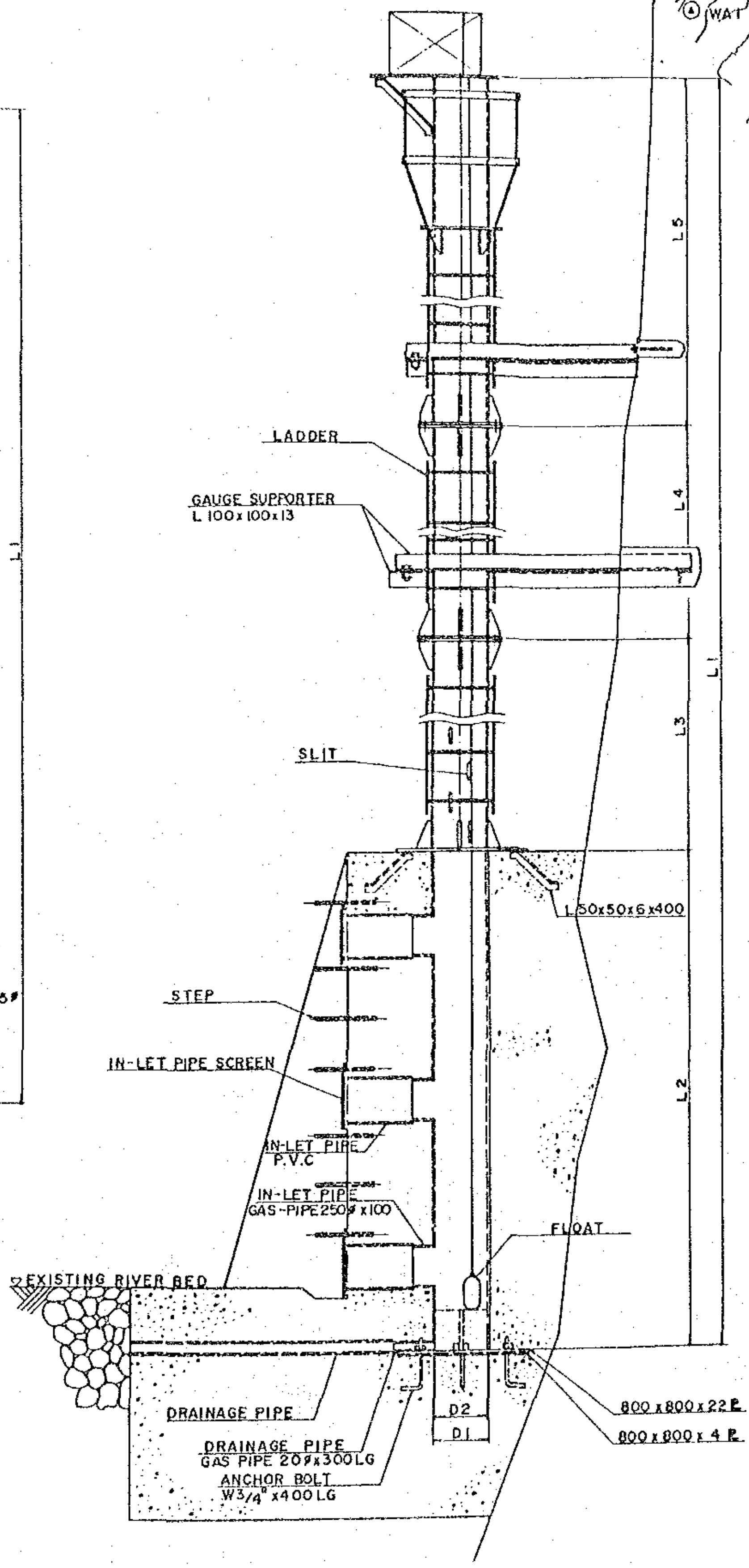


Fig. B-1-6(2) Structural Drawing of Steel Pipe Type Wadi Gauge

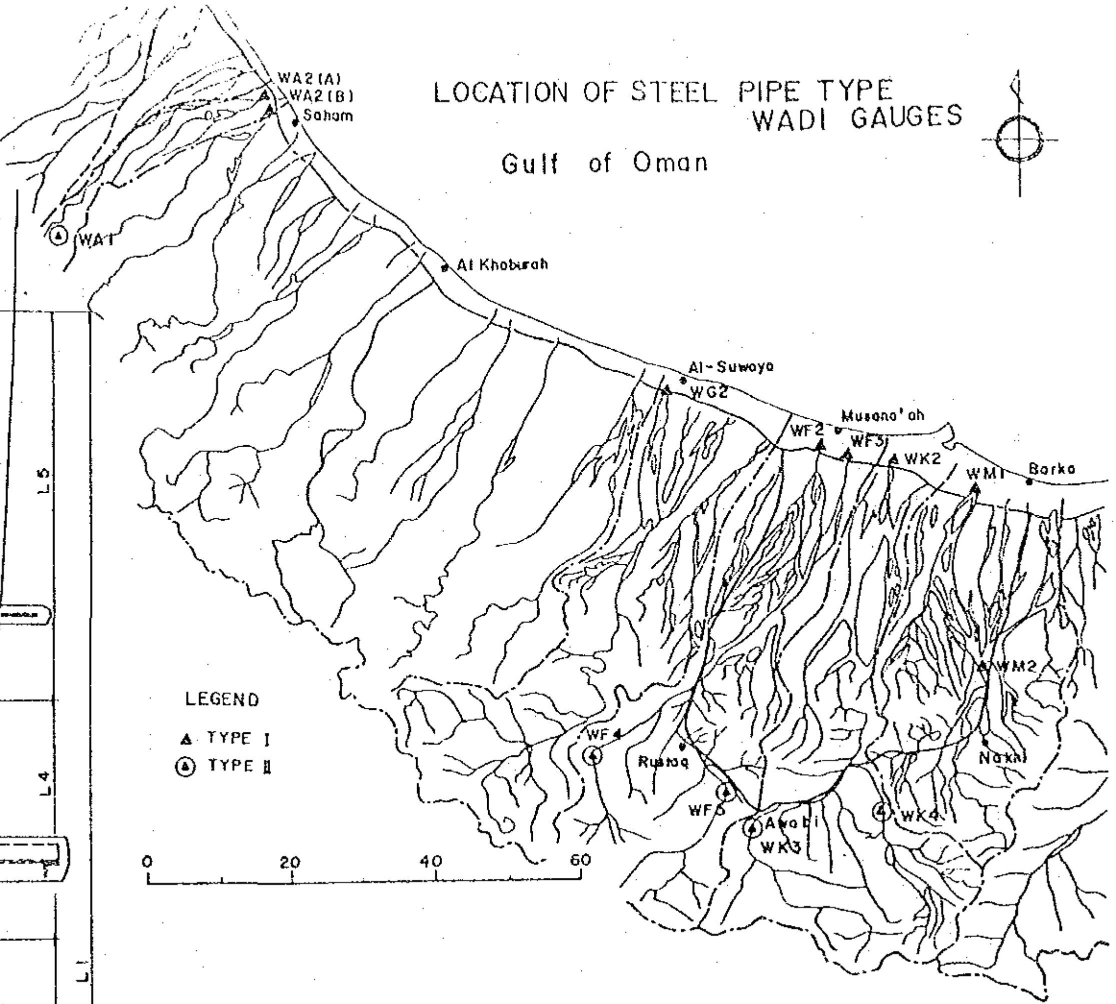
STEEL PIPE TYPE GAUGE (TYPE I)
Unit=mm



STEEL PIPE TYPE GAUGE(TYPE II)
Unit=mm



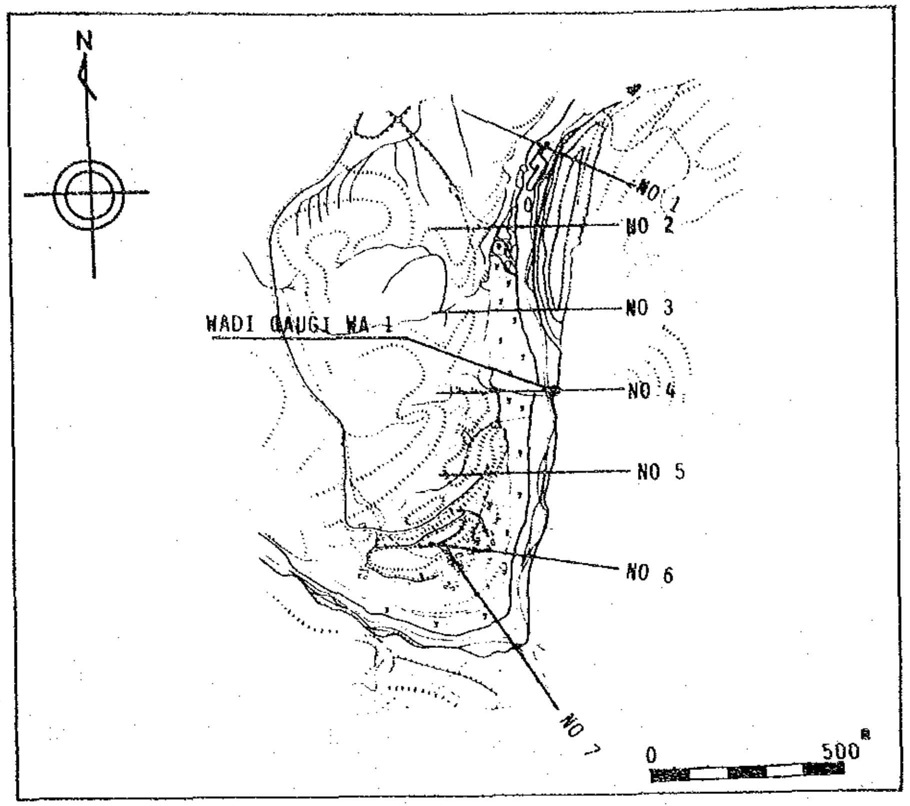
LOCATION OF STEEL PIPE TYPE WADI GAUGES

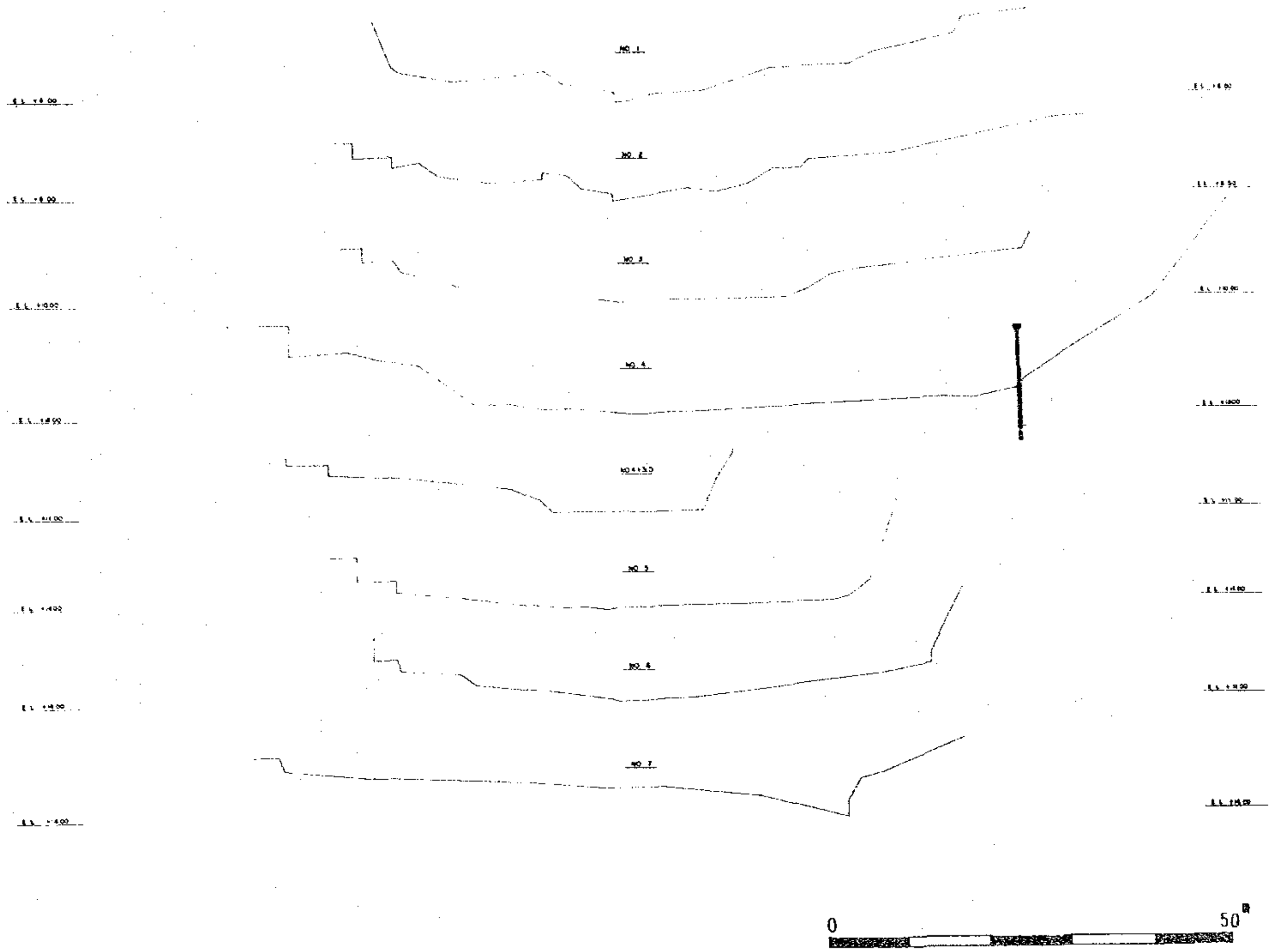


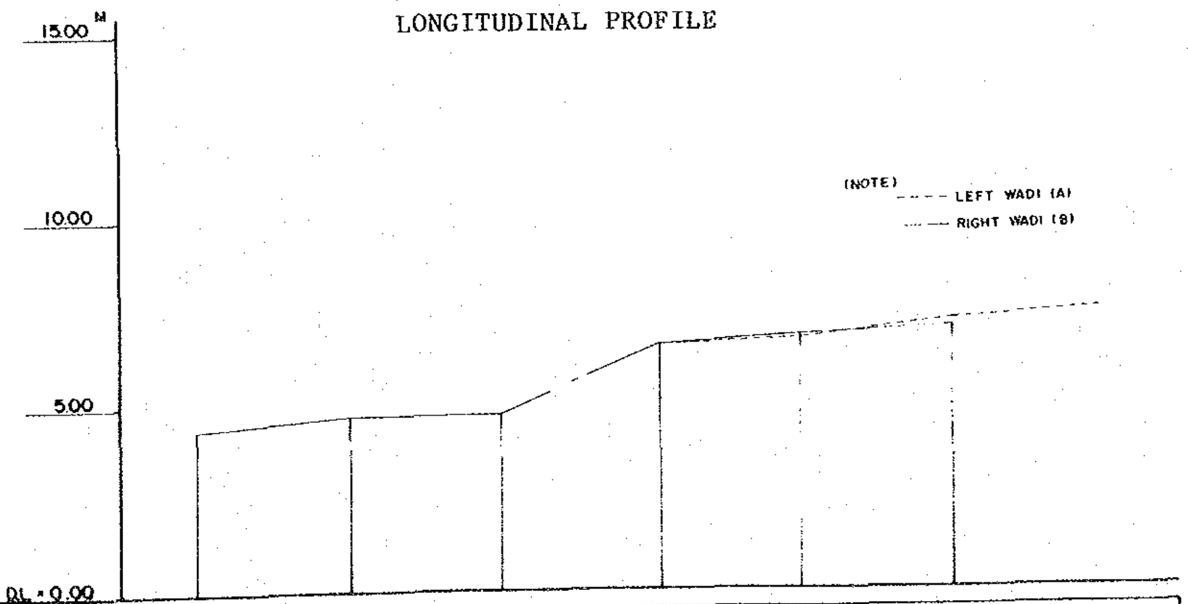
STEEL PIPE TYPE GAUGE DIMENSION

WADI	LOCATION	SYMBOL	BANK SIDE	TYPE	HEIGHT (m) L1	L2	L3	L4	L5	DIAMETER (mm) D1	D2
W, 'Ahin	AL-HEIL	WA 1	RIGHT	II	12.0	3.0	3.0	3.0	3.0	355.6	333.4
	SAHAM	WA 2(A)	RIGHT	I	6.0	5.5	—	—	—	323.85	303.25
	SAHAM	WA 2(B)	RIGHT	I	6.0	5.5	—	—	—	323.85	303.25
W, Bani Ghafir	AL-SLIWEIQ	WG 2	RIGHT	I	6.0	5.5	—	—	—	323.85	309.65
W, Al-Fara	TARIF	WF 2	LEFT	I	6.0	5.5	—	—	—	323.85	303.25
	AL-MUSANAAH	WF 3	LEFT	I	6.0	5.6	—	—	—	323.85	309.65
	TABAQAH	WF 4	RIGHT	II	13.0	3.0	3.0	3.0	4.0	323.85	303.25
	FARA'	WF 5	LEET	II	10.0	3.0	3.0	0.0	4.0	323.85	303.25
W, Bani Kharus	BU ABALI	WK 2	RIGHT	I	6.0	5.5	—	—	—	323.85	309.65
	AL- AWABI	WK 3	LEFT	II	10.0	3.0	3.0	0.0	4.0	323.85	303.25
	AL- GHUBRAH	WK 4	RIGHT	II	10.0	3.0	3.0	0.0	4.0	323.85	303.25
W, Al-Ma'awil	BARKA	WM 1	RIGHT	I	6.0	5.5	—	—	—	323.85	303.25
	AFI	WM 2	RIGHT	I	8.0	7.5	—	—	—	323.85	303.25

Fig. B-1-7 (1) Cross-section and Longitudinal Profile of Wadi Gauge Site, WA1

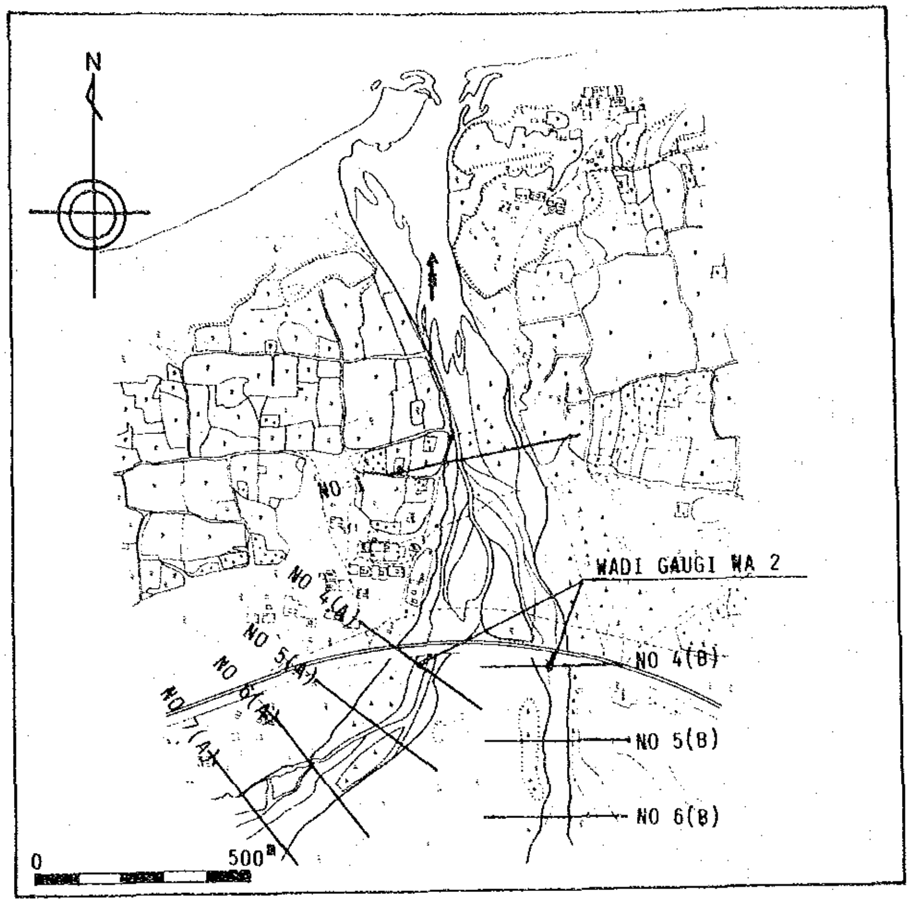


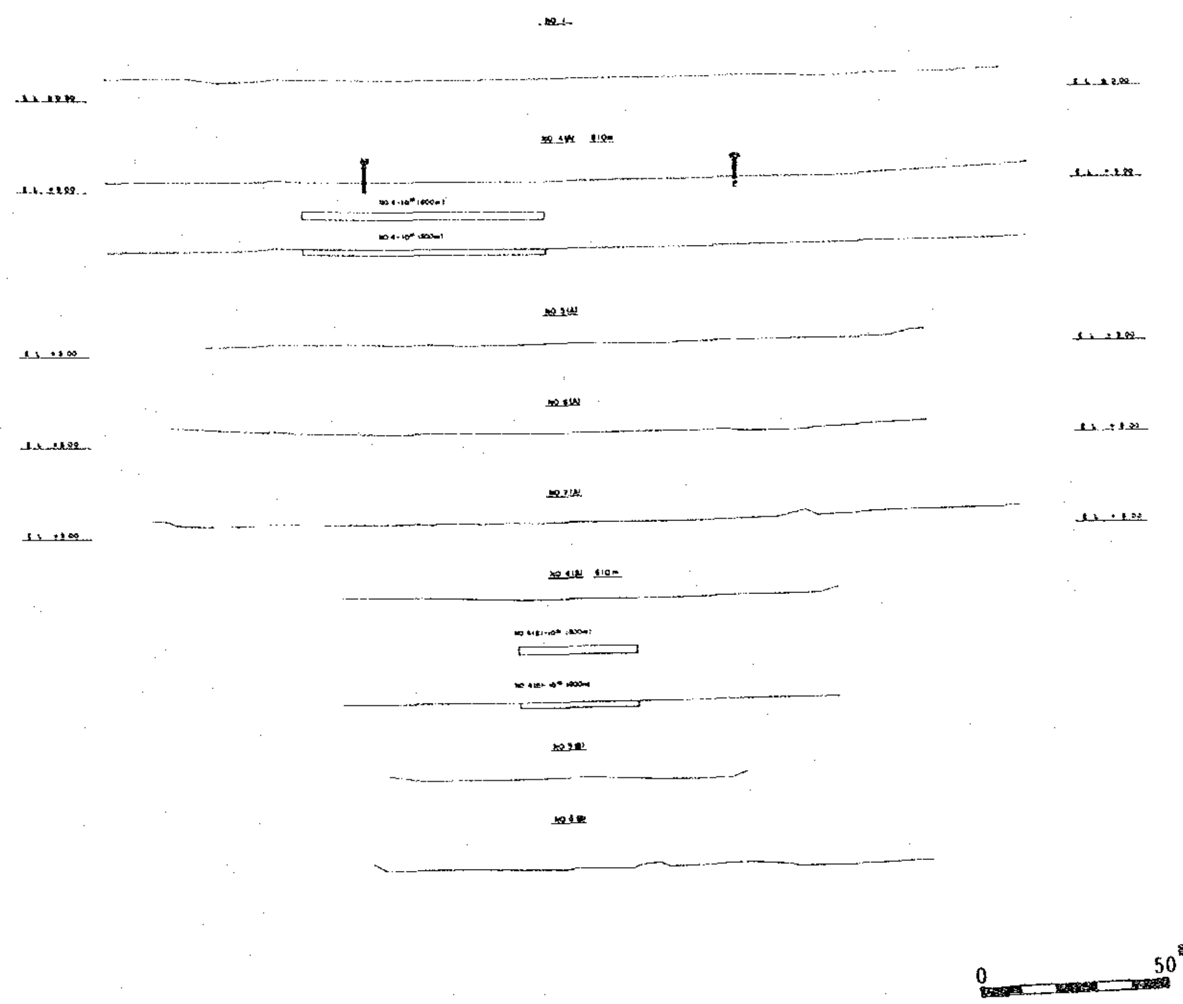


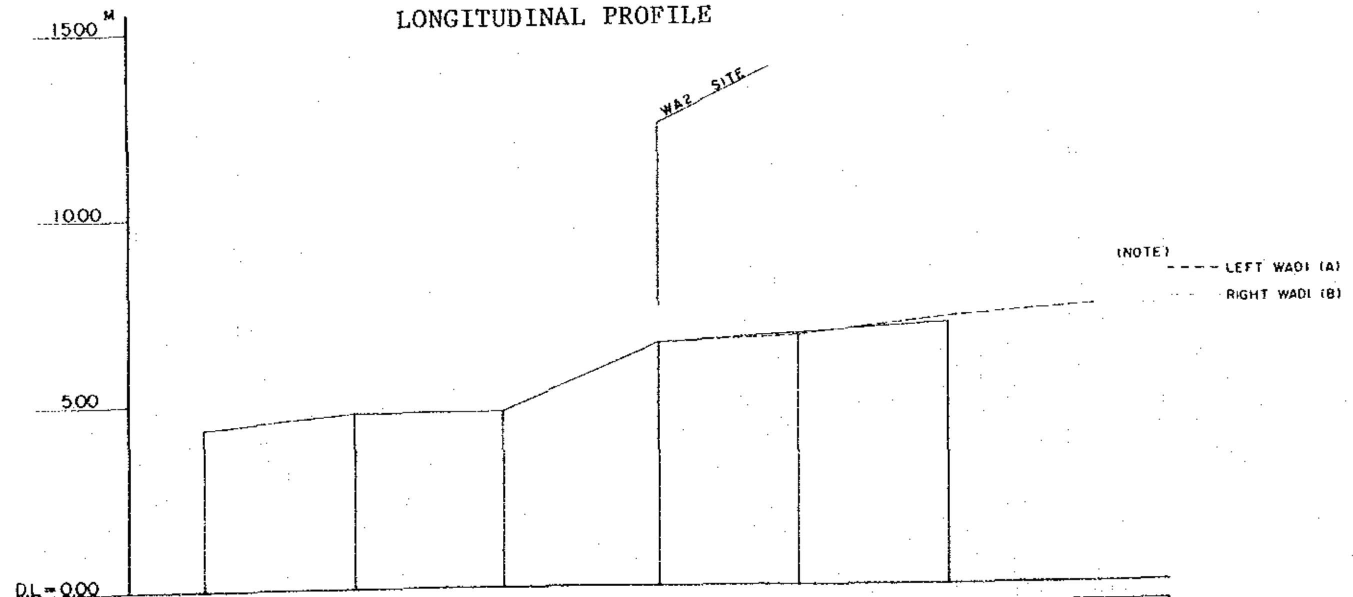


LONGITUDINAL SLOPE								
PRESENT ELEVATION (EL. m)	RIGHT BANK							
	LEFT BANK							
	MEAN RIVER BED							
	LOWEST RIVER BED	4.370	4.775	4.775	6.385 (6.860)	6.770 (6.825)	7.223 (7.085)	7.320
ACCUMULATED DISTANCE		0	200	400	610	800	1,000	1,200
DISTANCE		0	200	200	210	190	200	200
STATION No.		1	2	3	4	5	6	7

Fig. B-1-7(2) Cross-section and Longitudinal Profile of Wadi Gauge Site, WA2

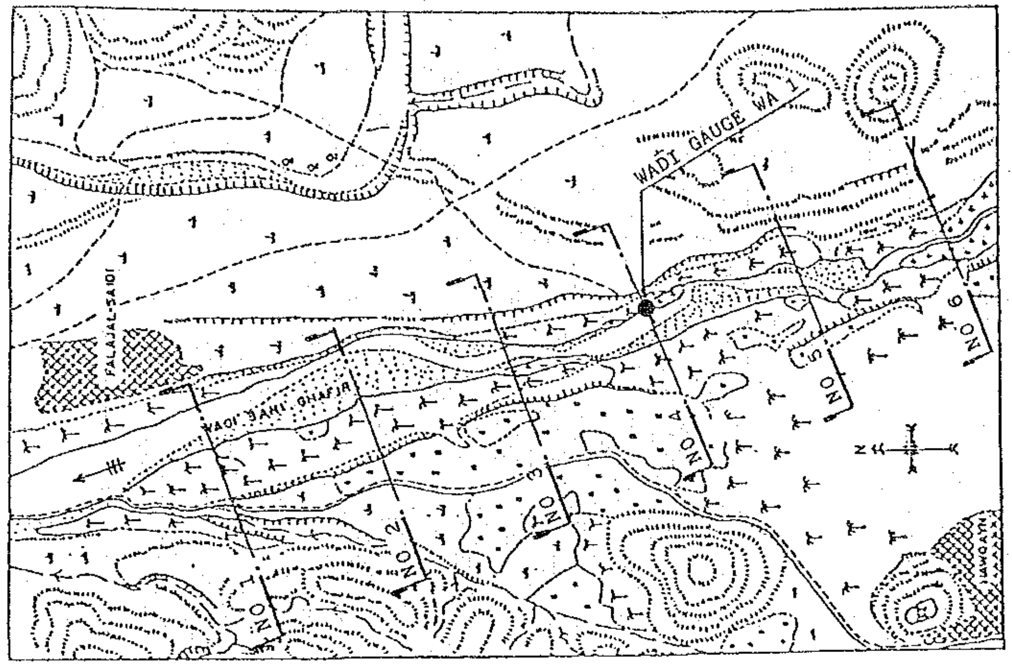


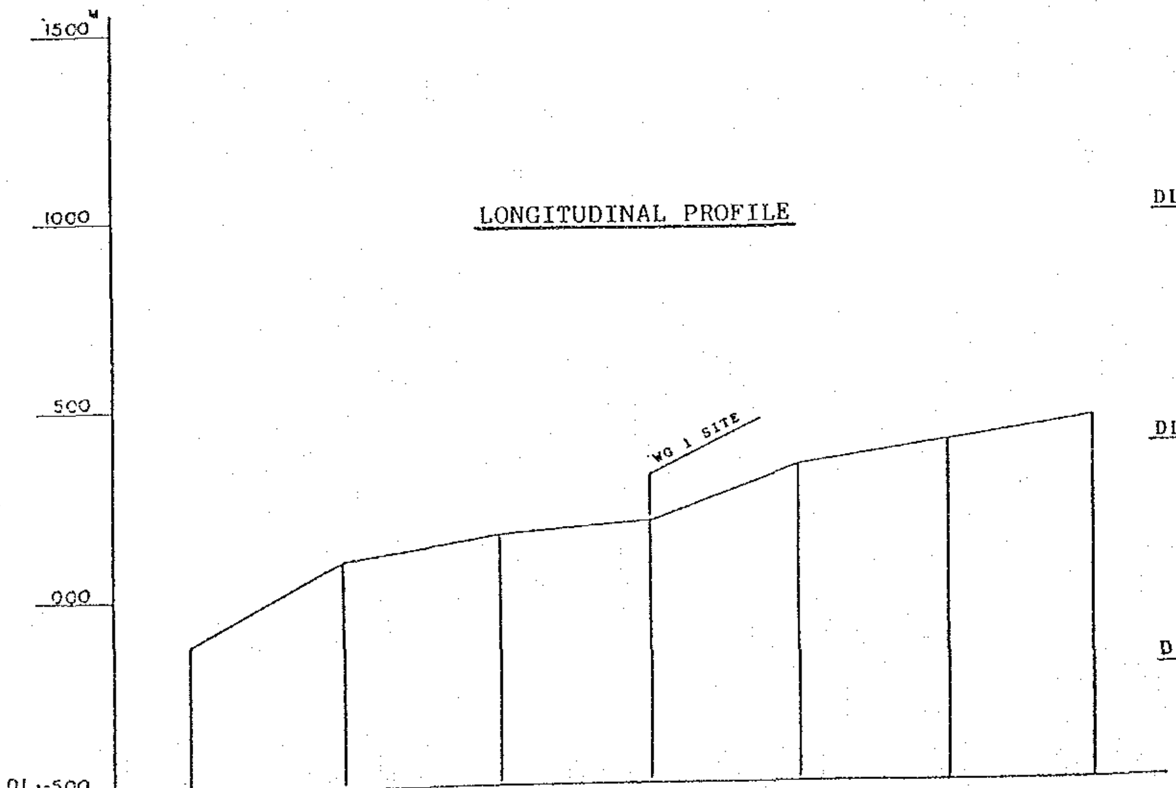




LONGITUDINAL SLOPE	4.370	I=1/980 L=400M	4.775	6.585	I=1/600(1/780) L=390 M	7.225 (7.085) I=1/670 L=200M	7.520
PRESENT ELEVATION (EL. m) RIGHT BANK							
LEFT BANK							
MEAN RIVER BED							
LOWEST RIVER BED	4.370	4.775	4.775	6.585	6.770 (6.625)	7.225 (7.085)	7.520
ACCUMULATED DISTANCE	0	200	400	610	800	1,000	1,200
DISTANCE	0	200	200	210	190	200	200
STATION No	1	2	3	4	5	6	7

Fig. B-1-7 (3) Cross-section and Longitudinal Profile of Wadi Gauge Site, WG1





LONGITUDINAL SLOPE		-0.985	I=1/249 L=600m		1.425	I=1/323 L=400m	2.665
PRESENT ELEVATION (EL m) — RIGHT BANK							
PRESENT ELEVATION (EL m) — LEFT BANK							
PRESENT ELEVATION (EL m) — MEAN RIVER BED							
PRESENT ELEVATION (EL m) — LOWEST RIVER BED	-3.200	-0.985	-0.300	0.000	1.425	2.065	2.665
ACCUMULATED DISTANCE	0	200	400	600	800	1000	1200
DISTANCE	0	200	200	200	200	200	200
STATION No.	1	2	3	4	5	6	7

