d) Installation of New Observation Gauge

The following gauges have been newly installed in the Wadi Jizzi basin by the Survey Team of the Project (see Figure 3-2).

Rain Gauge

In the Wadi Jizzi basin, there exist five rain guage stations in the mountain area but no records are available on the hourly rainfall. In the Project, five automatic rain gauges have been installed at the same places as above except Farfar Station, which was replaced by Khan Station in view of the maintenance.

Water Level Gauge

In the Wadi Jizzi basin, Mulayyinah is a suitable site for the measurement of discharge. Gauges No.1 and No.2 have been installed at Mulayyinah site for the purpose of obtaining highly accurate data. Gauges No.3 and No.4 have been installed to measure the amount of the waters wasted into the sea.

Groundwater Level Gauge

Six observation wells have been provided in the basin and automatic groundwater level gauges have been installed on the observation wells.

3.2.3. Geology

a) General Geology

Geologically, the Wadi Jizzi basin consists of the following members in ascending order; the Hawasina group of limestone and chert, the Semail ophiolite complex of alpine stage, the Hawasina mēlangē, the Neogene tertiary formation of mudstone and conglomerate,

FIGURE 3-3 GEOLOGICAL MAP OF WADI JIZZI BASIN

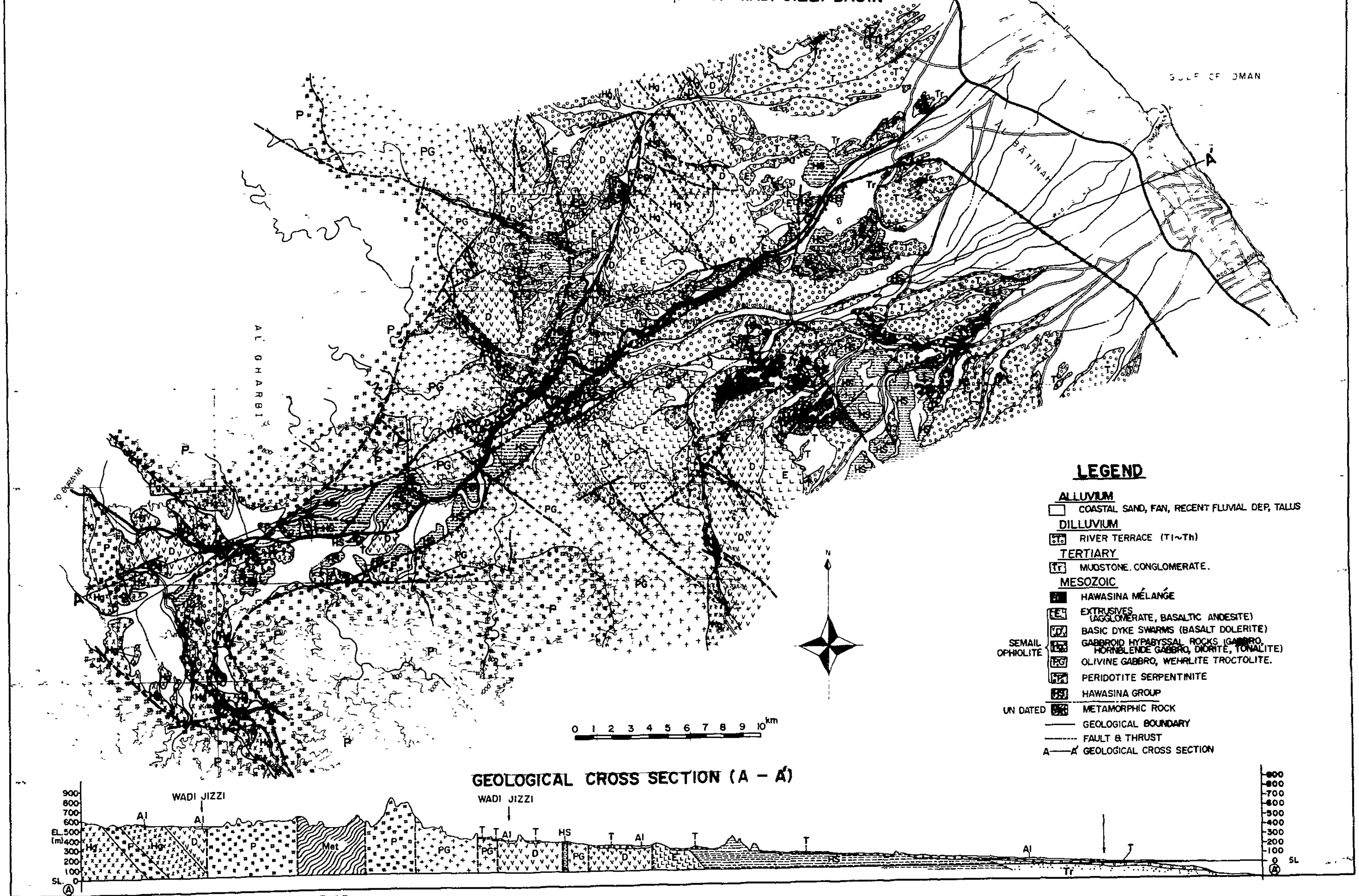


Table 3-2 Stratigraphic Succession of the Wadi Jizzi Basin

Age		Formation	Rock Facies	Remarks
Quaternary	Al	Alluvium dune, fan, talus deltaic fan	clay, silt, sand gravel	unconsolidated, widely distributing in the lower stream area
Quaternary	Dl	Dilluvium river terrace deposits	sand, gravel	widely distributing in the lower stream area, classified into 4 steps, consolidated except the lower one
Ter-tiary		Neogene Tertiary Formation	mudstone, conglomerate	in the lower stream area, small in scale
Mesozoic		Hawasina Mélangé	limestone, chert, blocks of basic rocks & schist	in the middle stream area, forming monadnocks
Mesozoic		Semail Ophiolite Complex	basalt lava, agglomerate, basic dykes, gabbroic hy-pabyssal rocks, wehrlite, peridotite	widely distributing in the middle to upper stream areas, zonally arranged from east to west, peridotite being the lowest horizon and the biggest body
Mesozoic		Hawasina Group	limestone, chert	elongated distribution in the middle to upper stream areas, siliceous and having many cracks, basement of the dam
Un-dated		Metamorphic	amphibolite	near Al Wasit, small in scale

- Effusive rocks situated at the uppermost horizon of the complex. They show various rock facies such as pillow lava, volcanic breccia, agglomerate and basalt lava, and are distributed in the middle stream area forming lower hills.

