THE GOVERNMENT OF SULTANATE OF OMAN

HYDROLOGIC OBSERVATION PROJECT IN THE BATINAH COAST OF SULTANATE OF OMAN

FINAL REPORT

VOLUME 1

MAIN REPORT

MARCH 1986

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

It is with great pleasure that I present this report on the "Hydrologic Observation Project in the Batinah Coast" to the Government of Sultanate of Oman.

This report embodies the result of a survey which was carried out in the Batinah Coast from March, 1982 to March, 1986 by a Japanese survey team commissioned by the Japan International Cooperation Agency following the request of the Government of Sultanate of Oman to the Government of Japan.

The survey team, headed by Mr. Makoto Tanaka, Pacific Consultants International, had a series of close discussion on the project with the officials concerned of the Government of Sultanate of Oman, conducted a wide scope of field survey and has completed the report.

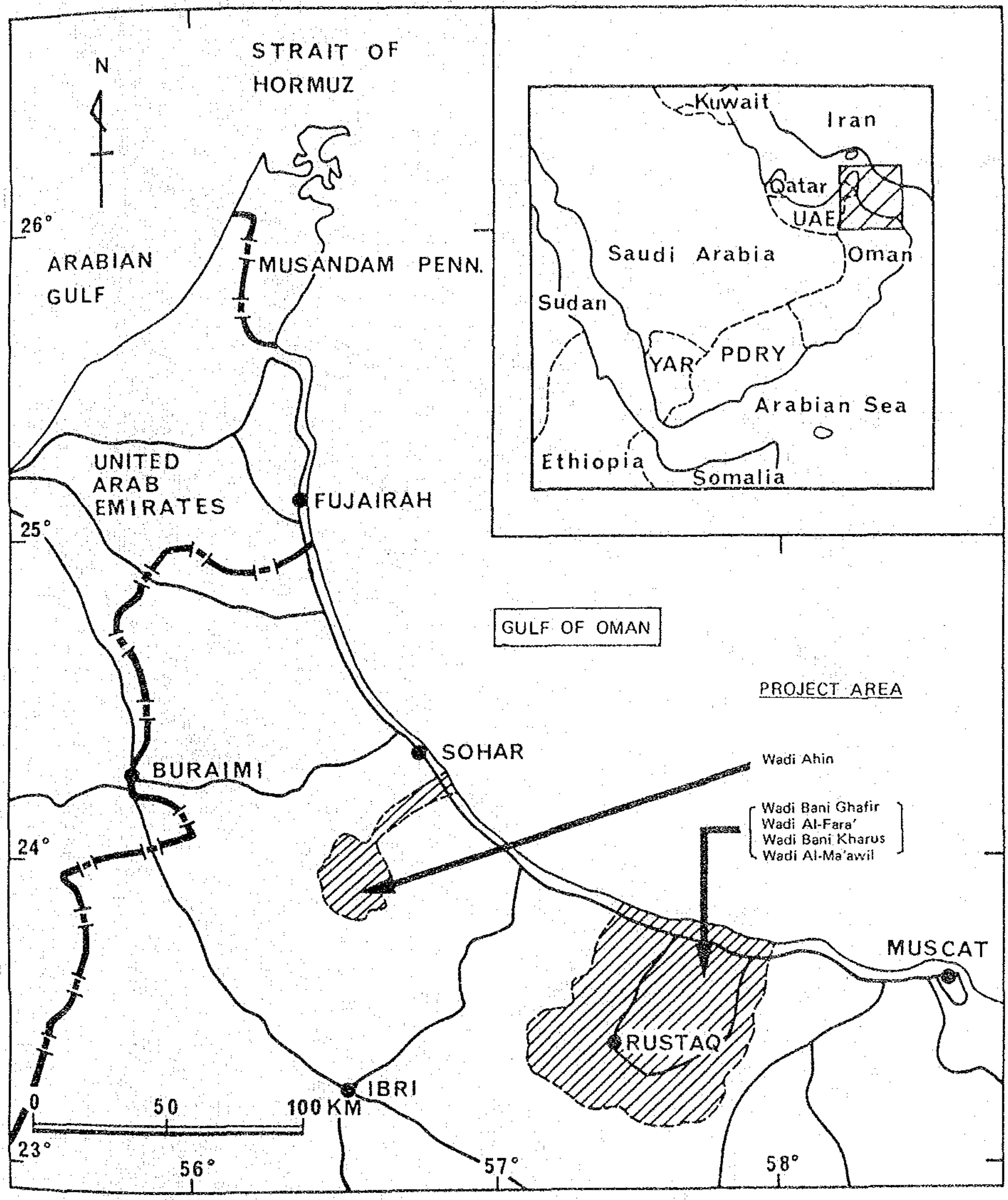
I hope that this report will be useful as a basic reference for water resources development on the Batinah Coast and contribute to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of Sultanate of Oman for their close cooperation extended to the survey team.

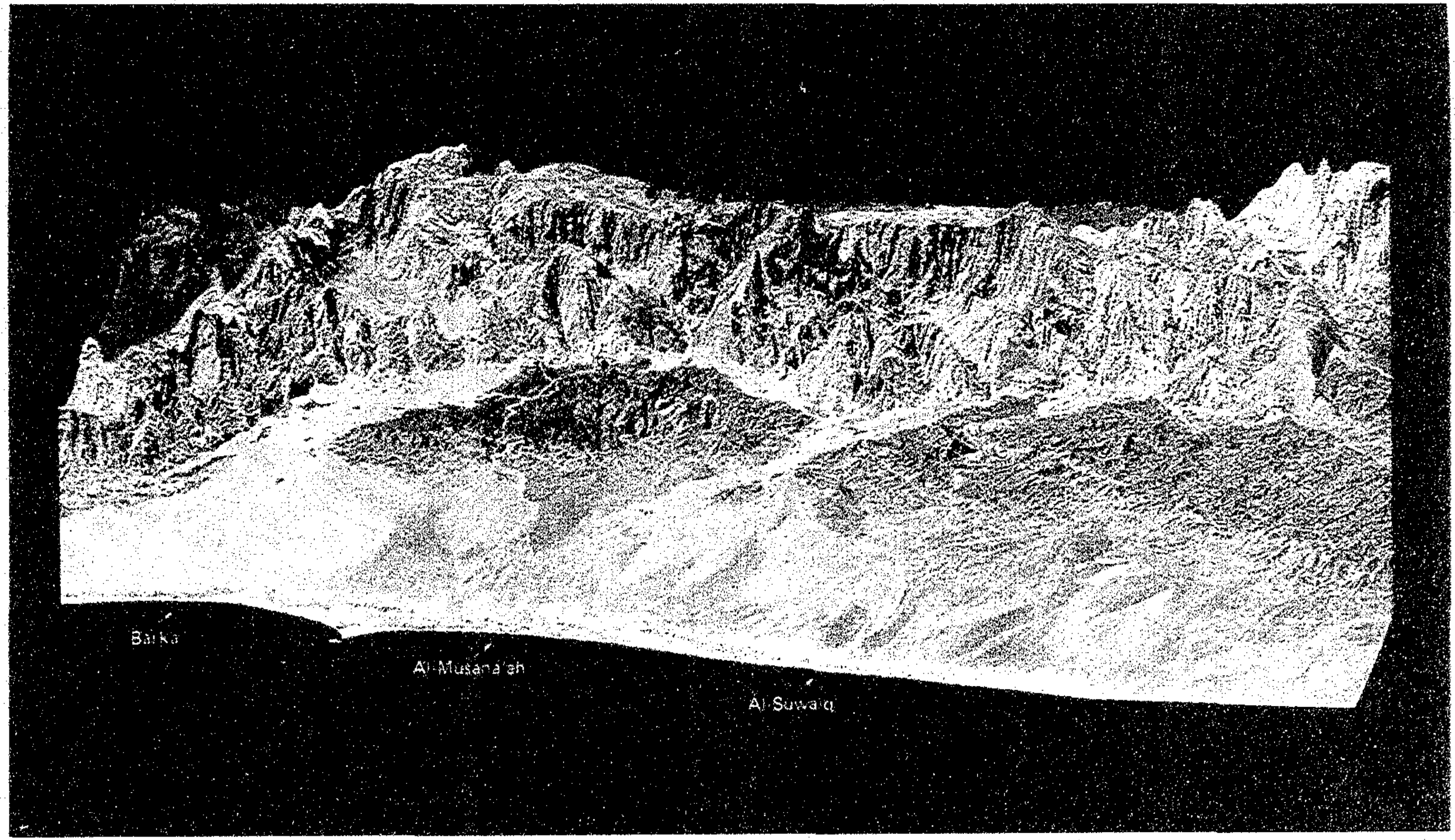
March, 1986

Keisuke Arita
President
JAPAN INTERNATIONAL COOPERATION AGENCY

LOCATION MAP OF THE PROJECT AREA



SATELLITE BIRD'S-EYE VIEW OF THE BATINAH COAST



LANDSAT Three-Dimensional Display Image; Facing South, Bird-eye View Angle = 45 Deg. Z Scale = 5 Norte, October 2, 1981

SUMMARY

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1. Introduction

The Sultanate of Oman gives a high priority to the promotion of agricultural development and water resources development, since the Government wishes to achieve economic independence from oil and self sufficiency in the supply of food, a goal since the first five-year plan (1976-1980).

The Batinah coast is the most important area and the main agricultural area of Oman, where one third of the population and one half of the farm land are concentrated. However at the coastal agricultural area, the salinity problem of groundwater is pronounced over a wide area.

In addition to existing farmlands (the Project area) estimated as 10,005 ha (7,580 ha in the coastal area and 2,425 ha in the mountain area) by the air photograph (MAF, 1981), new farmlands are increasing along the national road. It is clear from the data of the Ministry of Housing that the Government has already given permission for 10,070 ha of new development in the coastal area.

This new development will make the water demand of 285.8 MCM/year (2.5 times larger than current demand) for the coastal area irrigation with current unit water consumption.

Although agriculture in the coastal area depends on groundwater, the groundwater storage (estimated based on the groundwater level data from 1976 to 1984) is decreasing in the four wadi basins, and the Electric Conductivity (EC) value distribution map of two stages : 1976 (Gibb), 1983 (MAF), shows an increase by 1000 - 6000μs/cm in EC value in Abu Abali and Al-Suwadi areas.

The continuation of current water use and the uncoordinated reclamation of new farm lands likely will cause the increase of salinity problems and deteriorate the existing farmland in the coast area.

The control of intake and new water resource development are expected for the determent of groundwater salinization.

On the other side in the mountain area, they are depending on springs and aflaj for irrigation. But the discharges of aflaj fluctuate largely (1983/84: 169.5 MCM/year, 1984/85: 73.9MCM/year). For example, the survey conducted during a long spell of drought from August, 1983 to August, 1985, revealed that 24 aflaj out of surveyed 60 ones could not take water at all. It is indispensable to consider any counterplans to obtain the minimum amount of water during the drought season.

The way to develop new water resources in the Batinah Coast is to make effective use of flood water which outflow into the sea, with dam-type structures which will recharge the groundwater and increase the groundwater resources.

Although the development potential of surface water for new water resources might be rather small in comparison with the current demand for agriculture, it is still very important.

In order to cope with the regional deficit of water resources and the increase of salinity problems, it is also indispensable to economize the current water use, in line with the development of surface water for recharging groundwater.

The main stumbling block to water resources development in the Batinah Coast has been the lack of accurate long term hydrologic data, which is indispensable for making a plan for increasing the water supply on a dependable basis.

The purpose of this Project was to set up a hydrologic observation network in the Batinah Coast and to carry out hydrological survey, hydrogeological survey and land/water use survey to form the basis for development of water resources in the Project area.

The surveys included an estimation of the hydrological water balance and water resources development potential of each wadi basin in the Project area, and on-the-job training to the Omani counterparts through the Project.

This Summary presents the results of the installation of hydrologic observation network, hydrologic observation and survey of five wadi basins (approx. 6,000 sq.km) in the Batinah Coast area.