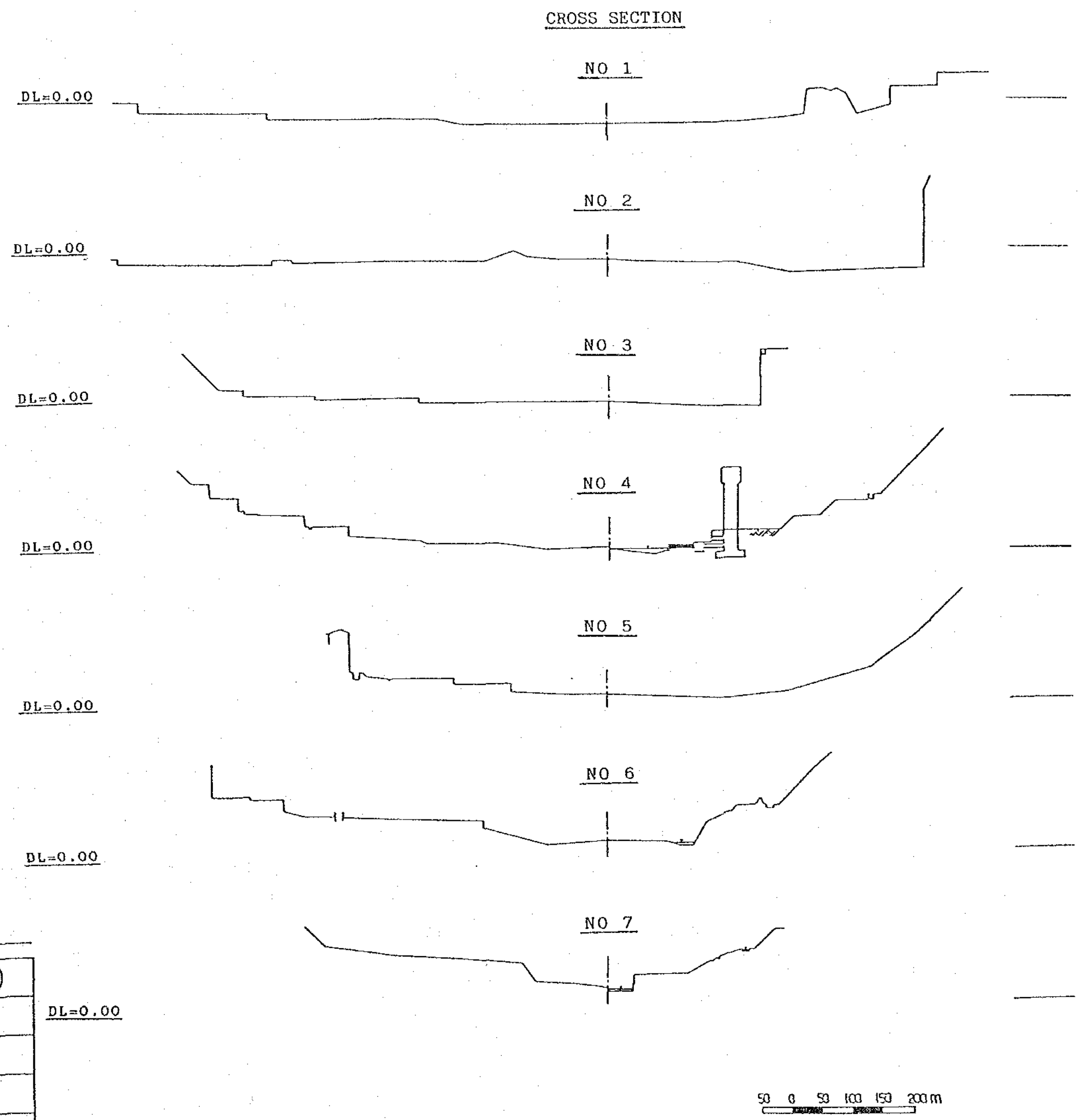
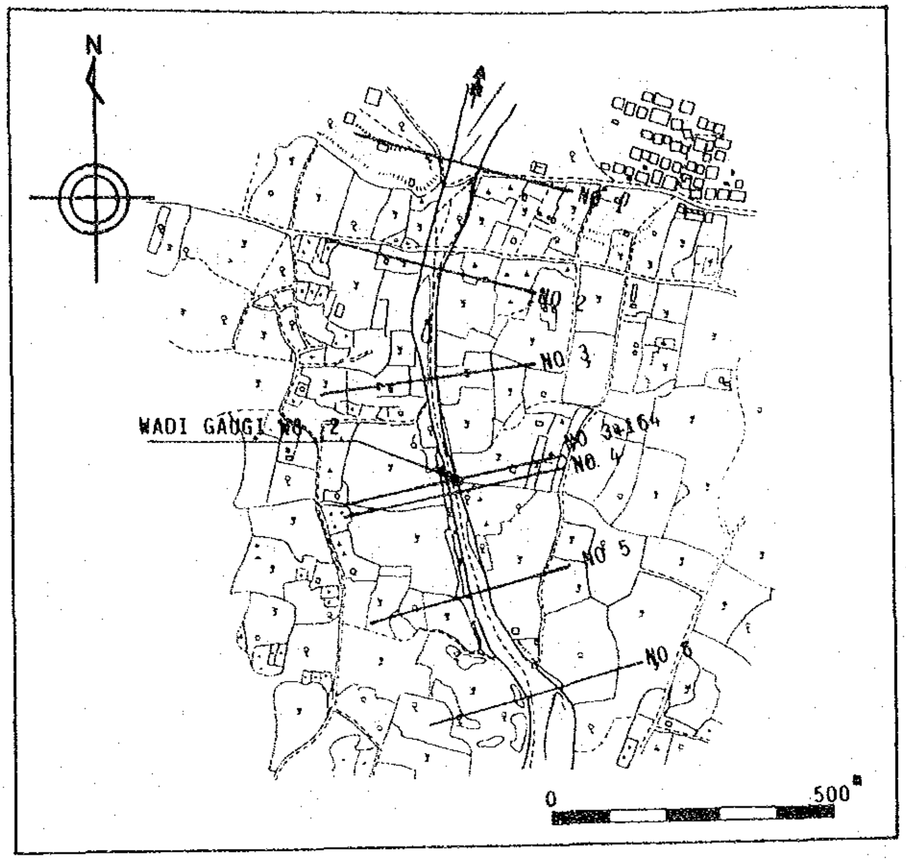
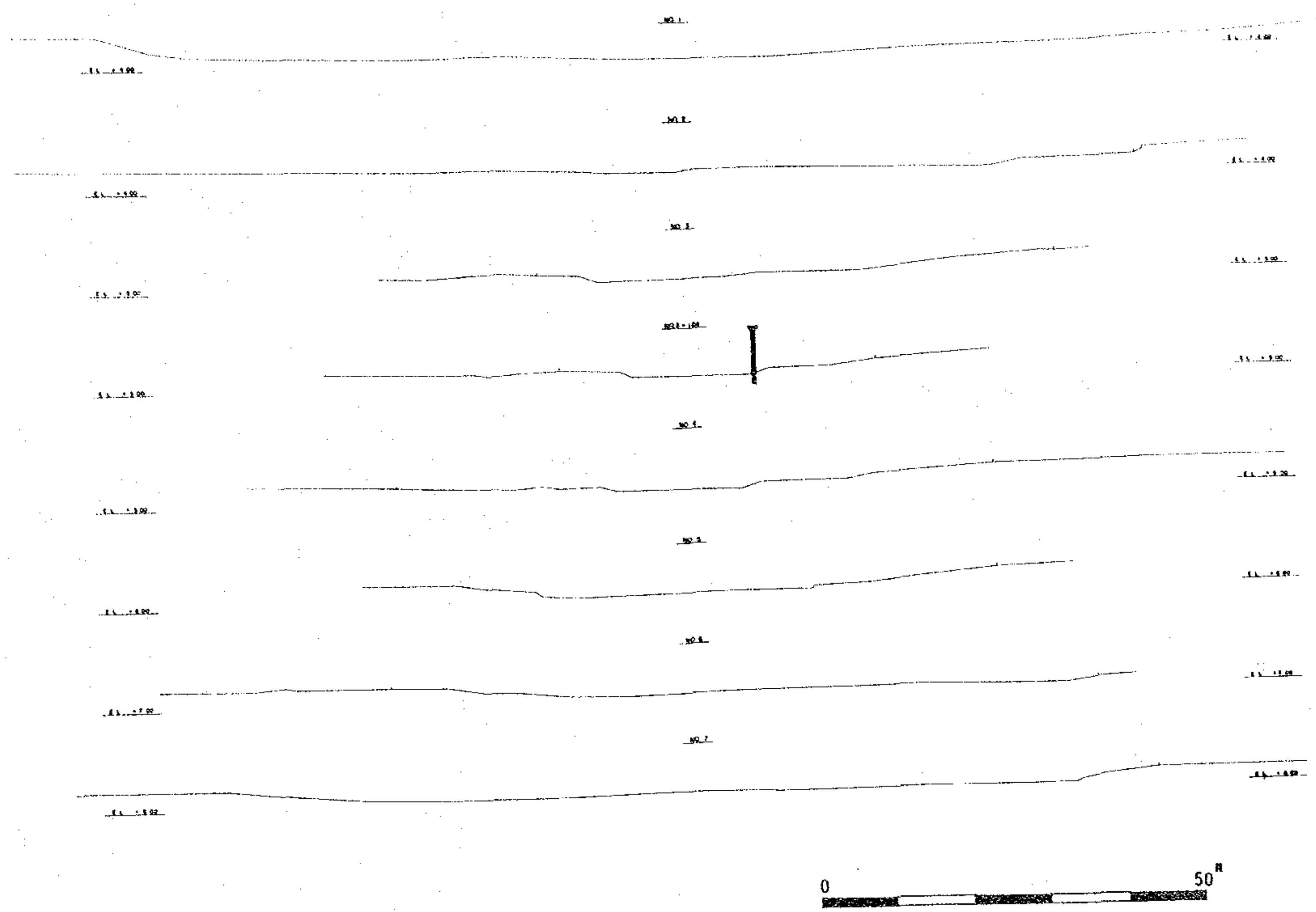
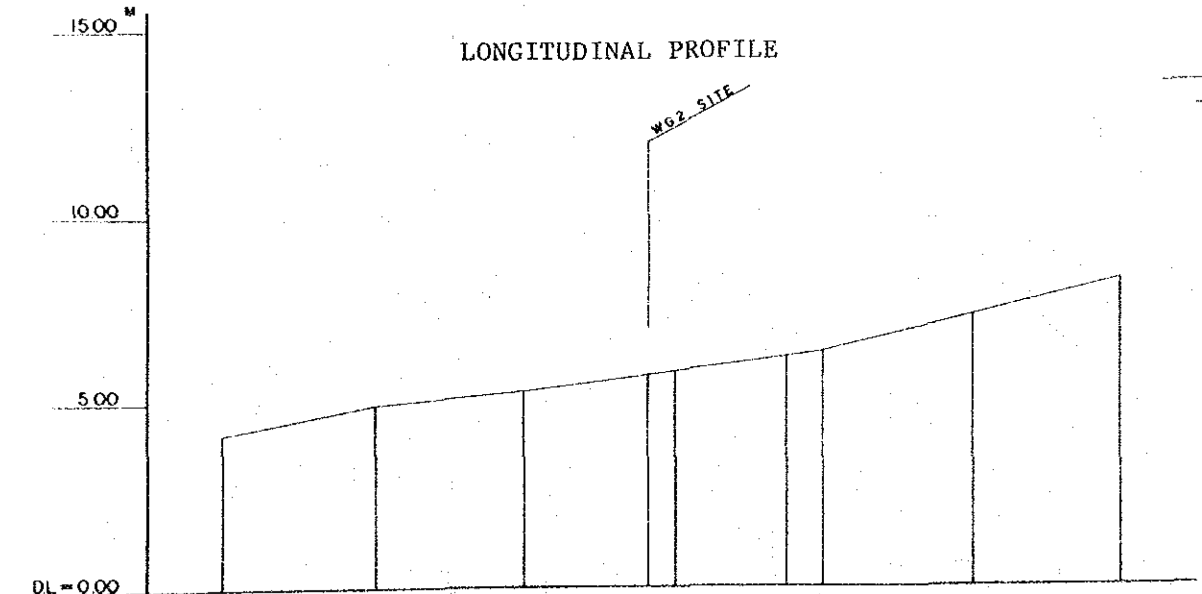


Fig. B-1-7 (4) Cross-section and Longitudinal Profile of Wadi Gauge Site, WG2

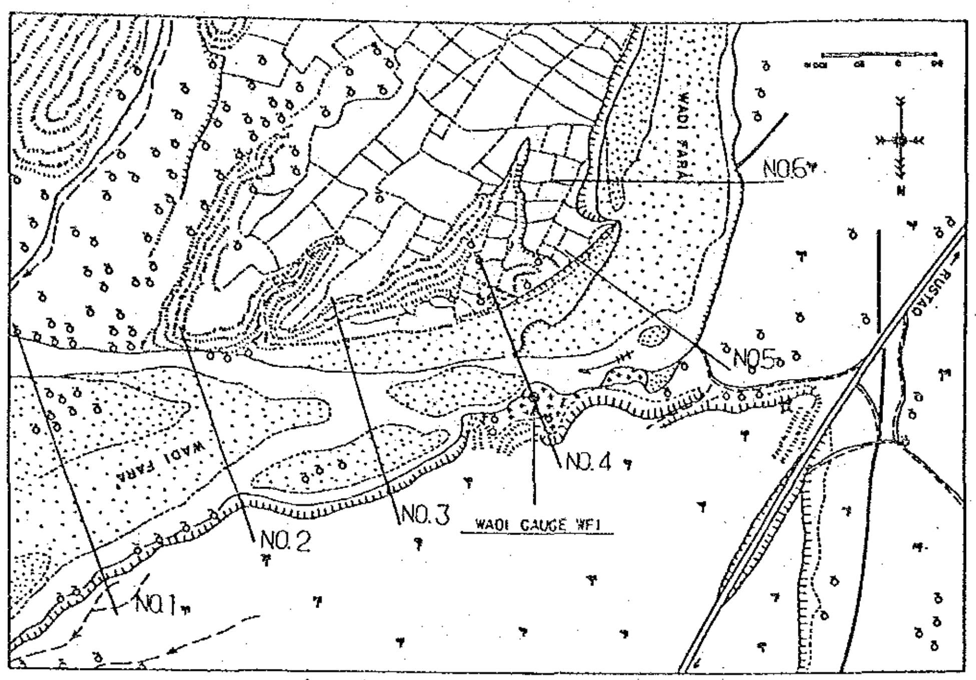


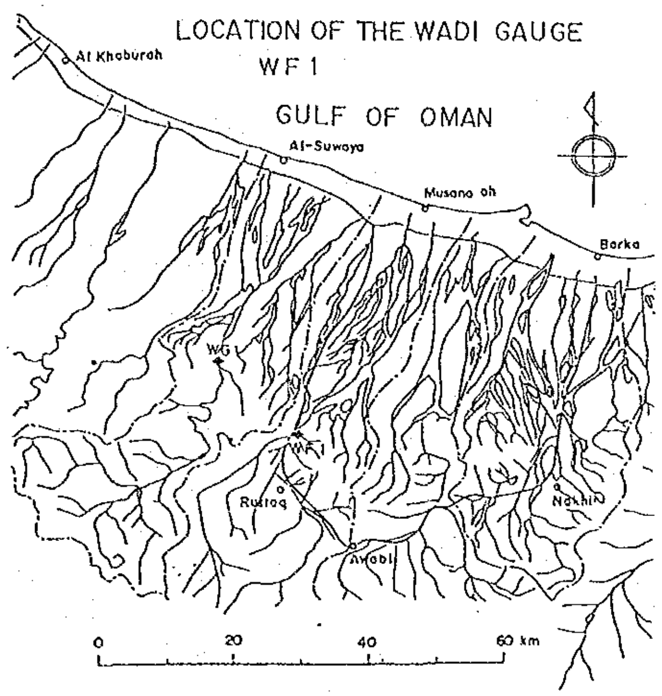


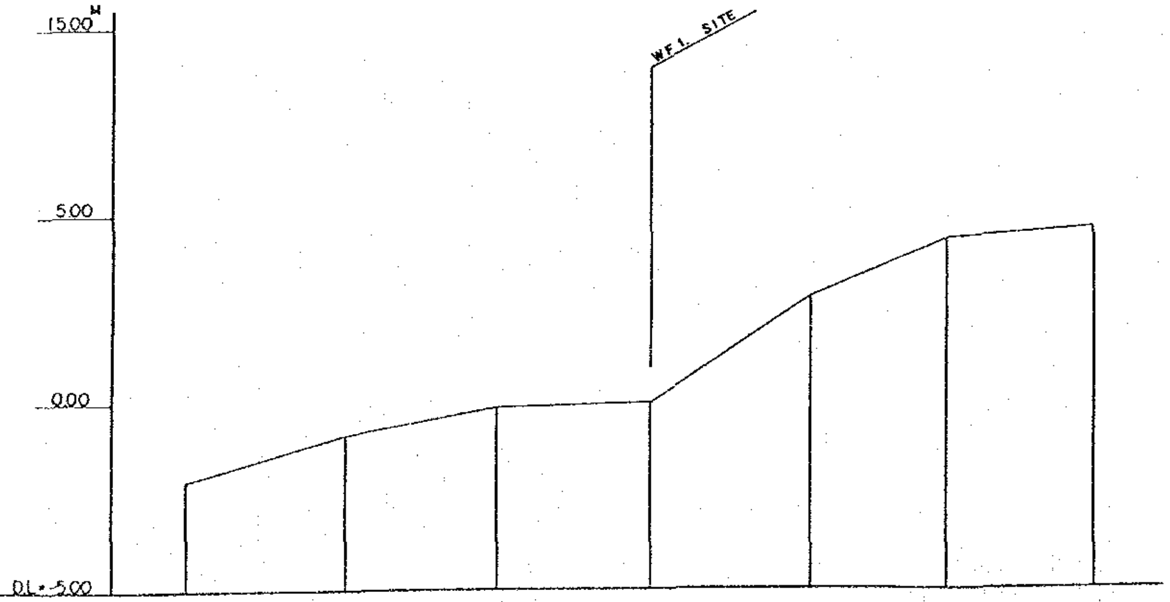


LONGITUDINAL SLOPE			4.920 — I = 1/420, L = 600m — 6.345							
PRESENT ELEVATION (EL m)	RIGHT BANK									
	LEFT BANK									
	MEAN RIVER BED									
	LOWEST RIVER BED	4.185	4.920	5.300	5.720	5.830	6.218	6.345	7.360	8.320
ACCUMULATED DISTANCE		0	200	400	564	600	750	800	1,000	1,200
DISTANCE		0	200	200	164	36	150	50	200	200
STATION No.		1	2	3	+164	4	+150	5	6	7

Fig. B-1-7 (5) Cross-section and Longitudinal Profile of Wadi Gauge Site, WF1







		1	2	3	4	5	6	7
LONGITUDINAL SLOPE		-2.07		I=1/196 L=815M		2.09 (I=1/93 L=185M)	4.39 (I=1/645 L=200M)	4.70
PRESENT ELEVATION (EL. m)	RIGHT BANK							
	LEFT BANK							
	MEAN RIVER BED							
	LOWEST RIVER BED	-2.07	-0.84	-0.100	0.00	2.09	4.39	4.70
ACCUMULATED DISTANCE		0	200	400	600	815	1,000	1,200
DISTANCE		0	200	200	200	215	185	200
STATION No		1	2	3	4	5	6	7

Cross section

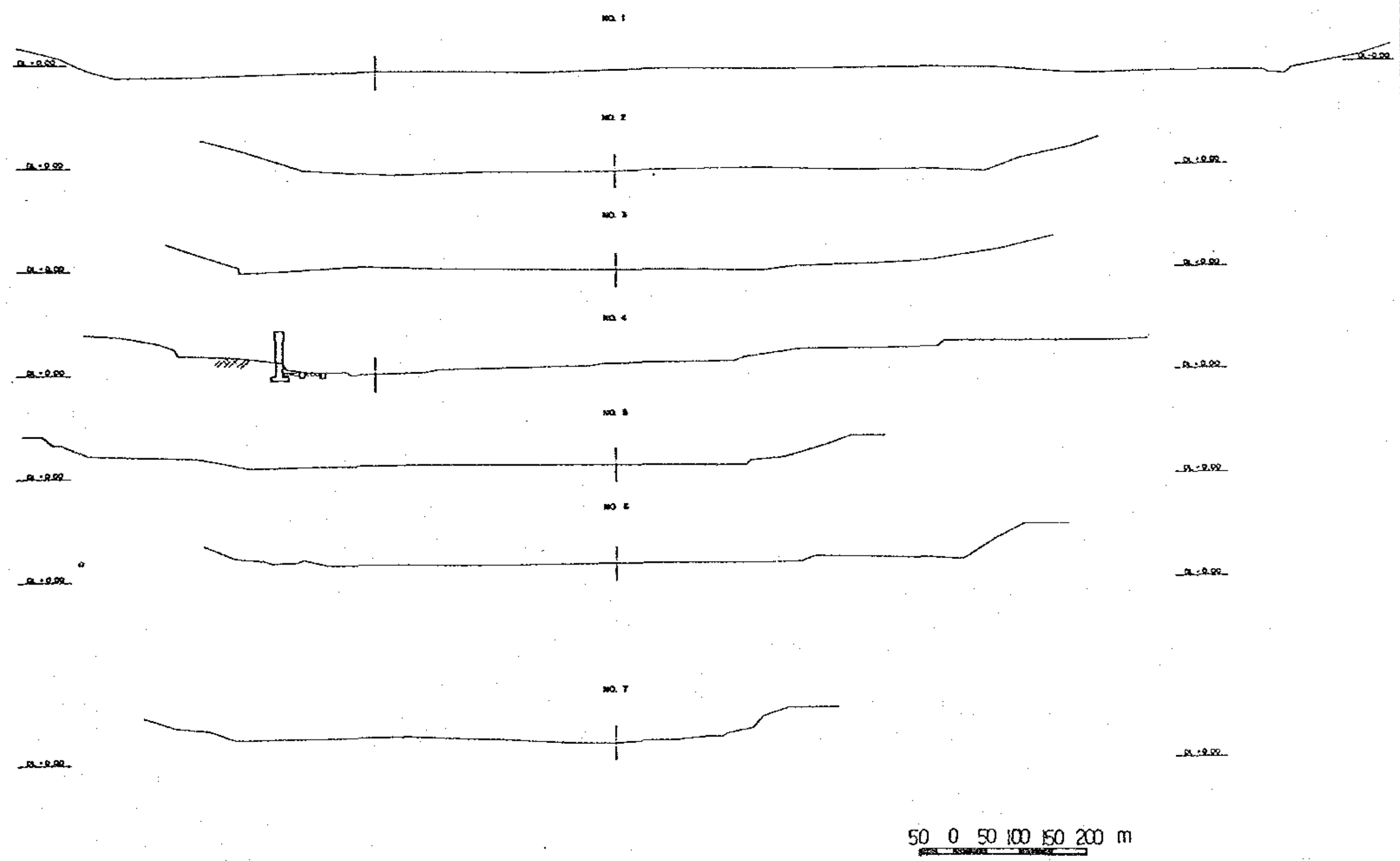
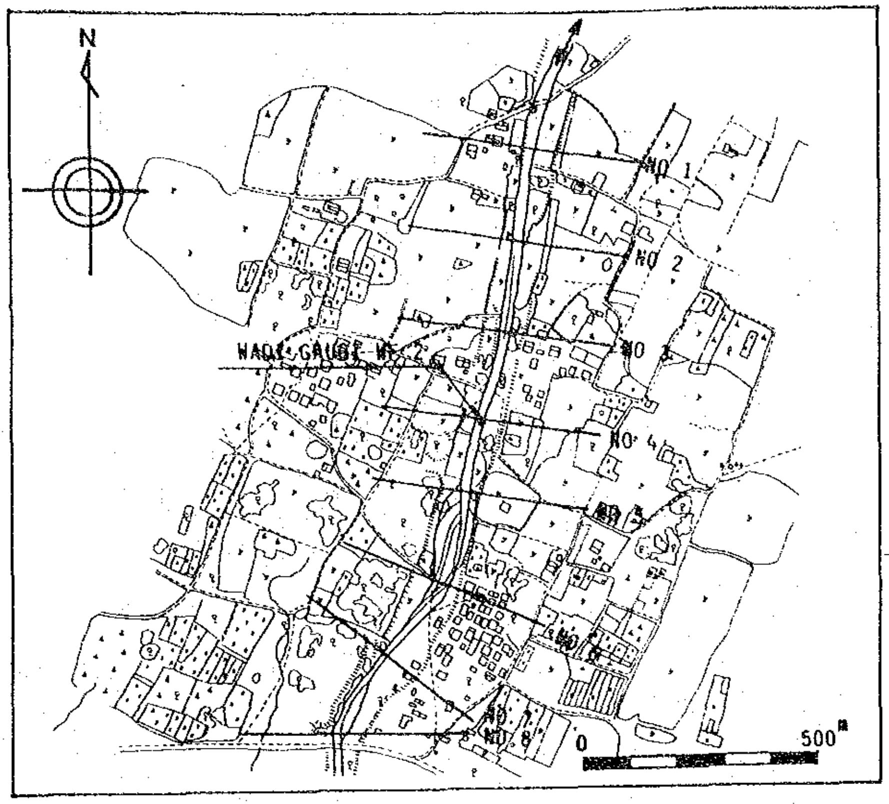
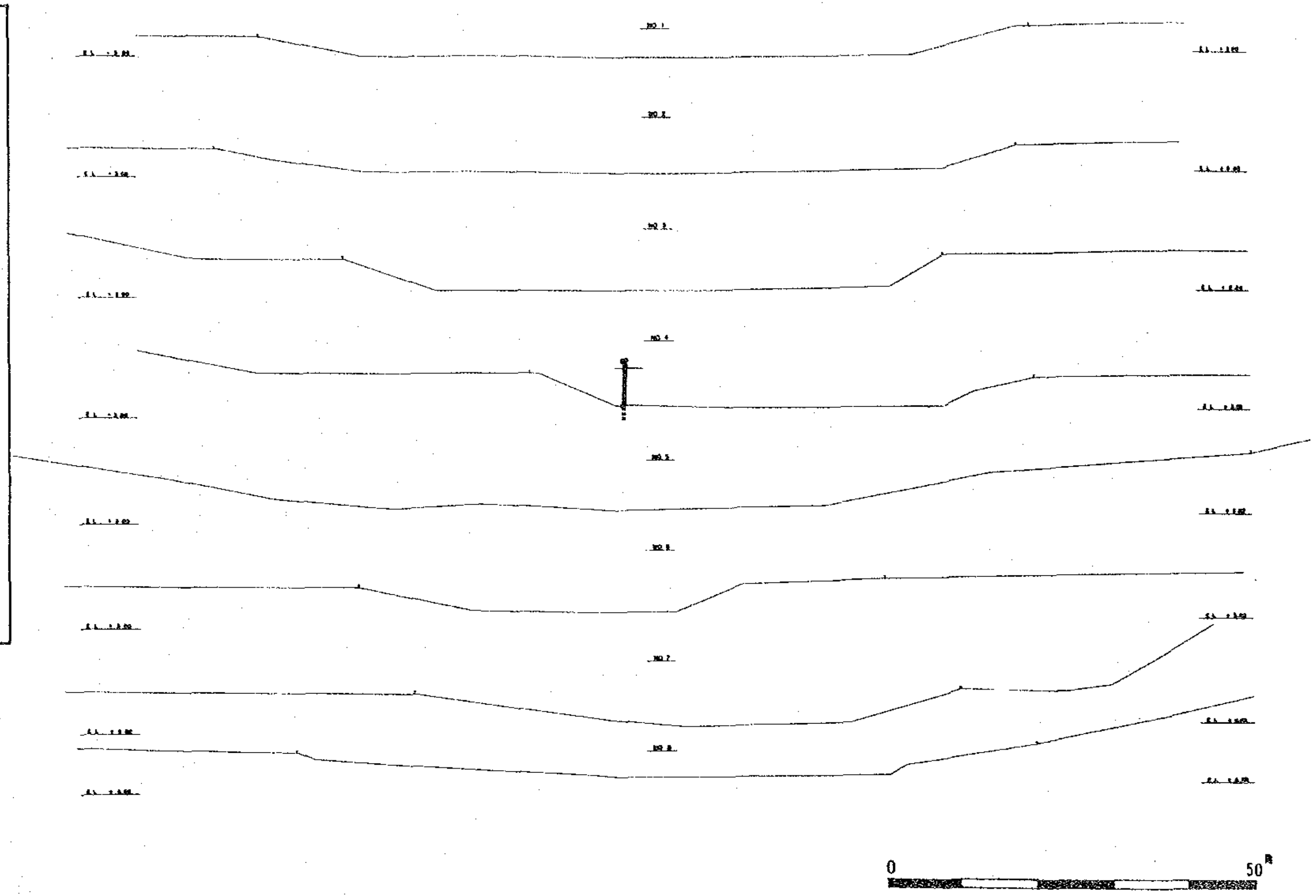