- Basic dyke swarms of basalt, dolerite, and diabase. They occupy the lower horizon of above-mentioned effusive rocks and crop out in the middle stream with N-S trending extension, and also along the Wadi Jizzi with the spotted distribution. This formation is topographically characterized by low-relief mountains and hills.

- Gabbroic hypabyssal rocks. The lower part of dyke swarms is graded into this formation and composed of uralite gabbro, hornblende gabbro, diorite, and tonalite. Topographically, they constitute basins on the upper streams and medium-relief mountains on the middle.

- Basic to ultrabasic rocks. They appear at the eastern side of the underlying peridotite, in five to eight kilometer width, forming high-relief mountains. Such rock facies as olivine gabbro, troctolite, and wehrlite are recognized.

- Peridotite. The rock body is widely distributed in the middle to upper reaches of the basin with N-S trending extent, and topographically characterized by strong-relief mountains. The rock is partly serpentinized.

iv) Hawasina Mélangē

The formation shows a narrow distribution along the Hawasina group on the middle stream of the Wadi Jizzi and topographically forms peculiarly low monadnocks. It is a mixture of limestone and chert of the Hawasina group with blocks of basalt, serpentinite, and biotite schist belonging to the Semail ophiolite complex.

v) Neogene Tertiary Formation

The formation is overlain by terrace deposits, and crops out in the lower stream area. The formation is small in scale and mostly consists of yellowish brown soft mudstone mixed with round pebbles. At the Wadi Yambu, tightly consolidated basal conglomerate is observed on the underlying chert bed.

vi) Dilluvium

The investigated area is widely covered with river terrace deposits, especially both at the upstream basins and the lowstream area. The river terrace deposits can be classified into four groups with respect to their relative altitude above river level; the lower terrace of zero to three meter in altitude, the middle terrace of five to 15 m, the upper terrace of 20 m, and the higher terrace of more than 30 m. Among these four terrace deposits, the upper terrace has the largest extent, and abutments of both river sides of the dam site are of these terrace deposits.

They commonly consist of sand and gravel, and are well cemented by calcareous matrix which seem to be a conglomerate, except the lower terrace. The lower part is harder than the upper.

vii) Alluvium

Sand dunes, taluses, fan, fluvial and coastal deposits belong to Alluvium, occupying most of the lower stream area. The largest one in scale is the fan deposits of the Wadi Jizzi, forming an extensive gravel plain. The constituent is mostly sand and gravel, and partly silt and clay.

b) Economic Geology

Cupriferous massive sulfite deposits embedded in the Semail ophiolite complex are the most important metallic resources in this area from the economic view point. These deposits are observed in the lower part of the pillow lava including effusive rocks of the ophiolite complex, and are considered to be the Cyprus-type. Three mines exist in the surveyed area i.e. Lasail, Aarja, and Bayda, and the biggest one, Lasail is about to be exploitated.

Chromite deposits are observed in ultrabasic rocks of the ophiolite complex, however, they are generally small in scale.

Gravel and pebble of the fan deposits are extensively quarried for construction purposes, especially for roads construction.

Clay in the fan deposits is used for the production of bricks.

3.3. Water Resources

3.3.1. Surface Water

A part of rainfall turns into surface run-off while the other infiltrates into the soils or the joints of rocks, and flows down by gravity to reach stream channels, and forms a base flow. Some parts of waters are lost through evaporation.

Many complicated factors affect the volume and the duration of the direct surface run-off (hereinafter referred to as "flood") and the base flow. Hourly rainfall and hydrograph are available only since 1981. During the survey period, hourly rainfall distribution and hydrograph at Mulayyinah and the river-mouth were recorded for three days from February 14, 1982. The multiple regression method was applied to analyze the relationship between the rainfall and the run-off analysis of frequency in the flood volume, and the peak discharge was made based on the rainfall data in due consideration of the limited flood data.