The result of the survey is compiled as "Hydrologic Observation Project in the Batinah Coast of Sultanate of Oman" which consists of the following volumes:

- Volume 1 - Main Report
- Volume 2 - Supporting Reports I
  - A Surface Geology and Fluvial Morphology
  - B Meteorology and Hydrology
- Volume 3 - Supporting Reports II
  - C Hydrogeology
  - D Groundwater
  - E Land and Water Use
- Volume 4 - Supporting Reports III
  - F Remote Sensing
  - G Hydrologic Water Balance
  - H Miscellaneous

- Operation Manual of Observation Network
- Facility Inventory of Hydrologic Observation Project in the Batinah Coast
- Hydro-Meteorological Yearbook 1984

2. Background of the Project

The Government of the Sultanate of Oman requested technical cooperation to the Government of Japan for this project.

In response to the request, the Government of Japan, through its executing agency, the Japan International Cooperation Agency (JICA), agreed to undertake the Project and agreed on the Scope of Work in December 1981. The agreed duration of the Project was from March 1982 through March 1985, but in November 1983, the Project was extended one year until the end of March 1986.

3. Outline of the Survey

3.1 Objective of the Survey

The Project was conducted with a view to promoting water resources development in the Batinah-coast Region. The following works were carried out:

1. Hydrologic observation network was set up in the Project area.

2. Hydrologic and hydrogeologic surveys were carried out for the Project.

3. Hydrologic water balance in the Project area was estimated and the present water resources were evaluated.

4. Technology was transferred to Omani counterparts through the course of the survey and study.

3.2 Project Area

The Project area consists of the following five wadi basins (approx. 6,000 sq.km):

	Name of Wadi	Basin area (sq.km)
1.	Wadi Ahin	1,127.5
2.	Wadi Bani Ghafir	951.9
3.	Wadi Al-Fara'	1,546.8
4.	Wadi Bani Kharus	1,292.3
5.	Wadi Al-Ma'awail	1,029.8
Total basin area		5,948.3

The Project area is divided into four geomorphological areas as follows:

1.	Major Mountain	:	Basement rock, Hajar Super Group and Hawasina Super Group.
2.	Frontal Mountains	:	Semail Ophiolite
3.	Marginal Wadi Plain	:	Tertiary Limestone, Clastic Sediments
4.	Sand/Gravel Plain	:	Clastic Sediment

Fig. 1 shows the geomorphological classification and Fig. 2 for present land use in the project area. Summaries of each wadi basin are explained in Table 1.

Table 1 Summary of Wadi Basin

ITEMS \ WADI BASIN		Wadi Ahin	Wadi Bani Ghafir	Wadi Al-Fara'	Wadi Bani Kharus	Wadi Al-Ma'awil	Total
Drainage Area	(km^2)	1127.5	951.9	1,546.8	1,292.3	1,029.8	5,948.3
Mountenous Drainage Area	(Km^2)	7658.3	591.1	698.2	750.6	319.1	3,127.3
Sound/Gravel Plain Drainage Area	(Km^2)	359.2	360.8	848.6	541.7	710.7	2,821.0
Mean Annual Rainfall	mm/year MCM/year	106.3 (118.9)	132.0 (123.0)	121.0 (184.8)	141.0 (175.8)	102.6 (102.5)	121.1 (704.0)
" in Mountain Area	mm/year MCM/year	118.4 (90.5)	151.9 (98.7)	151.3 (127.3)	164.4 (138.5)	121.5 (51.8)	143.8 (506.8)
" in Sand/Gravel Plain	mm/year MCM/year	80.1 (28.3)	86.3 (24.3)	83.4 (56.5)	92.6 (37.3)	88.5 (50.8)	86.1 (197.2)
Annual Sunface Discharge to Sea (by HORN)	MCM/year	5.5	4.5	4.1	5.4	0.4	19.9
Groundwater Discharge to Sea	MCM/year	5.1	0.0	0.0	0.0	0.0	5.1
Groundwater Storage Change	MCM/year	+1.07	-0.23	-1.05	-0.41	-0.03	-0.65
Current Farm Area (Total)	(ha)	613	2,128	2,764	1,709	2,791	10,005
Current Farm Area (Mountain Area)	(ha)	73	298	1,084	269	701	2,425
Current Farm Area (Coastal Area)	(ha)	540	1,830	1,680	1,440	2,090	7,580
Estimated Water Use (TOTAL)	mm/year MCM/year	9.1 (10.3)	38.4 (36.6)	37.9 (58.7	23.2 (30.0	51.9 (53.4)	31.8 (189.1)
Estimated Water Use (Mountain Area)	mm/year MCM/year	1.9 (2.1)	9.2 (8.8)	21.5 33.2)	6.3 (8.1)	21.0 (21.6)	12.4 (73.9)
Estimated Water Use (Coastal Area)	mm/year MCM/year	7.2 (8.2)	29.2 (27.8)	16.4 (25.5)	16.9 (21.9)	30.9 (31.8)	19.4 (115.2)
Current Source of Irrigation Water in Mountain Area		Falaj	Falaj	Falaj	Falaj	Falaj	—
Current Source of Irrigation Water in Coastal Area		Pump-up	Pump-up	Pump-up	Pump-up	Pump-up	—
Newly Registered Farm	(ha)	1,240	1,540	2,970	1,700	2,620	10,070
Water Demand for New Farm *	MCM/year	21.0	26.1	50.3	28.8	44.4	170.6
Water Demand for Future Irrigation	mm/year MCM/year	27.8 (31.3)	65.9 (62.7)	70.5 (109)	45.5 58.8)	95.0 (97.8)	60.5 (359.7)

Note: *Unit Water Consumption 2258 mm/year, cropping ratio 75%

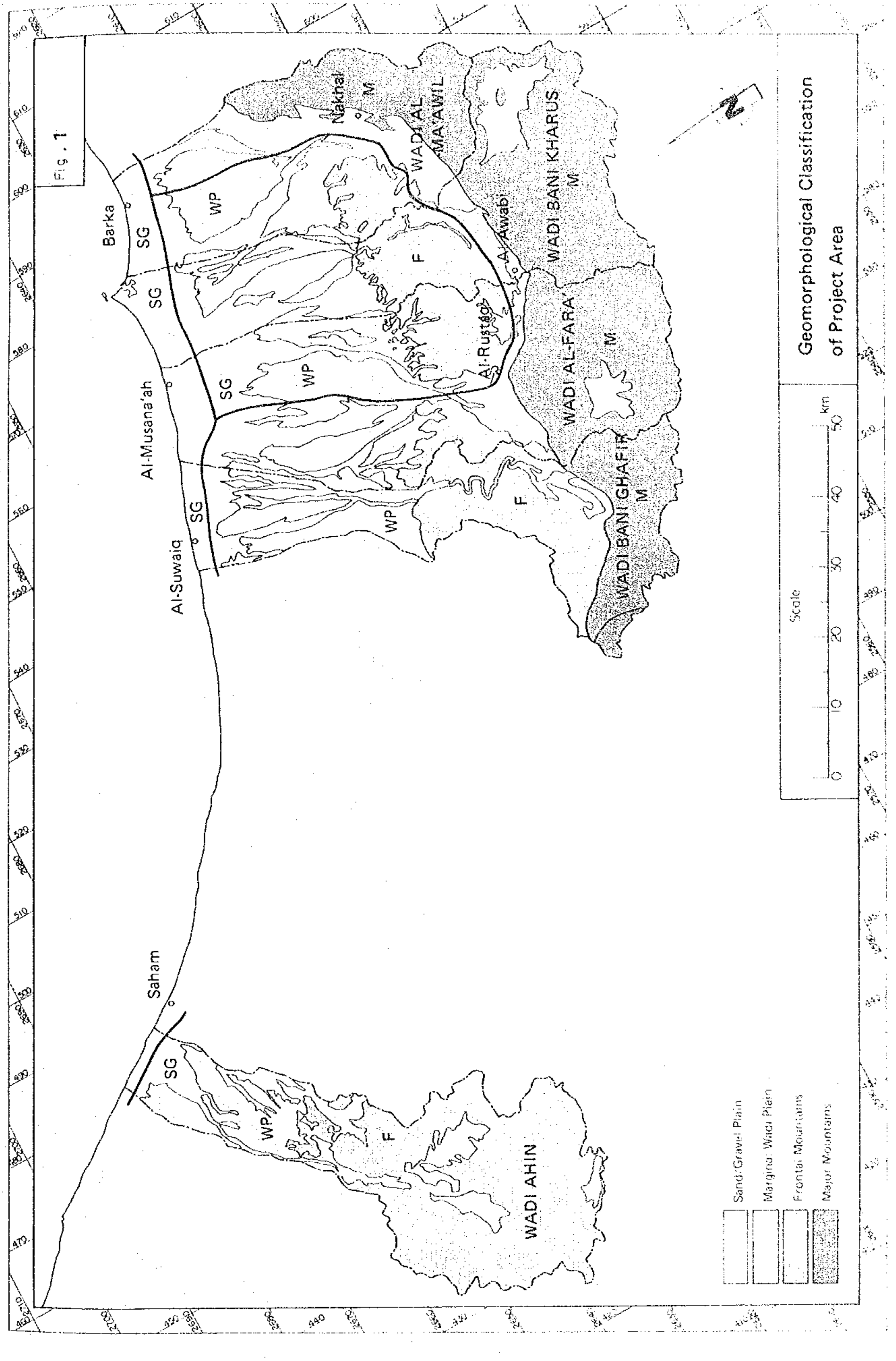
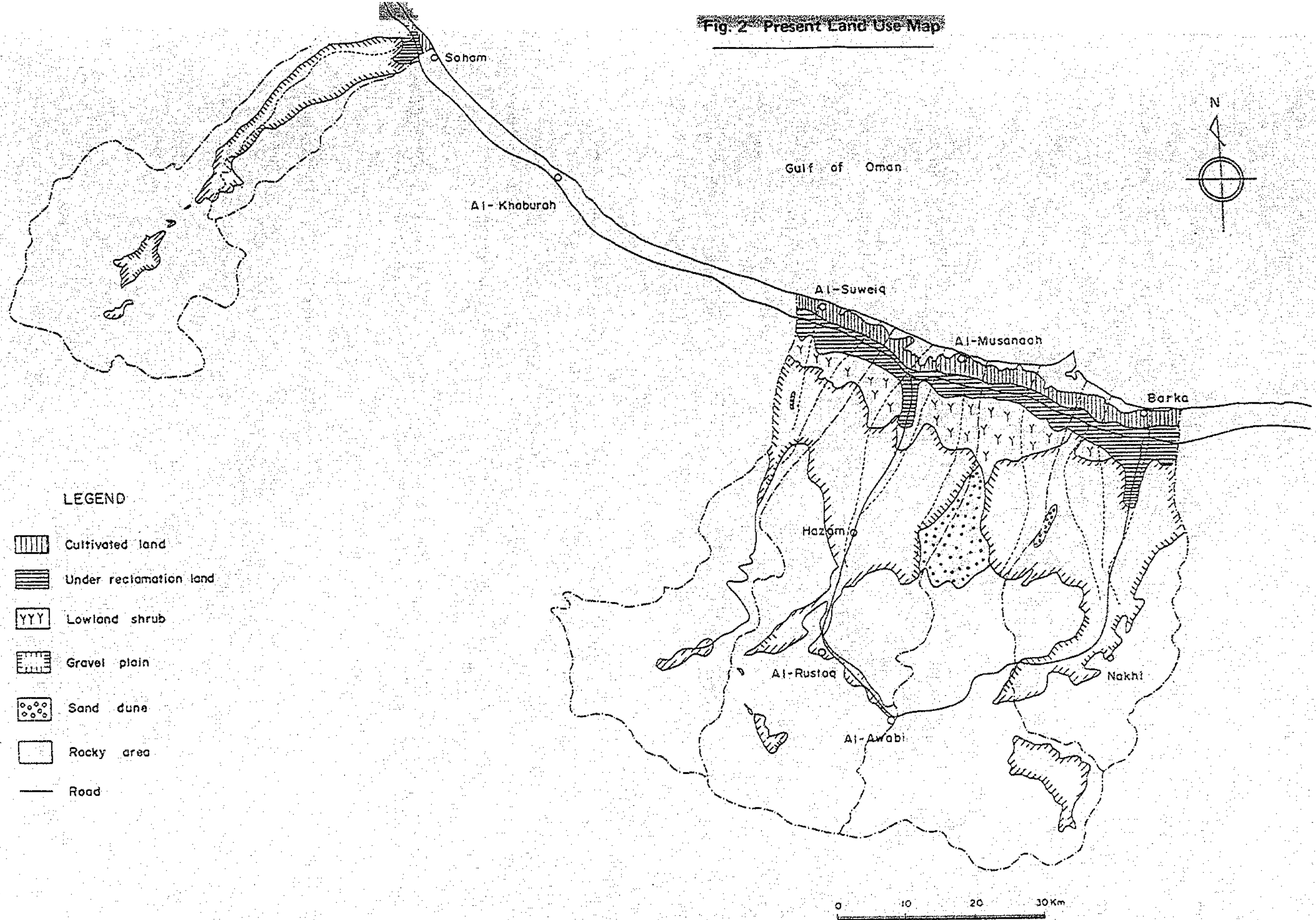


Fig. 1 Geomorphological Classification of Project Area

Fig. 2 Present Land Use Map



3.3 Progress of the Survey

The Project was commenced in March 1982. During the first year, basic survey for formulation of the implementation program for the Project and preparation for installation of observation networks were carried out. Construction and installation of observation networks were started in December 1983 and completed in February 1984.