Fig. B-1-7 (6) Cross-section and Longitudinal Profile of Wadi Gauge Site, WF2





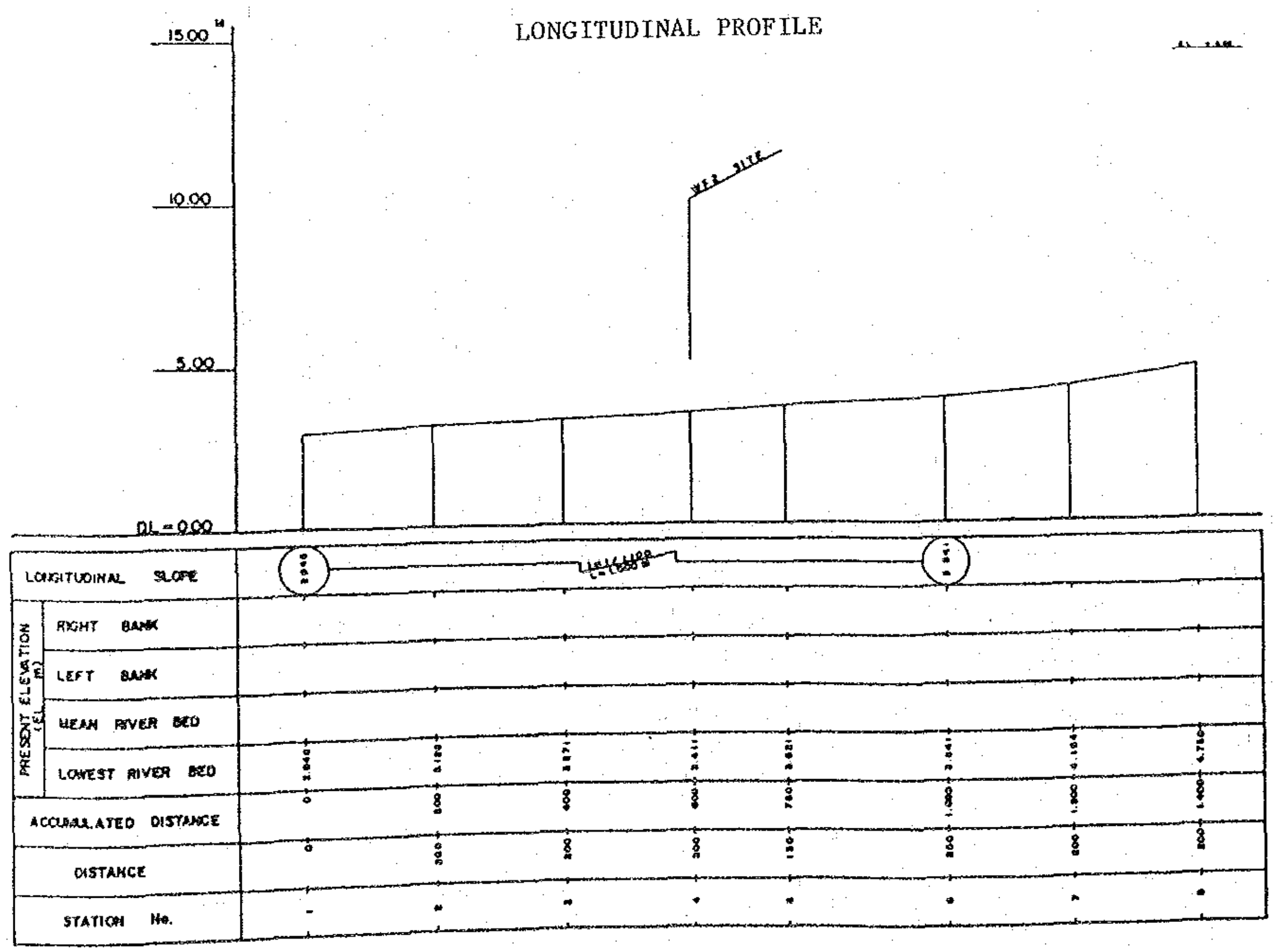
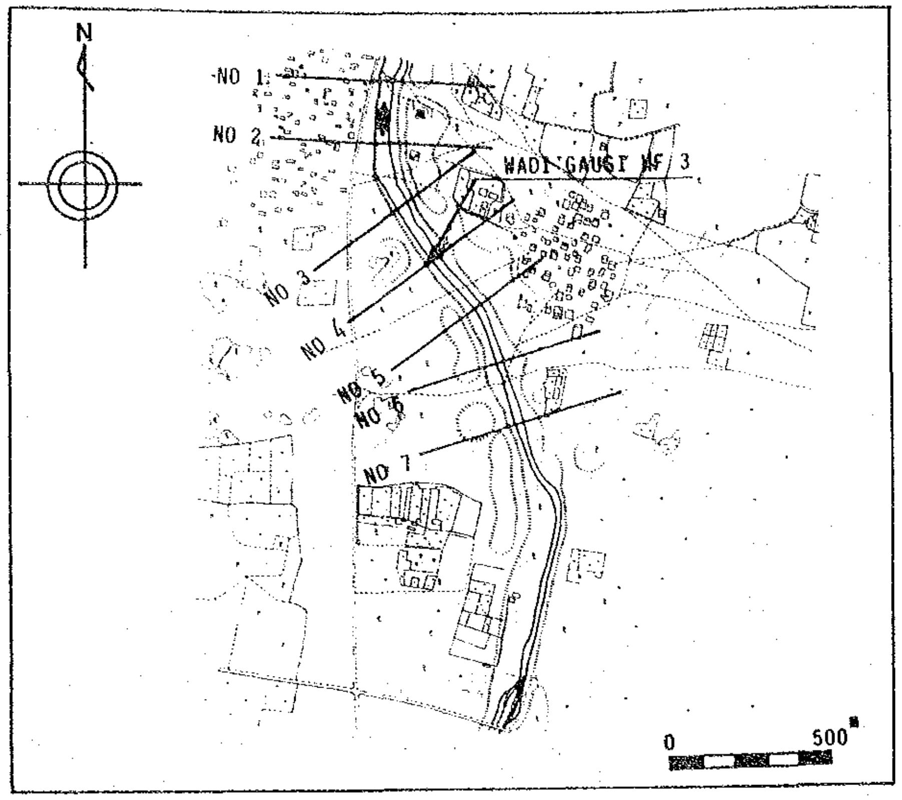
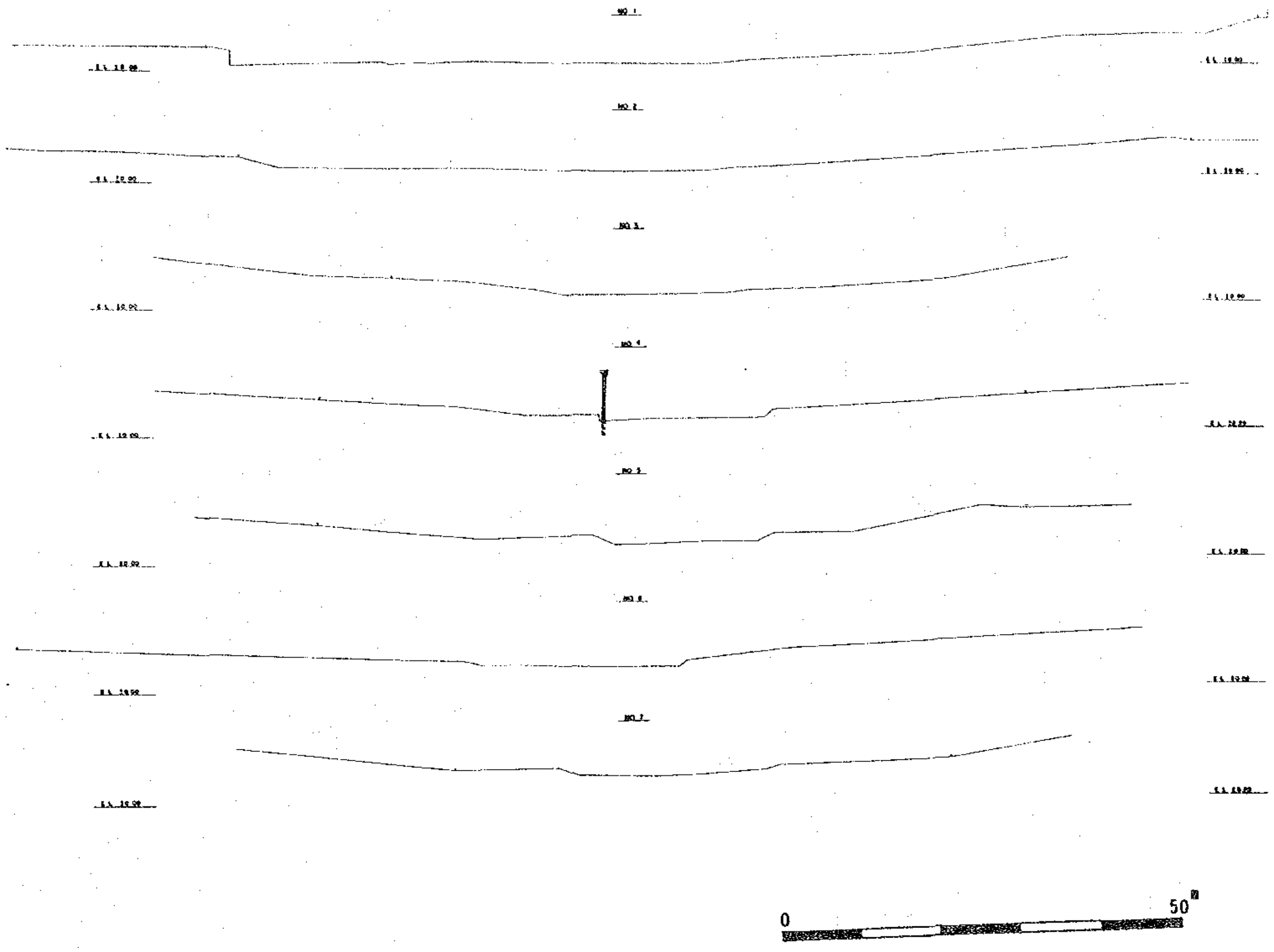
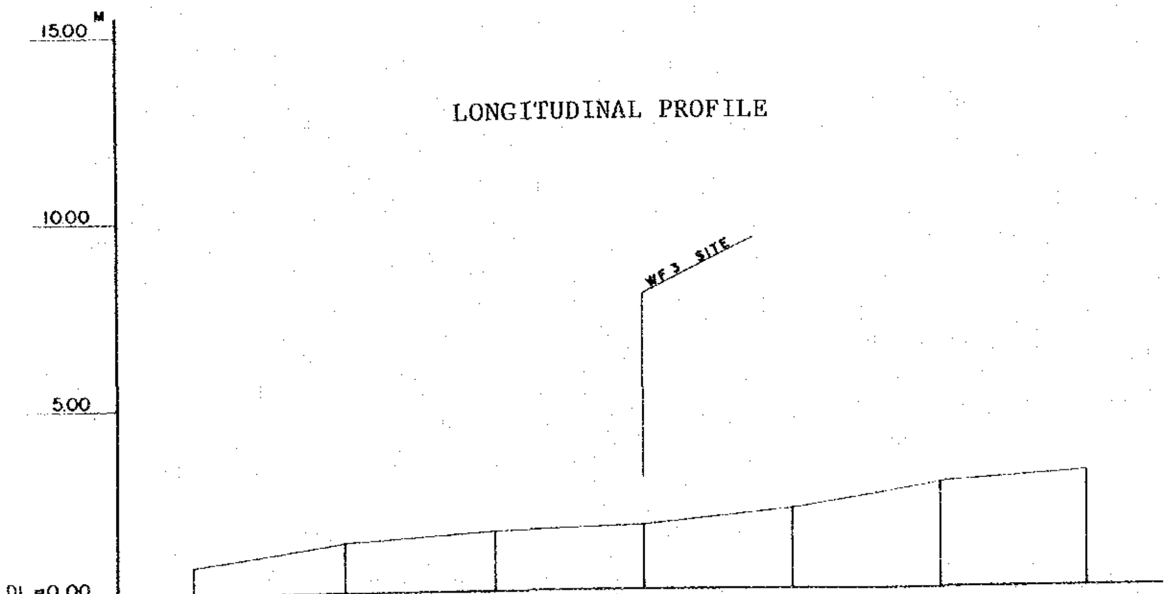


Fig. B-1-7 (7) Cross-section and Longitudinal Profile of Wadi Gauge Site, WF3

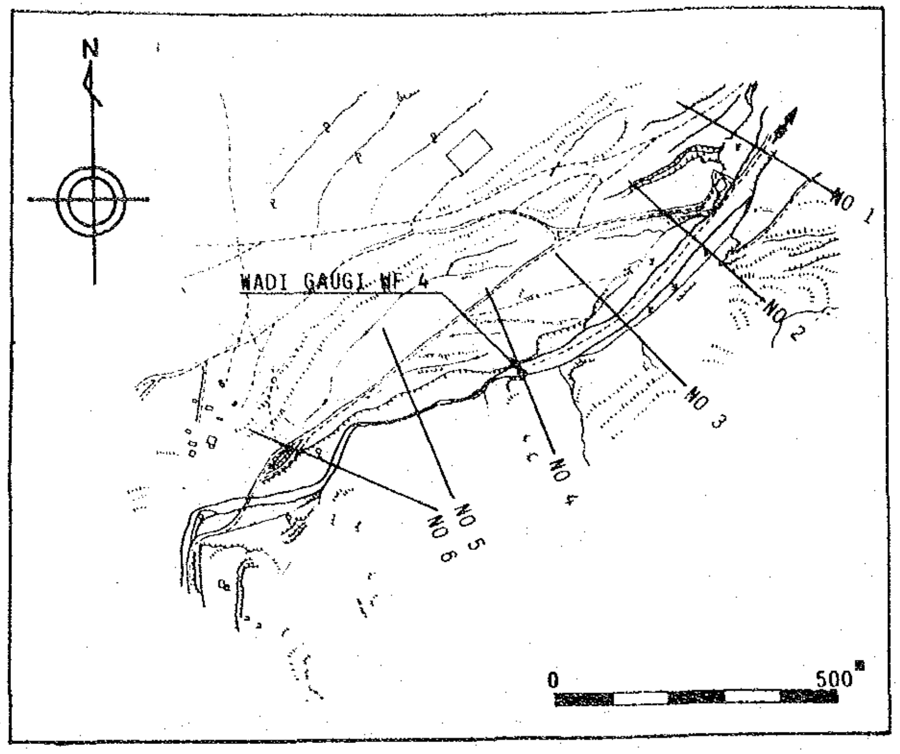


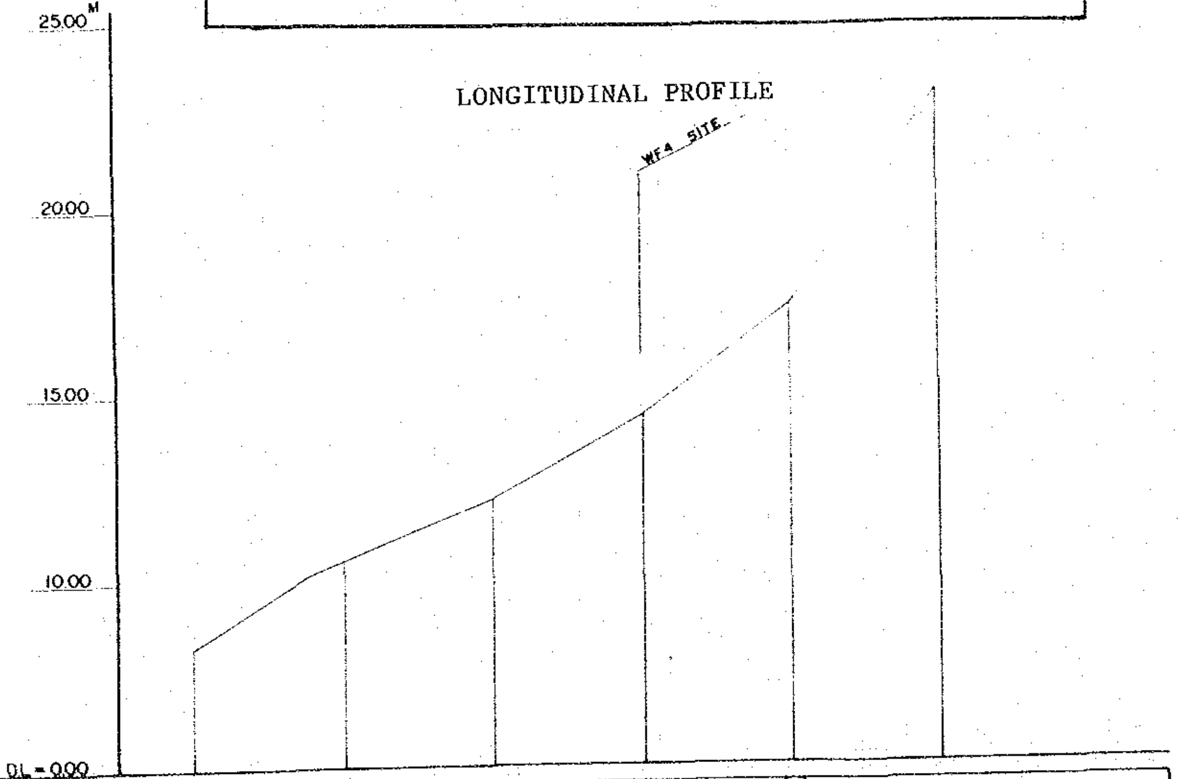




LONGITUDINAL SLOPE		1.330		I = 1/330 L = 800m		2.840	
PRESENT ELEVATION (EL. m) RIGHT BANK							
PRESENT ELEVATION (EL. m) LEFT BANK							
PRESENT ELEVATION (EL. m) MEAN RIVER BED							
PRESENT ELEVATION (EL. m) LOWEST RIVER BED	0.790	1.330	1.625	1.720	2.180	2.840	3.110
ACCUMULATED DISTANCE	0	200	400	600	800	1,000	1,200
DISTANCE	0	200	200	200	200	200	200
STATION No.	1	2	3	4	5	6	7

Fig. B-1-7(8) Cross-section and Longitudinal Profile of Wadi Gauge Site, WF4





LONGITUDINAL SLOPE			(7.190) — I=1/73, L=400		(12.390)		
PRESENT ELEVATION (EL m) — RIGHT BANK							
PRESENT ELEVATION (EL m) — LEFT BANK							
PRESENT ELEVATION (EL m) — MEAN RIVER BED							
PRESENT ELEVATION (EL m) — LOWEST RIVER BED	3.280	5.195	7.190	9.485	12.390	18.115	21.640
ACCUMULATED DISTANCE	0	200	400	600	800	1,000	1,200
DISTANCE	0	200	200	200	200	200	200
STATION No.	1	2	3	4	5	6	7

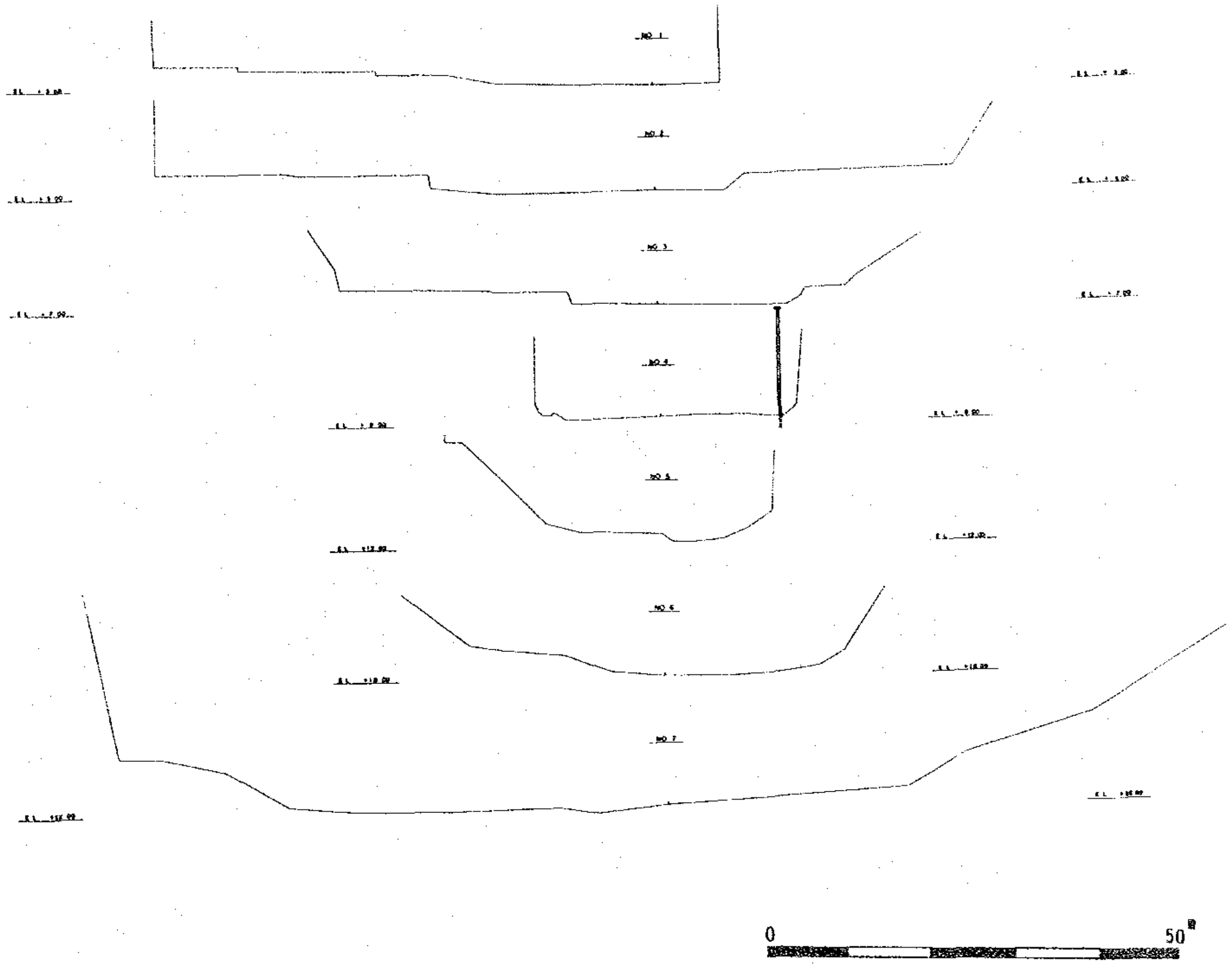
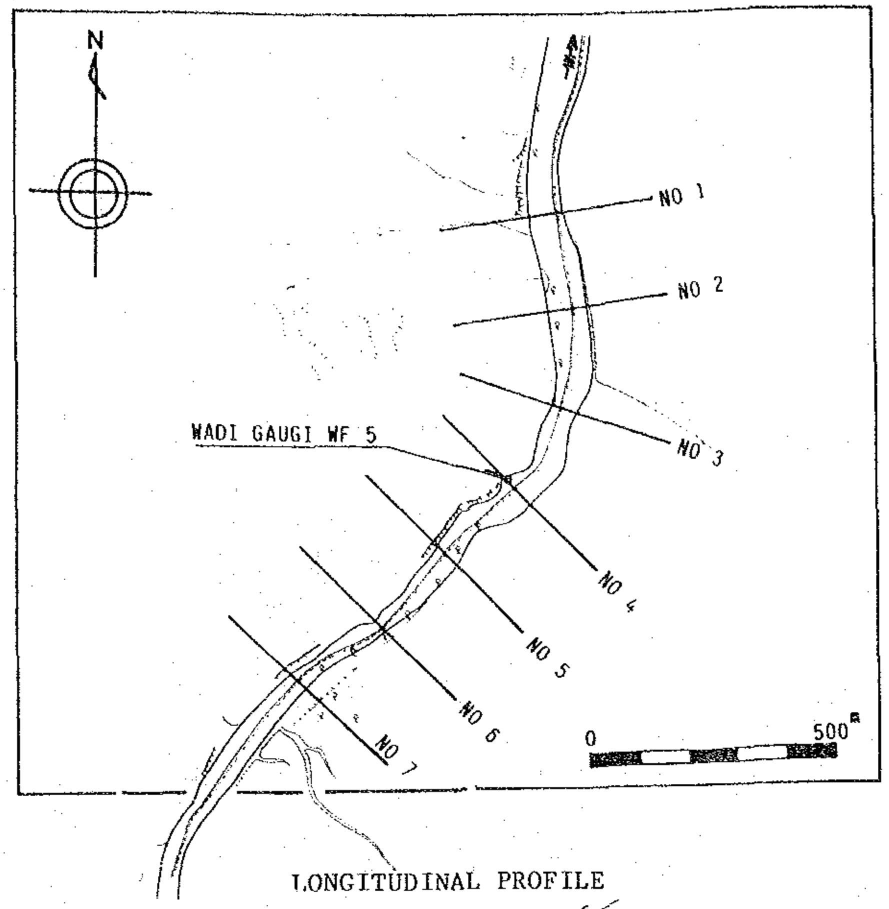
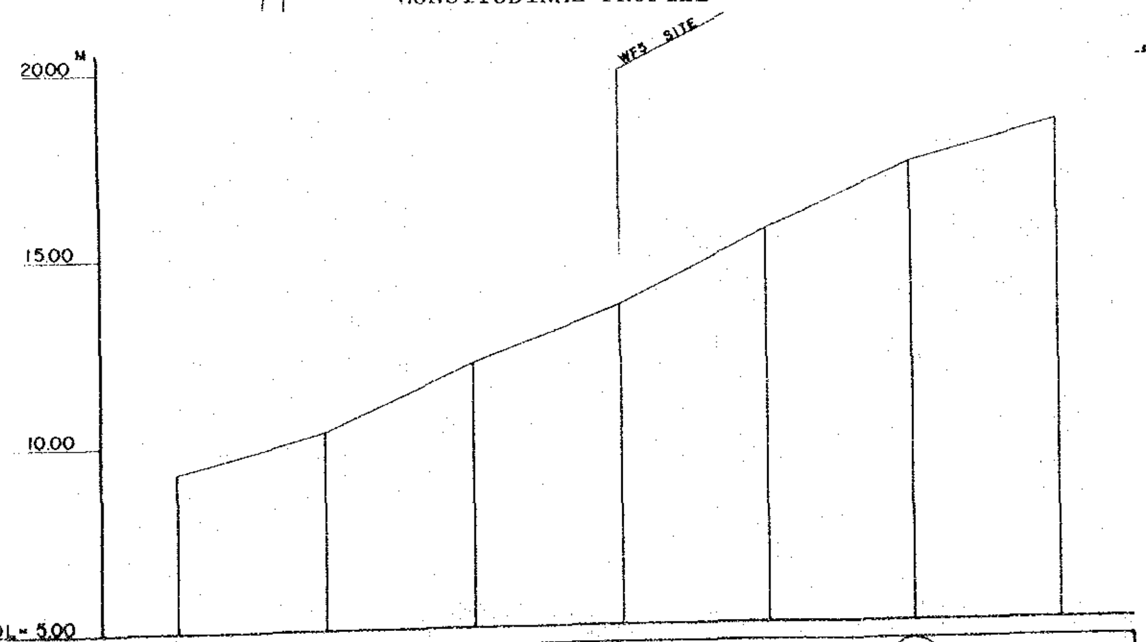


Fig. B-1-7(9) Cross-section and Longitudinal Profile of Wadi Gauge Site, WF5





LONGITUDINAL SLOPE		10.315		I=1/110 L=800M		17.410	
PRESENT ELEVATION (EL. M) RIGHT BANK							
LEFT BANK							
MEAN RIVER BED							
LOWEST RIVER BED	9.275	10.315	12.135	13.853	15.670	17.410	18.510
ACCUMULATED DISTANCE	0	200	400	600	800	1,000	1,200
DISTANCE	0	200	200	200	200	200	200
STATION No	1	2	3	4	5	6	7

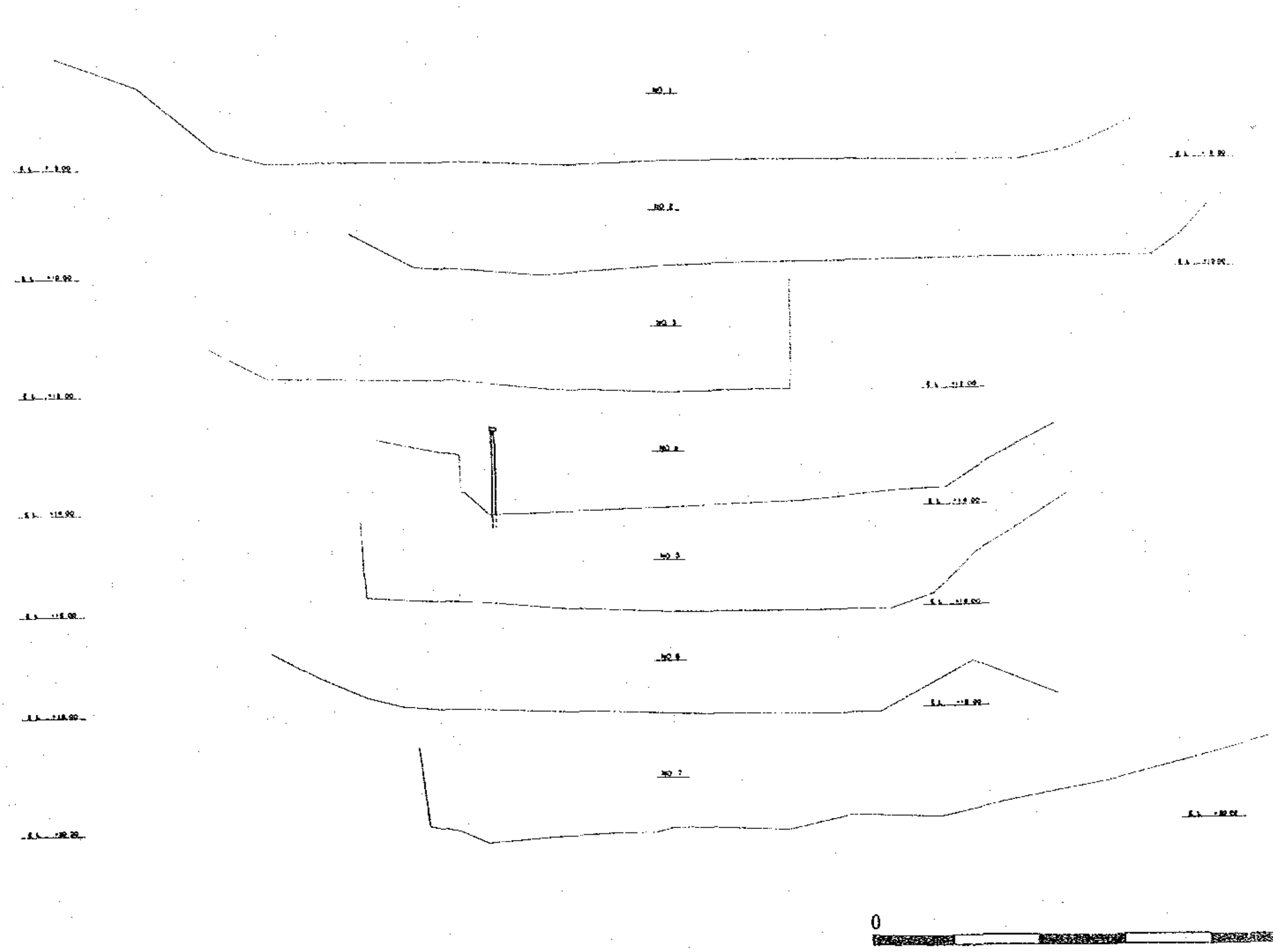
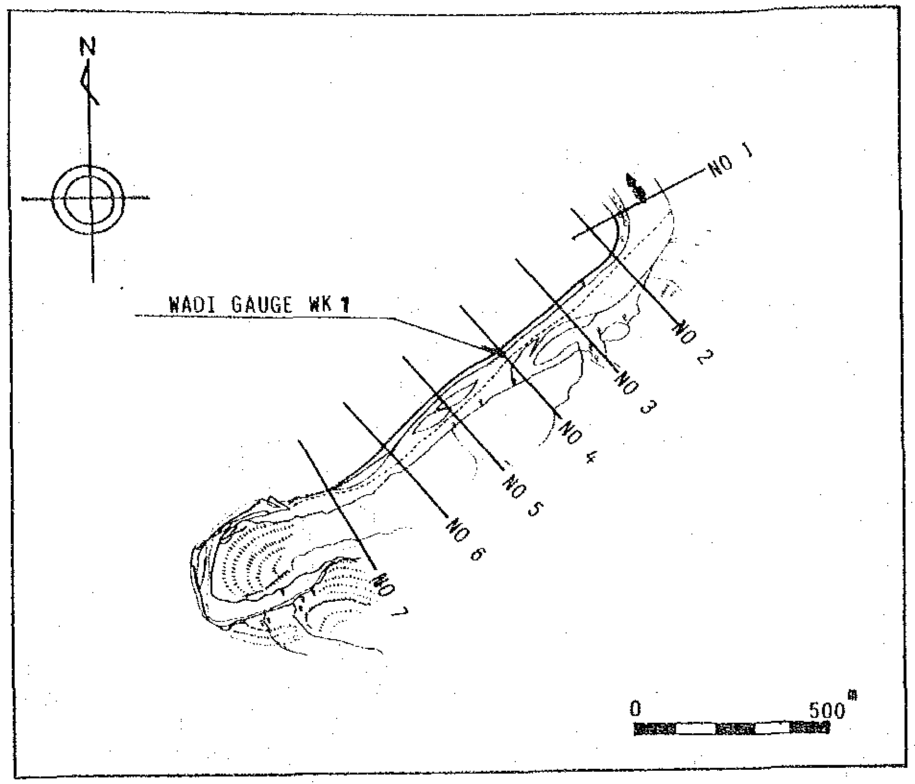
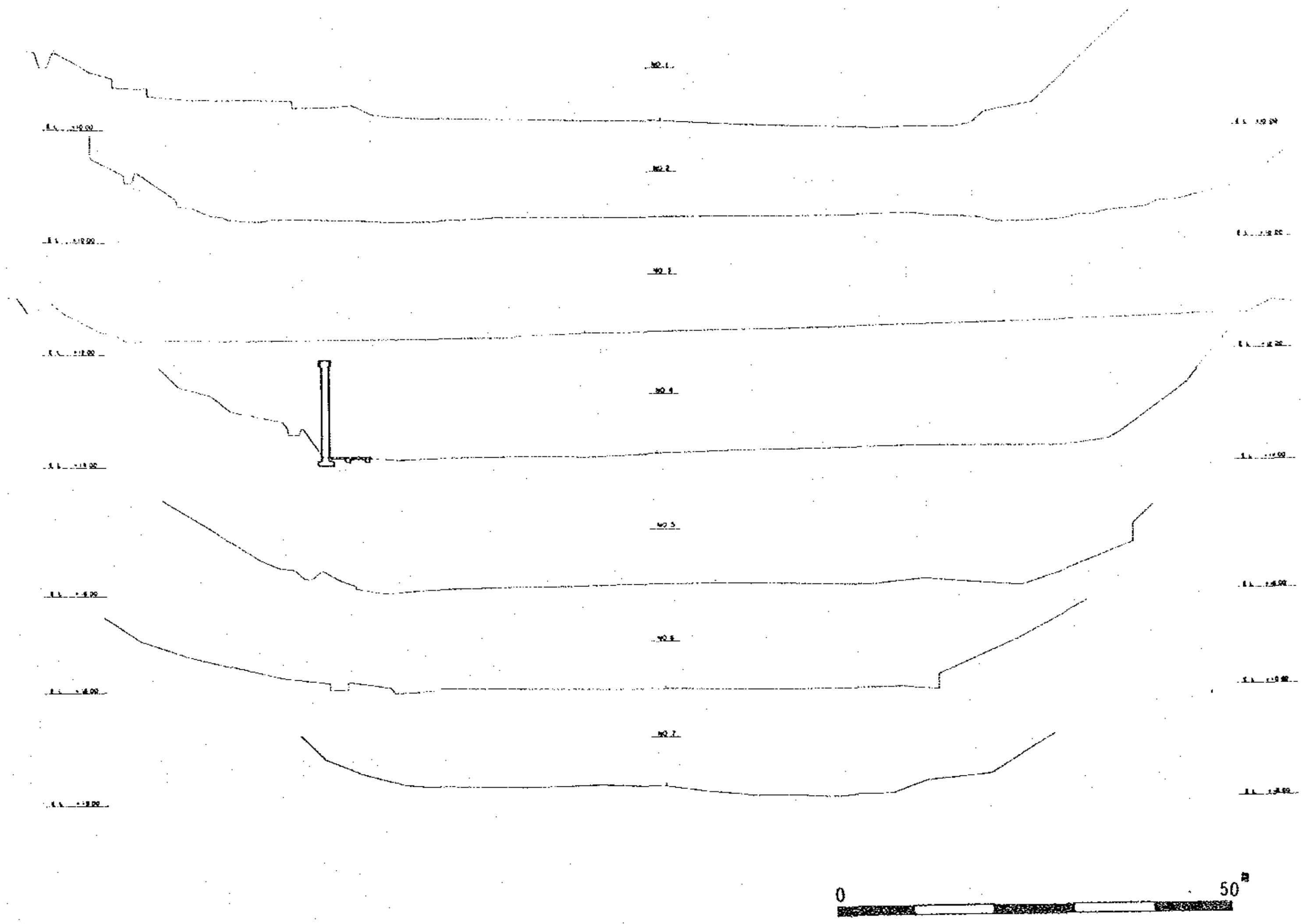
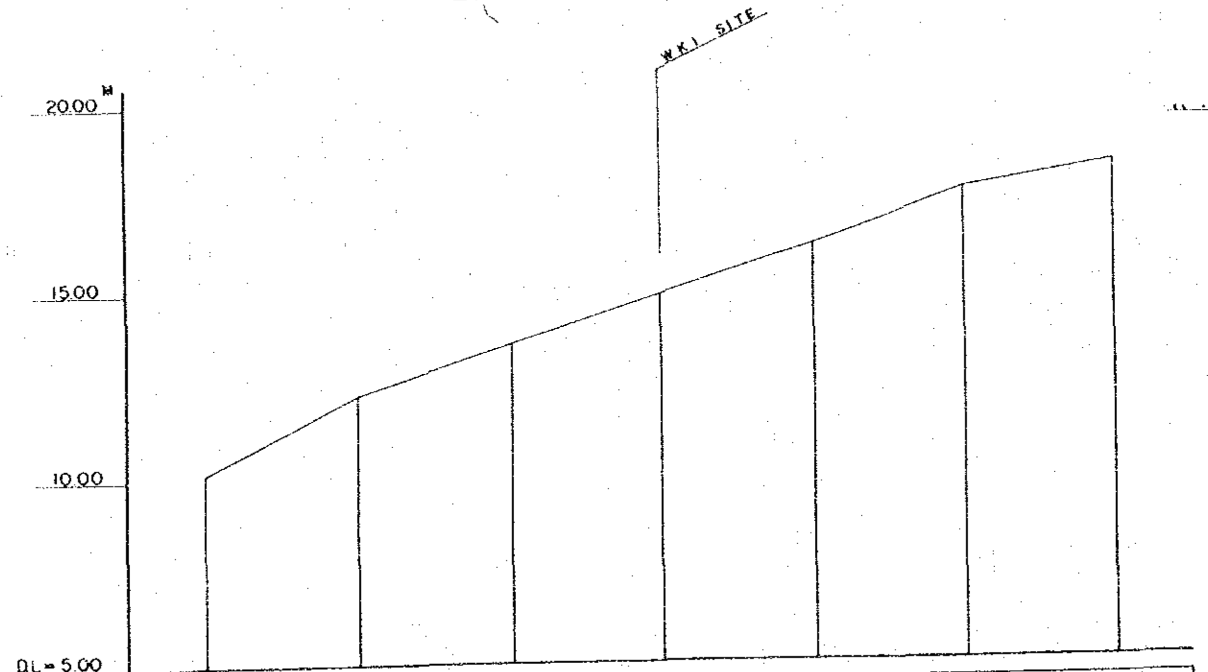