a) Base Flows

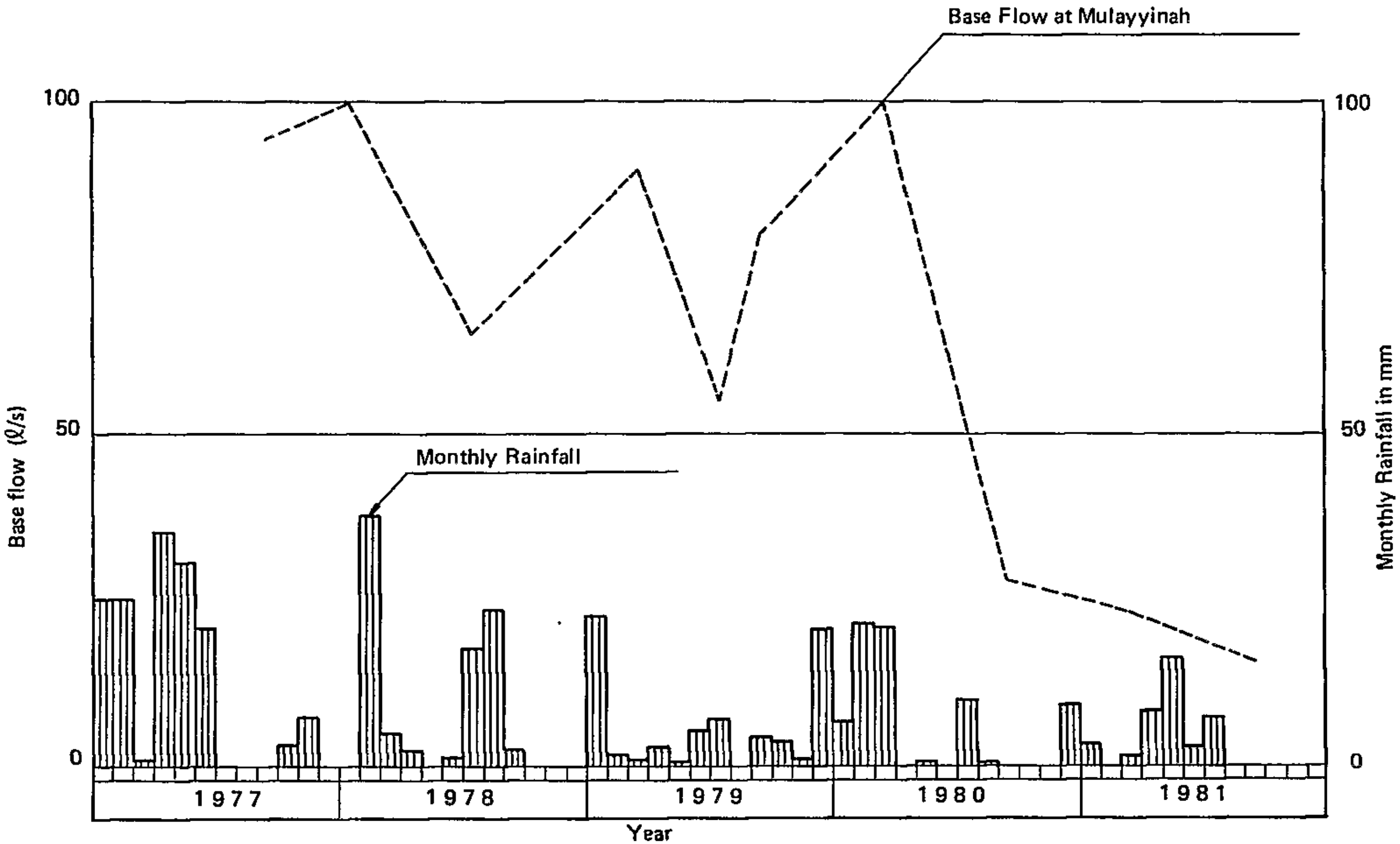
The surface water discharge has been measured by currentmeters since 1977 at Mulayyinah with a catchment area of 654 sq.km. The observed discharge records and the estimated base flow discharge are presented in Figure 3-4. The average base flow discharge is 67.2 lit/sec, which corresponds to 0.10 lit/sec/sq.km.

In order to grasp the total potential base flow discharge, the water used for the Falaj irrigation by the villages in the catchment area must be taken into consideration. The irrigated areas and the estimated Falaj discharges are provided in Table B-1, Appendix B-1. The average Falaj discharge in the catchment area is estimated at 78 lit/sec, which corresponds to 0.12 lit/sec/sq.km. The total potential base flow discharge, therefore, is 0.22 lit/sec/sq.km. The average specific base flow discharge per annum is 6.9 mm in depth. The ratio of the base flow discharge to the average annual rainfall was calculated at 5.3 percent.

b) Floods

Water level recorders were installed at Mulayyinah and the coastal road by the government in 1974/1975. Several records have

FIGURE 3-4 BASE FLOW AND MONTHLY RAINFALL



been obtained since then, but in most of the observation period, the recorders failed to work properly.

As previously stated, the records were obtained for the rainfall and the water level of the flood which occurred on February 14, 1982. The multiple regression method was applied to the flood hydrograph analysis. Appendix B-2 shows relations between the rainfall and the flood discharge in depth at Mulayyinah and the river mouth. The estimated flood discharges at the dam site and the river mouth are shown in Table 3-3 and 3-4. The average annual flood volumes at the dam site and the river mouth are 5.73 MCM and 2.51 MCM, respectively. The average specific flood flow discharge per annum is 7.1 mm in depth at the dam site. The average ratio of the flood flow discharge to the average annual rainfall was calculated at 5.4 percent. Consequently, the average ratio of the total surface run-off discharge to the annual rainfall is 10.7 percent.

The frequency of single flood volume derived from the multiple regression analysis is shown in Figure 3-5.

3.3.2. Groundwater

a) Hydrogeological Units

The Project Area consists of the following three hydrogeological units; the impervious formations, terrace deposits, and alluvial deposits.

1) Impervious Formations

The impervious formations consist of the Hawasina group, basic volcanic rocks, and tertiary sedimentary formations forming the main central ranges and their flanks in the upstream of the Wadi Jizzi.

Table 3-3 Flood Flow Runoff at Damsite (Catchment 812 km^2)

(Unit: MCM)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1974	-	1.91	-	-	-	-	-	-	-	-	-	-	1.91
1975	-	(0.28, 4.14) 4.42	-	-	-	-	-	0.16	-	-	-	-	4.58
1976	1.06	(2.72, 2.07, 6.98) 11.77	(0.85, 2.35, 8.00) 11.20	(3.25, 0.12) 3.37	-	-	-	(0.32, 0.16) 0.48	-	-	0.28	-	28.16
1977	0.61	0.89	-	2.68	2.07	(0.16, 0.12) 0.28	-	-	-	-	0.04	-	6.57
1978	-	2.35	-	-	-	-	-	0.28	-	-	-	-	2.63
1979	0.24	-	-	-	-	-	-	-	-	-	-	0.16	0.40
1980	-	0.16	0.73	-	-	-	-	-	-	-	-	-	0.90
1981	-	-	-	-	0.53	-	0.12	-	-	-	-	-	0.65
Mean													5.73

Note: The figures in parenthesis are single flood discharge.