The observation was primarily started in March 1984, but partially in May 1983. In parallel with the observation, hydrological, hydrogeological and water/land use surveys were carried out.

3.4 Arrangement of Hydrological Observation Network

The aim of the Project was to build overall hydrologic observation networks for promoting water resources development in the Batinah Coast.

Arrangements of meteorological stations, rain gauges and wadi gauges were attached more importance than that of well observation network because of the insufficiency or lack of the latter.

For the groundwater observation network, MAF's observation network was reinforced in places.

In order to estimate the amount of water use in the Project area, Aflaj and production wells in farms were included in the network.

The hydrologic observation network set up shown in Table 2, Figs. 3 and 4.

(1) Agro-meteorological Station:

One new agro-meteorological station was established at Al-Muladdah and the observation equipment in the existing meteorological station at Al-Rustaq was reinforced.

Evaporation and evapotranspiration from the ground are large factors in the hydrological water balance of a semi-arid zone. For regular observation concerning these factors, a new agro-meteorological station was established at Al-Muladdah and additional instruments were installed at the meteorological station (MAF) at Al-Rustaq.

(2) Rain Observation Network

Twenty eight (28) automatic rain gauges were installed. Prior to the Project, there were twelve (12) rain gauges in and around the Project area and daily rainfall data were available at only nine (9) stations located mainly on the marginal wadi plain and in the coastal area. In the major mountains, there is only one station at Saiq (about 2,000M a.s.l) which is located outside the Project area.

In order to grasp hydrological characteristics of each zone in the Project area, twenty eight (28) automatic rain gauges (seventeen (17) in the mountains and eleven (11) in the gravel plain) were installed. The density of rain gauges is approximately 1/200 sq.km.

Since surface run-off of arid zones depends heavily on the rainfall intensity, rain gauges are utilized to record the amount of rainfall once in every 15 minutes.

(3) Surface Runoff Observation Network

Sixteen (16) wadi gauges and three (3) radio flowmeters were installed. Previously, nine (9) wadi gauges were installed by Gibb and ILACO during their water resources study (1974 - 1975), however, their wadi gauges all stopped functioning before 1981, damaged or washed away by flash floods.

The sixteen (16) wadi gauges to obtain quantitative hydrological data of floods were installed at the following zones of each wadi:

Zone	Nos. of Wadi Gauges	Nos. of Radio Flowmeters
At the outlet valley zone of Major Mountains in the upper reach of wadi.	4	-
Between Frontal Mountains and Marginal Wadi Plain	5	3
At the coastal strip zone	7	-

A float type waterlevel recorder was installed at each gauge. The waterlevel recorder is the same type as the former gauge. A radio flowmeter with an automatic switch was installed for measuring the surface velocity of floods at each of the three concrete tower-type wadi gauges.

(4) Groundwater Observation Network

The major aquifer of the Batinah coast is located in the coastal plain. In order to observe aquifer behavior a groundwater observation network was built to cover the area of 2700 Km^2. Prior to this project, many observation wells had been drilled by the preceding projects: ILACO (1975) and Gibb (1976). However, many of these wells were already so deteriorated that they could not perform scientific observation. The deterioration was caused by materials dumped inside the wells. The observation wells drilled by Gibb and ILACO were transferred to MAF. Of the total, forty-one (41) wells were selected for this project; however, twelve (12) wells had to be cleaned out. In addition, twelve (12) new wells at eight sites were drilled.

There are two routine observations of the groundwater level; manual measurement and automatic recording.

Automatic recording started in January, 1984, at 14 wells by A.OTT R-16 type recorders. There are six more recorders already installed by the previous project in the project area. So all together, twenty (20) recorders were in action.

(5) Water Use Observation Network

In order to clarify the actual water use situation in the Project area, the following gauges/meters were installed:

Staff gauges were installed for periouıcal observation in six (6) selected aflaj for monitoring water intake in the aflaj systems.

Twenty (20) cumulative flowmeters were installed at pumps for checking the amount of discharge once or twice a month at sixteen (16) selected sample farms.

The rountine observation items for falaj flow survey are: reading the water depth of falaj by staff gauges, measuring the velocity of falaj stream by current meter, water temperature and electric conductivity.

The routine observation items for pumpting stations are: reading cumulative flowmeter, water temperature and measuring electric conductivity.

3.5 Field Survey

Further information regarding hydrogeological characteristics and groundwater recharge was collected in parallel with the observation, electric protecting survey, pumping tests and hydro-chemical analysis (four cations, four anions, stable isotope: oxygen-18, Deuterium, Tritium). A land use survey was carried out for grasping the actual irrigation area.

In order to evaluate the surface conditions of the Project area, remote sensing data from the earth satellites (NOAA and LANDSAT) were studied due to the large project area of 6,000 sq.km. short survey period and relatively inaccessible geography.

3.6 Technical Transfer

To promote the expansion of hydrologic observation in Oman, on-the-job training was carried out through the hydrological observation and field surveys.

To continue accurate observation and good maintenance by Omani staff, Operation Manual and Facility Inventory of Observation Network were prepared. As an example of data compilation, a Hydro-Meteorological yearbook (1984) was also compiled hydrological data including groundwater data observed prior to the Project.

Table 2 List of Observation Facilities

Observation Facility	Nos. of Sites			Nos installed by JICA			Remarks
	Total	MAF	JICA	1982/83	1983/84	1984/85	
• Agro-meteorological Station, Al-Muladdah	1	-	1	1	-	-	Observation house (96m^2) Automatic meteorological observation system
• Meteorological Station, Al-Rustaq	1	-	1	1	-	-	Reinforcement of instrumentation
• Rain-gauge	28*	(12)**	28	25	-	3	Automatic rain gauge
• Wadi Gauge	16	-	16	2	14	-	Concrete tower type: 3 sites Steel pipe type : 13 sites Radio flow-meter: 3 sites
• Observation Well							- Drilled well: 12 wells
- Well for water level gauging	46	41	5	-	4	1	- Cleaned well: 12 wells
- Well for salinization monitoring	3	-	3	-	3	-	- Water level recorder: 14 wells
• Water use							
- Cumulative flow meter for pumping Staff-gauge for falaj.discharge	20	-	20	20	-	-	Coastal area
- Falaj.observation sites by staff-gauge	6	-	6	6	-	-	Mountain area

Note: * included in Al-Muladdah Agro-meteorological Station

** not included in the observation network of the Project.

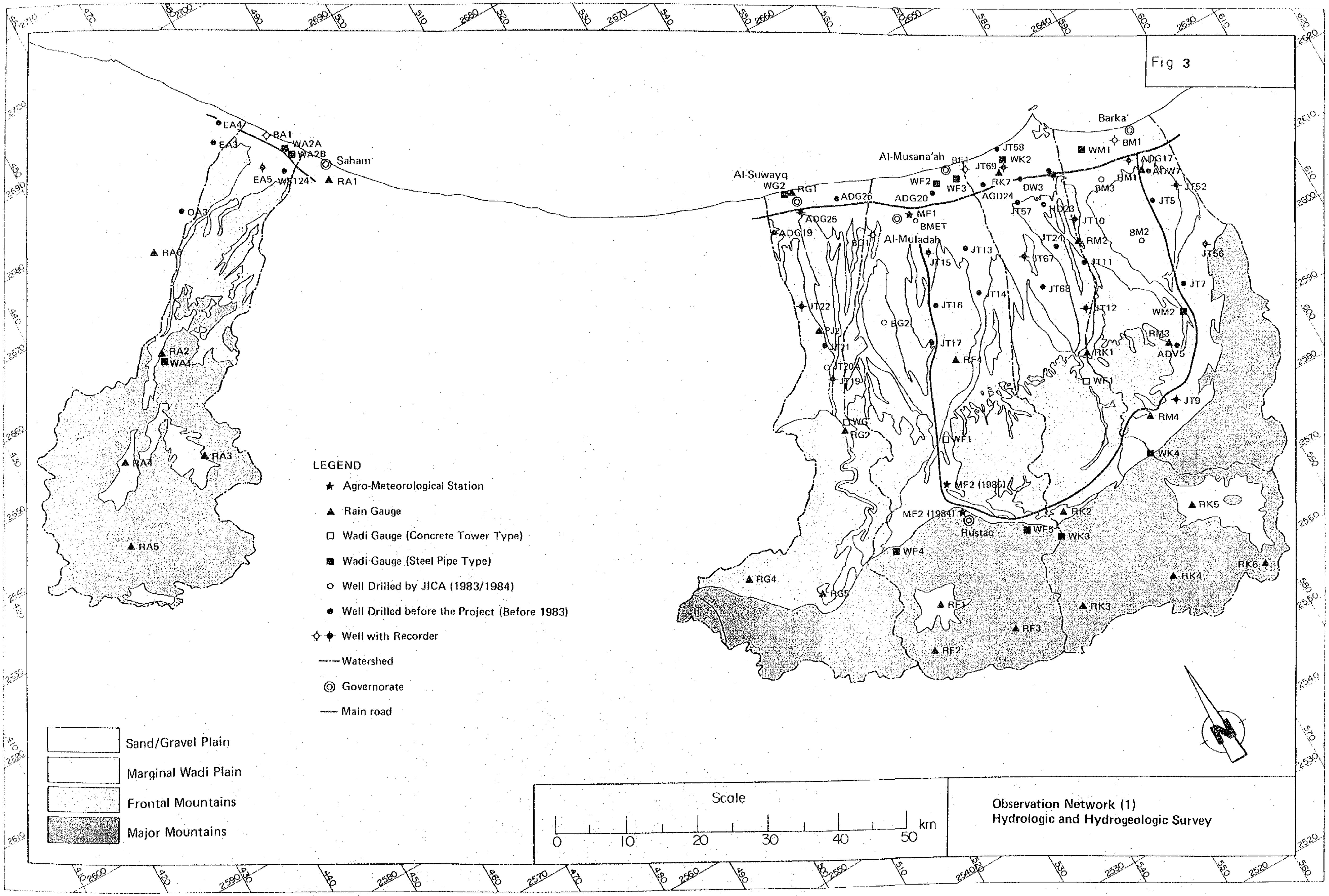


Fig 3
Saham
Al-Suwayq
Al-Musana'ah
Barka'
Al-Muladah
Rustaq
LEGEND
Agro-Meteorological Station
Rain Gauge
Wadi Gauge (Concrete Tower Type)
Wadi Gauge (Steel Pipe Type)
Well Drilled by JICA (1983/1984)
Well Drilled before the Project (Before 1983)
Well with Recorder
Watershed
Governorate
Main road
Sand/Gravel Plain
Marginal Wadi Plain
Frontal Mountains
Major Mountains
Scale
0 10 20 30 40 50 km
Observation Network (1)
Hydrologic and Hydrogeologic Survey