Fig. B-1-7 (10). Cross-section and Longitudinal Profile of Wadi Gauge Site, WK1



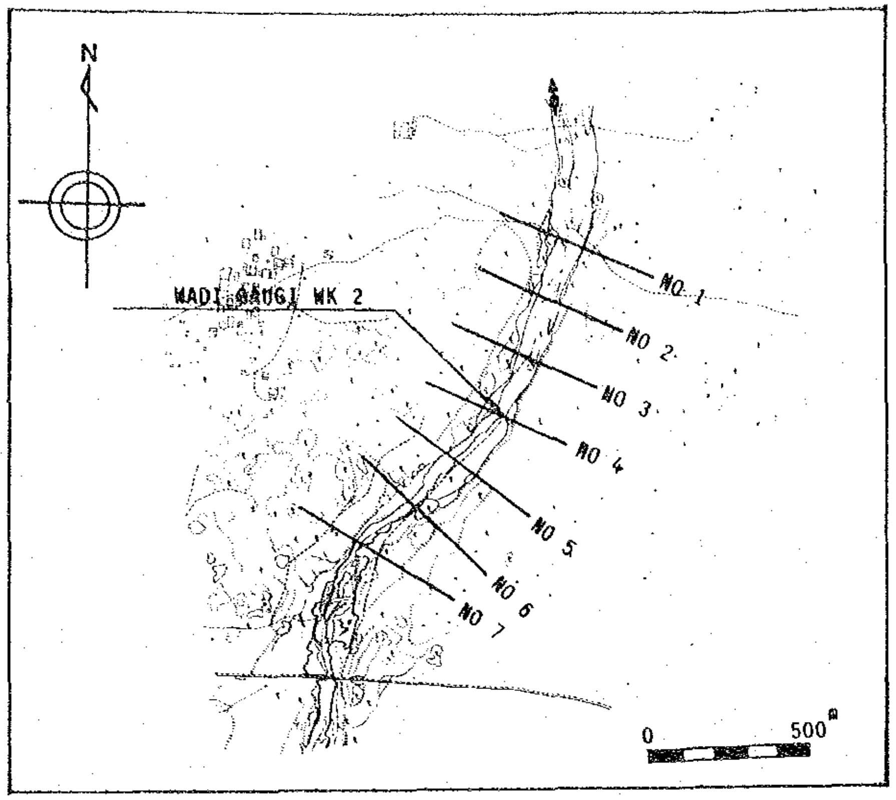


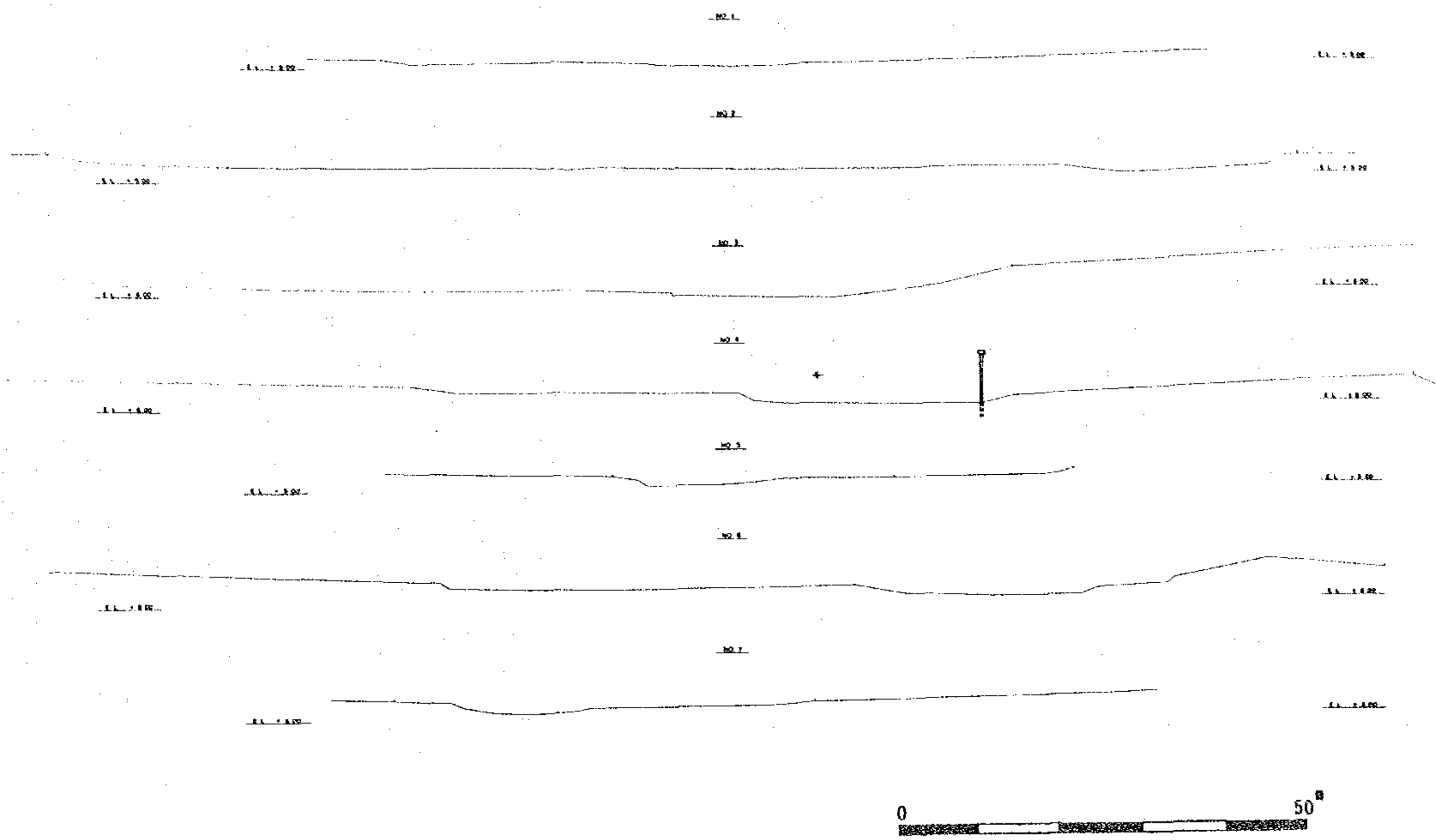
LONGITUDINAL PROFILE

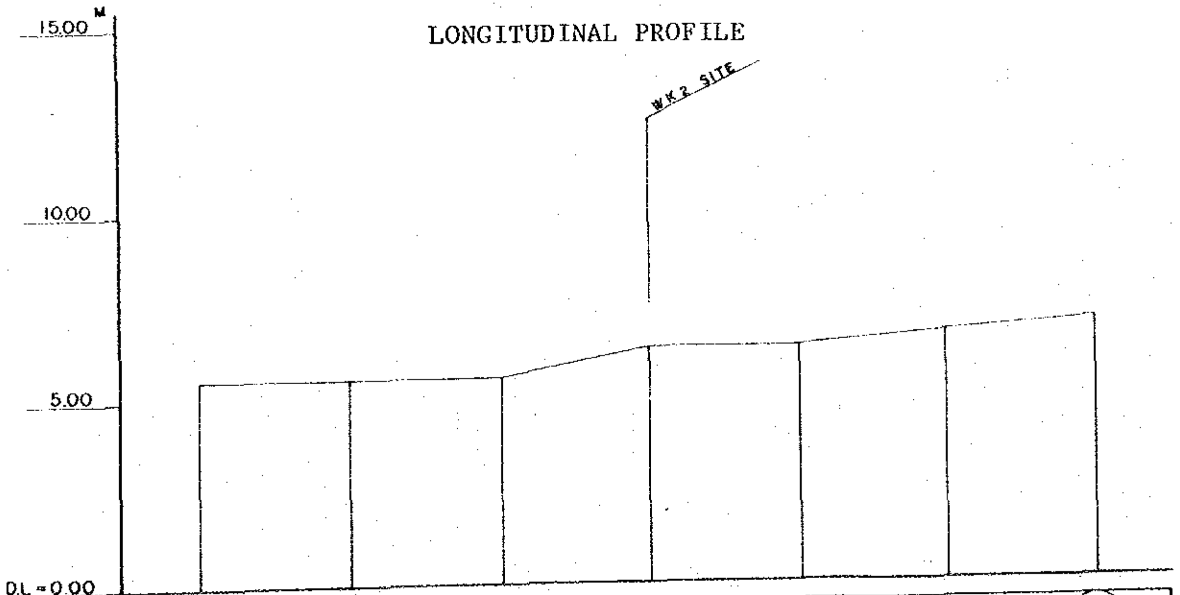


LONGITUDINAL SLOPE		12.246		i=1/145 L=800 M		17.755	
PRESENT ELEVATION (EL m) RIGHT BANK							
LEFT BANK							
MEAN RIVER BED							
LOWEST RIVER BED	10.136	12.246	13.611	14.951	16.281	17.755	18.455
ACCUMULATED DISTANCE	0	200	400	600	800	1,000	1,200
DISTANCE	0	200	200	200	200	200	200
STATION No.	1	2	3	4	5	6	7

Fig. B-1-7(11) Cross-section and Longitudinal Profile of Wadi Gauge Site, WK2

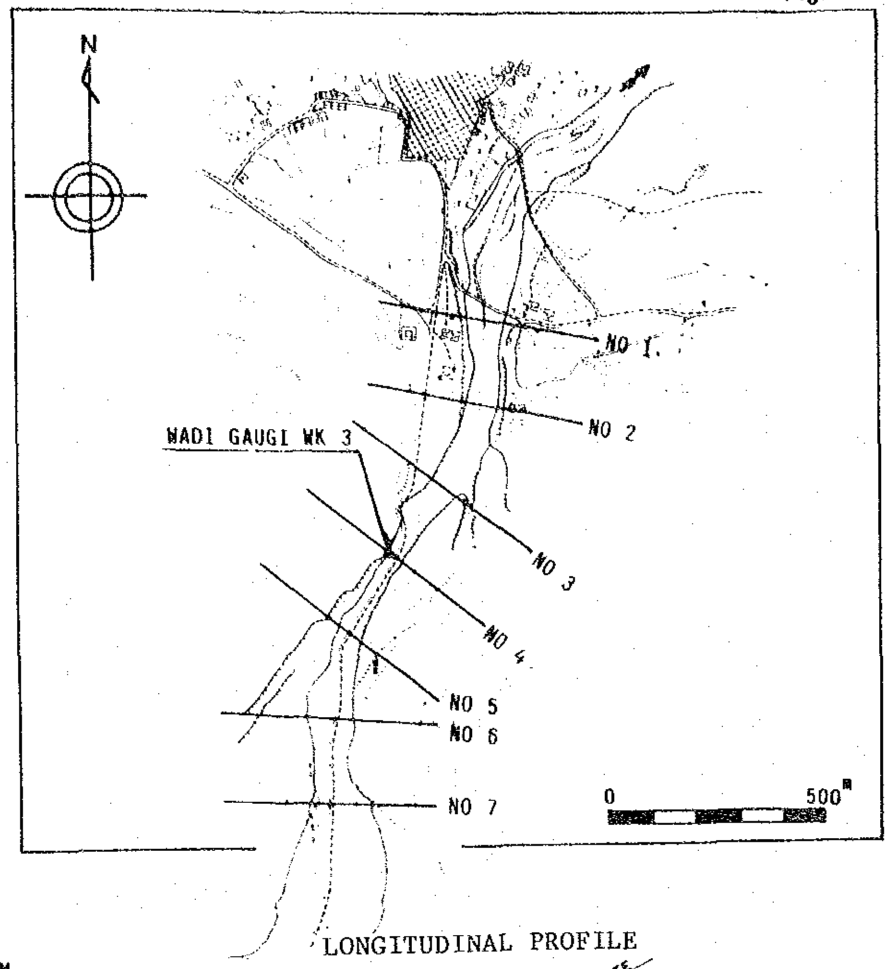


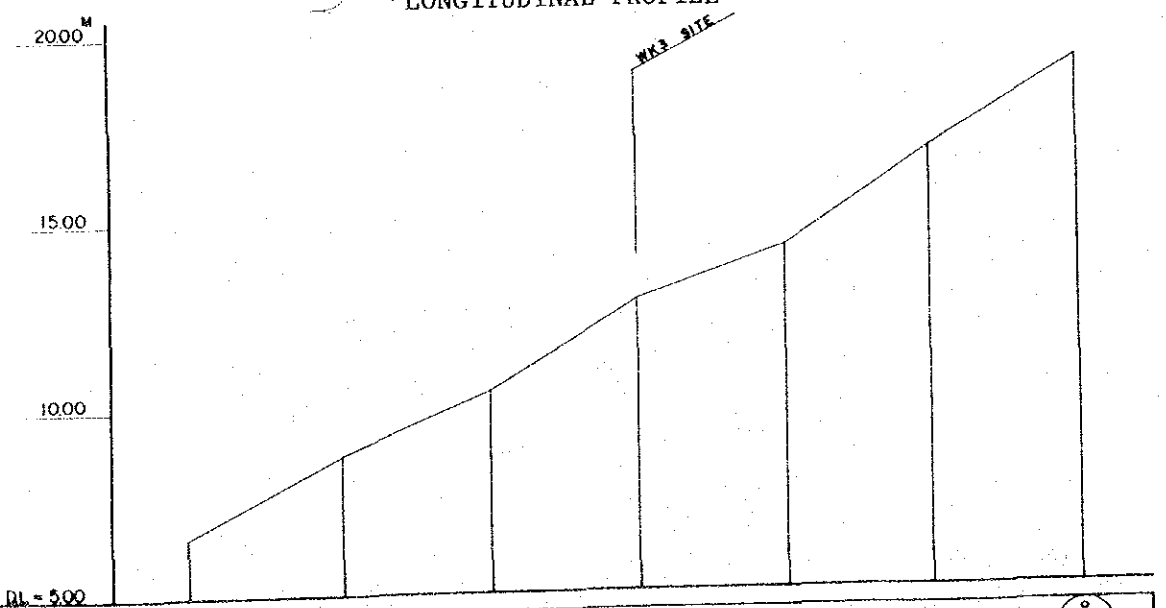




		1	2	3	4	5	6	7
LONGITUDINAL SLOPE				5.580	I = 1/540 L = 800m			7.055
PRESENT ELEVATION (EL m)	RIGHT BANK							
	LEFT BANK							
	MEAN RIVER BED							
	LOWEST RIVER BED	5.550	5.545	5.580	6.350	6.350	6.705	7.055
ACCUMULATED DISTANCE		0	400	400	600	800	1,000	1,200
DISTANCE		0	200	200	200	200	200	200
STATION No.		1	2	3	4	5	6	7

Fig. B-1-7 (12). Cross-section and Longitudinal Profile of Wadi Gauge Site, WK3





LONGITUDINAL SLOPE	6.510	I = 1/95, L = 1207m					19.230
PRESENT ELEVATION (EL m) RIGHT BANK							
LEFT BANK							
MEAN RIVER BED							
LOWEST RIVER BED	6.510	8.780	10.425	12.865	14.225	16.865	19.230
ACCUMULATED DISTANCE	0	207	407	607	807	1,007	1,207
DISTANCE	0	207	200	200	200	200	200
STATION No	1	2	3	4	5	6	7

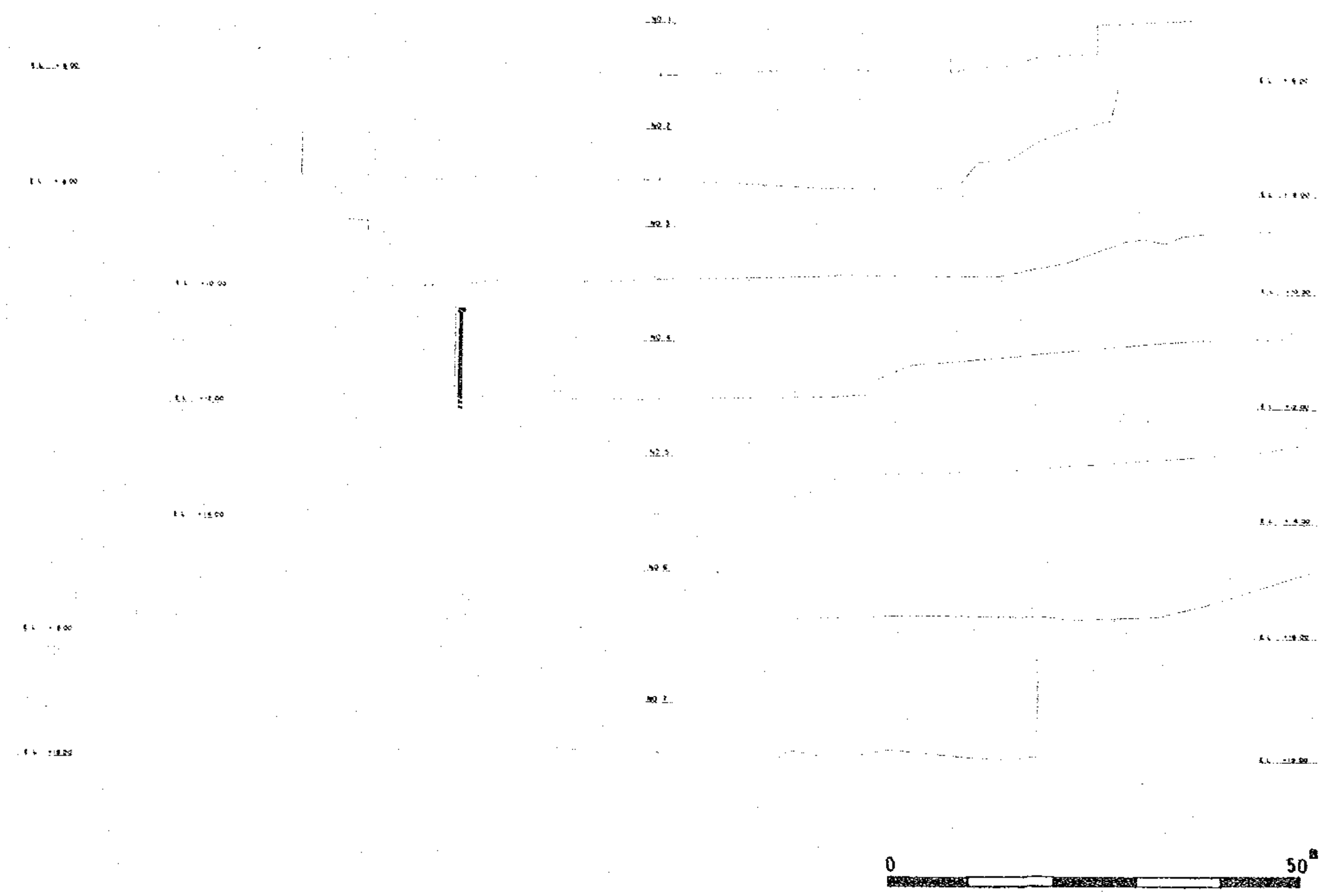
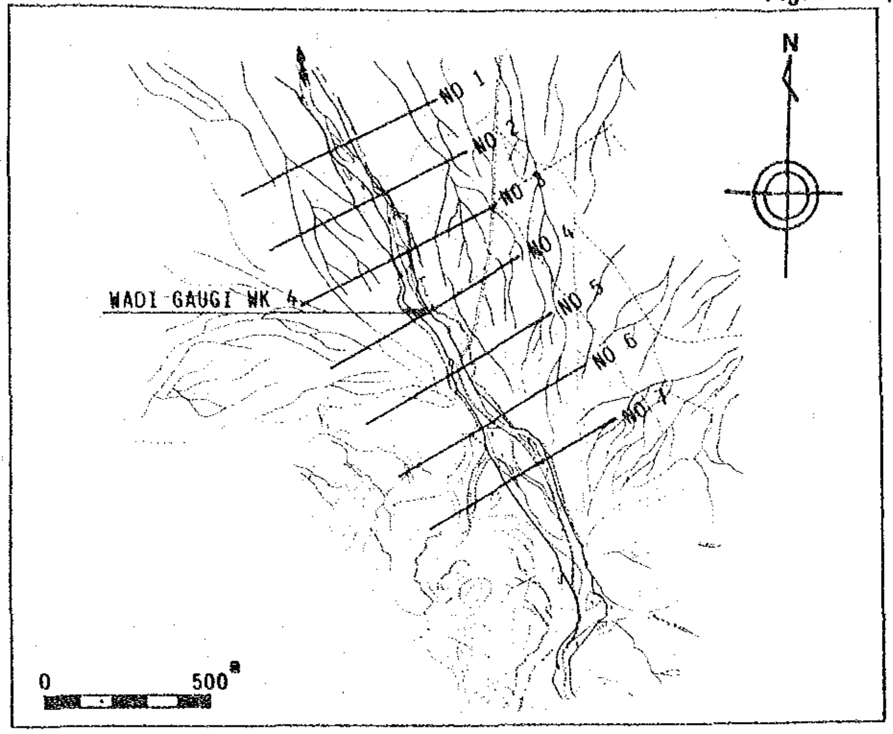
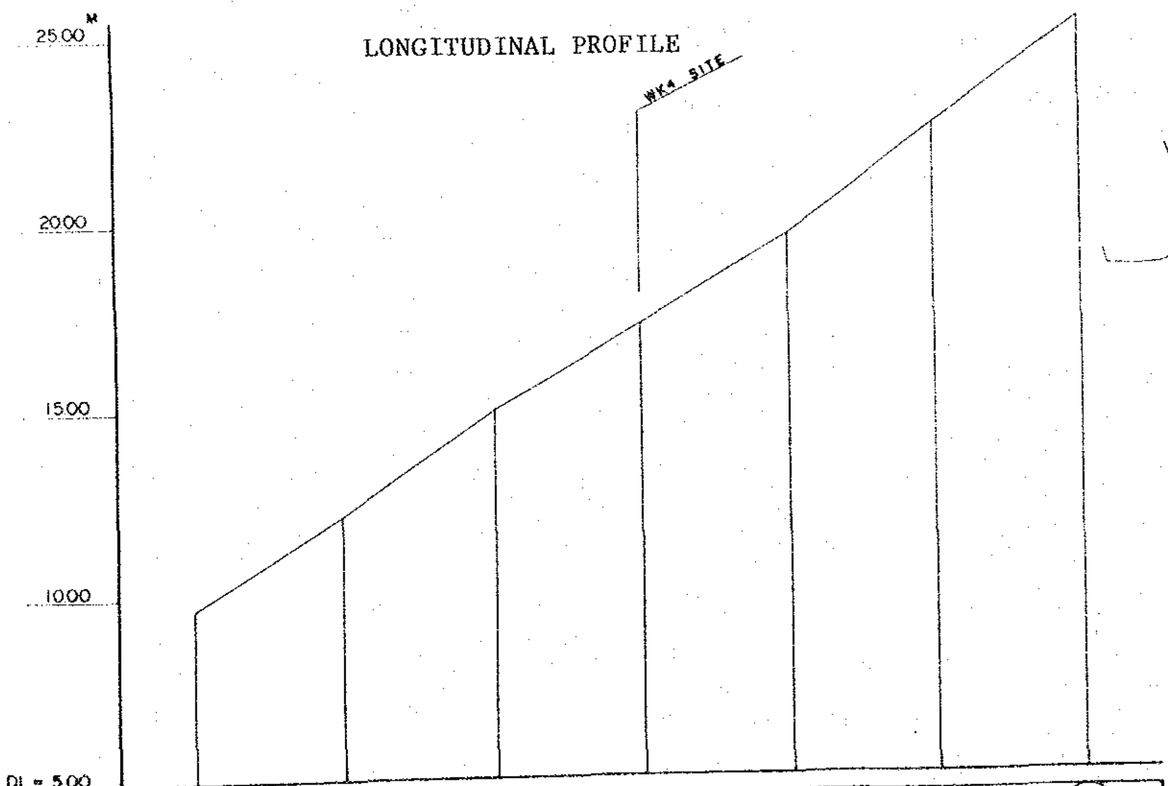


Fig. B-1-7 (13) Cross-section and Longitudinal Profile of Wadi Gauge Site, WK4





		1	2	3	4	5	6	7
LONGITUDINAL SLOPE		9.860		I=1/80 L=600m		19.645	I=1/70 L=400m	25.430
PRESENT ELEVATION (EL m)	RIGHT BANK							
	LEFT BANK							
	MEAN RIVER BED							
	LOWEST RIVER BED	9.860	12.115	14.970	17.230	19.645	22.620	25.430
ACCUMULATED DISTANCE		0	200	400	600	800	1,000	1,200
DISTANCE		0	200	200	200	200	200	200
STATION No.		1	2	3	4	5	6	7

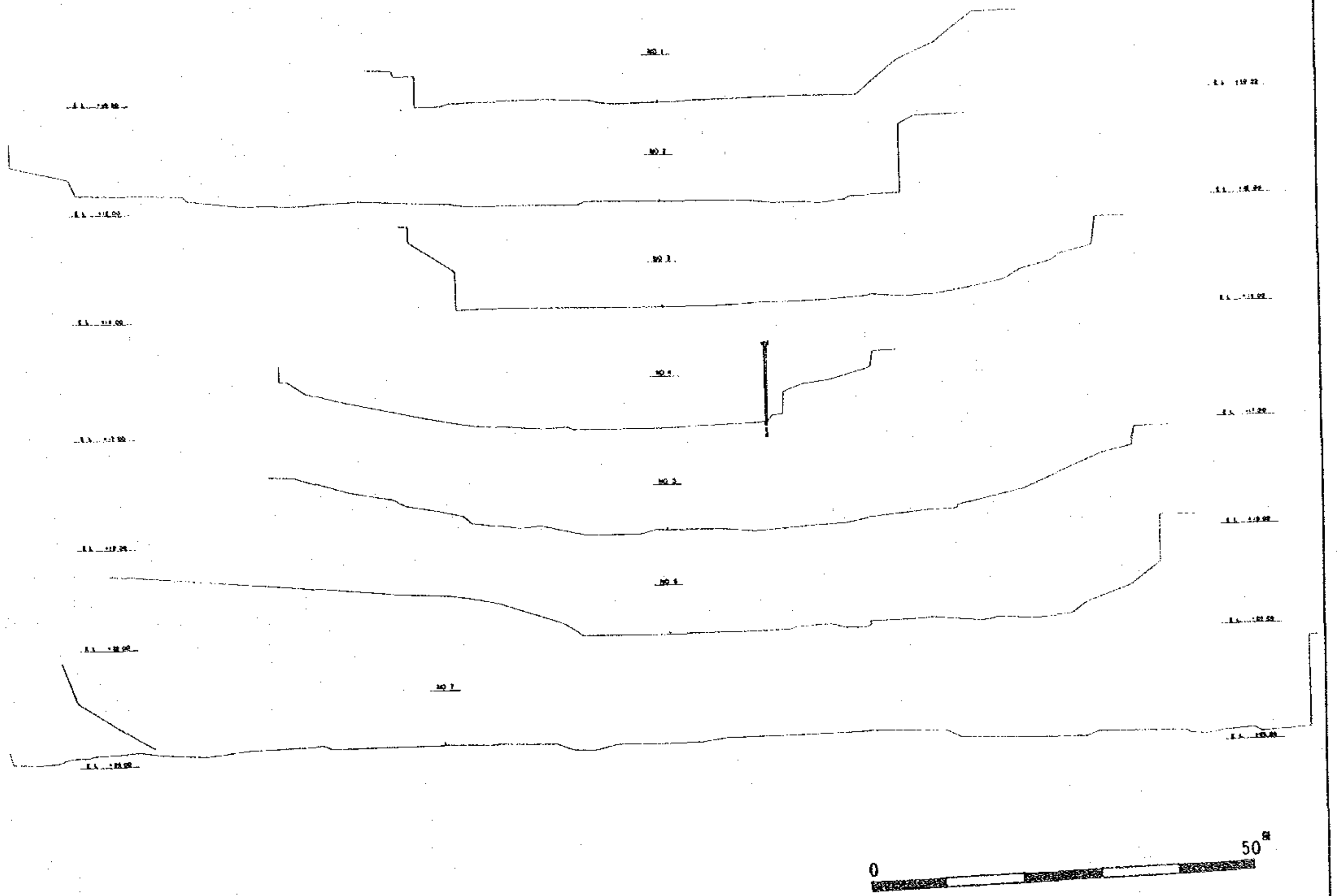
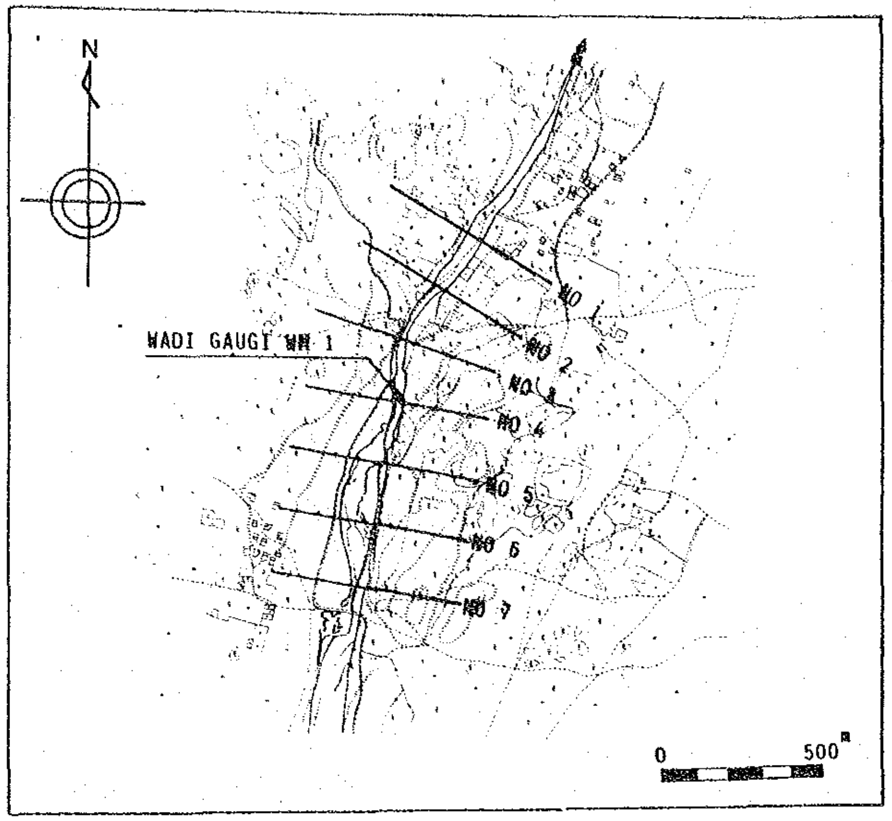
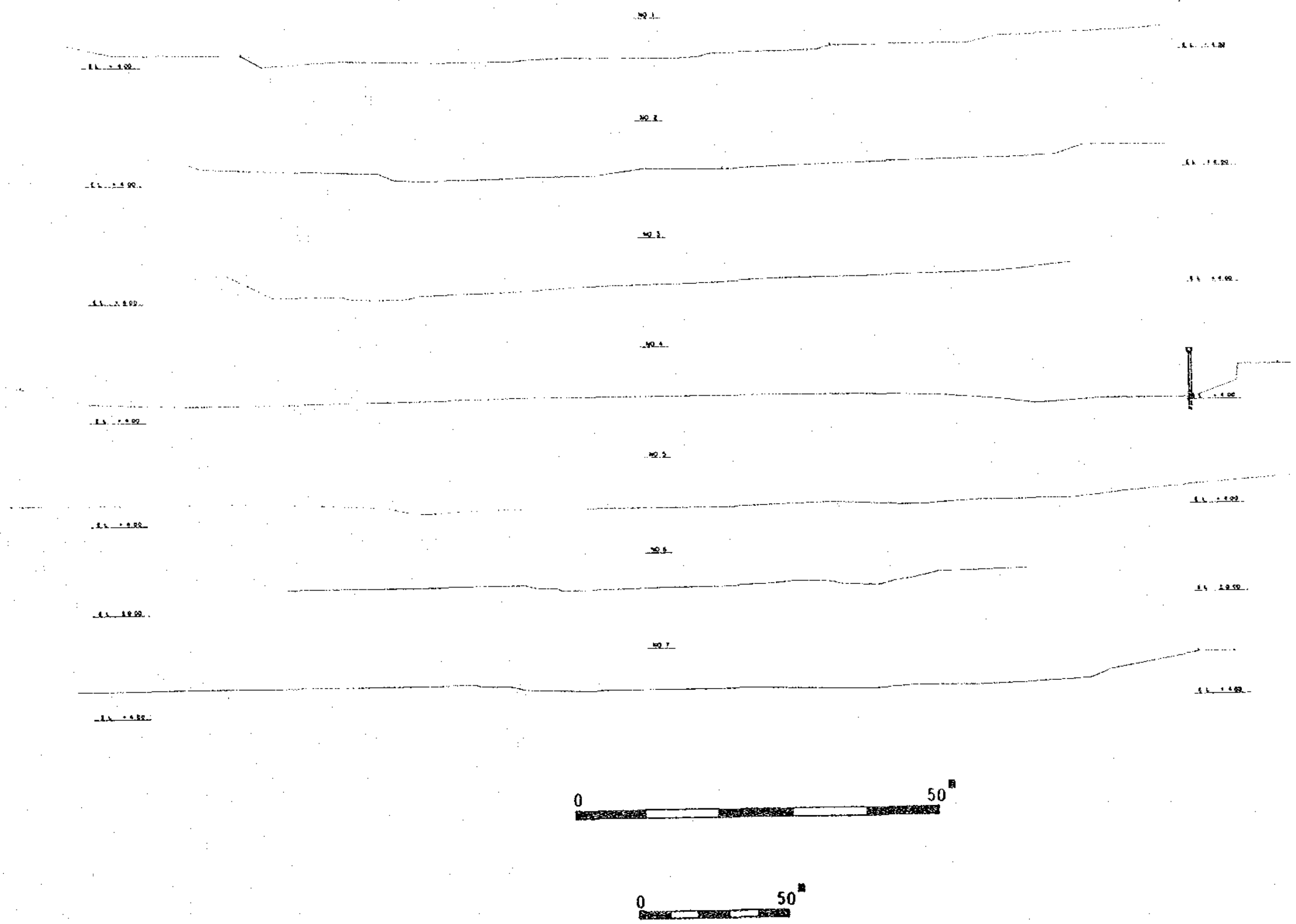
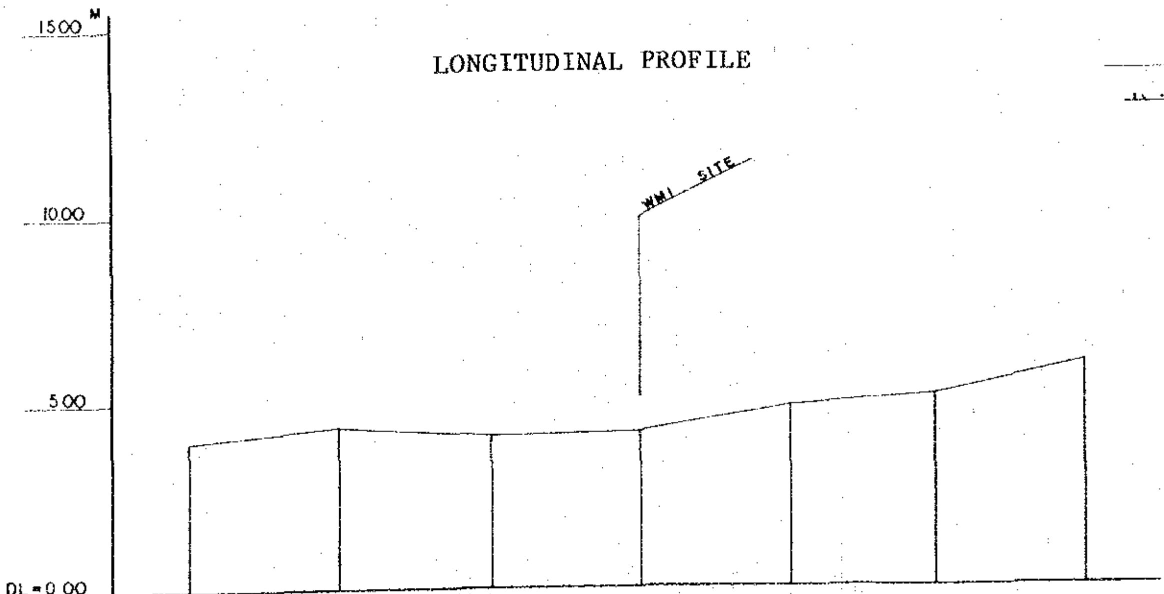