Table 3-4 Runoff at the River-mouth (Catchment 1,283 Km^2)

(Unit: MCM)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1974	-	1.46	-	-	-	-	-	-	-	-	-	-	1.46
1975	-	1.74	-	-	-	-	-	-	-	-	-	-	1.74
1976	0.30	5.48	4.31	1.59	-	-	-	-	-	-	-	-	11.68
1977	0.66	0.56	-	1.41	0.79	-	-	-	-	-	-	-	3.42
1978	-	1.16	-	-	-	-	-	-	-	-	-	-	1.16
1979	0.04	-	-	-	-	-	-	-	-	-	-	0.27	0.31
1980	-	-	0.14	-	-	-	-	-	-	-	-	-	0.14
1981	-	-	-	-	0.14	-	-	-	-	-	-	-	0.14
Mean													2.51

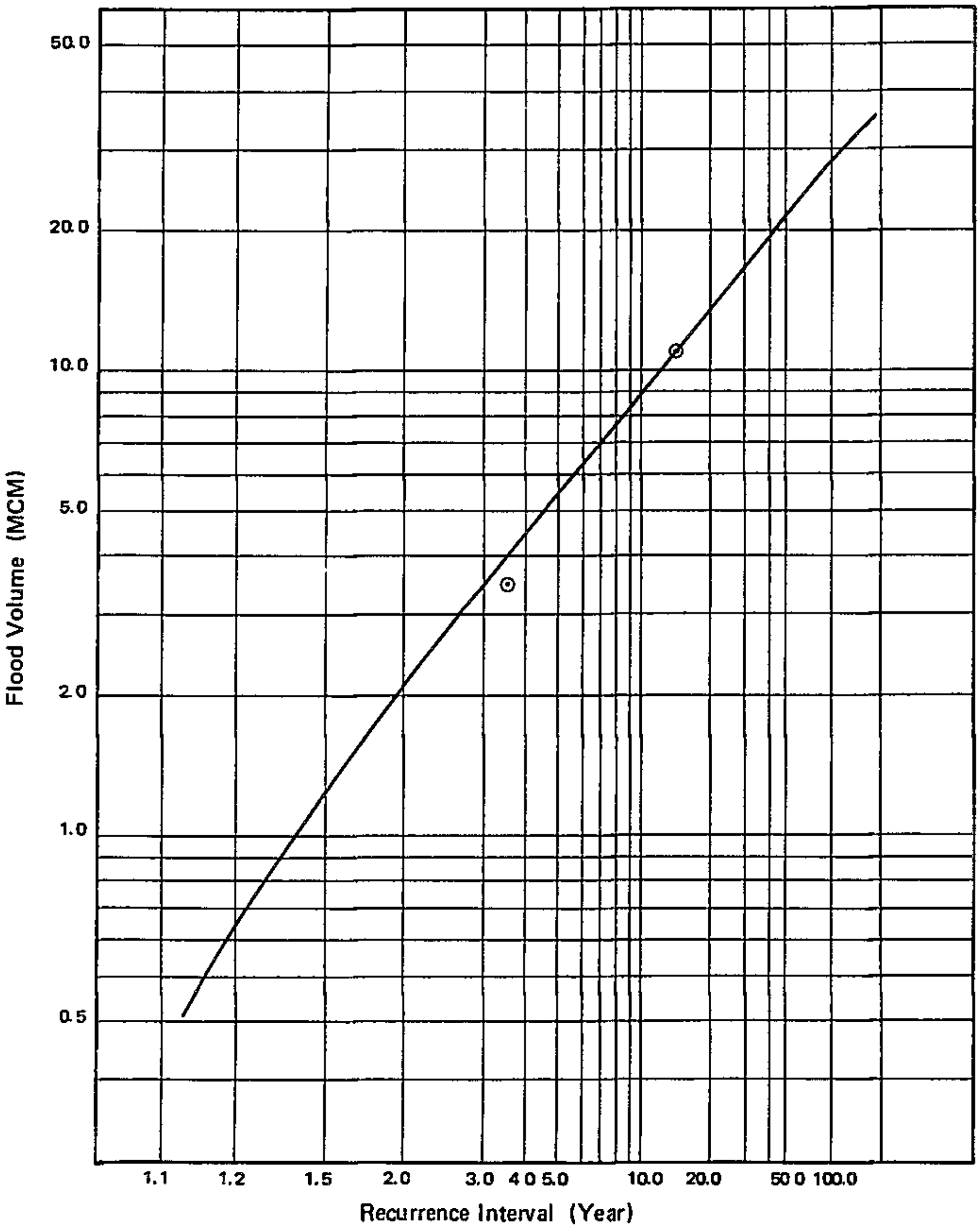


FIGURE 3-5 SINGLE EVENT FLOOD VOLUME-FREQUENCY

The Hawasina group consists of silicified limestone, mudstone, and chert with the well stratified beds of some ten centimeters in thickness. The basic volcanic rocks are mainly composed of Oman Ophiolite forming the main central ranges in the mountainous area in the mid-basin of the Wadi Jizzi.

The tertiary sedimentary formations consist of mudstone and limestone, etc., forming the basement of terrace deposits and low hills in the west edges of the gravel plain. The formations were found by the exploratory well drillings at the gravel plain in the depth of 40 to 50 meter below ground surface in weakly consolidated condition. Depth to the tertiary formations along the gas pipeline was confirmed by drillings 34 meter below ground surface (16 meter above mean sea level) at well site of JA-5 and 44 meter below ground surface (6 meter below mean sea level) at existing well site of TS-8. Though little precise geologic information of the coastal plain is available, it is considered that clay layers with 100 m in thickness starting depth of 118.7 meter below ground surface bored by exploratory hole of Sohar Expansion Farm (SE-0) is correlated with the tertiary mudstone.

The evidence that the depth to the basement of the alluvial deposits is found by 100 meter below mean sea level is consistent with the remark that the regression along the Persian Gulf at Würm glacial age was estimated at more than 100 m (H. Felber, 1978).