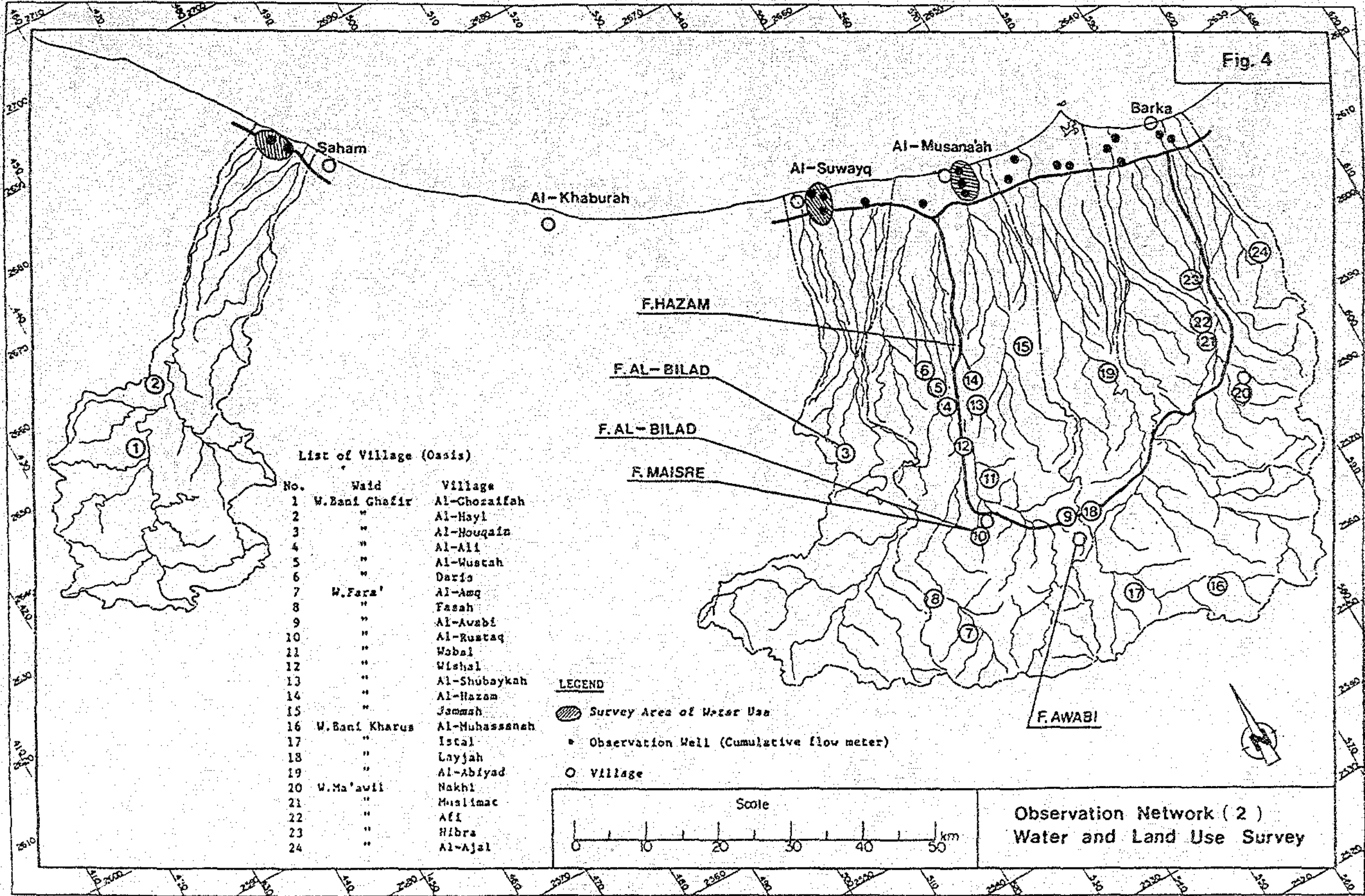


Fig. 4
Barka
Al-Musana'ah
Al-Suwayq
Al-Khaburah
Saham
F.HAZAM
F.AL-BILAD
F.AL-BILAD
F.MAISRE
F.AWABI
List of Village (Oasis)
No. Waid Village
1 W.Bani Ghafir Al-Ghozaifah
2 " Al-Hayl
3 " Al-Houqain
4 " Al-Ali
5 " Al-Wustah
6 " Daris
7 W.Fara' Al-Amq
8 " Fasah
9 " Al-Awabi
10 " Al-Rustaq
11 " Wabal
12 " Wishal
13 " Al-Shubaykah
14 " Al-Hazam
15 " Jammah
16 W.Bani Kharus Al-Muhassanah
17 " Istal
18 " Layjah
19 " Al-Abiyad
20 W.Ma'awil Nakhl
21 " Muslimat
22 " Afi
23 " Hibra
24 " Al-Ajal
LEGEND
Survey Area of Water Use
Observation Well (Cumulative flow meter)
Village
Scale
0 10 20 30 40 50 km
Observation Network (2)
Water and Land Use Survey

4. Survey Results

Villagers depend on Aflaj in the mountain area and wells in the coastal area for water. The aflaj discharge amount and the actual water use at the coastal area in the last two years was estimated as follows:

Aflaj discharge and actual water use

(Unit: MCM/Year)

Area	1983/83	1984/85
Coastal	108.2	115.2
Mountains	169.5	73.9

The area of farms was estimated as 10,005 ha (mountain area: 2,425 ha, coastal area: 7580 ha) based on air photographs (MAF 1981).

Since 1981, new farm lands have been increasing in the area along the National road of the Batinah coast. (Fig. 2)

The data collected from Ministry of Housing shows that people were given permission for new development of farm land totalling 10,070 ha from 1981 to 1984.

Since 1976, DGWRI of MAF has been conducting groundwater level monitoring through approximately 60 bore holes in the Batinah coast. The data consists of both monthly manual measurements and automatic recordings.

In addition to these data, the Project has contributed its own observation for 1984.

The change of groundwater storage was estimated based on the groundwater level data from 1976 to 1984 as follows:

Estimated Average Annual Change of Groundwater Storage Volumes

	Change (MCM/Year)	Data Period
W. Ahin	1.07	1984
W. B. Ghafir	-0.23	1976 - 1984
W. Al-Fara'	-1.05	1976 - 1984
W. B. Kharus	-0.41	1976 - 1984
W. Al-Ma'awil	-0.33	1976 - 1984

Regarding groundwater salinity, the EC value distribution map from 1976 (Gibb) and 1983 (MAF) shows the increase in EC values in Abu Abali and Al-Suwadi areas. (Fig. 5)

The current water requirement in the mountain area was not surveyed. The minimum water requirement in the mountain area was estimated as 73.9 MCM/year which is the discharge level of aflaj just before the falaj keepers reported the water shortages in the spring of 1984.

It is likely that the falaj discharge amount is far over the minimum water demand of the mountain areas in ordinary years.

The annual average water use was estimated as 112 MCM/year. However the survey results of sixteen sample farms showed that half of the sample farms were over drafting the groundwater by two to three times larger amount than their required amount. Management of wells belongs to individuals in the coastal area, however in the mountain areas, traditional falaj systems are used for water management.

Both in the Coastal and in the mountain area, some existing farms have been deserted. In the coast, the reasons obtained by questionnaires stressed salinity problems, cyclone damage, lack of manpower, low crop productivities, and lack of funds for renewal of pumping facilities. The reason for the desertion in the mountain area is inferred to be decline of irrigation water supply and/or preference for urban life.

The rainfall observations of MAF in and around the project area are summarized in Table 3 and Fig. 6, and daily rainfall recorded from rainfall observation network by the project are summarized in Fig. 7.

The data suggest widely fluctuating rainfalls.

Characteristic features of rainfall at the Batinah coast are summarized as follows:

There are two periods of rainfall: Summer and winter rainfalls. Summer and winter rainfalls are assumed to occur during June to September and October to May, respectively. The rainfall amounts increase by the altitude and during summer season, rainfall is unlikely below 170 Meter above sea level. As the result of analysis, the following three types of rainfall were identified:

1. Rainfall caused by synoptic scale disturbance

   Those rainfalls occur mainly in winter. The front, extending from the cyclone and moving easterly, brings rain over wide area, both in the mountain and in the gravel plain.

2. Rainfall caused by sea breeze

   The sea breeze transports humid air from the Gulf of Oman to the Hajar Mountain. Then the humid air mass rises and changes to cumulus or cumulonimbus clouds, which cause intense and short rainfall over a narrow area in the mountain.

3. Rainfall caused by tropical cyclone

   Tropical cyclones, develop at the Indian Ocean or the Arabian Sea and move westerly with heavy rainfall. It is reported that few tropical cyclones attack the Batinah Coast. Tropical cyclone with rainfall more than 10 mm at Muscat comes once in about 50 years (Renardet Sauti ICE).

The annual rainfalls in the project area were estimated as follows:

Rainfall in the Project Area

(Unit: mm/Year)

Year	1976	1977	1978	1979	1980	1981	1982	1983	1984	Average
Rain-fall		174	82	101	59	95	288	140	28	121

Note: Supporting Report B.4

Floods were observed eight times (WF1 : 2, WF4 : 1, WG1 : 1, WA1 : 2, WM2 : 1 and WK1 : 1) during the observation period from Sept. 1983 to Aug. 1985.

The flood waters were of small scale and disappeared before reaching the gravel plain.

During the observation period, no data was able to be produced to show the relation between rainfall and runoff. This should be clarified by further observation.

From recent flood records, flood waters which originated in the mountain area were lost due to infiltration before reaching the gravel plain. The floods in the coastal area were most often caused by winter rain.

Data of flood outflow into the sea were estimated by ILACO (1975)/Gibb (1976) based on their survey data of short period and by Horn (1979)/Cardew (1980) based on previous survey data. Their findings are shown in Table 4.

The major aquifer of the Project area is located in the coastal plain. Proceeding projects for water resources development in Northern Oman presented a hydrogeological concept dividing the study area into two distinctive zones differentiated by the properties of the dominant geologic formation in each locality: Hard Rock Zone and Soft Rock Zone (Gibb, 1976).

The two hydrogeological zones introduced above are grouped into four geomorphological zones by the Project: Major Mountains and Frontal Mountains are of Hard Rock Zone, and Marginal Wadi Plain and Sand/Gravel Plain are of Soft Rock Zone.

The following two rechard zones are suggested by the survey:

1. The upper recharge zone cannot be definitely determined, at the present survey level, although the Hajar limestone zone and/or the foothill Tertiary limestone belt fringing the ophiolitic Frontal Mountain are the most probable sites.

2. The lower recharge zone is inferred to be in the belt where Sand/Gravel Plain changes facies from coarse deposit to fine alluvial deposit.

The result of tritium content analysis also suggests infiltration zones: one in the foothill or inland and the other in the coastal alluvial plan.

Tritium is a radio-active hydrogen isotope naturally produced by cosmic rays. The thermo-nuclear experiments in the atmosphere in 1950s and 1960s dramatically increased the artificial tritium level in the natural environment. Any natural water of less than 1 T.U. is regarded as aged water originated from the rain prior to 1950s.

In Wadi Ahin in the west, coastal well waters contrast outstandingly with each other in their tritium level. The west bank wells contain more than 5 T.U., but adjacent wells on the east bank have a zero level although they are located nearby, approx. 1 km, and are very similar in ionic composition.

In the eastern coastal area, higher tritium contents are not always located near the major wadi beds. Instead they tend to appear at the terminal points of inter-wadi basins. The majority of coastal wells have zero level of tritium content.

These points suggests that there are some groundwater replenishments in the coastal strip but they are neither frequent nor significant. Most of the flood water may just be discharged into the sea or be evaporated even when located inland of the coastal farming zone.

According to the data of groundwater temperature, there is a clear-cut distribution of thermal characteristics: the coastal wells have comparatively wide temperature range with a steep thermal lapse rate (approx. 40°C per 100 m), but the mid and upper plain wells have narrow range and seem to have homogeneous thermal condition.

However, the proper vertical distribution of ground temperature due to the different locations of each well is not present. Hence, the steep thermal gradient should not be regarded as an actual geothermal lapse rate. Instead it may be governed by the groundwater flow, which transport water and heat to the coast, and can be understood better in terms of distance from the coast. However, the sudden change in the thermal tendency at the mid-plain wells may have resulted from the regional up-welling of deep-born groundwater of homogeneous temperature.