Fig. B-1-7 (14) Cross-section and Longitudinal Profile of Wadi Gauge Site, WM1

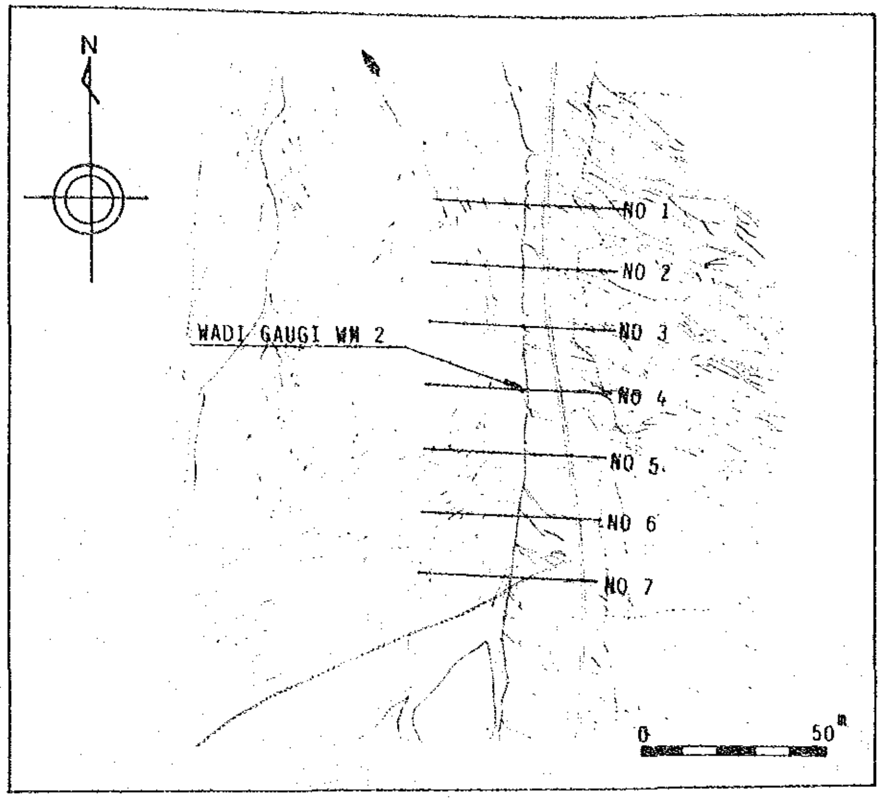


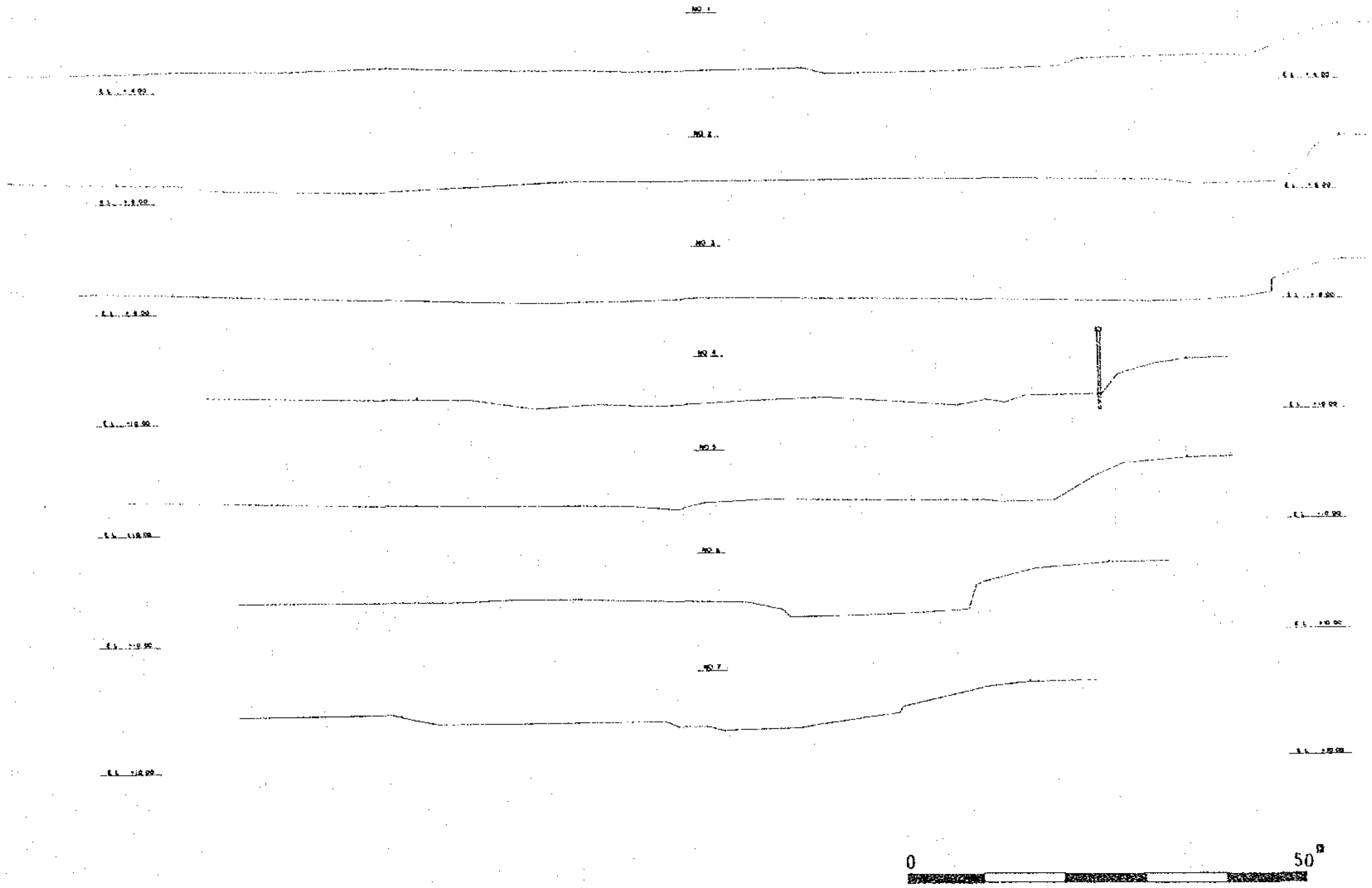




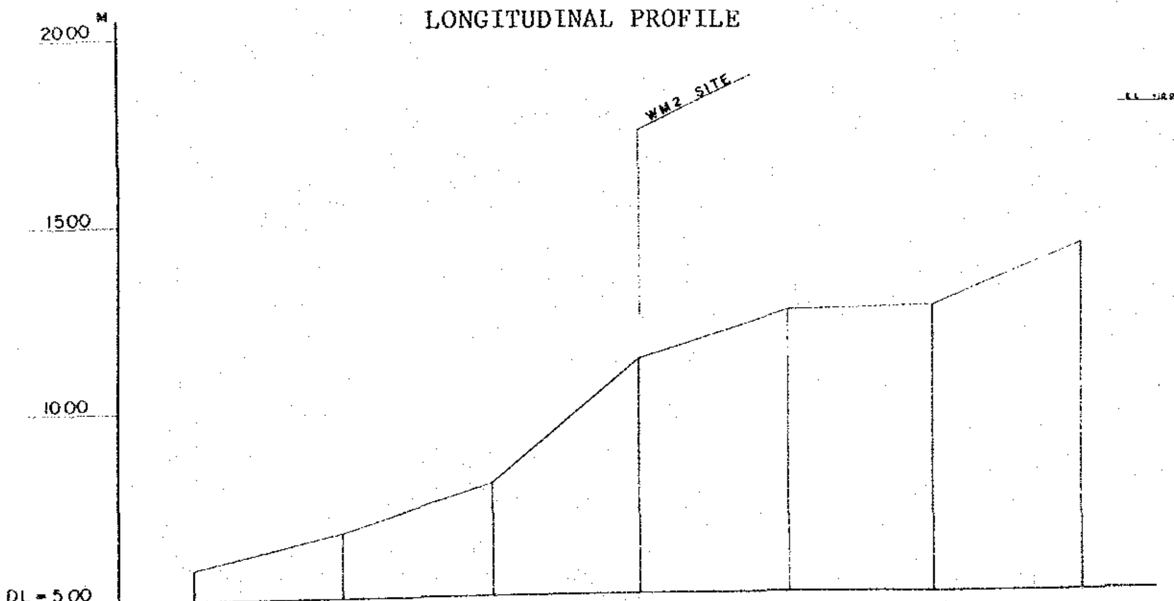
LONGITUDINAL SLOPE	3.993	i=1/2,850 L=600M		4.218	i=1/430 L=400M	5.143	
PRESENT ELEVATION (EL m) RIGHT BANK							
LEFT BANK							
MEAN RIVER BED							
LOWEST RIVER BED	3.993	4.343	4.113	4.218	4.693	5.143	6.023
ACCUMULATED DISTANCE	0	200	400	600	800	1,000	1,200
DISTANCE	0	200	200	200	200	200	200
STATION No	1	2	3	4	5	6	7

Fig. B-1-7 (15) Cross-section and Longitudinal Profile of Wadi Gauge Site, WM2





LONGITUDINAL PROFILE



LONGITUDINAL SLOPE	5.835			I=1/149 L=1,200M			14.395
PRESENT ELEVATION (EL) RIGHT BANK							
LEFT BANK							
MEAN RIVER BED							
LOWEST RIVER BED	5.835	6.785	8.030	11.340	12.650	12.705	14.395
ACCUMULATED DISTANCE	0	200	400	600	800	1,000	1,200
DISTANCE	0	200	200	200	200	200	200
STATION No	1	2	3	4	5	6	7

CHAPTER 2 OBSERVED DATA OF PREVIOUS STUDIES

2.1 Meteorology

Some reports regarding the climate of Oman focus (*), the groval and synoptic circulation. Mean sea level pressure and predominant winds in January and in July which for the tropics are shown in Fig. B-2-1. The factors which control the overall climate are summarized below.

The climate of Oman is characterized by two climatic seasons -- summer and winter. In summer a depression over North-West India and the Arabian Gulf and an anticyclone over the South Indian Ocean produce south-westerly winds over Oman. The south-westerly winds transfer humid air masses from the sea and bring rainfall on only a narrow coastal strip in South Oman. The inter-tropical convergence zone (ITCZ), forming over the Arabian Peninsula, does not seem to be active.

In winter the Asiatic High stretching to the Arabian Peninsula, and a depression over the Indian Ocean produce dry north-westerly winds. Synoptic disturbances -- cyclones and fronts -- migrating from west bring wide-spread rainfall over Oman.

Although durations of summer and winter vary yearly, summer is from June to September and winter is from October to April in a normal year. May and October are transition months between summer and winter.

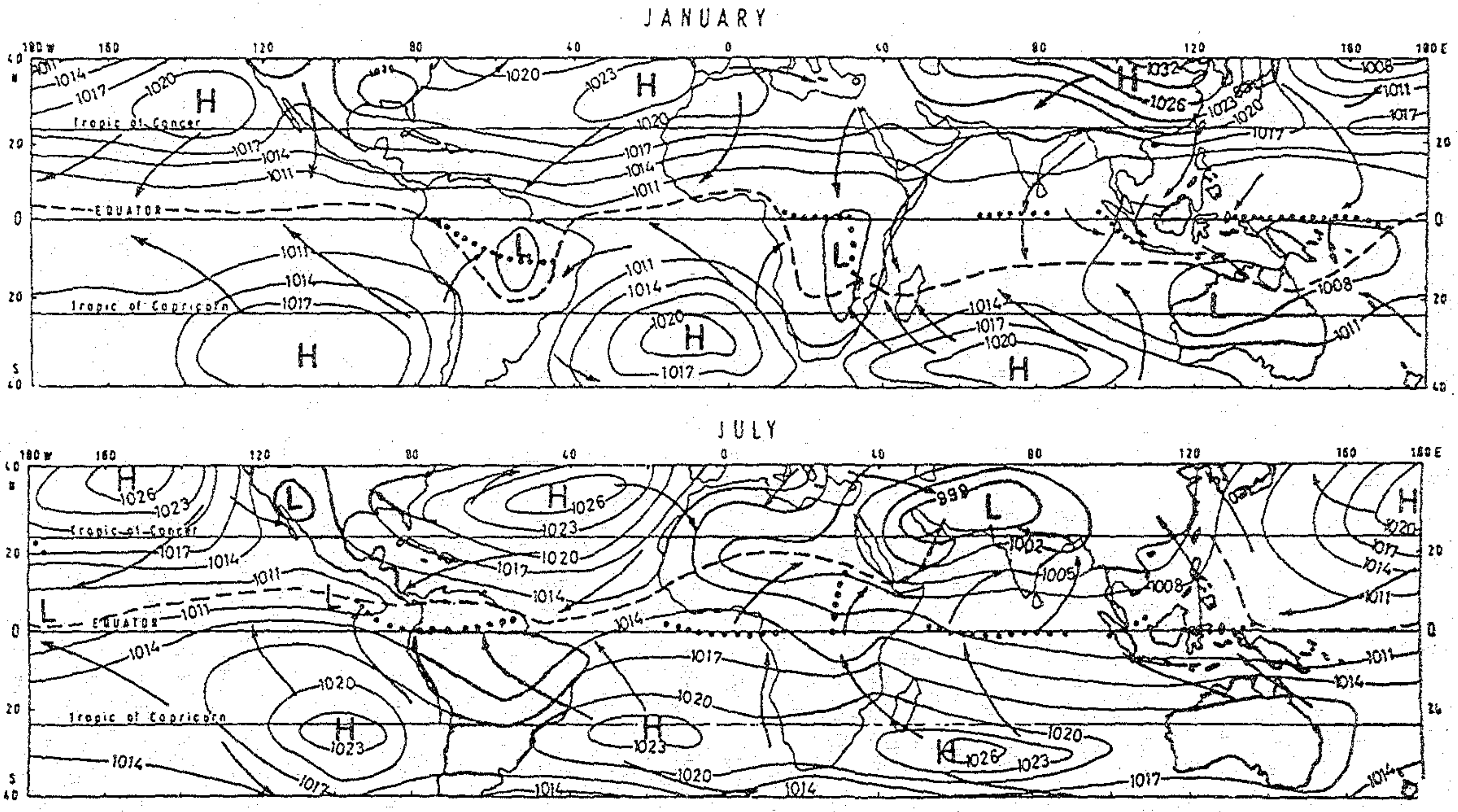
Even though some of the tropical cyclones growing in the Indian Ocean or in the Arabian Sea migrate towards the Arabian Peninsula, the cyclones very rarely affect the weather in Oman.

*Sir Alexandar Gibb and Partners "Water Resources Ruvey of Northern
Oman" June 1976

Renardet Sauti Ice "Water Resources Survey in North-East Oman"

FAO Project OMA/77/001 "Climate of the Batinah 1973-1977"
Dec., 1977

Fig. B-2-1 Mean Sea Level Pressure and Predominant Surface Wind in January and July



Note: Dashed line: mean position of the I.T.C.Z.; dotted line; secondary convergence areas (From. S. Nieuwolt "Tropical Climatology" 1977)

2.2 Rainfall

Monthly rainfall observed by MAF in and around the project area are shown in Table B-2-1 (1) - (10). The rain gauges sites are shown in Fig. B-1-3.

The large standard deviations compared with the means indicate that rainfall variation is large. Annual rainfall can be divided into summer and winter rainfalls. Summer is from June to September and winter from October to May from the climatic point of view. The relations between elevation and seasonal and annual rainfalls are shown in Fig. B-2-2. The characteristics of the rainfalls are mentioned below.

- The higher the altitude, the greater the rainfall is in both summer and winter.
- There is little rainfall at low elevations in summer.
- Rainfall in winter is more than that in summer.
- Rainfall in Wadi Ahin is less than that in the other four wadi basins in winter.

Annual rainfall distribution estimated from the relation between elevation and rainfall (Fig. B-2-2) is shown in Fig. B-2-3.

Table B-2-1 (1) Rainfall Data Collected by MAF (1/10)

Station Saham

(unit: mm)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
	(X)	(X)	(X)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(0)	(0)	(X)
1974	X	X	X							29.5			X
	(0)	(3)	(0)	(0)	(0)	(0)	(0)	(1)	(0)	(0)	(0)	(X)	(X)
1975		29.6						0.8				X	X
	(0)	(0)	(3)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(4)
1976			118.0									15.2	133.4
	(2)	(1)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(4)
1977	34.0	25.2	61.0										120.2
	(1)	(1)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(3)
1978	16.5	28.0	15.4										59.9
	(1)	(0)	(0)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(4)	(6)
1979	16.4			3.0								97.4	116.8
	(0)	(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(2)
1980		1.2											1.2
	(1)	(0)	(0)	(0)	(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(3)
1981	1.6				47.8								49.4
	(1)	(3)	(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(1)	(8)
1982	4.9	73.5	26.6								9.6	21.5	136.1
	(0)	(4)	(1)	(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(7)
1983		64.5	0.6	11.8									76.9
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(0)	(0)	(3)	(4)
1984									1.0			12.0	13.0
Mean	7.3	22.2	22.2	1.3	4.3	0.0	0.0	0.1	0.1	2.7	0.9	14.6	69.7
Standard deviation	11.5	27.8	38.9	3.6	14.4	-	-	0.2	0.3	8.9	2.9	30.2	51.2

( ) number of rain-days

X no record

Table B-2-1 (2) Rainfall Data Collected by MAF (2/10)

Station Sohar

(unit: mm)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
	(2)	(3)	(2)	(1)	(0)	(0)	(0)	(0)	(0)	(2)	(0)	(0)	(10)
1974	0.6	71.6	2.7	0.6						2.2			77.7
	(2)	(9)	(0)	(0)	(0)	(0)	(0)	(2)	(0)	(0)	(0)	(0)	(13)
1975	2.6	44.5						6.2					53.3
	(2)	(9)	(5)	(5)	(0)	(0)	(0)	(0)	(0)	(1)	(0)	(4)	(26)
1976	2.5	118.0	51.9	55.2						8.2		17.3	253.1
	(6)	(2)	(0)	(3)	(2)	(0)	(0)	(0)	(0)	(0)	(3)	(1)	(17)
1977	68.1	26.3		41.3	6.9						17.4	0.2	160.2
	(0)	(3)	(1)	(1)	(0)	(0)	(1)	( )	( )	( )	( )	(1)	(7)
1978		34.2	6.5	2.0			3.6					0.3	46.6
	(3)	(0)	(3)	(1)	(0)	(0)	(0)	(0)	(0)	(1)	(1)	(4)	(13)
1979	21.4		1.5	2.3						36.0	0.7	58.4	120.9
	(3)	(0)	(3)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(0)	(8)
1980	1.6		3.9	1.2							0.8		7.5
	(1)	(0)	(3)	(4)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(9)
1981	4.8		1.5	18.2	12.6								37.1
	(0)	(6)	(6)	(2)	(0)	(0)	(0)	(0)	(0)	(0)	(2)	(5)	(21)
1982		137.2	56.3	2.0							16.6	10.4	222.5
	(1)	(5)	(7)	(4)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(17)
1983	0.2	60.0	37.9	23.7									121.8
	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(0)	(0)	(5)	(7)
1984	0.4								4.9			9.7	15.0
Mean	9.3	44.7	14.7	13.3	1.8	0.0	0.3	0.6	0.4	4.3	3.2	8.8	101.4
Standard deviation	20.5	48.3	22.3	19.3	4.1	-	1.1	1.9	1.5	11.0	6.8	17.5	82.6

( ) number of rain-days

Table B-2-1 (3) Rainfall Data Collected by MAF (3/10)

Station Al-Ghoraifah

(unit: mm)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
	(0)	(2)	(1)	(0)	(0)	(0)	(1)	(0)	(1)	(2)	(0)	(0)	(7)
1974		27.5	0.5				6.6		4.0	23.1			61.7
	(1)	(4)	(0)	(0)	(2)	(0)	(0)	(1)	(0)	(0)	(0)	(0)	(8)
1975	2.0	48.0			15.7			10.0					75.7
	(1)	(4)	(4)	(3)	(0)	(0)	(0)	(1)	(1)	(1)	(1)	(1)	(17)
1976	7.2	48.4	93.0	62.5				17.1	5.0	9.0	18.5	1.2	261.9
	(2)	(2)	(1)	(2)	(1)	(0)	(0)	(0)	(0)	(1)	(0)	(0)	(9)
1977	29.5	40.0	4.0	18.0	19.5					6.0			117.0
	(0)	(1)	(1)	(0)	(1)	(0)	(1)	(4)	(0)	(0)	(0)	(0)	(8)
1978		30.0	11.0		1.0		8.5	20.4					70.9
	(2)	(0)	(1)	(0)	(1)	(0)	(0)	(1)	(1)	(1)	(0)	(3)	(10)
1979	14.6		1.5		9.0			1.5	3.0	1.0		21.0	51.6
	(0)	(2)	(1)	(1)	(0)	(1)	(0)	(2)	(0)	(0)	(0)	(1)	(8)
1980		4.7	17.0	2.0		1.0		30.5				6.5	61.7
	(1)	(1)	(1)	(1)	(2)	(1)	(0)	(0)	(0)	(1)	(0)	(0)	(8)
1981	12.0	1.0	2.0	2.5	17.5	25.0				20.0			80.0
	(0)	(9)	(5)	(0)	(0)	(0)	(0)	(0)	(3)	(0)	(1)	(1)	(19)
1982		125.3	15.7						41.3		4.0	3.0	189.0
	(0)	(3)	(2)	(3)	(0)	(0)	(0)	(1)	(0)	(0)	(0)	(0)	(9)
1983		36.5	15.0	63.0				48.0					162.5
	(0)	(0)	(1)	(1)	(0)	(0)	(1)	(0)	(0)	(0)	(0)	(0)	(3)
1984			1.0	1.0			4.5						6.5
Mean	5.9	32.9	14.6	13.5	5.7	2.4	1.8	11.6	4.8	5.4	2.0	2.9	103.5
Standard deviation	9.5	36.2	26.8	24.9	8.1	7.5	3.2	16.0	12.1	8.6	5.6	6.3	73.5

( ) number of rain-days

Table B-2-1 (4) Rainfall Data Collected by MAF (4/10)

Station Al-Qufais

(unit: mm)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
	(X)	(X)	(0)	(0)	(0)	(0)	(1)	(0)	(1)	(1)	(0)	(0)	(X)
1974	X	X					24.9		4.9	3.1			X
	(1)	(3)	(0)	(0)	(1)	(0)	(1)	(0)	(2)	(0)	(X)	(X)	(X)
1975	2.7	71.2			6.4		26.0		40.5		X	X	X
	(3)	(1)	(9)	(2)	(0)	(0)	(0)	(1)	(1)	(0)	(0)	(1)	(18)
1976	34.6	46.2	201.5	33.2				24.0	5.0			1.2	345.7
	(2)	(1)	(0)	(3)	(1)	(1)	(1)	(0)	(0)	(0)	(0)	(0)	(9)
1977	24.0	36.0		10.0	24.2	10.0	15.5						119.7
	(0)	(1)	(1)	(0)	(0)	(1)	(0)	(3)	(0)	(0)	(0)	(0)	(6)
1978		40.0	6.6			11.0		36.4					94.0
	(2)	(0)	(0)	(1)	(0)	(0)	(0)	(1)	(1)	(2)	(0)	(2)	(9)
1979	21.0			2.1				14.5	41.2	16.5		27.9	123.2
	(1)	(2)	(1)	(0)	(0)	(4)	(0)	(0)	(0)	(0)	(0)	(0)	(8)
1980	6.5	4.5	14.0			33.9							58.9
	(0)	(0)	(1)	(2)	(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(5)
1981			4.7	4.5	22.0								31.2
	(0)	(5)	(3)	(0)	(1)	(1)	(0)	(0)	(0)	(0)	(1)	(0)	(11)
1982		125.4	53.9		4.5	10.0					10.0		203.8
	(1)	(2)	(2)	(4)	(0)	(0)	(0)	(3)	(0)	(0)	(0)	(0)	(12)
1983	2.0	11.2	34.3	81.1				40.7					169.3
	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(0)	(1)	(0)	(0)	(0)	(2)
1984							3.6		4.5				8.1
Mean	9.1	33.5	28.6	11.9	5.2	5.9	6.4	10.5	8.7	1.8	1.0	2.9	121.2
Standard deviation	12.7	40.5	59.9	25.0	9.1	10.4	10.5	16.0	16.0	5.0	3.2	8.8	102.8

( ) number of rain-days

X no record

Table B-2-1 (5) Rainfall Data Collected by MAF (5/10)

Station Haibi

(unit: mm)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
1974	(X) X	(X) X	(2) 5.5	(0)	(0)	(0)	(1) 20.0	(0)	(2) 11.0	(5) 40.6	(0)	(0)	(X) X
1975	(0)	(5) 74.4	(0)	(0)	(3) 20.0	(1) 25.5	(0)	(1) 28.1	(1) 10.2	(0)	(0)	(X) X	(X) X
1976	(4) 43.8	(4) 68.8	(3) 34.5	(4) 57.0	(X) X	(X) X	(X) X	(X) X	(2) 17.3	(3) 39.4	(0)	(1) 7.8	(X) X
1977	(2) 35.3	(1) 32.0	(0)	(1) 40.0	(1) 19.0	(2) 38.4	(0)	(0)	(0)	(1) 20.0	(0)	(X) X	(X) X
1978	(0)	(1) 50.0	(1) 10.3	(1) 3.0	(1) 8.0	(0)	(3) 37.1	(2) 14.4	(3) 33.3	(0)	(0)	(0)	(12) 156.1
1979	(1) 0.4	(0)	(0)	(0)	(0)	(0)	(1) 30.0	(0)	(0)	(3) 40.9	(1) 10.8	(0)	(6) 82.1
1980	(0)	(1) 3.0	(1) 13.0	(0)	(0)	(0)	(0)	(0)	(0)	(2) 12.3	(0)	(0)	(4) 28.3
1981	(1) 3.0	(2) 50.5	(0)	(1) 2.0	(1) 20.3	(1) 3.0	(0)	(0)	(0)	(0)	(0)	(0)	(6) 78.8
1982	(0)	(7) 163.0	(2) 60.0	(0)	(0)	(0)	(0)	(0)	(1) 28.0	(0)	(1) 13.0	(0)	(11) 264.0
1983	(0)	(0)	(3) 89.5	(1) 13.0	(0)	(0)	(0)	(2) 69.2	(0)	(0)	(0)	(0)	(6) 171.7
1984	(0)	(0)	(0)	(0)	(0)	(0)	(1) 14.0	(0)	(0)	(0)	(0)	(0)	(1) 14.0
Mean	8.3	44.2	19.3	10.5	6.7	6.7	10.1	11.2	9.1	13.9	2.2	0.9	134.9
Standard deviation	16.6	51.0	30.0	19.6	9.3	13.7	14.3	22.5	12.3	18.1	4.8	2.6	88.7

( ) number of rain-days

X no record

Table B-2-1 (6) Rainfall Data Collected by MAF (6/10)

Station Al-Houqain

(unit: mm)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
	(X)	(X)	(X)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(X)	(X)
1974	X	X	0.2									4.5	X
	(X)	(X)	(0)	(0)	(X)	(0)	(0)	(X)	(0)	(0)	(0)	(0)	(X)
1975	9.6	54.3			5.7			10.5					80.1
	(X)	(X)	(X)	(X)	(0)	(0)	(0)	(1)	(0)	(1)	( )	(3)	(X)
1976	53.3	59.0	38.5	45.8				4.0		21.0		50.1	271.7
	(3)	(2)	(2)	(1)	(1)	(1)	(0)	(0)	(0)	(1)	(1)	(0)	(12)
1977	34.1	10.0	44.0	20.0	12.0	10.0				32.0	88.0		250.1
	(1)	(1)	(1)	(0)	(0)	(0)	(1)	(0)	(0)	(0)	(0)	(0)	(4)
1978	1.0	20.0	1.0				17.0						39.0
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(4)	(0)	(4)	(8)
1979										98.0		32.0	130.0
	(0)	(1)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(1)	(2)	(6)
1980		1.0	16.0							22.0	3.0	80.0	122.0
	(0)	(0)	(2)	(2)	(1)	(0)	(2)	(0)	(0)	(0)	(0)	(0)	(7)
1981			4.0	7.0	65.0		15.0						91.0
	(2)	(8)	(5)	(0)	(0)	(0)	(0)	(0)	(0)	(2)	(2)	(4)	(23)
1982	23.5	131.0	45.0							10.5	62.0	42.0	314.0
	(0)	(3)	(2)	(6)	(0)	(0)	(0)	(2)	(1)	(0)	(0)	(0)	(14)
1983		25.0	7.0	88.0				9.0	15.0				144.0
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(1)
1984												10.0	10.0
Mean	12.2	30.0	12.6	14.6	7.5	0.9	2.9	2.1	1.4	16.7	13.9	19.9	132.4
Standard deviation	18.8	41.8	18.3	28.2	19.4	3.0	6.5	4.0	4.5	29.3	30.8	26.1	101.7

( ) number of rain-days

X no record

Table B-2-1 (7) Rainfall Data Collected by MAF (7/10)

Station Al-Rustaq

(unit: mm)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
	(X)	(X)	(X)	(1)	(1)	(0)	(0)	(0)	(5)	(6)	(0)	(2)	(X)
1974	X	X	X	4.3	22.2				15.3	83.2		6.4	X
	(5)	(4)	(3)	(2)	(2)	(2)	(3)	(1)	(3)	(0)	(1)	(1)	(27)
1975	10.6	36.5	2.8	6.0	6.0	4.7	6.4	81.5	11.2		1.5	4.7	171.9
	(1)	(6)	(11)	(4)	(1)	(1)	(2)	(4)	(0)	(5)	(2)	(2)	(39)
1976	18.0	82.6	50.5	52.0	0.5	0.7	7.0	5.3		53.9	5.5	6.8	282.8
	(3)	(3)	(3)	(4)	(3)	(4)	(1)	(1)	(1)	(3)	(3)	(0)	(29)
1977	29.2	19.0	17.1	30.2	4.8	47.5	0.6	2.0	4.7	61.8	28.1		245.0
	(1)	(1)	(2)	(3)	(0)	(0)	(4)	(3)	(0)	(3)	(0)	(0)	(17)
1978	9.5	11.5	19.5	4.8			13.0	19.7		13.8			91.8
	(1)	(0)	(0)	(1)	(0)	(0)	(1)	(0)	(0)	(5)	(3)	(6)	(17)
1979	0.5			5.0			4.2			52.1	7.0	47.9	116.7
	(2)	(2)	(5)	(2)	(0)	(0)	(0)	(0)	(0)	(2)	(3)	(3)	(19)
1980	1.2	13.6	7.4	8.6						2.6	32.4	12.4	78.4
	(0)	(0)	(4)	(2)	(2)	(0)	(4)	(0)	(0)	(4)	(0)	(3)	(19)
1981			21.4	6.2	29.6		40.0			23.5		8.8	129.5
	(4)	(8)	(8)	(1)	(0)	(0)	(0)	(0)	(0)	(5)	(3)	(0)	(29)
1982	45.6	95.3	124.0	15.0						53.2	44.7		377.8
	(0)	(0)	(2)	(8)	(0)	(0)	(0)	(5)	(2)	(0)	(1)	(2)	(20)
1983			7.6	51.0				39.2	12.2		0.2	0.4	110.6
	(2)	(1)	(0)	(1)	(0)	(0)	(0)	(0)	(2)	(0)	(0)	(0)	(6)
1984	0.4	0.2		1.6					5.0				7.2
Mean	11.5	25.9	25.0	16.8	5.7	4.8	6.5	13.4	4.4	31.3	10.9	7.9	158.5
Standard deviation	15.4	35.5	37.9	18.9	10.3	14.2	11.9	25.7	5.9	30.3	16.2	13.9	105.2

( ) number of rain-days

X no record

Table B-2-1 (8) Rainfall Data Collected by MAF (8/10)