2) Terrace Deposits

The Terrace deposits have a large exposure in the middle stream of the Wadi Jizzi and the west edge of the gravel plain but their distribution is limited to an upper stream of the Wadi. The deposits are divided into four kinds of sediments based on height of their platform, three of which are distributed in the Wadi Jizzi basin and the lowest one is distributed in the mouth of the catchment of the Wadi Bani Umar, forming the alluvial fan.

The deposits are composed of partially cemented sand and gravel of fluvial origin with various sizes of grains of the basic volcanic and sedimentary rocks.

Although the deposits seem aquifuge, occasionally their uncemented thin layers of sand and granule among the deposits function as aquifers. Therefore, they act as part of aquifer in terms of hydrogeology. Thickness of each deposit and estimated height of their platforms at the ancient river mouth in comparison with the recent sea level are shown in the following table.

Name of Terrace	Height at the Ancient River Mouth (mamsl)	Thickness (m)
Terrace dep. I	110	5 ±
Terrace dep. II	60	15 ±
Terrace dep. III	40	35 ±

The terrace deposits III, the lowest one with about five meter high to the recent wadi course in the gravel plain, is exposed in the right bank of the Wadi, instead of the left bank where it was eroded and filled by the recent wadi deposits. Distribution of these deposits is restricted to the area in the edge of gravel plain, where the altitude is more than 40 meter above mean sea level.

3) Alluvial Deposits

The alluvial deposits are exposed in a limited area along the wadi course in the catchment; however, they have a large exposure in the coastal plain. The deposits consist of sand and gravel with partially cemented beds of alluvial origin. Thickness of the deposits range from several meters at the river beds in the catchment to 10 m in the mouth of gravel plain and more than 80 m in coastal plain where the deposits grow excellent as unconfined aquifers.

b) Aquifer Characteristics

The main aquifers in the Project Area are restricted to the terrace deposits and alluvial deposits. The aquifer characteristics in the coastal plain, especially of alluvial aquifers, have been obtained by the aquifer tests since 1973; however, their characteristics in the terrace deposits were not available except a few data. Summarized data on wells including the existing wells are shown in Table 3-5. As is shown in the table, specific capacity and transmissivity of the alluvial aquifers in the east edge of the gravel plain range from 30 to 60 cu.m/hr/m and from 4,000 to 50,000 sq.m/day, respectively. Storativity which was obtained by aquifer tests at production well No.1 of Sohar Expansion Farm was calculated at 0.05 in an average showing reasonable value for the alluvial unconfined aquifer.

c) Hydrogeological Structure

The groundwater basin comprising the terrace deposits and alluvial deposits is corresponds to the depth of the impervious formations in the gravel plain.

The groundwater basin is enclosed by the impervious formations at the north and west edges with depth less than 40 m and its thickness to the east reaches more than 100 m at the coast. The basin ends near Qabail and Majis where the impervious formations crop out near the sea. Location of the south end of the basin is estimated at the south of Wadi Ahin where the impervious formations crop out near the sea. An entire area of the groundwater basin mainly developing in the downstream of the Wadi Jizzi extends about 20 km in length along the coast with eight kilometer width. Furthermore, the depth of groundwater was estimated at 50 to 60 m at

Table 3-5 Summary of Well Data at Wadi Jizzi Basin

Well No.	Location UTM	Altitude of Site (mamsl)	Depth (m)	Casing Dia. (mm)	Screen Type	Screen Depth (m - m)	S.W.L (mbgs)	Tested Yield (m^3/hrs)	Draw-Down (m)	Specific Capacity (m^3/hr/m)	T (m^2/day)	S	Well Efficiency (%/m^3/d)
JA-1	4696,26896	24.04	82	250	Slot	33-79	20.5	45.7	0.75	60.9	16,900	-	86/2,000
JA-2	4679,26967	11.00	40	250	Slot	12-34	6.5	56.9	1.71	33.1	4,300	-	77/2,000
JA-3	4641,26957	30.00	45	250	Slot	22-39	24.4	15.1	7.25	2.1	150	-	-
JA-4	4611,26952	50.00	55	250	Slot	10-33	24.1	28.8	2.12	13.7	3,200	-	-
JA-5	4647,26922	42.00	55	250	Slot	32-55	36.1	4.7	2.28	2.1	60	-	-
WST-26	4691,26928	13.68	60	370	Slot	42-55	12.0	49.0	0.45	108.9	-	-	-
JT-64	4746,26888	-	35	240	Slot	23-34	11.8	28.5	3.00	9.5	85	-	-
JT-65	4741,26889	-	35	240	Slot	24-35	13.1	28.5	4.40	6.5	110	-	-
WD-78	4672,26928	25.63	73	200	Slot	33-69	20.0	79.1	1.16	68.2	1,800	-	-
WD-79	4670,26929	27.17	70	255	Johnson	24-60	21.1	82.6	1.64	50.4	1,440	-	-
SE-1	4708,26898	20.00	56	273	Johnson	44-56	15.6	220.0	3.28	67.1	47,000	0.05	72/4,000
SE-2	4704,26904	18.60	50	273	Johnson	41-50	14.3	215.0	8.56	25.1	18,700	-	75/4,000
SE-3	4715,26900	18.40	55	273	Johnson	43-46 49-55	14.4	217.0	3.84	56.5	34,000	-	75/4,000
SE-4	4712,26959	17.50	56	273	Johnson	47-56	13.6	215.0	7.06	30.5	28,000	-	82/4,000
SD-5	4743,26887	15.70	35	244	Slot	23-35	12.3	82.8	11.54	7.2	11,000	-	57/2,000
SD-6	4749,26885	14.40	35	244	Slot	23-34	11.1	91.4	7.75	11.8	13,000	-	74/2,000
SD-7	4742,26881	17.20	44	273	Slot	30-44	13.2	93.7	3.70	25.3	6,400	-	63/2,000
SD-8	4745,26879	17.10	36	273	Johonson	27-36	13.1	68.5	11.97	5.7	7,200	-	63/2,000
SD-9	4748,26877	16.80	44	273	Slot	30-44	12.4	95.3	3.15	30.3	7,500	-	78/2,000
SD-10	4745,26879	17.10	55	324	Johonson	46-55		215.0	4.08	52.7	21,000	-	90/4,000
EA-1	4665,26930	30.00	200	240	Slot	50-75	23.46	31.5	0.89	35.4	15,050	-	
EA-2	4708,26875	27.40	130	240	Slot	42-104	21.15	31.5	0.56	56.3	4,800	-	