EC values reflect the ionic concentration and eventually the salinity of water. Fig. 8 presents an interesting tendency in which EC does not simply increase toward the coast. Instead, the minimum values are found in the mid-plain. The mid-plain may bear a hydrogeologic structure which still has not been probed in detail. The structure may be responsible for the depressed water tables, the geothermal anomalies and the zones of low EC.

Regarding the hydrologic water balance, the data for studying the relationship between rainfalls and runoffs were not obtainable since the survey period (from 1983 to 1985) had the most drought during the last 9 years.

The hydrologic water balance was tentatively estimated and is shown in Table 5. Characteristic features of the hydrologic water balance in the survey area are summarized as follows:

1. Groundwater storage over the southern 4 wadi basins (Wadi Bani Ghafir, Wadi Al-Fara', Wadi Bani Kharus and Wadi Al-Ma'awail) is estimated decreasing during 9 years from 1976 to 1984. Also the groundwater discharge to the sea is surveyed as zero.

2. Groundwater storage in Wadi Ahin is not found out because of lack of groundwater level data. But the groundwater discharge to the sea is estimated 5.1 MCM/year.

3. The surface water discharge to the sea is estimated in a range of 1 to 3 % against the annual mean rainfall through the previous studies.

Table 3 Summary of Rainfall Data Observed by MAF (1974–1984)

(unit: mm)

Site	Elevation (m)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Saham	5	7.3 (11.5)	22.2 (27.8)	22.2 (38.9)	1.3 (3.6)	4.3 (14.4)	0.0 (-)	0.0 (-)	0.1 (0.2)	0.1 (0.3)	2.7 (8.9)	0.9 (2.9)	14.6 (30.2)	69.7 (51.2)
Sohar	20	9.3 (20.5)	44.7 (48.3)	14.7 (22.3)	13.3 (19.3)	1.8 (4.1)	0.0 (-)	0.3 (1.1)	0.6 (1.9)	0.4 (1.5)	4.3 (11.0)	3.2 (6.8)	8.8 (17.5)	101.4 (82.6)
Al-Ghozaifah	480	5.9 (9.5)	32.9 (36.2)	14.6 (26.8)	13.5 (24.9)	5.7 (8.1)	2.4 (7.5)	1.8 (3.2)	11.6 (16.0)	4.8 (12.1)	5.4 (8.6)	2.0 (5.6)	2.9 (6.3)	103.5 (73.5)
Al-Qufais	600	9.1 (12.7)	33.5 (40.5)	28.6 (59.9)	11.9 (25.0)	5.2 (9.1)	5.9 (10.4)	6.4 (10.5)	10.5 (16.0)	8.7 (16.0)	1.8 (5.0)	1.0 (3.2)	2.9 (8.8)	121.2 (102.8)
Haibi	570	8.3 (16.6)	44.2 (51.0)	19.3 (30.0)	10.5 (19.6)	6.7 (9.3)	6.7 (13.7)	10.1 (14.3)	11.2 (22.5)	9.1 (12.3)	13.9 (18.1)	2.2 (4.8)	0.9 (2.6)	134.9 (88.7)
Al-Houqain	225	12.2 (18.8)	30.0 (41.8)	12.6 (18.3)	14.6 (28.2)	7.5 (19.4)	0.9 (3.0)	2.9 (6.5)	2.1 (4.0)	1.4 (4.5)	16.7 (29.3)	13.9 (30.8)	19.9 (26.1)	132.4 (101.7)
Al-Rustaq	350	11.5 (15.4)	25.9 (35.5)	25.0 (37.9)	16.8 (18.9)	5.7 (10.3)	4.8 (14.2)	6.5 (11.9)	13.4 (25.7)	4.4 (5.9)	31.3 (30.3)	10.9 (16.2)	7.9 (13.9)	158.5 (105.2)
Afi	170	13.1 (14.2)	41.8 (50.7)	19.1 (24.5)	10.8 (16.5)	3.3 (9.9)	3.8 (10.3)	3.3 (6.7)	1.8 (3.4)	1.9 (4.4)	7.6 (16.8)	5.2 (13.0)	8.4 (12.3)	118.7 (88.0)
Al-Rumais	15	4.4 (9.4)	27.7 (31.0)	11.0 (20.5)	9.7 (16.6)	5.1 (16.9)	1.2 (3.6)	0.0 (-)	0.0 (-)	0.0 (-)	1.7 (4.5)	3.4 (8.0)	9.1 (17.1)	73.0 (66.0)
Saiq	2000	19.4 (23.1)	53.2 (77.6)	44.3 (49.1)	43.1 (63.8)	27.1 (31.1)	17.7 (14.4)	40.3 (43.0)	55.1 (42.2)	14.7 (11.2)	7.1 (8.9)	2.6 (3.9)	8.5 (17.1)	333.1 (146.9)

upper row: monthly mean rainfall
lower row: (standard deviation)

Table 4 Estimated Flood Discharge to the Sea for the Median Year

(Unit = MCM/year)

Reorters	Wadi Ahin	Wadi B. Ghafir	Wadi Al-Fara'	Wadi B. Kharus	Wadi Al-Ma'awil	Total
ILACO 1/	2.58	-	-	-	-	2.58
GIBB 2/	-	21.2	13.9	27.7	7.0	69.8
HORN 3/	5.5	4.5	4.1	5.4	0.4	19.9
CARDEW 4/	4.8	3.8	3.6	10.9	0.3	23.4

Note: 1/ ILACO JUL. 1975
"WATER RESOURCES DEVELOPMENT PROJECT NORTHERN OMAN"

2/ SIR ALEXANDER GIBB AND PARTINERS JUNE 1976
"WATER RESOURCES SURVEY OF NORTHERN OMAN"

3/ P.M. HORN-F.A.O. FEB. 1979
"WATER RESOURCES OF THE BATINAH"

4/ PRECCE CARDEW AND RIDER/SIR M MACDONALD AND PARTNERS SEP. 1980
"POWER AND URBAN WATER SUPPLY STUDY: PHASE II, WATER DEVELOPMENT PROGRAME"

Table 5 Hydrologic Cycle in the Survey Area

Unit: upper; MCM/year
lower; (%)

Wadi Basin	Wadi Ahin	Wadi Bani Ghafir	Wadi Al-Fara'	Wadi Bani Kharus	Wadi Al-Ma'awil	Total
Rainfall P	118.9 (100.0)	123.0 (100.0)	183.8 (100.0)	175.8 (100.0)	102.5 (100.0)	704.0 (100.0)
Water Use * W	10.0 (8.4)	37.9 (30.8)	56.3 (30.6)	29.8 (17.0)	50.5 (49.3)	184.5 (26.2)
Groundwater ΔG Storage Change	+1.07 (+0.9)	-0.23 (-0.2)	-1.05 (-0.6)	-0.41 (-0.2)	-0.03 (-0.03)	-0.65 (-0.09)
Surface Water D discharge to sea	5.5 (4.6)	4.5 (3.7)	4.1 (2.2)	5.4 (3.1)	0.4 (0.4)	19.9 (2.8)
Groundwater I discharge to sea	5.1 (4.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Remainder **	97.23 (81.8)	80.83 (65.7)	124.45 (67.7)	141.01 (80.2)	51.63 (50.4)	495.15 (70.3)

Note:

* Unit water consumption for the water use calculation:
Upper stream (Mountain area) ; 3000 mm/year
Lower stream (Coastal area) ; 2258 mm/year

** Remainder contains terms such as natural evapotranspiration from wadi basin, groundwater to/from alien basin and sea water into subsurface water.

Schematic Diagram of Hydrologic Water Balance Terms

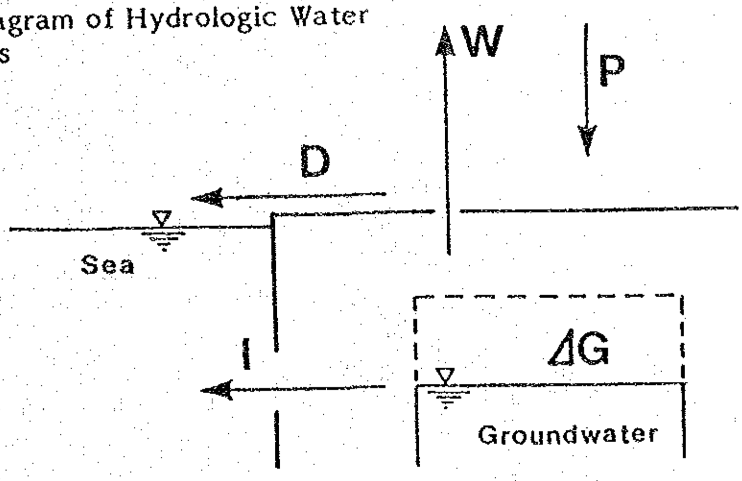


Fig. 5 Distribution of EC Change (ΔL) between 1975 and 1983 in the Shallow Wells
(ΔL = L 1983 - L 1975)