Station Afi

(unit: mm)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
	(X)	(X)	(X)	(X)	(0)	(0)	(X)	(X)	(0)	(X)	(0)	(0)	(X)
1974	X	X	X	X			8.0	10.3		0.1			X
	(X)	(X)	(0)	(X)	(X)	(0)	(0)	(X)	(X)	(0)	(0)	(0)	(X)
1975	9.8	64.9		10.2	3.3			4.3	14.5				107.0
	(X)	(X)	(X)	(X)	(0)	(X)	(X)	(0)	(1)	(0)	(0)	(1)	(X)
1976	30.2	105.0	70.0	20.5		8.0	1.5		1.5			6.5	243.2
	(1)	(2)	(0)	(1)	(0)	(2)	(0)	(0)	(1)	(0)	(5)	(1)	(13)
1977	35.0	81.0		15.0		34.0			5.0		43.0	1.0	214.0
	(1)	(2)	(2)	(1)	(0)	(0)	(1)	(0)	(0)	(0)	(0)	(0)	(7)
1978	18.0	12.0	50.5	2.0			5.0						87.5
	(0)	(0)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(2)	(2)	(3)	(8)
1979			1.0							54.0	2.0	22.5	78.5
	(0)	(1)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(0)	(0)	(3)
1980		8.0	1.0							7.0			16.0
	(2)	(0)	(3)	(2)	(2)	(0)	(2)	(0)	(0)	(0)	(0)	(2)	(13)
1981	30.0		23.0	4.0	33.0		22.0					9.0	121.0
	(2)	(7)	(4)	(1)	(0)	(0)	(0)	(0)	(0)	(1)	(1)	(4)	(18)
1982	7.0	145.0	42.0	2.0						22.0	12.0	37.7	267.7
	(0)	(6)	(1)	(6)	(0)	(0)	(0)	(1)	(0)	(0)	(0)	(0)	(14)
1983		44.0	14.0	56.0				5.0					119.0
	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(2)
1984	0.5											15.0	15.5
Mean	13.1	41.8	19.1	10.8	3.3	3.8	3.3	1.8	1.9	7.6	5.2	8.4	118.7
Standard deviation	14.2	50.7	24.5	16.5	9.9	10.3	6.7	3.4	4.4	16.8	13.0	12.3	88.0

( ) number of rain-days

X no record

Table B-2-1 (9) Rainfall Data Collected by MAF (9/10)

Station Al-Rumais

(unit: mm)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
	(X)	(4)	(0)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(X)
1974	X	16.5		13.0									X
	(3)	(5)	(1)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(2)	(12)
1975	2.5	45.7	0.2	0.3								28.7	77.4
	(2)	(X)	(X)	(4)	(0)	(0)	(0)	(0)	(0)	(1)	(0)	(1)	(X)
1976	6.2	88.1	68.0	34.5						1.1		4.0	201.9
	(2)	(1)	(1)	(2)	(0)	(1)	(0)	(0)	(0)	(0)	(2)	(0)	(9)
1977	30.5	10.0	1.5	10.0		12.0					14.0		78.0
	(1)	(2)	(2)	(1)	(0)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(7)
1978	1.8	6.1	6.1	0.2		1.0							15.2
	(0)	(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(0)	(4)	(7)
1979		16.0								15.0		14.1	45.1
	(1)	(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(0)	(1)	(5)
1980	1.5	3.9								2.3		1.0	8.7
	(0)	(0)	(1)	(0)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(2)
1981			18.0		56.2								74.2
	(1)	(6)	(4)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(2)	(5)	(19)
1982	1.4	75.5	23.5	0.5							23.8	52.8	177.5
	(0)	(5)	(2)	(5)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(12)
1983		43.1	3.8	48.4									95.3
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
1984													0.0
Mean	4.4	27.7	11.0	9.7	5.1	1.2	0.0	0.0	0.0	1.7	3.4	9.1	73.0
Standard deviation	9.4	31.0	20.5	16.6	16.9	3.6	-	-	-	4.5	8.0	17.1	66.0

( ) number of rain-days

X no record

Table B-2-1 (10) Rainfall Data Collected by MAF (10/10)

Station Al-Saiq

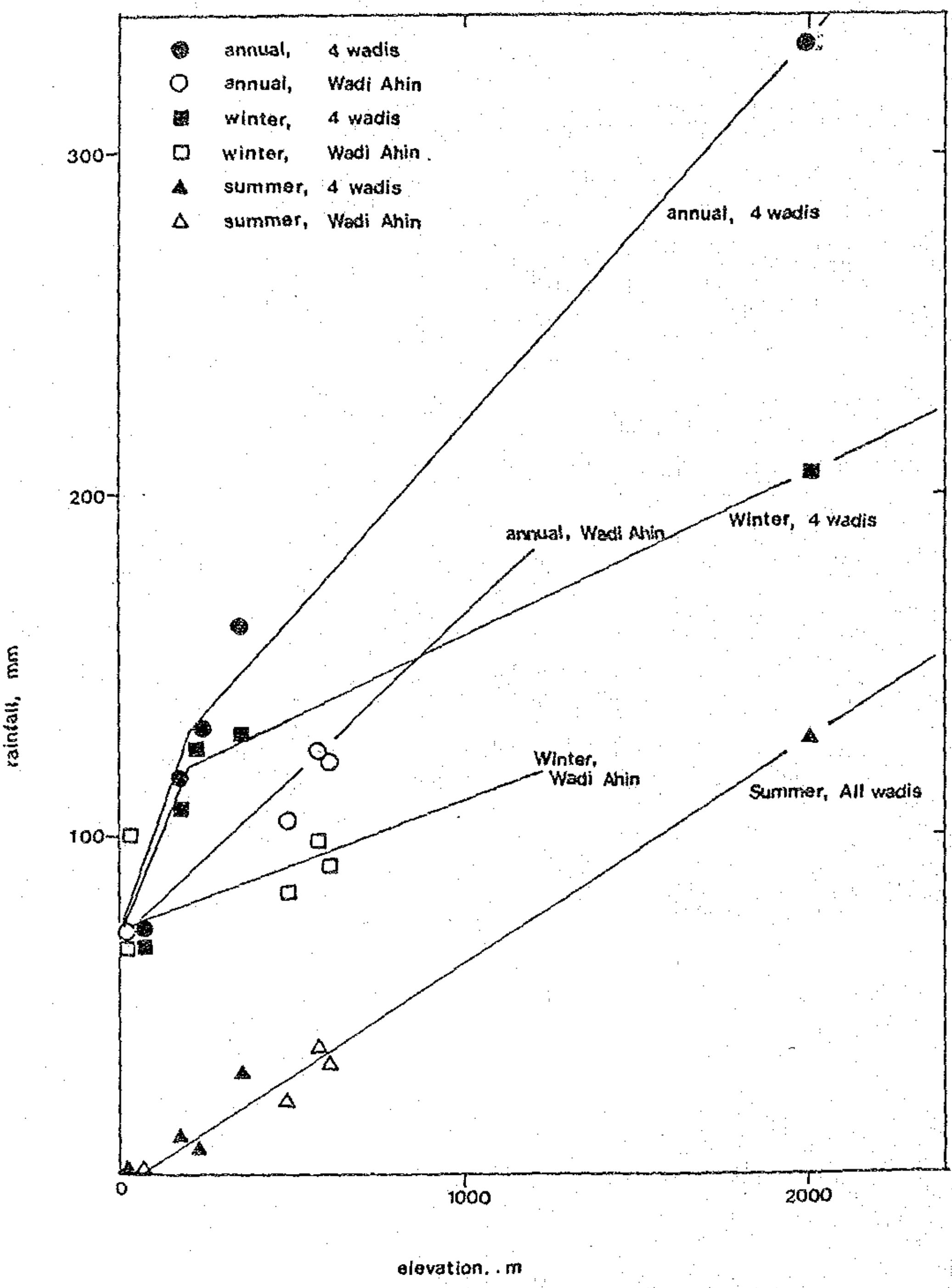
(unit: mm)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
	(3)	(3)	(6)	(6)	(4)	(2)	(4)	(1)	(3)	(3)	(0)	(0)	(35)
1974	8.8	6.2	11.3	17.9	31.4	13.0	10.2	8.8	9.6	4.4			121.6
	(3)	(8)	(0)	(4)	(7)	(5)	(15)	(11)	(3)	(0)	(0)	(1)	(57)
1975	8.4	86.9		12.7	37.0	14.8	70.6	86.1	30.6			2.2	349.3
	(2)	(6)	(10)	(3)	(1)	(2)	(7)	(12)	(2)	(6)	(1)	(1)	(53)
1976	12.5	67.2	88.2	56.5	1.5	30.5	53.2	116.1	3.4	23.4	4.2	18.5	475.2
	(6)	(2)	(3)	(4)	(5)	(8)	(4)	(4)	(1)	(2)	(4)	(0)	(43)
1977	66.6	61.2	12.3	13.3	97.1	37.7	14.9	31.7	2.5	7.2	6.2		350.7
	(4)	(3)	(2)	(6)	(1)	(1)	(13)	(7)	(2)	(0)	(0)	(0)	(40)
1978	53.0	11.0	24.3	31.2	2.5	2.6	147.2	92.4	1.3				365.5
	(3)	(0)	(0)	(2)	(3)	(5)	(3)	(5)	(3)	(4)	(1)	(3)	(32)
1979	19.7			14.0	9.1	41.4	19.0	18.8	14.5	21.5	4.0	5.2	167.2
	(4)	(4)	(11)	(2)	(2)	(1)	(9)	(3)	(5)	(2)	(3)	(2)	(48)
1980	25.0	24.4	50.7	7.5	5.1	5.5	43.2	22.0	19.6	11.0	11.6	4.5	230.1
	(0)	(0)	(4)	(5)	(3)	(1)	(2)	(3)	(4)	(1)	(0)	(0)	(23)
1981			84.2	21.6	56.5	14.5	9.5	32.2	17.2	2.5			238.2
	(1)	(10)	(8)	(4)	(4)	(0)	(4)	(5)	(1)	(1)	(0)	(7)	(45)
1982	0.3	256.0	150.2	36.3	30.7		10.9	40.3	15.7	1.0		54.3	595.7
	(1)	(3)	(5)	(5)	(1)	(3)	(3)	(9)	(5)	(0)	(0)	(0)	(35)
1983	0.1	19.0	21.8	220.0	0.1	17.2	24.0	127.8	11.2				441.2
	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(6)	(9)	(0)	(0)	(0)	(X)
1984								30.2	36.5				X
Mean	19.4	53.2	44.3	43.1	27.1	17.7	40.3	55.1	14.7	7.1	2.6	8.5	333.1
Standard deviation	23.1	77.6	49.1	63.8	31.1	14.4	43.0	42.2	11.2	8.9	3.9	17.1	146.9

( ) number of rain-days

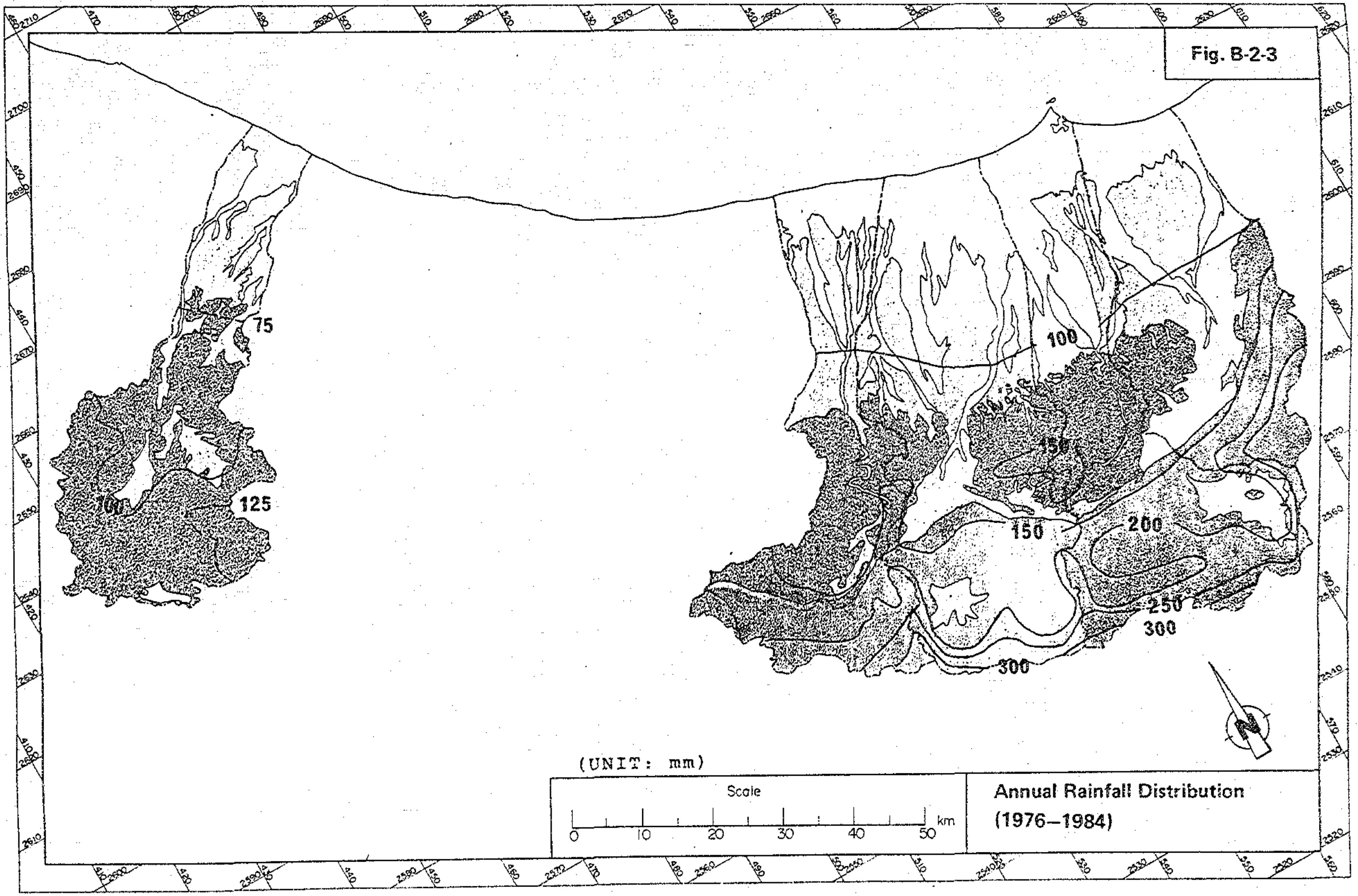
X no record

Fig. B-2-2 Relation between Elevation and Seasonal and Annual Rainfall (1974-1984)



Note: 1) 4 Wadi: Wadi Bani Ghafir, Wadi Bani Kharus and Wadi Al-Ma'awil

Fig. B-2-3



Annual Rainfall Distribution
(1976–1984)

2.3 Surface Runoff

(1) Ovservation Network

Surface runoff observation began in Study area on 1973 for the water resources survey by ILACO and GIBB.

Nine wadi gauges were installed in the study area by ILACO and Gibb during their survey in 1973 and 1974. Their locations are shown in Fig. B-2-4. They were handed over with other gauges to MAF in 1975. However, all the wadi gauges in the study area stopped functioning before 1981. Most of them were damaged or washed away by flash floods.

The instrumentation is listed in Table B-2-2.

(2) Observed Runoff Data of Previous Studies

During the previous surveys by ILACO and GIBB in the study area, the runoff measurements were carried out by the float type gauges and after runoff events by the slope area method utilizing Manning's equation. All the available data of previous studies relating the runoff in the study area were collected and are summarized in the Fig. B-2-5 (1) - (7). From this observation data, the general characteristics of the runoff are as follows.

1. Runoff occurs mainly in winter

   The number of the runoffs in winter surpasses the number in summer. Among the total runoff events, 21 events were recorded in winter (from October to May)

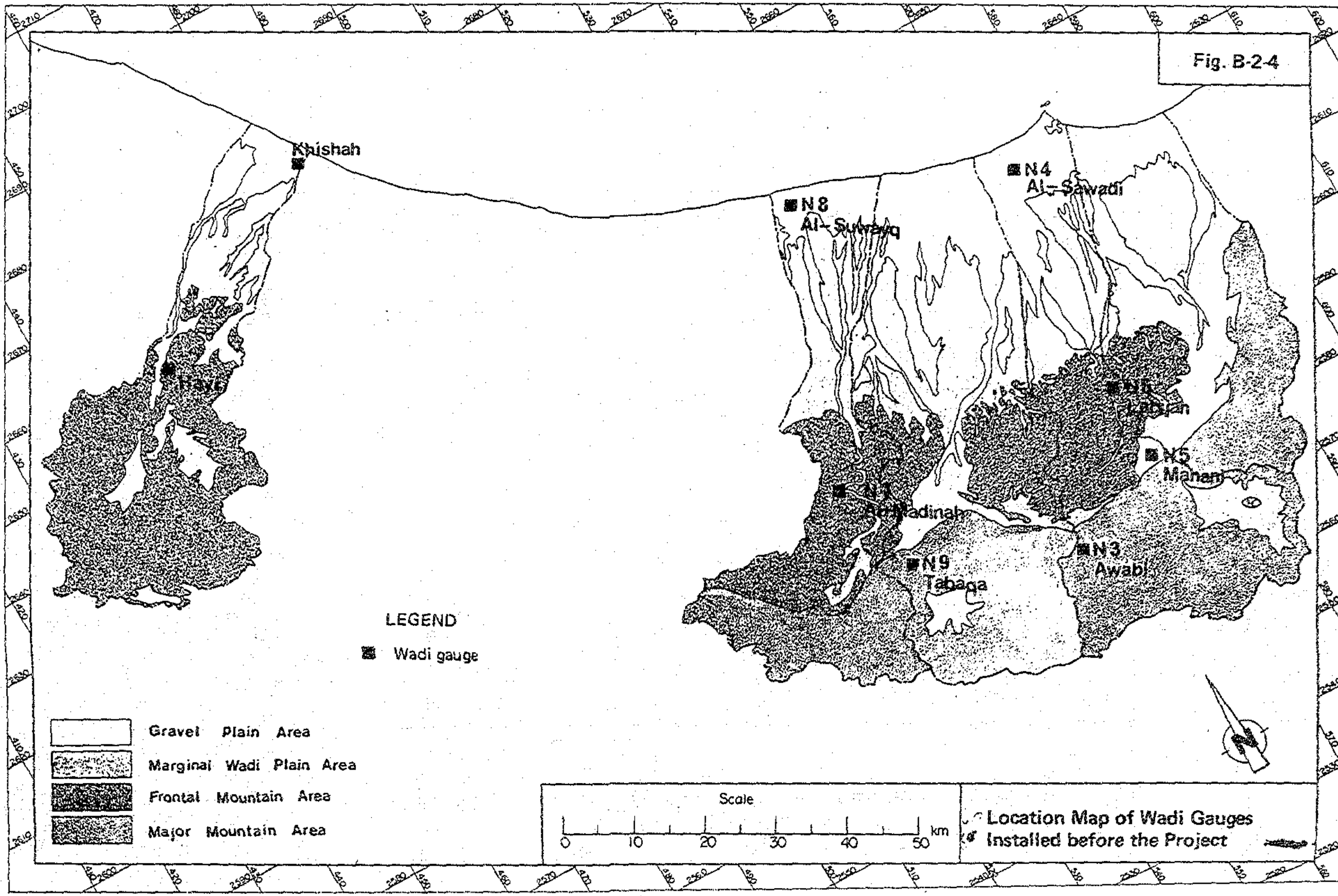
2. Most runoff is small-scale

   Small runoff with estimated peaks below 50 m^3sec were recorded on 19 events of the total 25. Large floods over 0.5 MCM in total discharge were recorded for only 4 events.

Table B-2-2 Observation Period of Wadi Gauges Installed before the Project

Wadi Basin	Gauge Site			Creator	Observation period								
	Name of place	Symbol	Coordinates		1973	1974	1975	1976	1977	1978	1979	1980	1981
W. Ahin													
	Heil	-	4560-6598	ILACO	Oct	Jun							
	Khishdah	-	4860-6765	ILACO	———	———							
W.B. Ghafir													
	Al-Madinah	N7	5300-5980	Gibb		Oct	Aug						
	Al-Suwayq	N8	5415-6340	Gibb		Mar	———	Nov					
W. Fara'													
	Tabaqa	N9	5316-5836	Gibb		May	———	———	Mar				
W.B. Kharus													
	Awabi	N3	5540-5755	Gibb		Mar	———	———	Jul				
	Al-Sawadi	N4	5720-6247	Gibb		Apr	———	Apr - - -	- - -	- - -	- - -	- - -	Nov
	Ma hani	N5	5691-5818	Gibb		May	———	———	May				
	Labijah	N6	5686-5919	Gibb		Apr Oct							

Fig. B-2-4



Location Map of Wadi Gauges Installed before the Project

Fig. B-2-5(1) Observed Runoff Hydrograph, N4

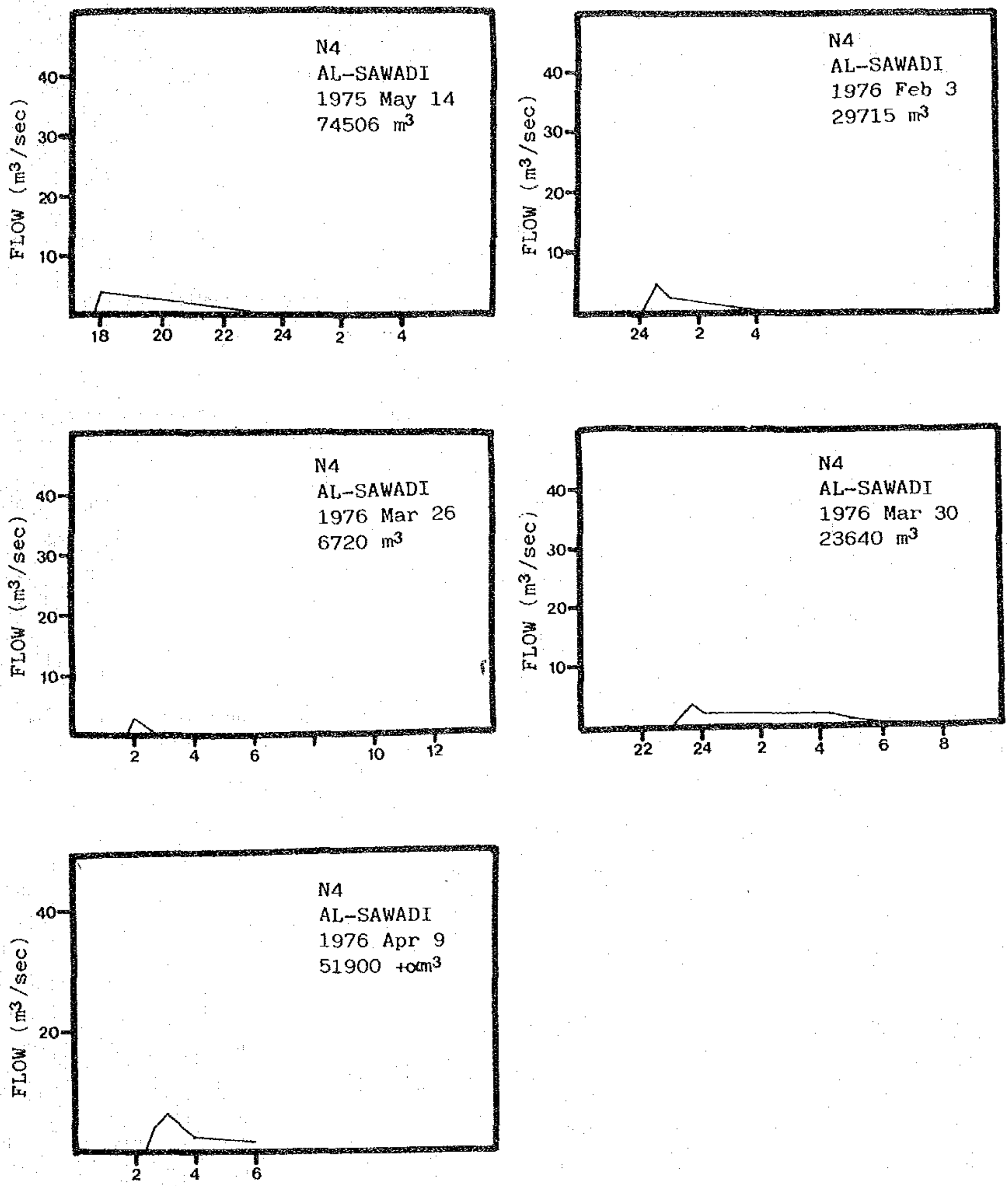
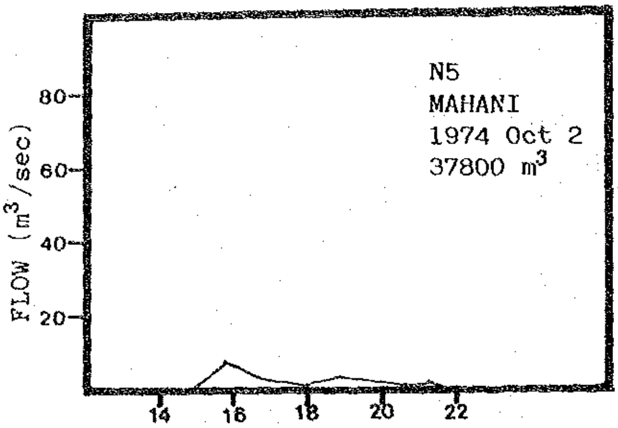
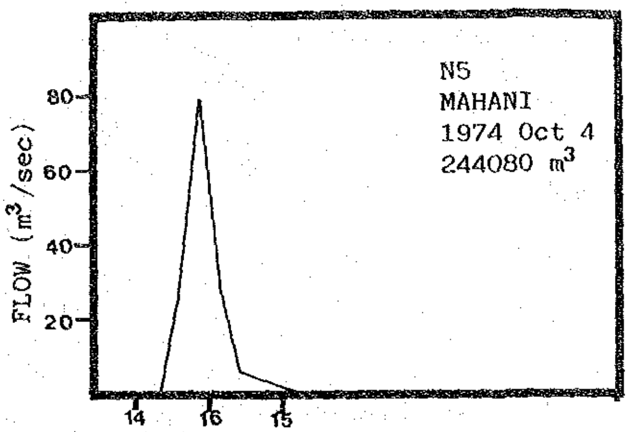
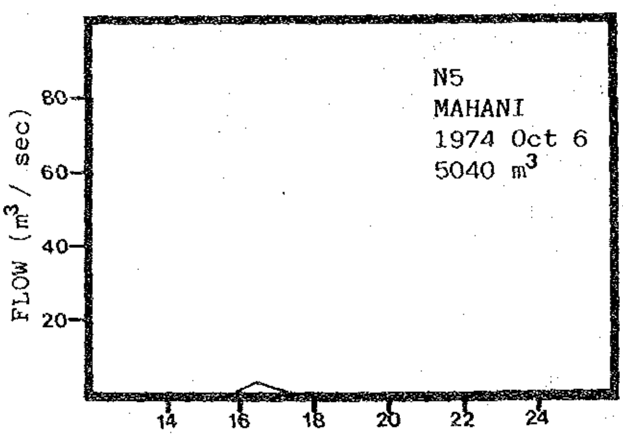
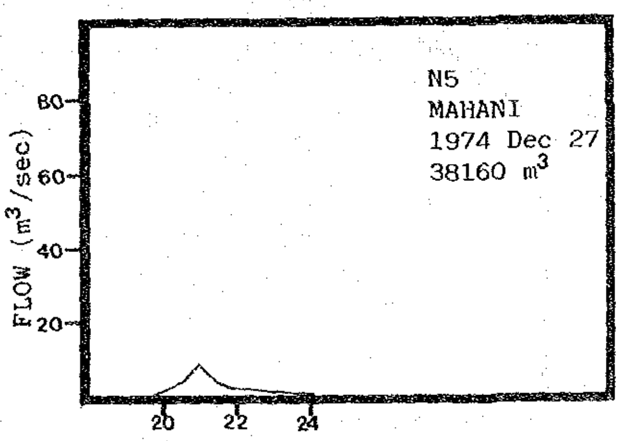


Fig. B-2-5 (2) Observed Runoff Hydrograph, N5 (1/3)









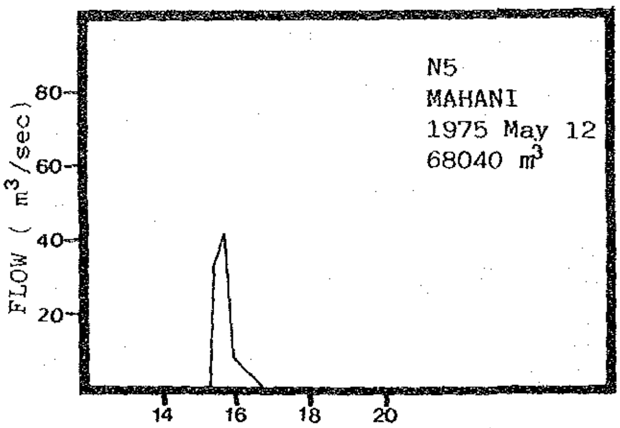
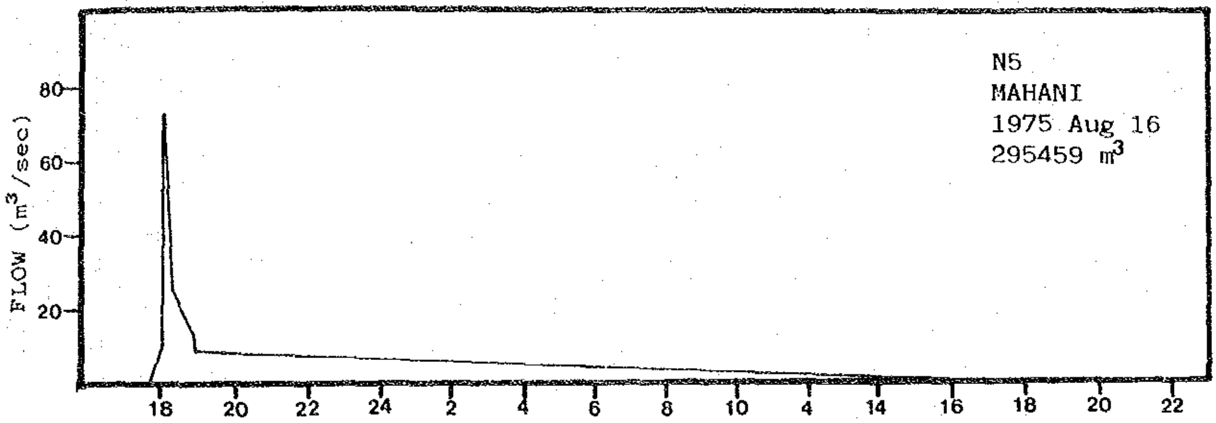
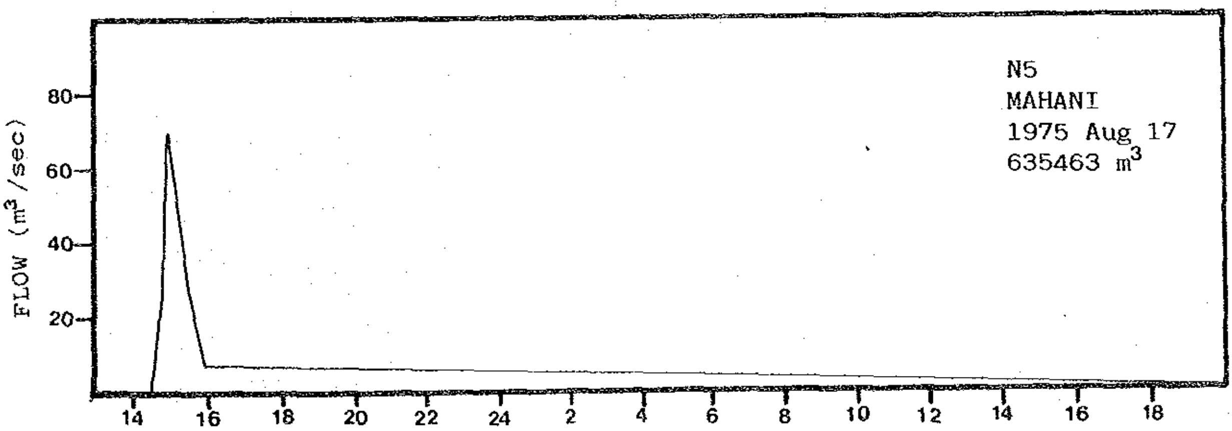
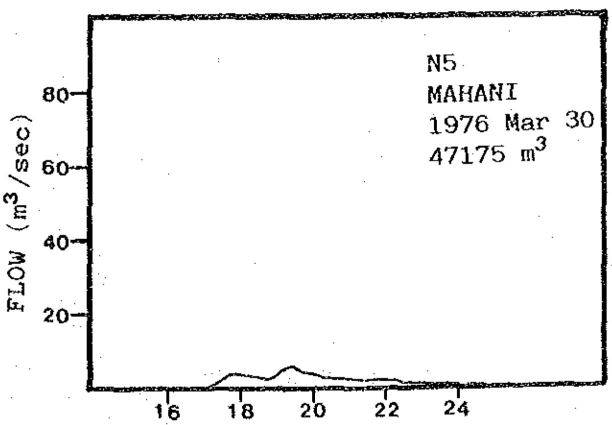


Fig. B-2-5 (3) Observed Runoff Hydrograph, N5 (2/3)







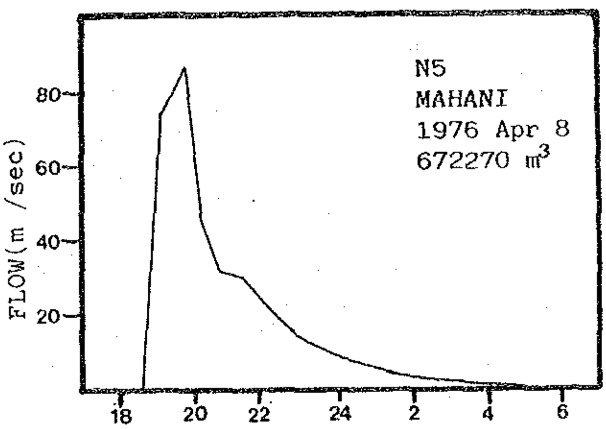


Fig. B-2-5(4) Observed Runoff Hydrograph, N5 (3/3)