Remarks : JA-Well: Tested by JICA
WSI-Well: Tested by ILACO
JT-Well: Tested by Gibbs
SD, SE-Well: Tested by IRI
EA-Well: Tested by ILACO
WD-Well: Tested by Macdonald

the west edge of the basin, deepening to over 100 m at the sea. Depth of the basin, especially in the west edge, is verified by the exploratory drilling at JA-5 and JA-6, the production wells for Mining Co., TS-6, 7, 8, 9 and geo-electric survey at lines ES-V1 and ES-V4.

The minor groundwater basin in the west edge of the gravel plain is composed of the aquifers of the terrace deposits with depth ranging from 40 m in maximum to less than 20 m at an outlet of the catchment and it extends to the wadi beds in the catchment with thickness decreased in aquifer.

The impervious formations which underlay the minor groundwater basin form one or two steps of platform caused by Pre-Würm glacial regressions. The schematic hydrogeologic profile along the Wadi Jizzi is shown in Figure 3-6. The figure is drawn based on data of the project drillings and the previous studies.

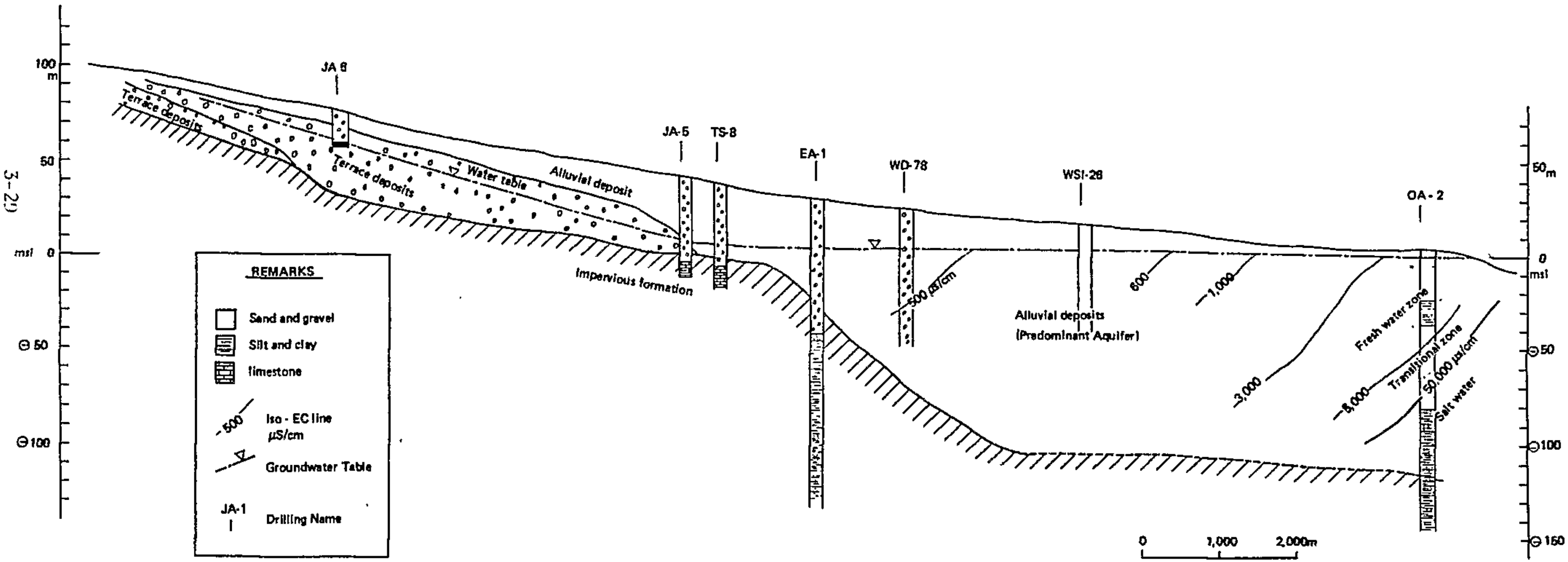
d) Movement of Groundwater

The groundwater in the Project Area is basically recharged by rainfall. However, the recharging method varies with locations of groundwater in the catchment. The groundwater in wadi beds flows as an under-flow with the same hydraulic gradient with that of river courses. The under-flow alters surface flow where the basement rocks are upheaved to the river bed.

The groundwater in the minor basin at the west edge of the gravel plain flows comparatively steep in contrast with the main groundwater basin in the coastal plain where it flows with moderate gradient, and flows through sediments deposited recently along the eroded river beds farmed during the glacial age regression.

Hydraulic gradient of the groundwater at the west edge of gravel plain which is calculated by water levels of OA-1 and JA-5 wells in drought month is about 1:100.

FIGURE 3 - 6 HYDROGEOLOGICAL PROFILE ON THE WADI JIZZI COASTAL PLAIN



The groundwater of the major basin in the coastal plain is stored with comparatively moderate flow having 1:2,000 of hydraulic gradient. Quantity of the groundwater flow was estimated several times that of the under flow because of large scale of flowing section in the basin.

Iso-depth contour lines to the impervious formations and the groundwater table contour lines on the coastal plain are drawn in the hydrogeological map in Figure 3-7. The figures summarize the groundwater flows at the coastal plain as follows;

Groundwater flow in drought month (the end of December 1981)

- The groundwater surface at five meter above mean sea level at the west end of the basin flows to the coast by 1:2,000 hydraulic gradient.