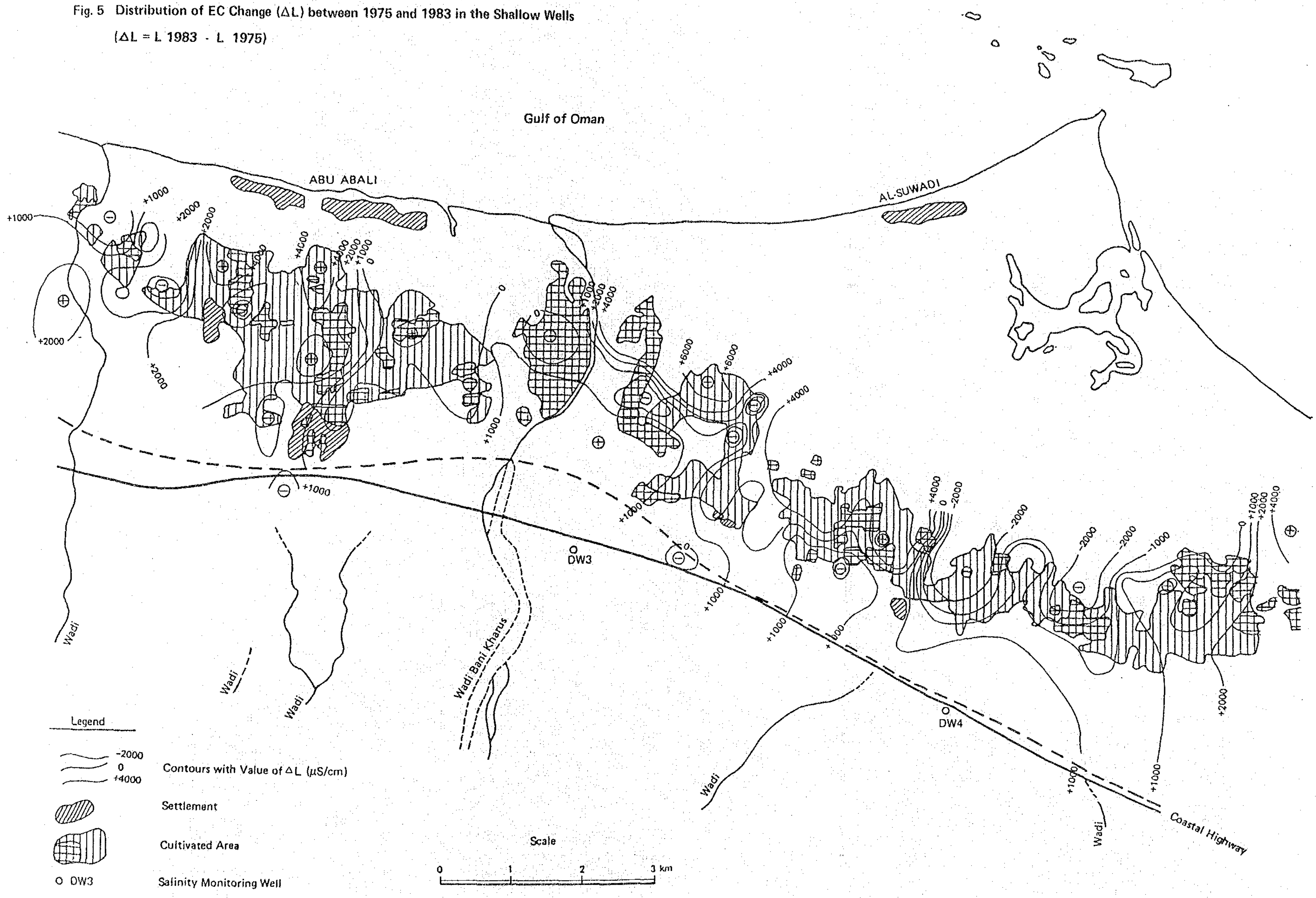
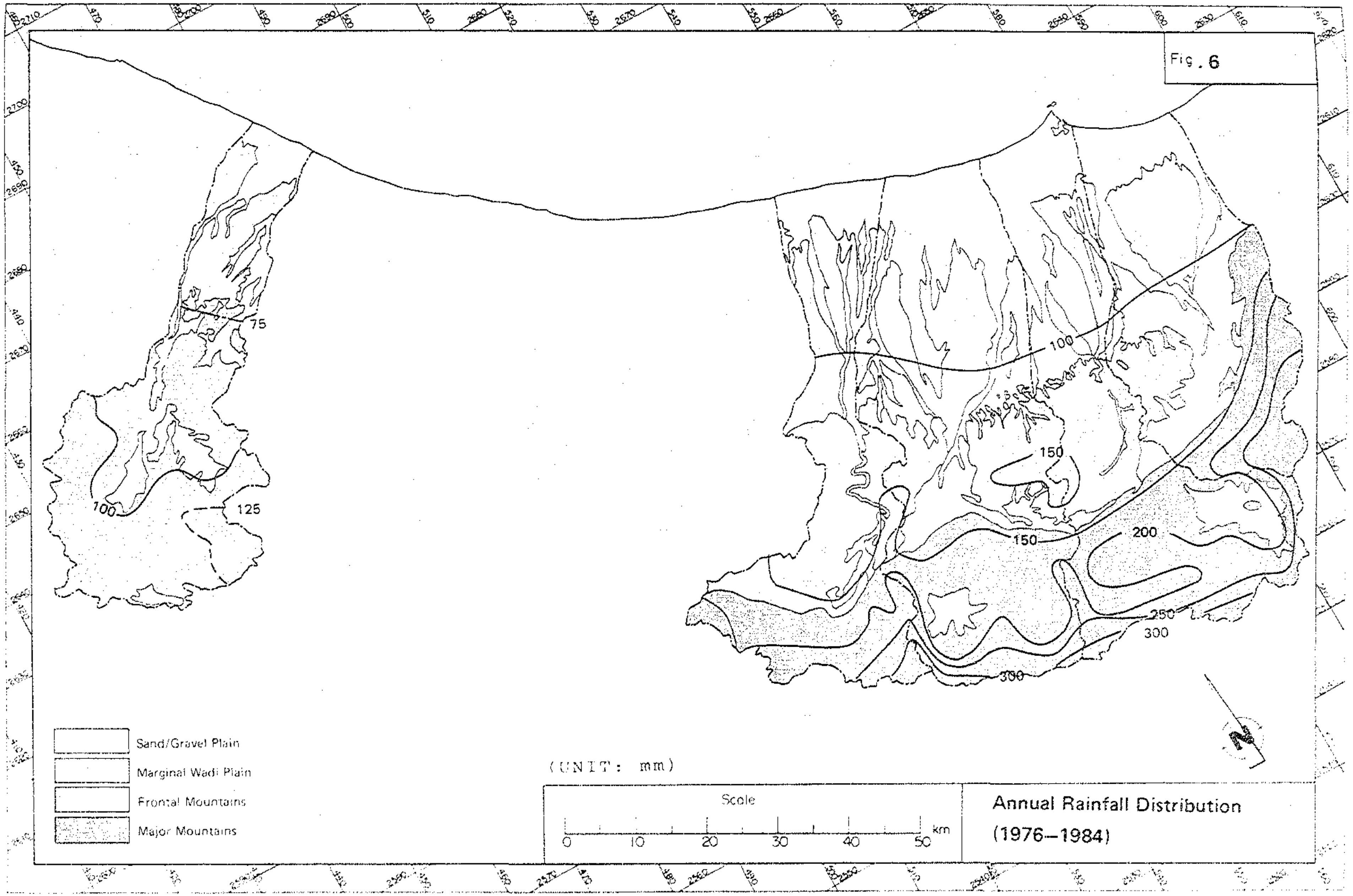
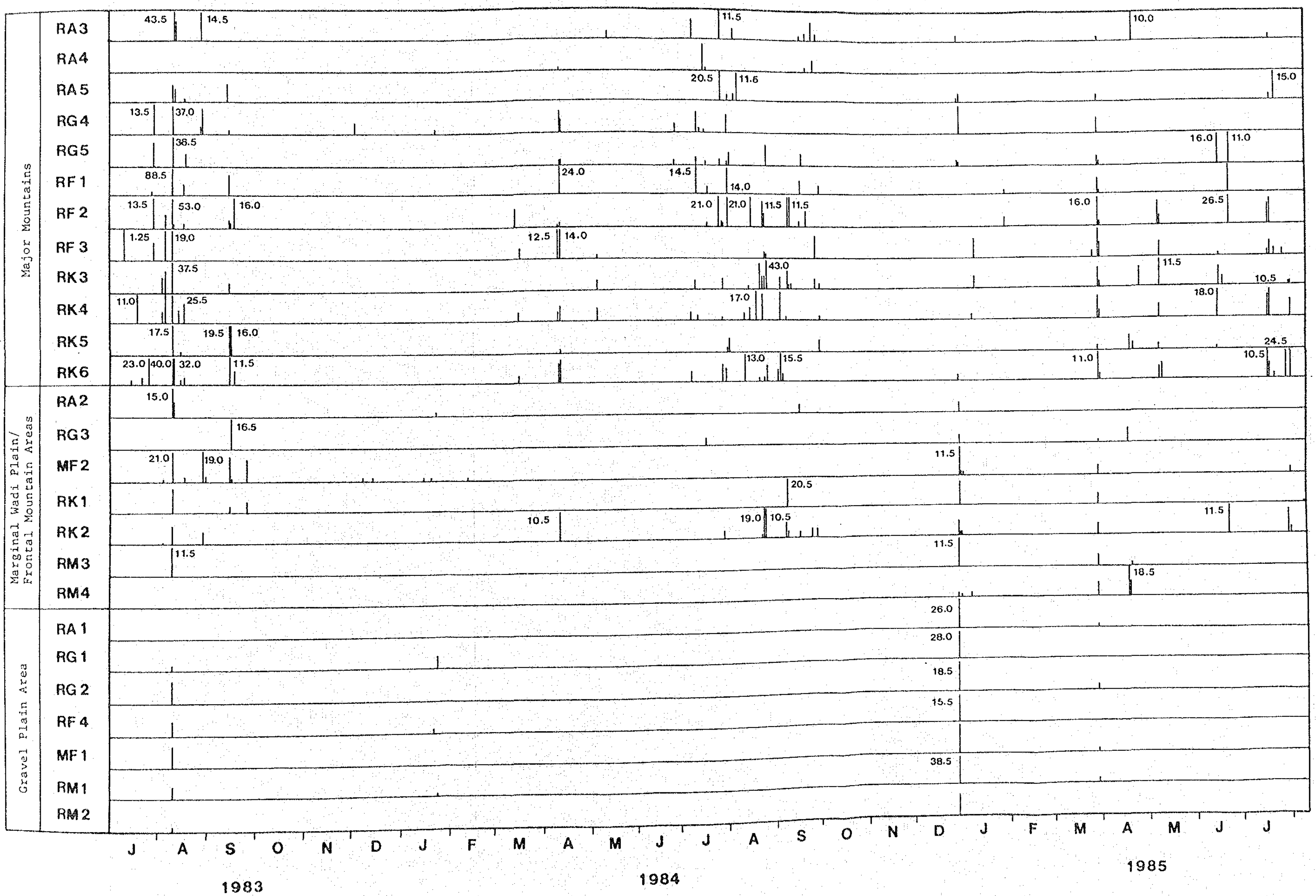


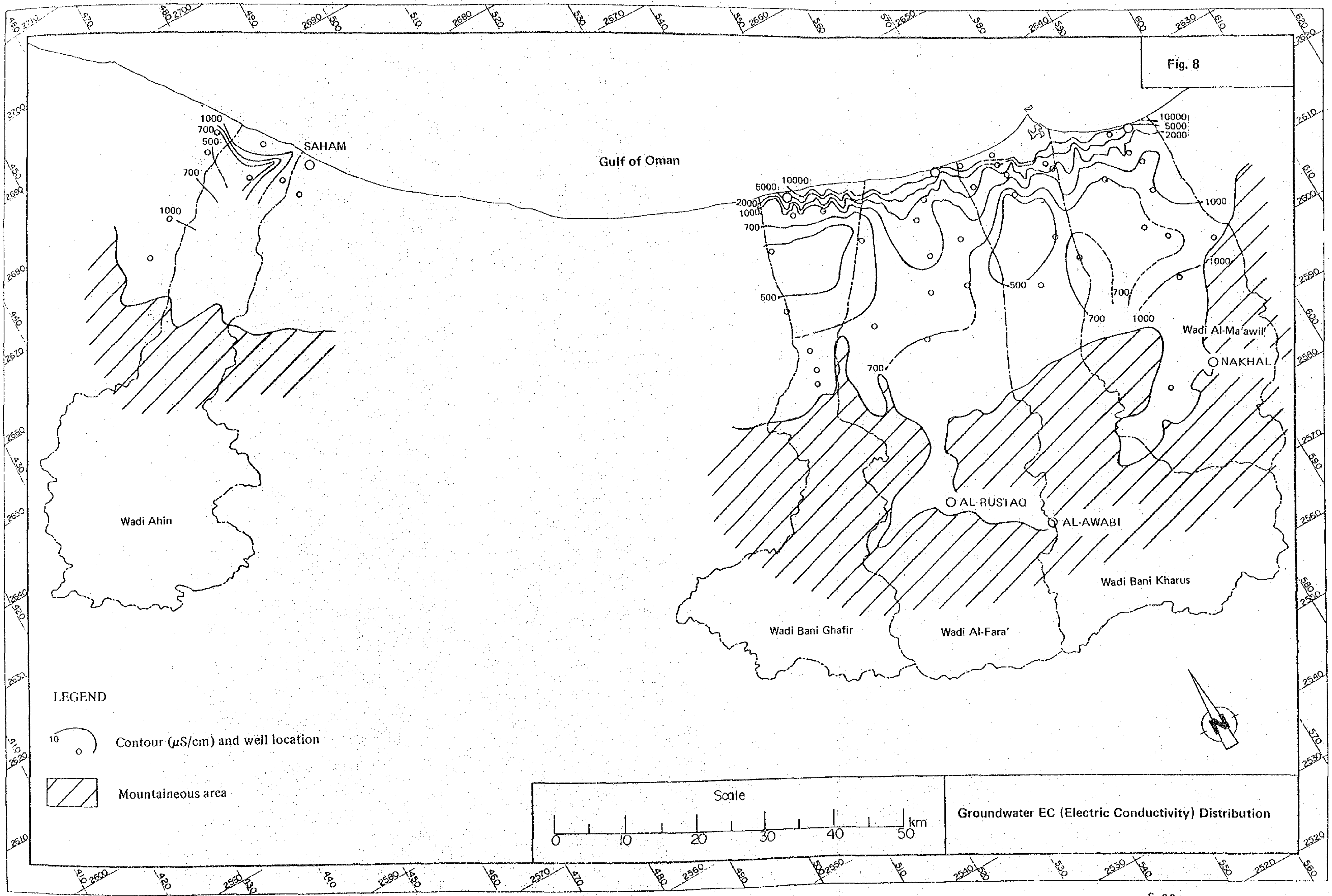
Fig. 6



Annual Rainfall Distribution (1976–1984)

Fig. 7 Daily Rainfall Time Series





Groundwater EC (Electric Conductivity) Distribution

5. Conclusion and Recommendations

5.1 Conclusion

Reclamation of new farm land is increasing in the Batinah coast area. It is remarkable that the continuation of the current progress rate of water use will cause the development of salinity problems in the coastal area.