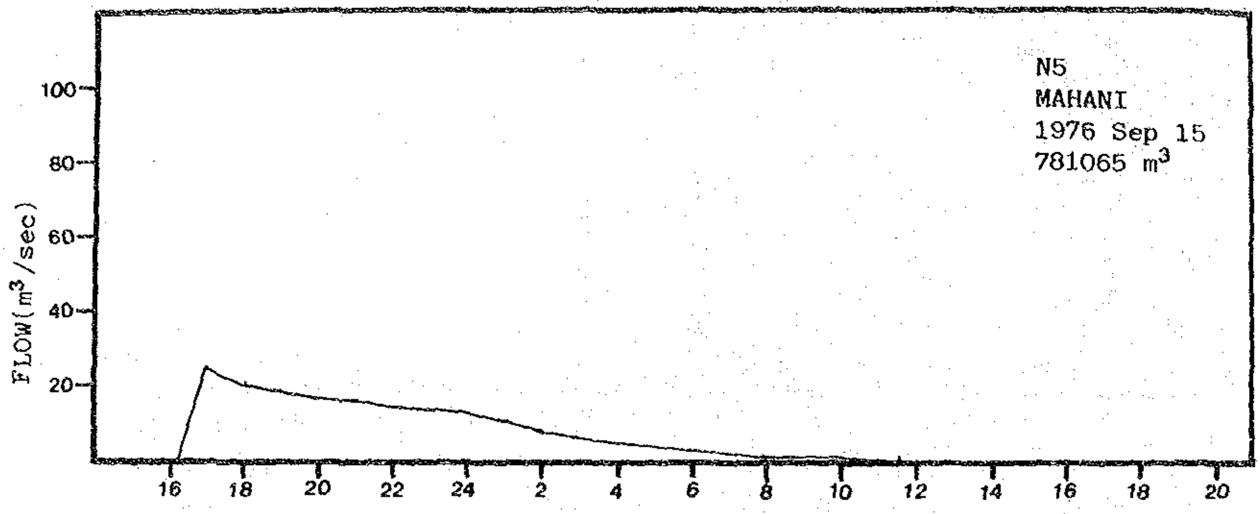
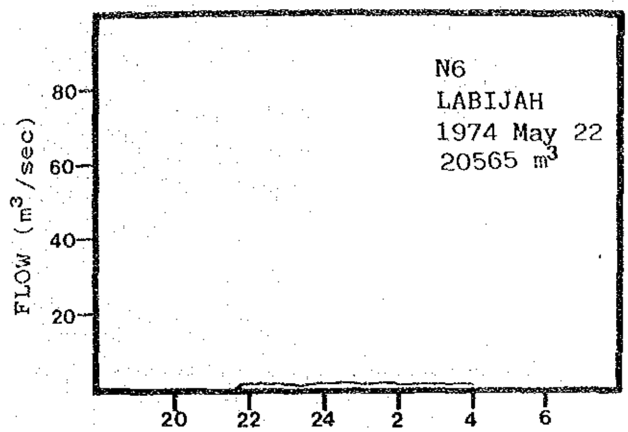
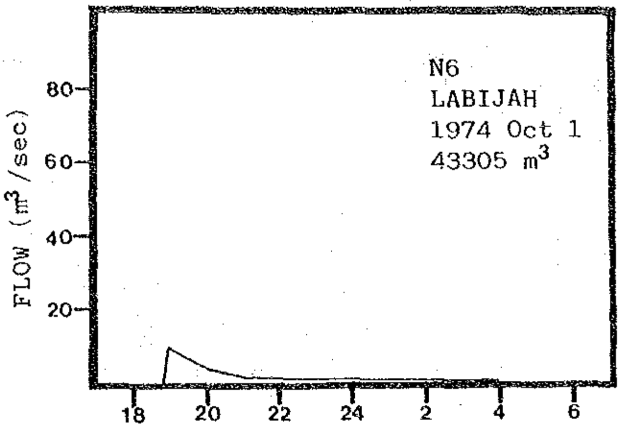
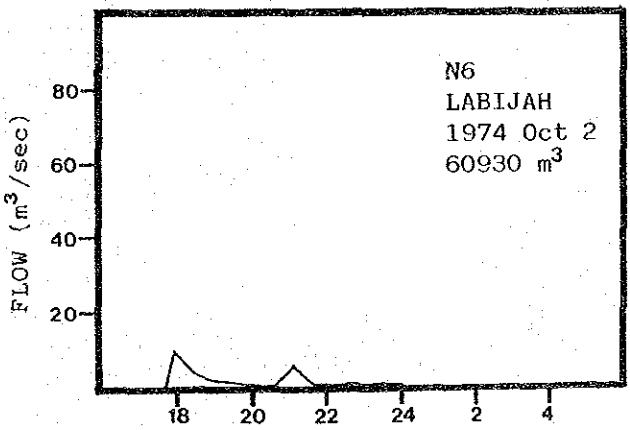


Fig. B-2-5(5) Observed Runoff Hydrograph, N6 and N3







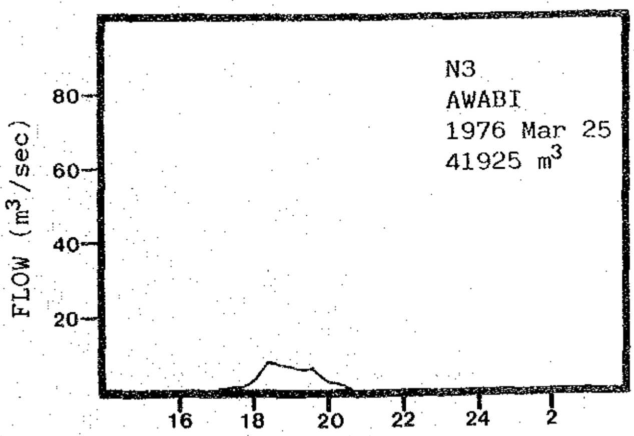
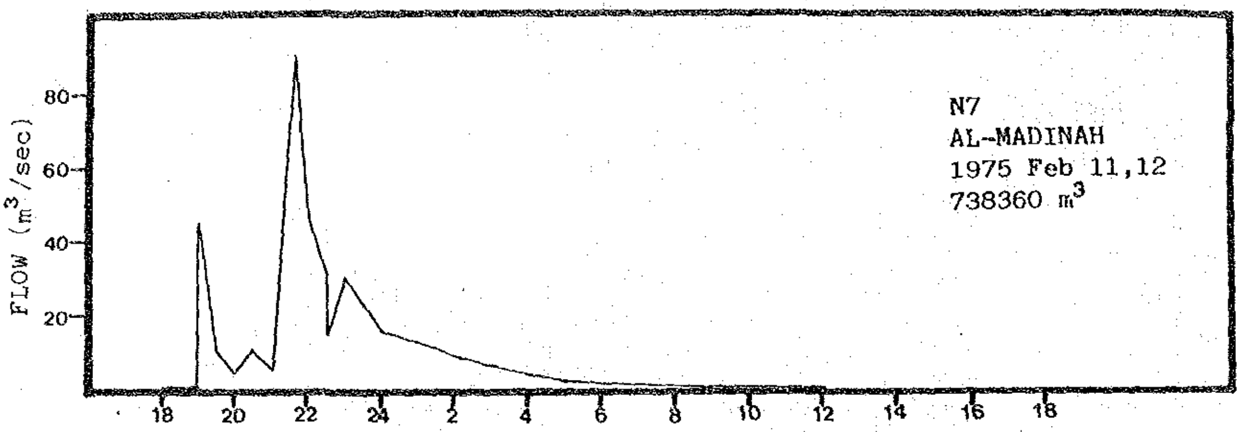


Fig. B-2-5 (6) Observed Runoff Hydrograph, N7



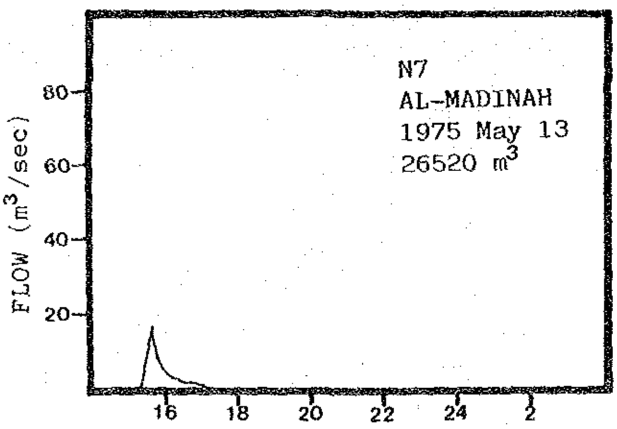
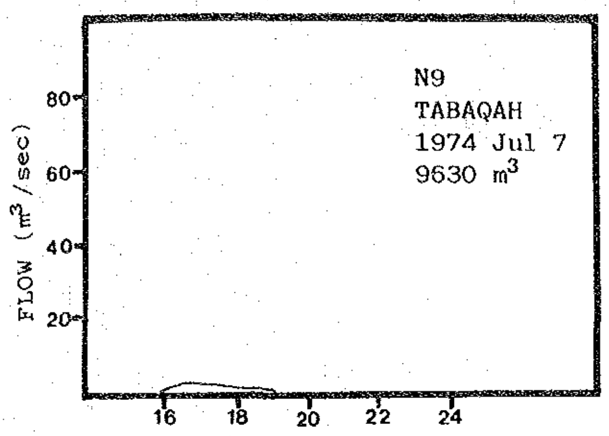
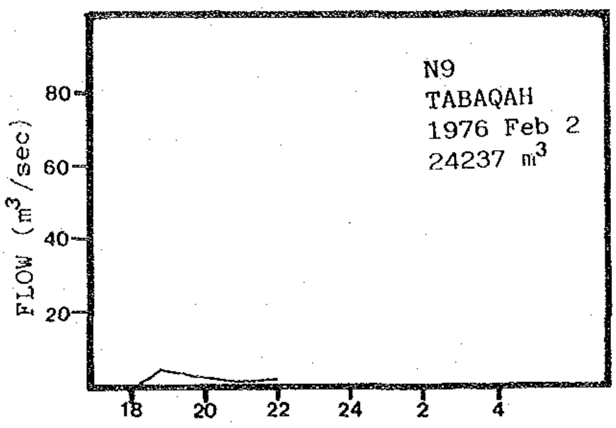
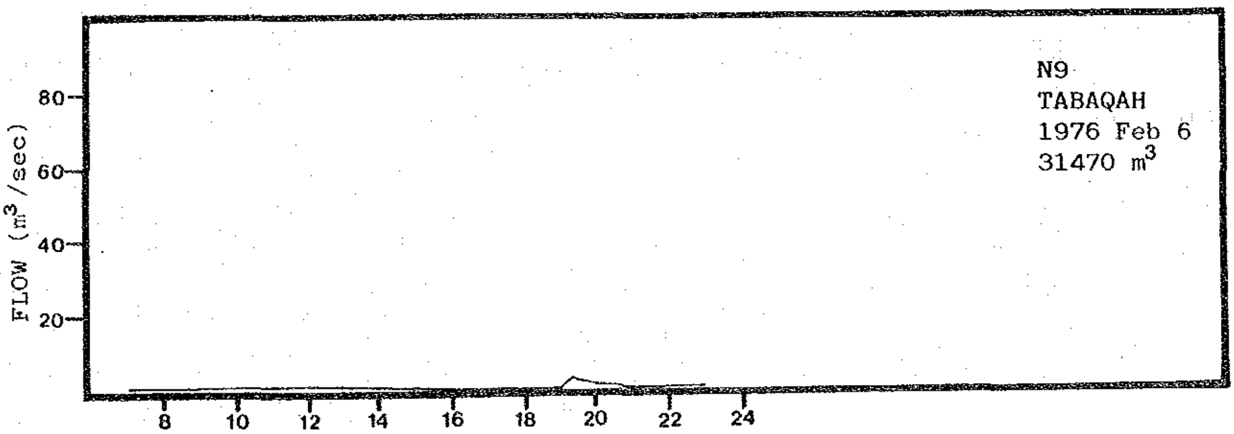
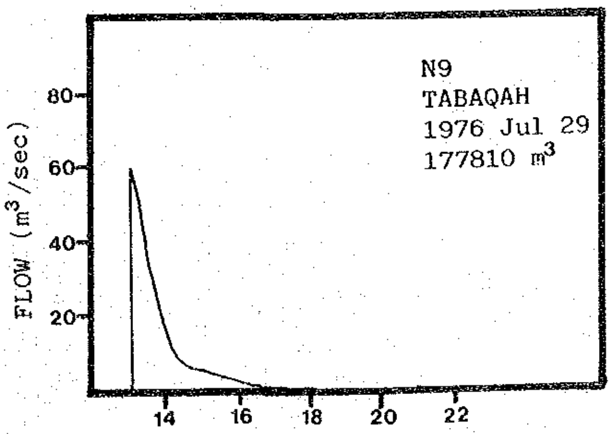


Fig. B-2-5 (7) Observed Runoff Hydrograph, N9









CHAPTER 3 ANALYSIS OF METEOROLOGICAL SITUATION

3.1 Wind

Monthly mean wind speed and monthly mean daily maximum wind speed observed at Al-Muladdah are shown in Fig. B-3-1. The maximum of monthly mean wind speed is 2.6 $m.s^{-1}$ during April to August and the minimum of it is 1.8 $m.s^{-1}$ during November to January. The maximum monthly mean daily maximum wind speed is 6.6 $m.s^{-1}$ during April to June and the minimum is 5.3 $m\cdot s^{-1}$ in December or January. Although the annual variation of wind speed is small, winds are stronger in summer than in winter.

Diurnal variations of wind in summer and in winter are shown in Fig. B-3-2. Daily windroses show two maxima -- north and south west -- in both seasons. The maximum south west wind is clearer in winter than in summer. Wind speeds begin increasing at sunrise, reach maximum at about three in the afternoon, and then decrease. According to the diurnal variation of the windroses, there are two maxima: north or north-northeast winds in daytime and south west wind at night. Al-Muladdah Agrometeorological Station is located 7 km inland from the coast extending on west-northwest and east-southeast. The two maxima coincide with the directions from and to the sea. Consequently, those winds are concluded to be sea and land breezes.

The basic pattern of sea and land breezes in the tropics are shown in Fig. B-3-3. Thermal differences between land and sea surfaces are their main cause. During the day, the land heats up rather quickly under the influence of solar radiation, while water surface remain cooler, because the heat is dissipated over thick layers of water by turbulences and waves. As a result, a small convectional system develops, winds near the earth's surface blowing towards the land -- the sea breeze. At night, the land cools rapidly, while the sea surface remains at about the same temperature as during the day, and a reverse pressure difference results in the land breeze. The wind speed depends upon temperature difference between sea and land surfaces.

The sea breeze is stronger than the land breeze in most tropical climates.

The sea breeze can generally reach inland as far as 40 km, where Hajar Mountain lies in the project area. The sea breeze is considered to be more developed, because the sea breeze joins the valley wind there. The effect of the seasonal wind in large scale (Fig. B-2-1) could not be determined in the data observed at Al-Muladdah. The wind in large scale is hidden under the local wind -- the sea and land breezes.

Fig. B-3-1 Monthly Mean Wind Speed (Al-Muladdah)

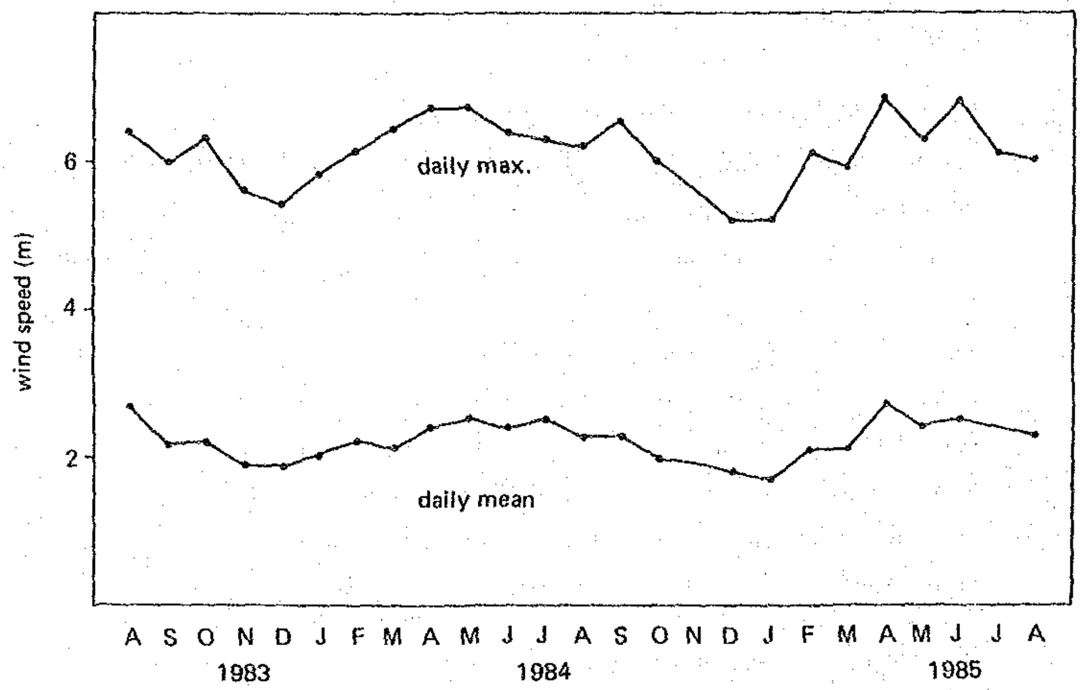
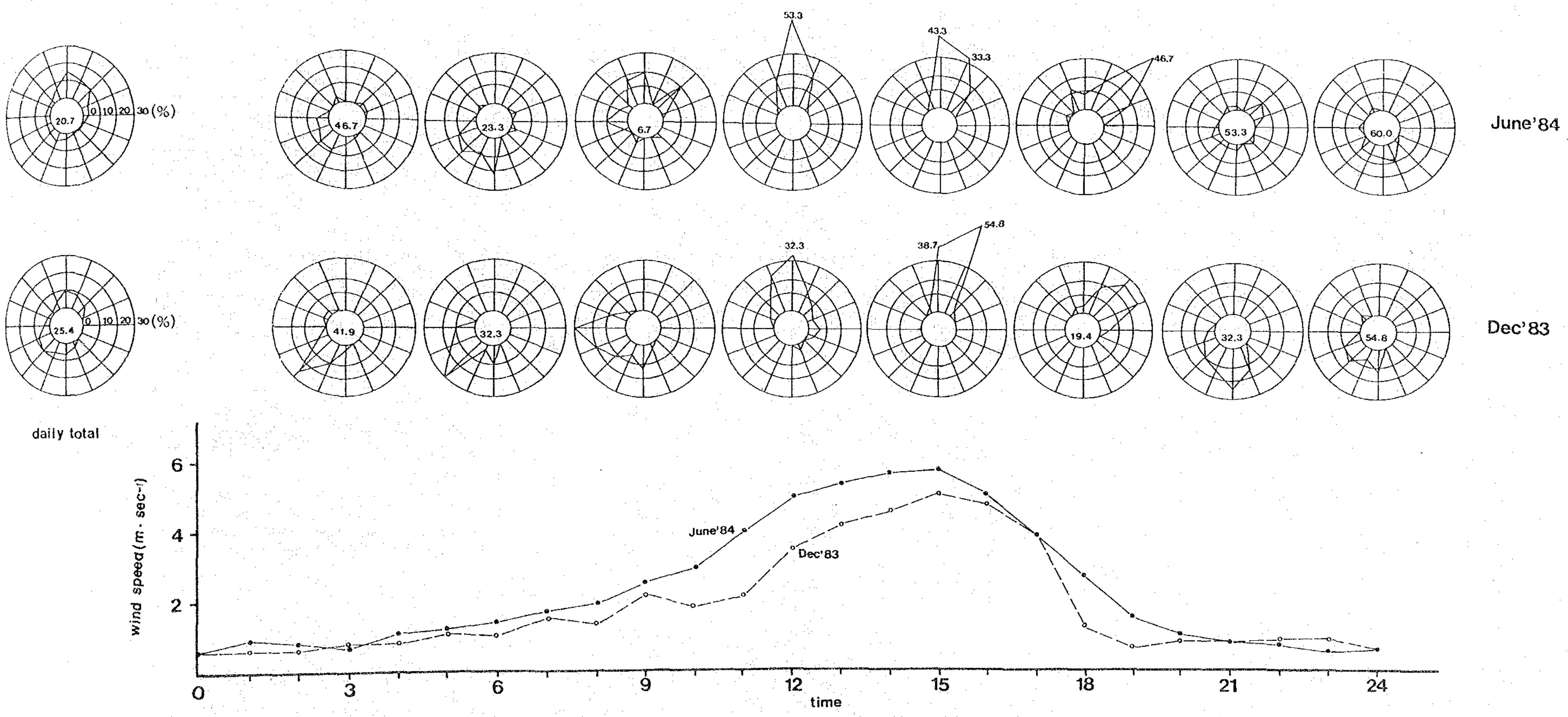
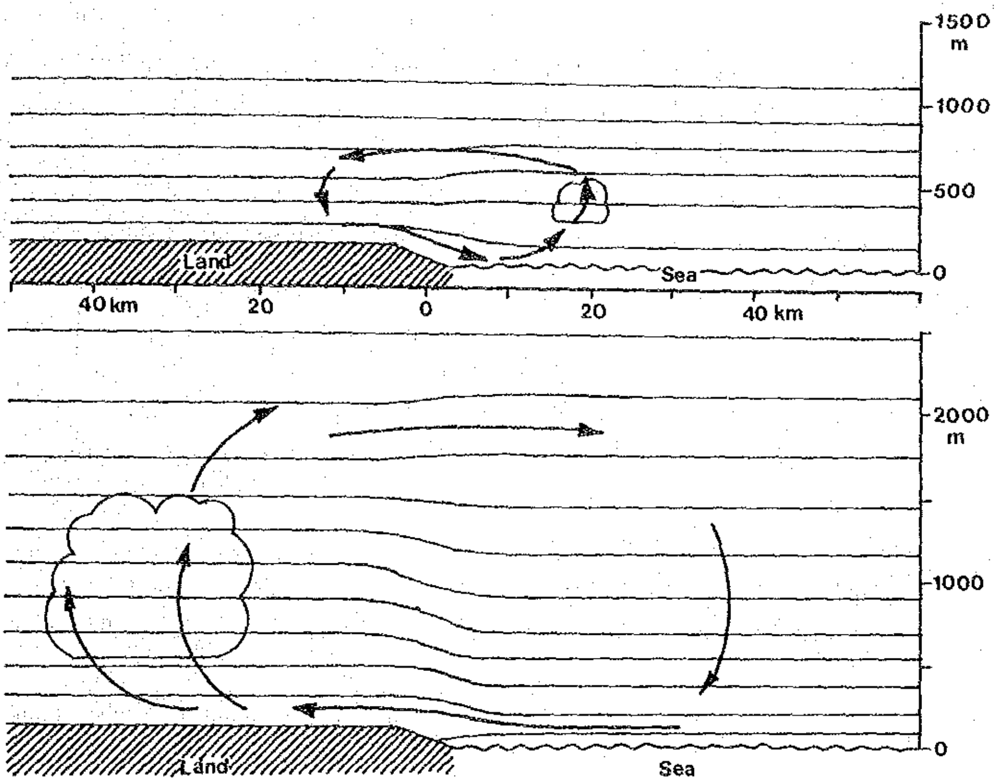


Fig. 4-2-3 Diurnal Wind Variation (Al-Muladdah)



note: number in the circle of windrose is the percentage of calm sequence

Fig. B-3-3 Basic Pattern of Sea and Land Breezes



Note: Top: At night: land breeze
Bottom: During the day: sea breeze
Thin lines represent isobaric su-faces.
(From S. Nieuwolt "Tropical Climatology" 1977)

3.2 Solar Radiation

Monthly mean solar radiation at Al-Muladdah and Al-Rustaq is shown in Fig. B-3-4. Annual mean solar radiation is 489 $cal \cdot cm^{-2} \cdot day^{-1}$ at Al-Muladdah and 468 $cal \cdot cm^{-2} \cdot day^{-1}$ at Al-Rustaq. The maximum monthly mean solar radiation at Al-Muladdah is about 600 $cal \cdot cm^{-2} \cdot day^{-1}$ during April to June and the minimum is about 330 $cal \cdot cm^{-2} \cdot day^{-1}$ in December.

The maximum is recorded before the elevation of the sun reaches the maximum -- the summer solstice. Based on incremental elevation, it can be considered that the increment of solar radiation is scattered with vapour which is increasing during February to August.

The solar radiation at Al-Rustaq is slightly less than at Al-Muladdah, because Al-Rustaq is surrounded by mountains which interrupt solar radiation.

Diurnal variations of solar radiation in summer and in winter are shown in Fig. B-3-5. Both of them have symmetrical axes at twelve o'clock.

Fig. B-3-4 Monthly Mean Solar Radiation (Al-Muladdah and Al-Rustaq)

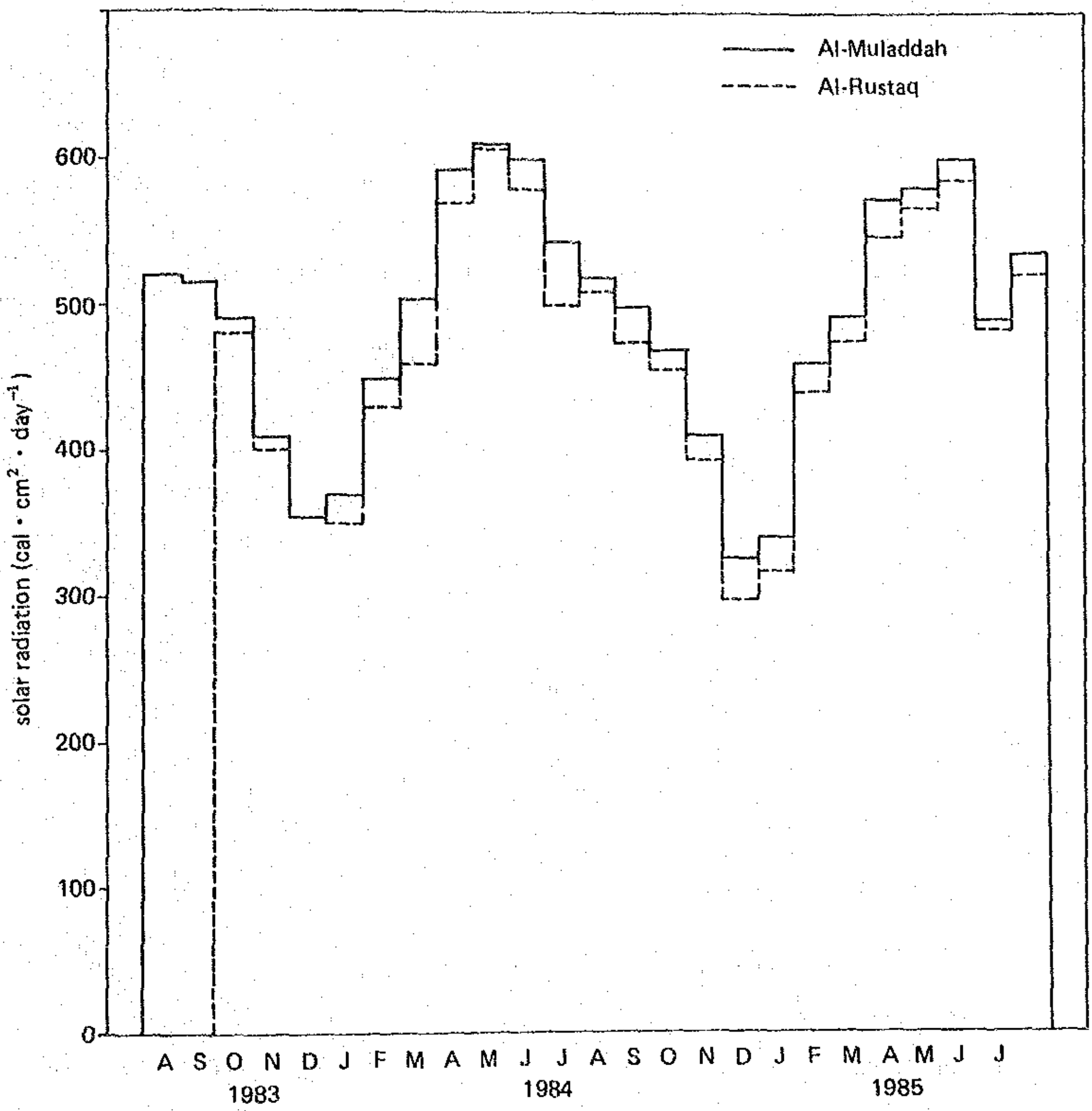
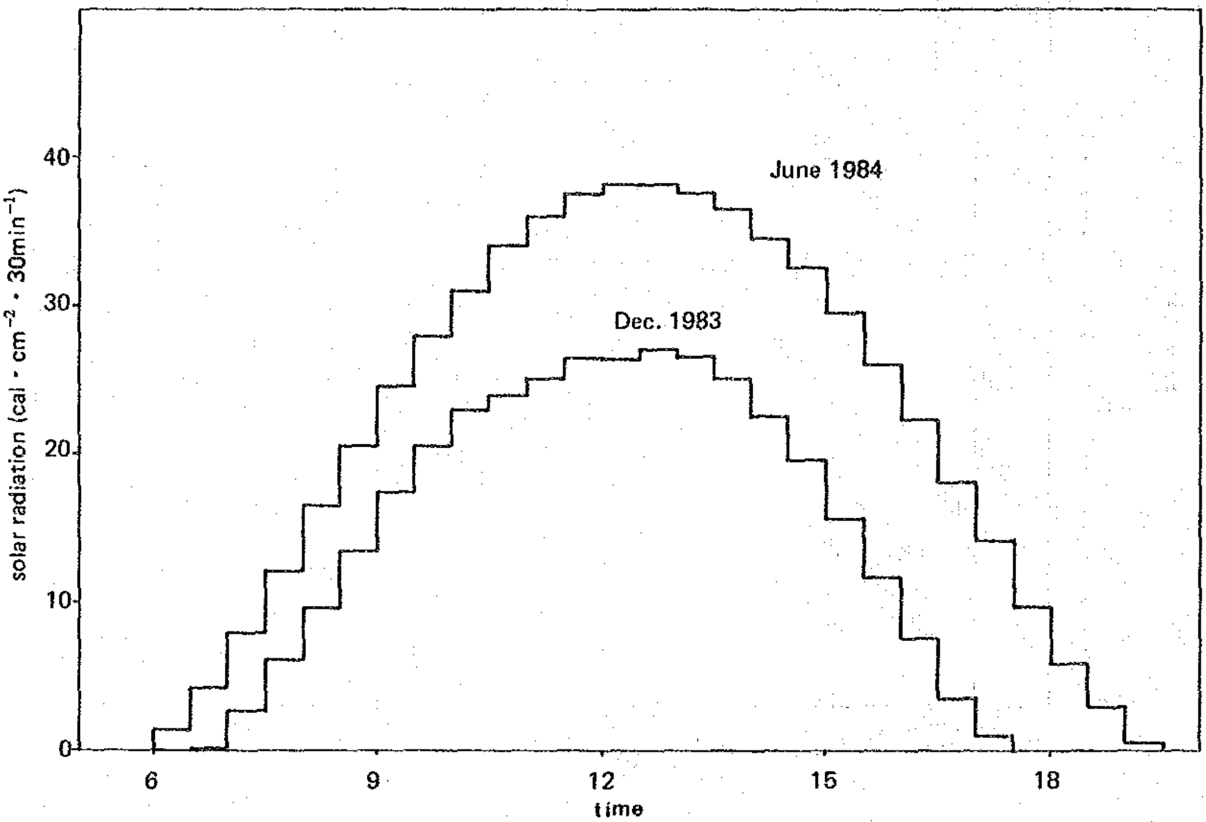


Fig. B-3-5 Diurnal Solar Radiation Variation (Al-Muladdah)



3.3 Air Temperature

Monthly mean daily maximum, mean and minimum air temperature and diurnal range of air temperature observed at Al-Muladdah are shown in Fig. B-3-6. Annual mean air temperature is 27.6°C. The maximum monthly mean daily maximum air temperature is about 41°C in June and the minimum is about 26°C in January. The maximum monthly mean air temperature is about 34°C in June or July and the minimum is about 20°C in February. The maximum monthly mean daily minimum air temperature is about 30°C in July and the minimum is about 13°C in February. The absolute maximum air temperature during August, 1983 to August, 1985 was 48.3°C on August 3, 1985 and the absolute minimum was 6.5°C on February 20, 1985.

Air temperature varies with a little phase lag after solar radiation (Fig. B-3-4). The order of lag among the air temperatures is daily maximum, mean and minimum respectively.

The diurnal ranges of air temperature have two maxima, about 15°C in October or November and May. The minima are about 9°C in June or August and about 11°C in December or January.

Diurnal variations of air temperature in summer and in winter are shown in Fig. B-3-7. The maximum is recorded between twelve and one in the afternoon and the minimum is recorded just before sunrise in both summer and winter. The time of the maximum air temperature coincides with the time of the maximum of solar radiation. The phase lag between solar radiation and air temperature could not be determined because the sea breeze --colder air mass -- flows into the land.