- The groundwater flow lines have almost right angle with a coastal line which extends from the mouth of Wadi Sallan to town of Sohar.

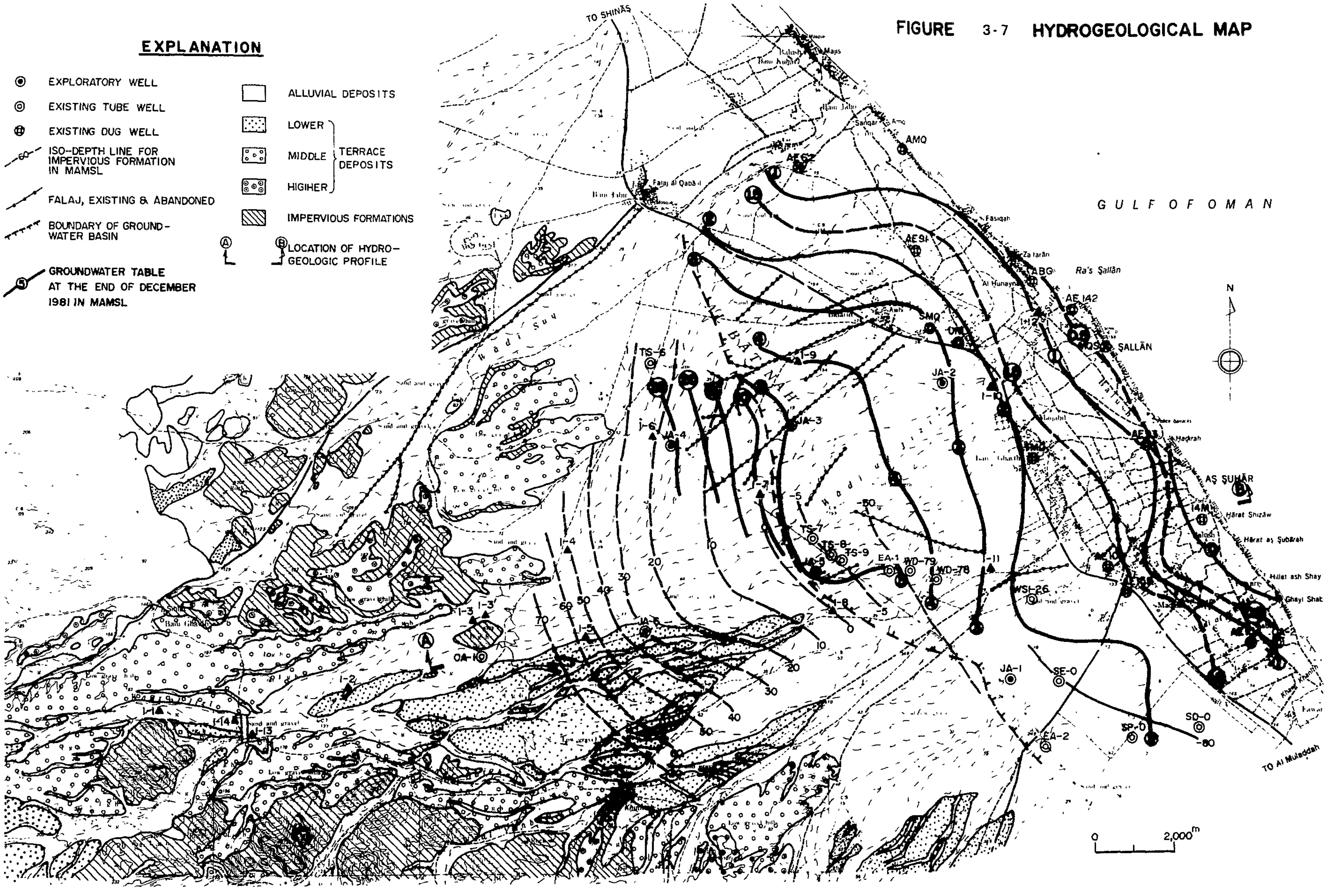
- The estimated northern end of the basin can be delineated by the line following JA-4, TS-6, and Majis.

- The groundwater contour line at zero meter above mean sea level penetrates one kilometer from the coast line at Amq and the south of Sohar town.

- The groundwater table trenches extending from Sohar twon to WSI-26 and JA-1 are intensified in the wet month, showing conspicuous boundary to the Wadi Hilti groundwater basin.

The location of groundwater table trench is consistent with the trench of Iso-EC lines (See Appendix C).

FIGURE 3-7 HYDROGEOLOGICAL MAP



e) Recharge and Run-off Groundwater

The groundwater basin in the coastal plain is extending downstream of the Wadi Jizzi and Wadi Hilti with eight kilometer width, 20 km length, and depth more than 100 m. the northern part of the basin is formed by the Wadi Jizzi groundwater sub-basin which extends from Amq to the Wadi Khadaq with 13 km length.

Quantity of groundwater stored in the basin was estimated on the following assumptions.

Storage for the basin = 8 km x 20 km x 80 m x 0.05 (Storativity)
= 640 MCM

Storage for the Wadi Jizzi sub-basin
= 8 km x 13 km x 80 m x 0.05
= 416 MCM

The source of the groundwater in the gravel plain is depended upon groundwater inflow from the catchment. The groundwater inflow is composed on the perennial under flow or the base flow and the inflow caused by floods. Surface water measurement by currentmeter has been carried out since 1977 at Mulayyinah with a catchment of 654 sq.km. The observed base flow discharge is 67.2 lit/sec on an average, which corresponds to 0.10 lit/sec/sq.km. Single flood discharge ratio at Mulayyinah varies depending on rainfalls' intensity. As mentioned in the Appendix B (Figure B-5), the ratio ranges from 16 percent at 83 mm rainfall to 7.4 percent at 33.2 mm. The recharge rate of flood to the groundwater is analyzed based on the flood on February 14, 1982. The rate of recharge was estimated at 76 percent on an average, although varying with rainfall intensity (See Appendix C).