The four wadi basins: W.B. Ghafir, W. Al-Fara', W.B. Kharus and W. Al-Ma'awail, are not supposed to have further development potential in groundwater, considering the deficit balance of groundwater storage during nine years (from 1976 to 1984), and the increase in EC values in some coastal areas.

For increasing groundwater resources in the Batinah coast, it is recommended to make effective use of flood water which flow into the sea, using dam-type structures which will recharge the flood water into the wadi alluvium and increase the groundwater resources.

The location of recharging structures should be planned based on the results of runoff analysis and hydrogeological surveys.

In order to cope with the regional scarcity of water resources and the development of salinity problems, it is indispensable to economize water use for irrigation, in line with develop the surface water runoff to the sea into recharging water for goundwater.

Before implementation of any water resources development scheme, it is indispensable to evaluate the technical and economic feasibility of it. For evaluating a project, new agricultural census should be prepared in line with continuation of hydrologic observation.

5.2 Recommendation

Based on the conclusions, it is recommended for the Government of Oman to under take the followings:

1. Continuation of hydrologic observation and improvement of hydrological observation networks

2. Execution of water resources development scheme

3. Groundwater conservation and rationalization of water use

The items and flow for further studies are summarized in Fig. 9.

5.2.1 Continuation of Hydrologic Observation and Improvement of Hydrological Observation Networks

For future water resources development and groundwater conservation, it is indispensable to continue of perform hydrological observation. Since hydrological conditions fluctuate yearly, 10 years are the minimum conventional planning term adopted widely for formulating a dependable water resources development scheme. For carrying out the proper observations, the following recommendations are made:

(1) To increase necessary staff and to strengthen the organization for the observation and maintenance of the hydrologic observation network.

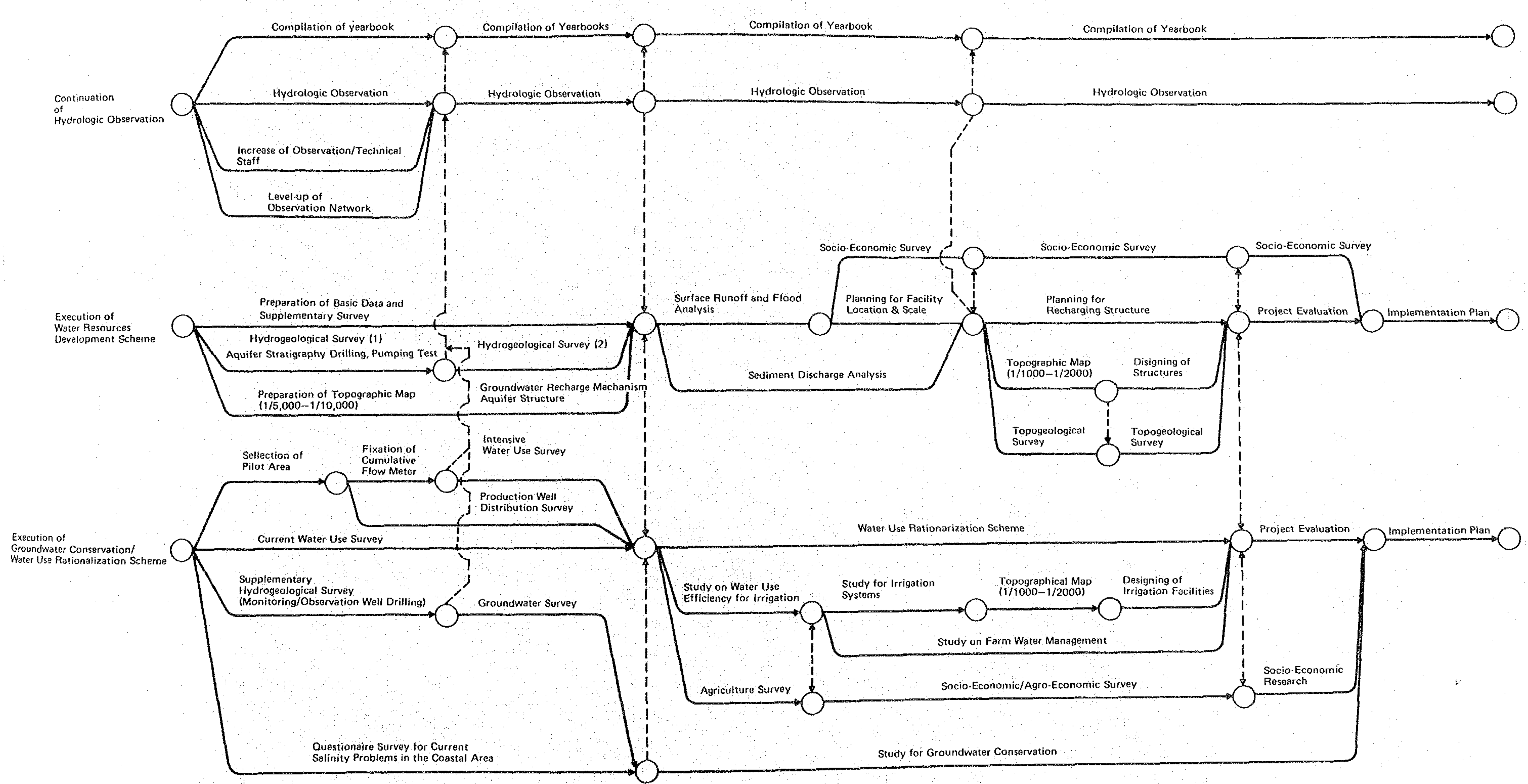
(2) To have the staff follow the observation and maintenance manual properly.

(3) To continue on-the-job training for the staff to improve their observation skills and to expand their scientific knowledge for the hydrological observation.

(4) To compile yearbooks of hydrological data to keep data properly and to contribute not only to the development of water resources but also other fields.

(5) To raise the level of observation networks for conservation of water resources at the coastal area and rationalization of water use.

Fig. 9 Flow Chart for Further Studies



5.2.2 Execution of Water Resources Development Scheme

Before starting a water resources development scheme, it is necessary to prepare basic data such as hydrological data of a long-term including numbers of floods, supplementary hydrogeological data (hydraulic properties of aquifer) and topographic map (1/5,000 - 1/10,000).

In order to promote a water resources development scheme at each wadi basin, the following recommendations are made:

(1) To analyse flood outflow and to study the scale and location of water resources development scheme.

(2) To carry out sediment discharge survey

Judging from topographic and land cover conditions, a large sediment discharge is presumed to occur during large floods. Therefore, the potential of sediment discharge should be studied.

(3) To carry out the study for water resources development schemes which includes the following:

1. Basic survey for recharging scheme structure plan
2. Project evaluation
3. Implementation program

5.2.3 Groundwater Conservation and Rationalization of Water Use

It is an urgent task to formulate effective use of the existing water resources to cope with the increasing demand for irrigation water and the salinity problems in the coastal area.

Rationalization of water use should be carried out for stopping the increase of salinity problems and economizing the current agricultural water use.

For domonstration of feasibility, establishment of farm practices and management practices, it is recommended to undertake pilot schemes on selected areas.

For execution of water conservation and rationalization of water use, the following recommendations are made:

(1) To carry out more intensive water use survey

1) To select the pilot scheme area and improve the observation network.

2) To carry out the survey for drawing up well location map (1/5,000 - 1/10,000)

3) To install cumulative flow meters to pumps (approx. 10% of the total number) sampled in pilot scheme areas, and to carry out water use survey (irrigation area, used amount and quality of water).

4) To carry out the questionnaire survey for current salinity problems in the coastal area.

(2) To carry out water use rationalization scheme

1) To study on water use efficiency

For rationalization of water use, it is necessary to improve current irrigation methods in order to minimize loss in the system or to introduce more efficient and more productive irrigation methods such as localized system, which will enable production of vegetables plus tree-crops, as major crops.

Before introducing any improvement or different irrigation methods, both technical and socio-economic considerations should be assessed based on the quality and quantity of the basic resources: water, land, labour investment capital and their inter-relationship with the desired level of agricultural production.

2) To study on farm water management for application of rationalized water use.

In the coastal area, management of wells belongs to individuals, however in the mountain area, management of a falaj system is usually done by a community (one village or a group of villagers).

For adjusting demand and supply of irrigation water and conserving water quality, a suitable collective or cooperative management system in parallel with an effective use of the water resources should be studied.

3) To carry out the study for rationalization of water use.

Based on the survey results, necessary improvement of irrigation system and facilities should be planned. For the purposes the following studies are required:

1. Irrigation survey and facility plan
2. Project evaluation
3. Implementation program

(3) To carry out the study for groundwater conservation

It is remarkable that the continuation of the current progress rate of water use will cause the development of salinity problems in the coastal area. It will be indispensable to establish the comprehensive water management. As the counterplans, the studies are to be carried out as follows:

1) To study the groundwater simulation model

2) To study the water management organization for the groundwater conservation

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MISCELLANEOUS

GLOSSARY AND ABBREVIATIONS

Arabic Glossary

Ain	Spring
Aflaj	Plural of Falaj
Athar	Time share on a falaj, approximately half-an-hour
Falaj	Water distribution system under or above ground
Jabal	Mountain
Qanat	A horizontal well transporting water from an aquifer by means of a tunnelled-allery
Sabkha	Salt-flat
Wadi	Valley or drainage channel in an arid region (normally dry)
Wali	Local Governor
Wilayah	Local Governorate
Wilayat	Plural of Wilayah

Abbreviation for Units and Terms

Measurements

Length

mm	Millimetre
cm	Centimetre
m	Metre
km	Kilometre

Area

sq.cm	Square Centimetre
sq.m	Square Metre(s)
sq.km	Square Kilometre
ha	Hectare
fd	Feddan = 0.42 ha
MSM	Million Square Metre

Volume

l	Litre
cu.m	Cubic Metre
MCM	Million Cubic Metre
bal	barrel = 31.5 gallon (U.S.) = 36 gallon (U.K.)
gal	gallon = 3.785 litre (U.S.) = 4.546 litre (U.K.)

Weight

mg	Milligram
g	Gram
kg	Kilogram
ton	Metric Ton

Others

s	Siemens = mho
El	Elevation above the mean sea level
sec	Second
min	Minute
hr	Hour
Min	Minimum
Max	Maximum
°C	Degree Centigrade
°F	Degree Fahrenheit
%	Percent
FY	Fiscal Year
a.	Annum = Year
mon	Month
G.D.P	Gross Domestic Product

Currency Conversion

R.O.	(Rial Omani)	1 R.O. = 2.90 U.S.$
U.S.$	(U.S. Dollar)	1 U.S.$ = 0.345 R.O.

Abbreviation of Organization Names

MAF	Ministry of Agriculture and Fisheries, Oman
DGWRI	Directorate General of Water Resources and Irrigation
DGA	Directorate General of Agriculture
DGF	Directorate General of Fisheries
MCI	Ministry of Commerce and Industry, Oman
MC	Ministry of Communications, Oman
DGCA	Directorate General of Civil Aviation
DGM	Directorate General of Meteorology
MD	Ministry of Defense, Oman
GSA	Government Survey Agency
MDA	Ministry of Diwan Affairs, Oman
MEY	Ministry of Education and Youth Affairs, Oman
MEW	Ministry of Electricity and Water, Oman
DGW	Directorate General of Water
DRW	Directorate of Rural Water Supply
MFA	Ministry of Foreign Affairs, Oman
MH	Ministry of Health, Oman
MINF	Ministry of Information, Oman
MI	Ministry of Interior, Oman
DTA	Directorate of Tribal Affairs
MJI	Ministry of Justice and AL-AWQAF & Islamic Affairs, Oman
MOH	Ministry of Housing
MNC	Ministry of National Heritage and Culture, Oman
MPM	Ministry of Petroleum and Minerals, Oman
MPT	Ministry of Posts, Telegraphs and Telephones, Oman
MSL	Ministry of Social Affairs and Labour, Oman
DC	Development Council, Oman
DGNS	Directorate General of National Statistics
PDO	Petroleum Development, Oman
PAWR	Public Authority for Water Resources, Oman
WRC	Water Resources Council, Oman
MFAJ	Ministry of Foreign Affairrs, Japan
MCJ	Ministry of Construction, Japan
MAFJ	Ministry of Agriculture, Forestry & Fisheries, Japan
JICA	Japan International Cooperation Agency
FAO	Food and Agriculture Organization, United Nations

WMO	World Meteorological Organization, United Nations
WHO	World Health Organization, United Nations
BKS	BKS Survey Limited
GIBB	Sir Alexander Gibb & Partners Consulting Engineers

CHAPTER 1. INTRODUCTION

CHAPTER 1 INTRODUCTION

1.1 Background of the Survey

The Sultanate of Oman is one of the oil producing countries in the Middle East, located at the South-eastern corner of the Arabian Peninsula. Oman occupies an area of about 300,000 sq. km with the population of 1.5 million as estimated for Government planning.