Fig. B-3-6 Monthly Mean Air Temperature (Al-Muladdah)

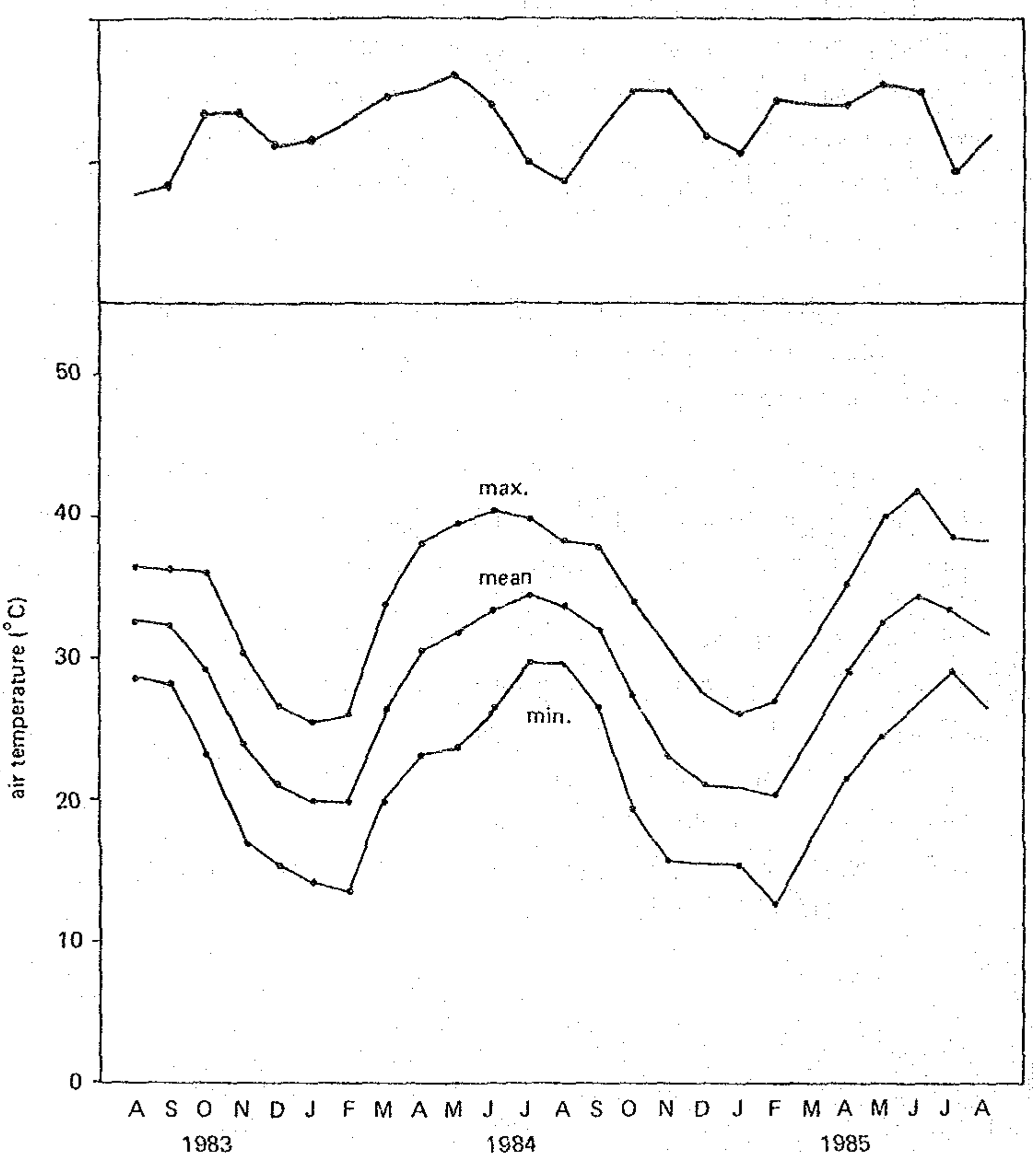
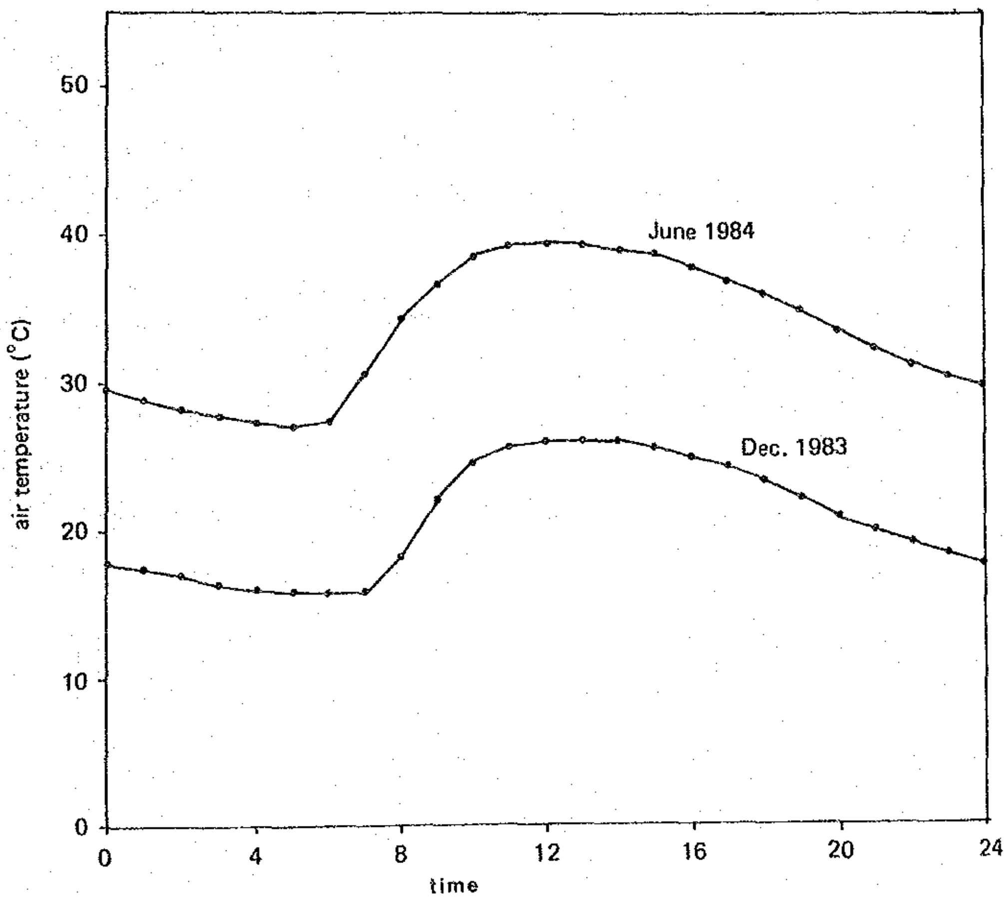


Fig. B-3-7 Diurnal Air Temperature Variation (Al-Muladdah)



3.4 Relative Humidity and Vapour Pressure

Monthly mean relative humidity and vapour pressure at Al-Muladdah are shown in Fig. B-3-8. Annual mean relative humidity is 64%, the maximum monthly mean relative humidity is 70 - 80% in August and during November to January and the minimum is 40 - 50% during April to June and 50 - 60% in September or October.

Annual mean vapour pressure is 23.68 mb, the maximum monthly mean vapour pressure is about 36 mb in July or August and the minimum is about 16 mb in February. Vapour pressure varies with phase lag after air temperature.

Diurnal variations of relative humidity and vapour pressure are shown in Fig. B-3-9. The diurnal variation of relative humidity has the reverse phase from air temperature.

Although the diurnal variation of vapour pressure in summer is almost the same as it is in winter, in summer it is slightly different from it in winter: vapour pressure in summer begins increasing after sunrise and then increases again during ten in the morning to one in the afternoon. The cause of it is considered to be inflow of the sea breeze -- humid air mass.

Fig. B-3-8 Monthly Mean Relative Humidity and Vapour Pressure (Al-Muladdah)

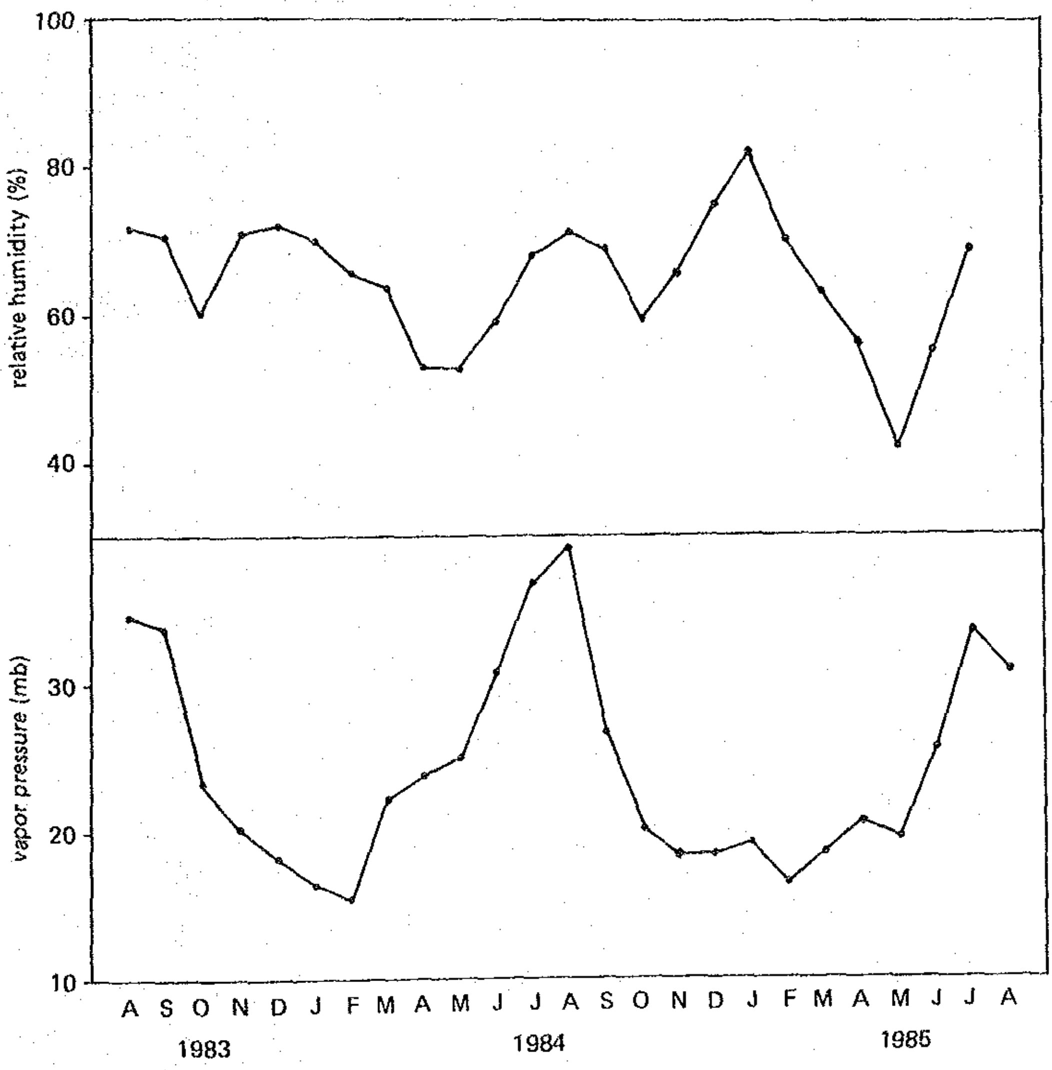
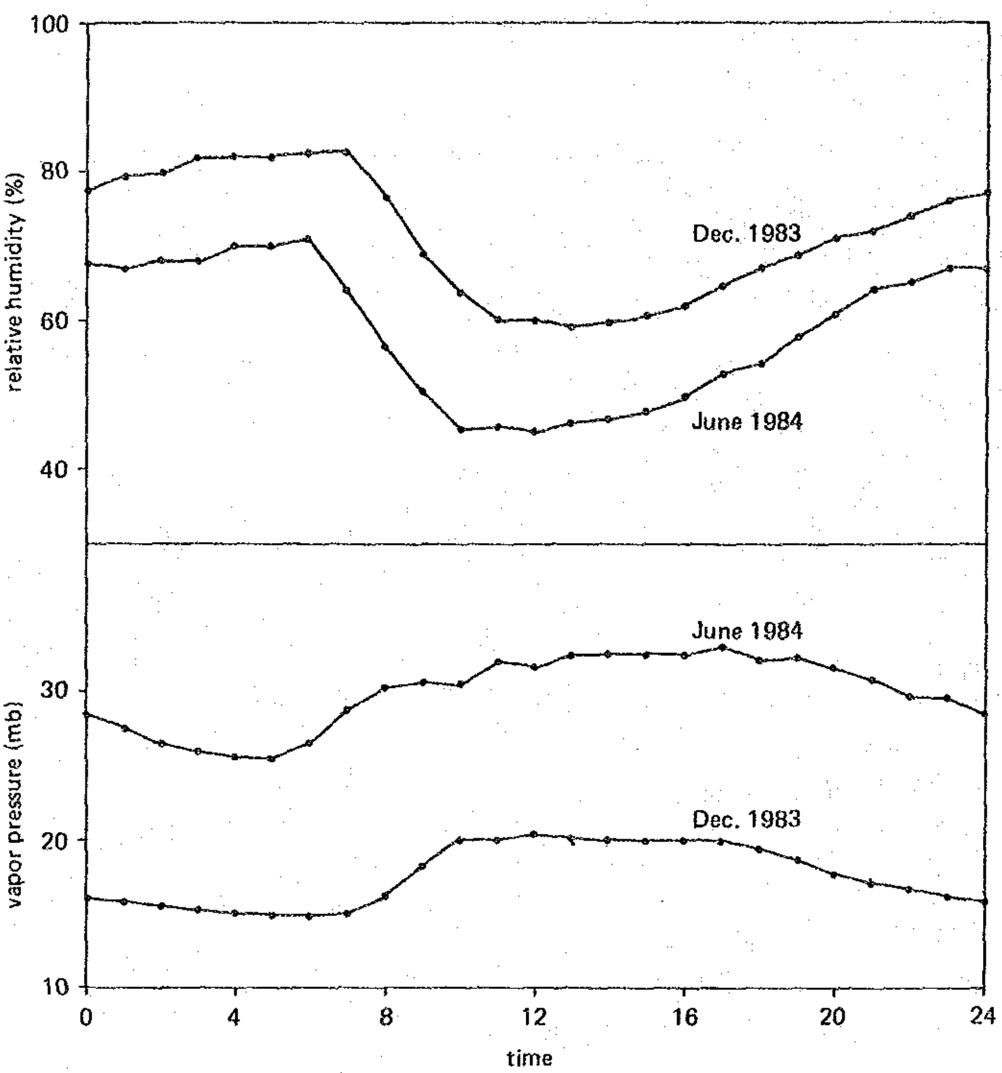


Fig. B-3-9 Diurnal Relative Humidity and Vapour Pressure Variation (Al-Muladdah)



3.5 Net Radiation

Monthly mean net radiation observed at Al-Muladdah is shown in Fig. B-3-10. Annual mean is 160.9 cal.cm^{-2}·day^{-1}. The maxima are about 200 cal.cm^{-2}·day^{-1}. The month of the maximum varies yearly, because it was recorded in August in 1984 and in April in 1985. As the minimum is about 90 cal.cm^{-2}·day^{-1} in December, the month of the minimum coincides with the month when solar radiation reaches the minimum.

The diurnal variations of net radiation in summer and in winter are shown in Fig. B-3-11. The variation of both are similar and the minima is reached just after sunset. The net radiation during night in summer is more than in winter, because of the higher surface temperature during night.

Fig. B-3-10 Monthly Mean Net Radiation (Al-Muladdah)

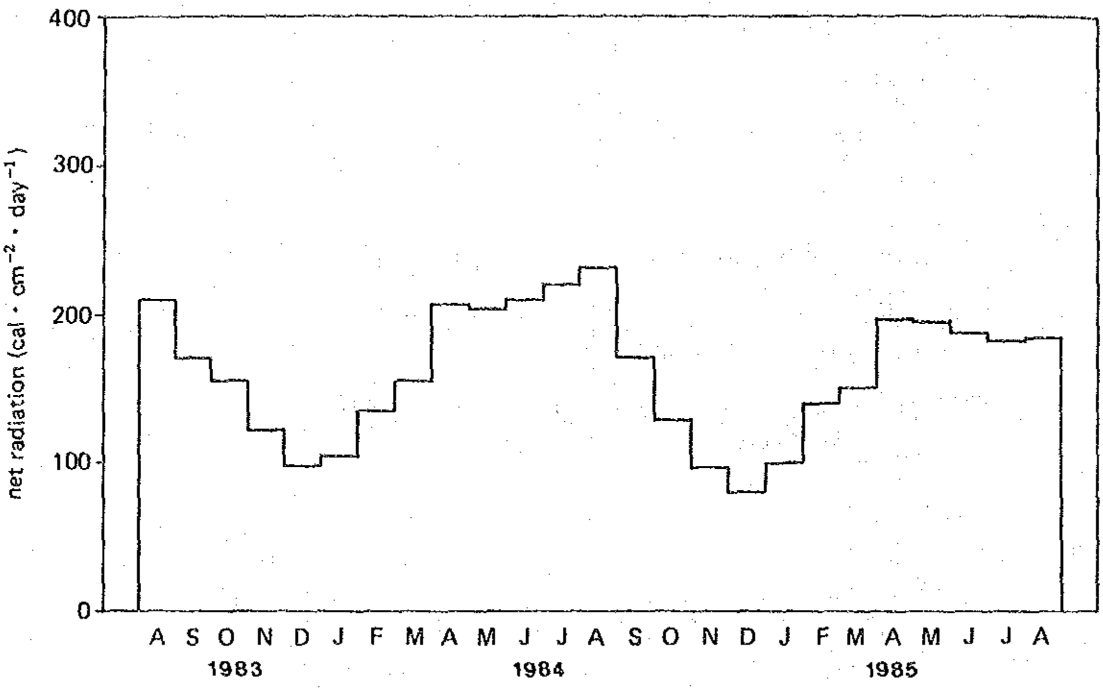
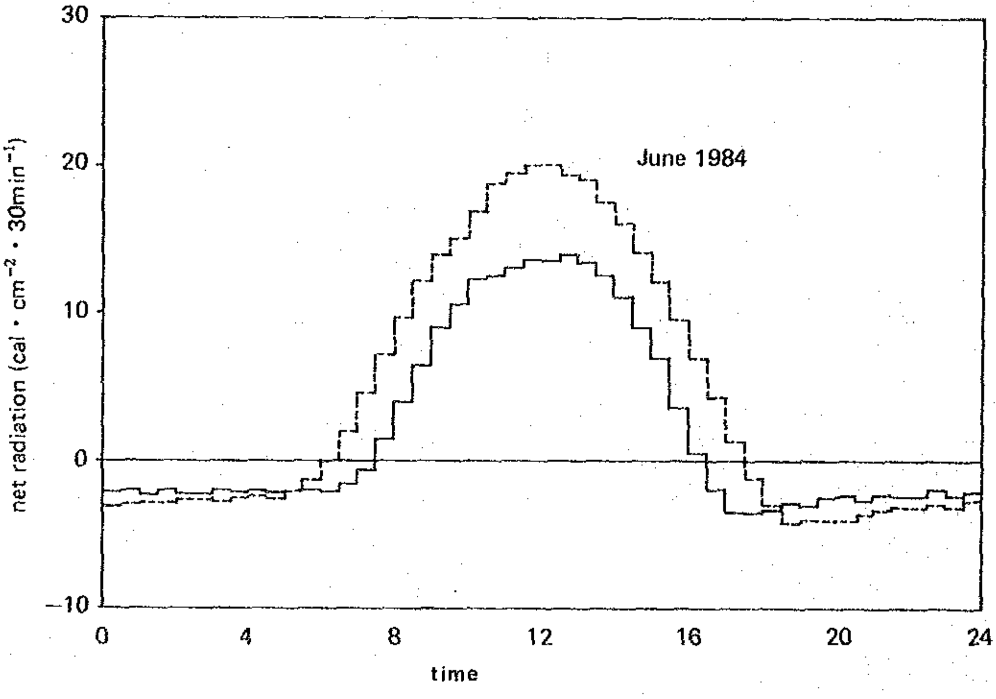


Fig. B-3-11 Diurnal Net Radiation Variation (Al-Muladdah)



3.6 Soil Temperature

Monthly mean of soil temperatures at 5, 60 and 120 cm depths are shown in Fig. B-3-12. Annual mean values are 32.8, 32.2 and 31.8°C respectively. The maximum at 5 cm deep is about 41°C in June or July and the minimum is about 23°C in January.

Diurnal variations of soil temperature at 5, 15, 30 cm deep in summer and in winter are shown in Fig. B-3-13. As the depth increases, the amplitude of soil temperature decreases and the phase of soil temperature lags it in both the annual and the diurnal variation. As the diurnal range below 60 cm is less than 0.1°C, clear diurnal variation disappears.

Fig. B-3-12 Montly Mean Soil Temperature (Al-Muladdah)

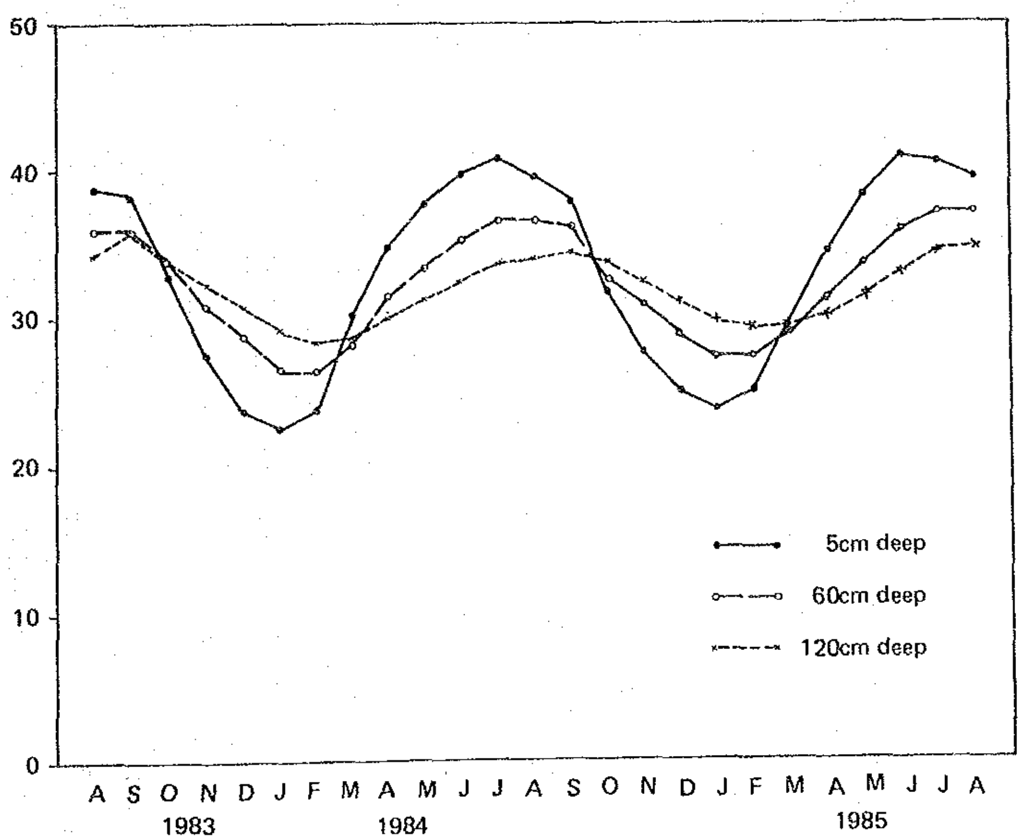
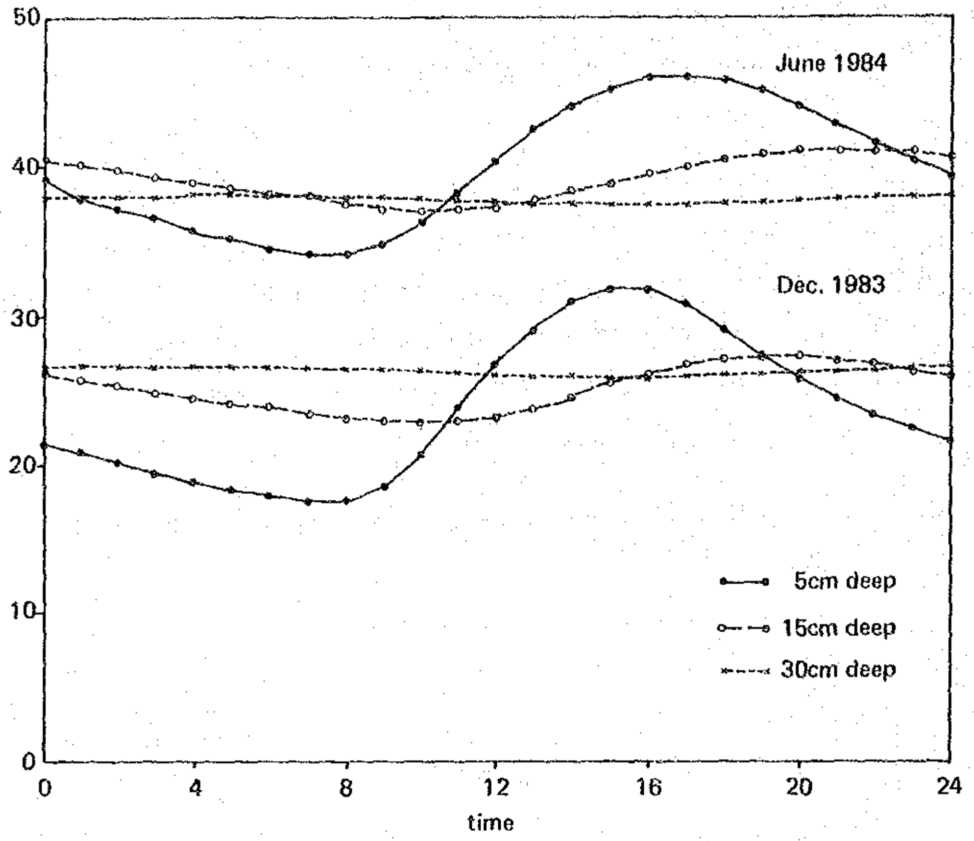


Fig. B-3-13 Diurnal Soil Temperature Variation (Al-Muladdah)



3.7 Soil Heat Flux

Monthly mean soil heat flux at 5 cm deep is shown in Fig. B-3-14. The plus value in the figure means heat flows downward. Heat flows upward in summer and downward in winter.

Diurnal variations in summer and in winter are shown in Fig. B-3-15. The patterns of both are similar, but soil heat flux in summer is larger than in winter.

Fig. B-3-14 Monthly Mean Soil Heat Flux, 5cm Deep (Al-Muladdah)

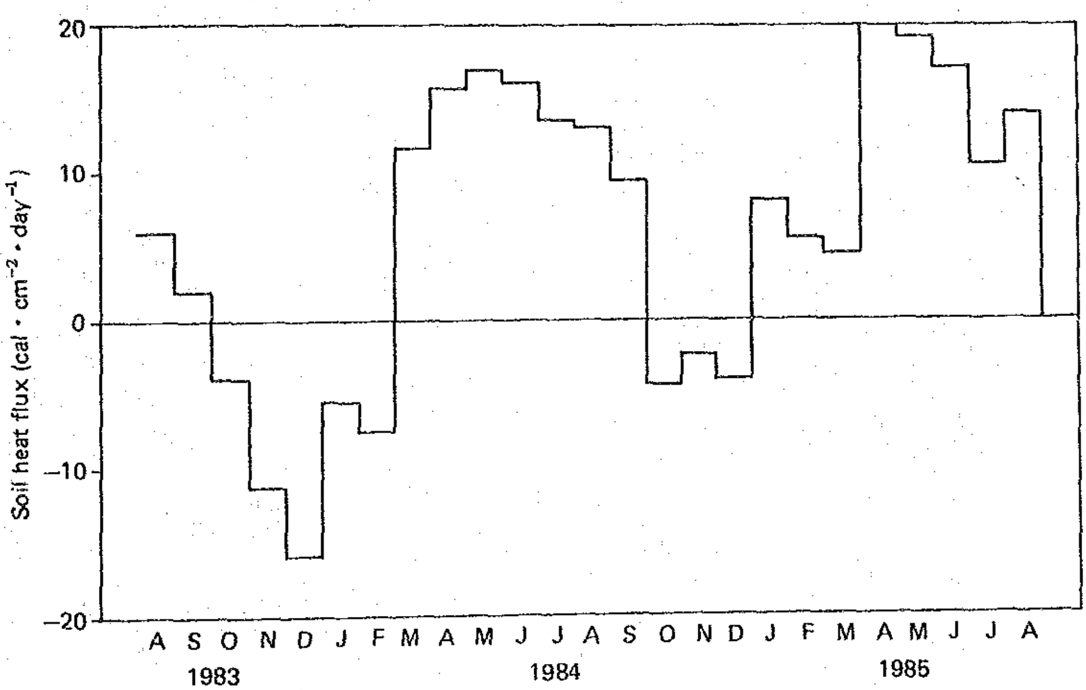
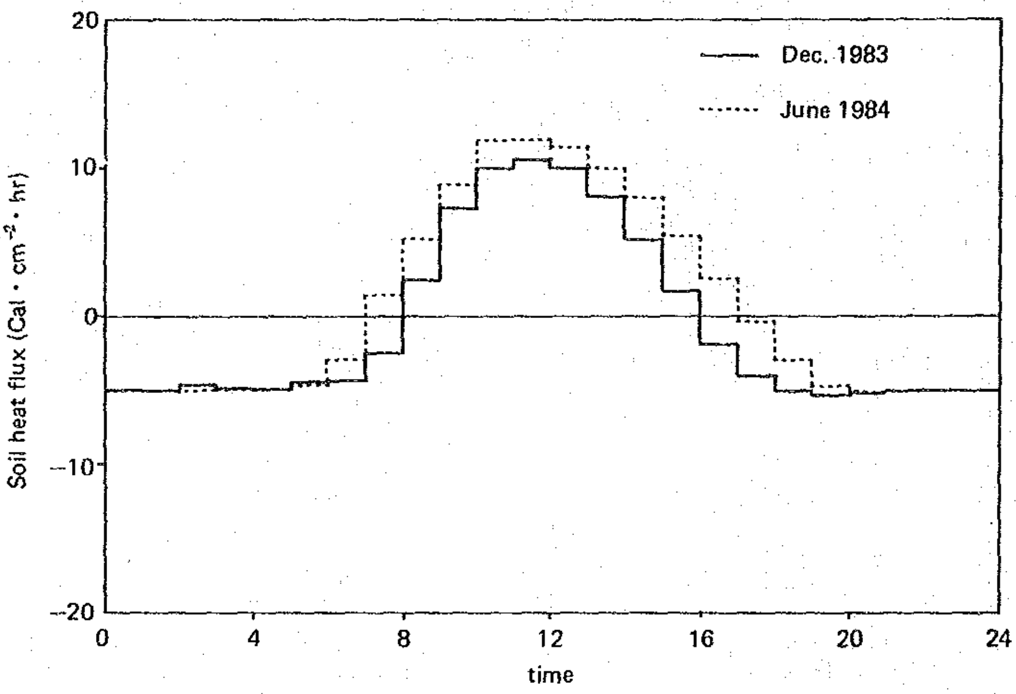


Fig. B-3-15 Diurnal Soil Heat Fluxies Variation 5cm Deep (Al-Muladdah)



3.8 Pan Evaporation

The start of observation of pan evaporation was delayed, because of delayed employment of an observer. After the observation began, there was some unreliable data. Pan evaporation observed at Al-Muladdah is shown in Table B-3-1.

Table B-3-1 Monthly Pan Evaporation (Al-Muladdah)

	Pan Evaporation (mm)
Nov 1984	207
Dec 1984	133
Jan 1985	126
Feb 1985	215
Mar 1985	247
Apr 1985	364
May 1985	424
June 1985	X
July 1985	X
Aug 1985	326

X: Unreliable data

3.9 Potential Evaporation and Potential Evapotranspiration

Potential evaporation is defined as the evaporation that would occur if water were plentiful. It can be calculated by Penman's equation as follows:

$$E = \frac{\Delta}{\Delta + \gamma} Qne + \frac{\Delta}{\Delta + \gamma} Ea$$

where, E is the evaporation, Δ is the slope of the saturation-vapour-pressure versus temperature curve at the temperature Ta, γ is the psychrometric constant, Qne is the net radiation exchanged expressed in the same unit as E, and Ea, drying power of the air, is defined by

$$E_a = 0.26\ (1 + 0.54U_2)\ (e_a{*} - e_a)$$

U_2 is the wind speed at 2m high, $e_a{*}$ is the saturation vapour pressure, and ea is the vapour pressure. Monthly potential evaporation, calculated by Penman's equation and the meteorological data observed at Al-Muladdah, is shown in Table B-3-2.

Calculated potential evaporation, pan evaporation and the ratio of them -- pan coefficient -- are shown in Table B-3-3. As the pan coefficient is adopted 0.7 generally, it almost coincides with the values shown in Table B-3-3. Consequently, the potential evaporation calculated by Penman's equation can be regarded as potential evaporation. As the result, annual potential evaporation is 2218 mm.

Potential evapotranspiration is defined as free-water evaporation provided there is a complete vegetal cover. Potential evapotranspiration was calculated by the three methods indicated by crop water requirement (FAO Irrigation and Drainage Paper 24): Blaney-Criddle method, Penman method and Pan method.

Calculated values by those methods are shown in Table B-3-4 and the values vary with the method. The values calculated by the pan method can be assumed as the nearest values, because pan evaporation is the observed value. The values in the month, when the values of pan evaporation are unreliable, were estimated by the interpolation of the values calculated by the Blaney-Criddle method. As a result, annual crop water requirement is calculated as 2052 mm and monthly values of it is shown in Table B-3-5.

Table B-3-2 Potential Evaporation (Al-Muladdah)

(mm/month)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1983	-	-	-	-	-	-	-	220	207	200	127	100	-
1984	103	122	187	247	266	261	245	227	206	171	126	85	2246
1985	84	126	167	228	260	267	199	221	-	-	-	-	-
Mean	94	124	177	238	263	264	222	223	207	186	127	93	2218

Table B-3-3 Comparison of Potential and Pan Evaporation (Al-Muladdah)

(mm)

	1984 Nov.	Dec.	1985 Jan.	Feb.	Mar.	Apr.	May	Aug.	Total
Potential Evaporation (mm/month)	126	80	84	126	167	228	260	221	1292
Pan Evaporation (mm/month)	207	133	126	202	247	364	424	326	2029
Ratio	0.61	0.64	0.67	0.62	0.68	0.63	0.61	0.68	0.64

Table B-3-4 Reference Crop Evapotranspiration(Al-Muladdah)

1983 (mm/month)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
Blaney-Criddle	-	-	-	-	-	-	-	248	234	208	168	140	-
Penman	-	-	-	-	-	-	-	271	255	230	145	108	-
Pan	-	-	-	-	-	-	-	-	-	-	-	-	-

1984

Blaney-Criddle	136	139	208	240	267	285	304	276	240	192	156	105	2548
Penman	111	134	215	296	309	321	309	277	247	197	135	86	2632
Pan	-	-	-	-	-	-	-	-	-	-	130	84	

1985

Blaney-Criddle	102	146	192	231	264	285	291	251					
Penman	92	150	199	271	296	328	239	281					
Pan	79	127	148	211	246	-	-	200					

Table B-3-5 Annual Reference Crop Evapotranspiration (Al-Muladdah)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
Reference Crop Evapotranspiration	79	127	148	211	246	231	242	200	192	162	130	84	2052