Oil was discovered in Oman in the 1960s and exports began in 1967. Beginning in 1970, a concentrated effort was begun to economically develop the country. Since then Oman achieved rapid economic growth due to increased oil revenues. In 1975, the Development Council introduced the five-year plan strategy. Oman started the First Five-Year Plan in 1976, and The Second Five-Year Plan in 1981. During the five-year plans, emphasis was placed on diversifying the economy away from heavy dependency on oil, however, the economic structure of Oman is still heavily dependent on oil. The share of oil revenue in the Government revenue (1,561 million R.O.) in 1984 is still as high as 70% (1,100 million R.O.) of the total.

Oman depends for most of its food on import. For food self-sufficiency Oman's agriculture is looked upon to play a key role in production and foreign exchange. The emphases are placed on agricultural development and water resources development.

The Project area is located near the Capital area and contains one-fourth of the agricultural land of Oman (Approx. 40,000 hectares), and is one of the most important agricultural centers. However, with the progress of Agricultural development, problems of salinity in groundwater have become evident.

It is said that demand for water are already exceeding the natural water balance. The several studies, regarding water resources development were carried out since 1974, but are bottlenecked due to lack of sufficient basic data in the hydrological field.

Based on this background, the Government of Sultanate Oman made a request to the Government of Japan to carry out a hydrologic observation project for future water resources development in the Batinah coast.

In compliance with the request the government of Japan agreed to carry out the project through the Japan International Cooperation (JICA). JICA dispatched a preliminary survey team, and agreed to the Scope of work in Dec. 1982. The duration of the project agreed was from March 1982 through March 1985, however in November 1983 it was extended one year until the end of March 1986.

1.2 Objectives of the Survey

The Project was conducted with a view to promoting water resources development in the Batinah-coast Region. The following works were carried out:

1 Setting up an hydrologic observation network in the Project area.

2 Carrying out both hydrologic and hydrogeologic surveys required for the Project.

3 Carrying out estimation of the hydrologic balance in the Project area and to evaluating the present water resources.

4 Transfering technology to the Omani counterparts through the course of the survey and study.

The Project Area consists of the following five wadi basins (approx. 6,000 sq. km):

Name of Wadi	Basin area (sq. km)
Wadi Ahin	1,127.5
Wadi Bani Ghafir	951.9
Wadi Al-Fara'	1,546.8
Wadi Bani Kharus	1,292.3
Wadi Al-Ma'awil	1,029.8
Total basin area	5,948.3

1.3 Scope of the Survey

The Project was commenced in March 1982, and will finish in March 1986. For fulfilling the objectives, the Project consists of following three stages:

1 Basic Survey

This survey is the first phase of the Project, where the basic approach were formulated after the basic field survey (from March 1982 to June 1982)

2 Field Survey

This stage comprised of two phases as follows:

- The hydrologic observation network was set up by the end of Feb. 1984.
- Intensive field works and studies, which consisted of hydrologic, hydrogeologic and water/land use surveys, were carried out.

3 Data process and analysis

- Data which were collected and observed were analyzed and the hydrologic balance and water resources developing potential were estimated.
- In order to get land-cover information over the entire area, earth satellite remote sensing data (LANDSAT/NOAA) were employed.

1.4 Composition of the Reports

The result of the survey is compiled as "Hydrologic Observation Project in the Batinah Coast of Sultanate of Oman" which consists of the following volumes:

- Volume 1 - Main Report
- Volume 2 - Supporting Report I

  A Surface Geology and Fluvial Morphology

  B Meteorology and Hydrology

- Volume 3 - Supporting Report II
    - C Hydrogeology
    - D Groundwater
    - E Land and Water Use
- Volume 4 - Supporting Report III
    - F Remote Sensing
    - G Hydrologic Water Balance
    - H Miscellaneous
- Operation Manual of Observation Network
- Facility Inventory of Hydrologic Observation Project in the Batinah Coast
- Hydro-Meteorological Yearbook 1984

CHAPTER 2. BACKGROUND

CHAPTER 2 BACKGROUND

2.1 Natural Conditions

2.1.1 Geography

The Sultanate of Oman is situated at the south-eastern corner of the Arabian Peninsula, with the coastline stretching for over 1,600 km, facing the Arabian Sea and the Gulf of Oman.

The Sultanate of Oman is located between latitudes 16°37'N and 26°30'N and longitudes 51°50'E and 59°40'E. It is bounded in the north-east by the United Arab Emirates, in the south-west by the Kingdom of Saudi Arabia and in the south-west by the People's Democratic Republic of Yemen.

The Hajar mountains provide the backbone of Northern Oman extending some 700 km from the Musandam Peninsula to the cape of Rasal Hadd running in a northwest-southeast direction, reaching a hight of 2980 m at Al Jabal Akhdar (green mountain).

The Batinah coast is a general term for the long coastal plain, varing from 10 to 60 km in width, stretch north-west at Muscat towards the Musandam Peninsula for about 270 km.

It consists of the following four geomorphological area:

1. Major Mountains
2. Frontal Mountains
3. Marginal Wadi Plain
4. Sand/Gravel Plain

In the four wadi basins in the Southern Batinah coast, the major mountains stand surounding the frontal mountains. The marginal wadi plain and sand/gravel plain are manifold alluvial fans formed by Wadi which are dissecting the Major and Frontal mountains. There are sand dunes and sabkha along the coast. Agricultural land and residential area are limited to the coastal strip of approx. 5 km width. The mountain area is the source of water such as shallow groundwater, springs or surface water.

2.1.2 Climate

The climate of the Project area is classified as semi-arid. The major mountain area is a main cause which brings rainfall in the area.

The climate is divided into two seasons: summer (from June to September) and winter (from October to May).

The rainfall amounts increase with the altitude in both seasons and the area below the altitude of 170 m above sea level has no rain in summer.

The rainfall in the Project area is classified into three types as follows:

1. Rainfall in winter mainly caused by the synoptic scale disturbance
2. Rainfall in summer caused by the sea breeze
3. Rainfall caused by a tropical cyclone

Annual rainfall of 150 - 400 mm is expected in the mountains*, but less than 100 mm in the coastal area. The average annual basin rainfall was calculated as 121 mm during the last 8 years (from 1977 to 1984)

The range of annual rainfall amounts is very wide. Heavy rainfall is very rare. According to the rainfall record at Muscat during the last 100 years, the amount of annual rainfalls varied between 10 mm and 300 mm.

Note: * Only source of mountain rainfall is at Saiq (southern slopes) giving an average of 350 mm/year at an altitude 2000 M above the sea.

2.2 Socio-Economic Background

2.2.1 Population

The Government estimates the total population at about 1,500,000. On the other hand, in a report of the United Nations, the population is estimated as 950,000 (1982) with an average growth rate of 3.15 % per annum. One-third of the total population are concentrated in the Capital and the Batinah coast areas.

One of the characteristics of population composition is the large number of expatriate manpower. It is reported that the expatriate employees in the Government numbered 20,639 which was 40% of the Government employees in 1982. Expatriate workers in the private sectors totalled 186,821. The total number of expatriate workers in 1982 were 207,460 (22%) of the total population of 950,000.

2.2.2 Economy

Rapid economic development in Oman began in 1970 when the Sultan Qaboos came to power. The economy before 1970 was dependent on the primitive agriculture and fisheries which were by far the most undeveloped in the Arab world. The existing infrastructure was small.

The sequence of economic development after 1970 is as follows:

(1) 1970 - 1975

This period is characterized as the period of preparation for future economic growth. The primary focus of early development efforts were construction of infrastructures such as ports, airports, roads, power stations, etc. While agriculture was not completely ignored in this process, it drew less attention, funds and activity than the most other sectors of the economy.

During this period, Gross Domestic Product (GDP) grew from 125.1 million R.O. in 1971 to 724.2 million R.O. in 1975 at an average rate of 55% per annum.

(2) 1976 - 1980: The First Five-Year Plan

Based on the experience over the five years from 1970-1975, the Sultan Qaboos organized the Development Council in 1975, and launched the First Five Year Plan.

The main objectives were as follows:

1. To diversify the economy away from heavy dependency on oil into industries based on agriculture, fisheries, minerals and into manufacturing.
2. To shift investment from the public sector to the private sector.
3. To create a balanced distribution of employment opportunities by locating development projects near areas of population.

Regarding agriculture development, an effort was made to initiate a comprehensive development program for the period. However, only modest success was achieved.

During this period, GDP grew at a high rate of 23.6% per annum, due mainly to rapid increase in oil export revenue caused by the high prices of crude oil in 1979.

GDP grew to 1,820 million R.O in 1980. However, the share of oil sector to GDP and export revenue were increased to 68% and 95% respectively.

(3) 1981 - 1985: The Second Five-Year Plan

Based on the achievements of the First Five-Year Plan, emphases of the Second Five-Year Plan were placed on the following:

1. To continue to maintain a sound financial position.
2. To establish a state General Reserve Fund to be capitalized from a percentage of oil revenues.
3. To restrain potential inflationary pressures.
4. To accelerate the rate of economic growth to the extent that does not overstrain the manpower situation.

5. To increase crude oil production to 330,000 b/d and maintain the level of production throughout the five years.

6 To give a strong and stimulating push to the private sector engaged in productive activities in agriculture, fisheries, manufacturing, mining and handicrafts.

7. To expand the program of constructing low-cost housing particularly in the interior.

8. To expand, substantially, the network of vocational training centers as an essential base for developing local manpower.

9. To give top priority to water resources development projects, particularly for irrigation and agricultural purposes.

10. To achieve an average annual growth rate in GDP amounting to 13.1%.

Regarding agriculture, Oman's agriculture is looked upon to play a key role in providing employment, production, and foreign exchange in an economy which cannot depend on oil indefinitely.

During the present period, it will be determined whether agriculture can actually meet these expectations and how rapidly it can begin to produce such results.

2.3 Administration of Water Resources Development

2.3.1 Government

The administrative system of the state, under his Majesty the Sultan Qaboos, consists of the Cabinet of Ministers, State Consultative Council and specialized councils.

The water resources sector is supervised by the Ministries listed below:

1. Ministry of Environment and Water Resources*
2. Ministry of Agriculture and Fisheries
3. Ministry of Electricity and Water
4. Ministry of State and Wali of Dhofar
5. Musandam Development Committee

The policies and targets of the water resources sector are decided upon by the Water Resources Council which were set up by Royal Decree. The Council consists of the following members:

1. H.M. the Sultan as the President
2. Minister of Environment and Water Resources as the Vice-President
3. Minister of Communications as the Assistant Vice-President
4. Minister of Agriculture and Fisheries
5. Minister of Electricity and Water
6. Minister of Interior
7. Minister of Health
8. Minister of Housing
9. Minister of Commerce and Industry
10. Minister of Petroleum and Minerals
11. Minister of Regional Municipalities Affairs
12. Minister of State and Wali of Dhofar
13. President of Royal Court Affairs
14. The Secretary-General of the Council

The Public Authority for Water Resources was established by Royal Decree under the Chairmanship of the Minister of Electricity and Water.

Note: * The title of the Ministry of Environment was amended as the Ministry of Environment and Water Resources by the Royal Decree issued in Dec. 1985.