Water balance calculation from 1974 to 1981 for determining the groundwater runoff is made by monthly time steps for the coastal plain in applying well hydrographs of EA-1, AE-104, AE-142 and OA-2.

The applied water balance formula is as follows;

$$P = (Ro-Ri) + E + (Go-Gi) \pm dH$$

P : Rainfall at plain
Ro: Surface outflow
Ri: Surface inflow
E : Evapotranspiration
Go: Groundwater outflow
Gi: Groundwater inflow
dH: Change groundwater storage

Applied values for the parameters are explained as follows;

P : Rainfall at Sohar (1974 - 1981)

Ro: Flood runoff from the catchment (FO) plus surface runoff (SG) caused by direct rainfall. Following formulas and parameters are applied for calculation of FO and SG

$$FO = RI-RF$$
$$RI = (F-29) \times 0.26 \times AR \qquad F \geqq 50$$
$$RI = (F-8) \times 0.19 \times AR \qquad F < 50$$
$$AR = A1/A2$$
$$RF = RI \times PR$$
$$SG = (P-13) \times 0.04/PR$$

where;

RI: Flood runoff from catchment
F : Sequential areal rainfall over 13 mm which probably bring flood
A1: Area of catchment (893 sq.km)
A2: Commanding area of respective wells at the plain EA-1 (56.6 sq.km) AE-104, AE-142 and OA-2 (317 sq.km)

RF: Recharge caused by flood

PR: Recharge ratio (76%)

Ri: Flood runoff (FO) from the catchment for well EA-1.
Flood runoff plus surface runoff (SG) caused by direct rain for well AE-104, AE-142 and OA-2.

Go: An unknown parameter for the coastal wells. For well EA-1, the formula "Go = P-(Ro-Ri) + Gi E $\pm$ dH" can be applied.

Gi: Baseflow runoff (RB) plus infiltrated flood (RF) for well EA-1.
RB + RE plus recharge caused by direct rain (RG) for the rest wells.

Following formulas and parameters are applied for calculation.

RB = (ES x R2) - RZ

R2 = AR x DR

RG = SGXPR - LO

LO = (D) x (EV)

where;

ES: Areal rainfall for the catchment brought five stations at the Wadi Jizzi basin.

DR: Runoff ratio for baseflow (5.7%)

RZ: Water consumption at the catchment (2.5 MCM/annum)

LO: Loss rain probably caused by soil detention

D : Sequential rain days

EV: Potential daily evapotranspiration calculated by the modified Penman method and the modified Blaney-Criddle method.

For the coastal calculation, "Go" from well EA-1 is converted into "Gi" for the rest wells.

E : If Rain $\leq$ Loss rain (= 13 mm), E = Rain
Rain > Loss rain, E = P - (SG + RG + LO) + LO

dH: Monthly changes of groundwater tables multiply storativity. Storativity is adopted by 0.05.

The results of an average of seven hydrological year from 1974 to 1981, are summarized in Table 3-6.

As is shown in the Table, groundwater inflow to the gravel plain is calculated by 17.6 MCM/annum comprising 6.7 MCM for base flow and 10.9 MCM for contribution from flood. In comparison with groundwater inflow, groundwater outflow at the coastal plain was estimated at 17.5 MCM including consumption in the plain. Groundwater recharge caused by direct rain does not counted by means of calculation. Minimum essential groundwater runoff to the sea is estimated at 8.0 MCM/annum as is mentioned in the latter part. Consumptive use by crops in the Project Area is estimated at 21.1 MCM/annum (refer to Appendix G-1). Average effective rainfall with respect to crops is also estimated 44 mm/annum which is equivalent to 14 MCM/annum for commanding area of the coastal wells.

Calculated losses at the coastal plain comprise mostly soil detention. Required groundwater extraction for consumptive use is obtained by the balance of calculated groundwater runoff (Go) and essential runoff plus change of groundwater storage.

Total surface runoff on the coastal plain is calculated at 4.6 MCM/annum, however most of surface runoff caused on the plain would not join to the wadi course in view of their topographic condition. Only the surface runoff which caused by flood on the catchment can be counted as the loss to the sea.

Table 3-6. Summary for Water Balance in the Plan (1974 - 1981)

(Unit: MCM/ANN)

Name of Well	EA-I	AE-104	AE-142	DA-2	Average
Catchment					
Area (sq.km)		893			
Areal Rainfall (mm)		130			
Input		116			
Discharge					
Base Flow		9.2			
Flood		14.3			
Total		23.5			
Plan					
Area (sq.km)	56.6	317			
Rainfall (mm)	98	98			
Input	5.6	31.1			
Recharge					
Baseflow	6.7				
Flood	10.9				
Total	17.6	17.4	17.4	17.4	17.4
Surface Inflow					
Total	3.4	3.6	3.6	3.6	3.6
Surface Outflow					
Flood	3.4	3.6	3.6	3.6	3.6
Rain	0.2	1.0	1.0	1.0	1.0
Total	3.6	4.6	4.6	4.6	4.6
Evapotranspiration					
Evaporation		16.0	16.0	16.0	16.0
Losses		14.1	14.1	14.1	14.1
Total	5.4	30.1	30.1	30.1	30.1
Change Groundwater	+0.3	-0.5	+0.4	-0.2	-0.1
Groundwater Runoff	17.3	17.9	17.0	17.6	17.5
Consumptive Use					
Groundwater		10.4	8.6	9.8	9.6
Rain (Loss)		10.7	12.5	11.3	11.5
Total		21.1	21.1	21.1	21.1
Essential G.W Flow		8.0	8.0	8.0	8.0
Coastal G.W. Balance		-0.5	+0.4	-0.2	-0.1

Consequently, the loss to the sea is estimated by 3.6 MCM/annum in contrast with 2.5 MCM analyzed by hydrological manners.

f) Groundwater Balance at the Coastal Plain

Groundwater balance at the coastal plain can be estimated by using time series records of the well water levels. Changes in the groundwater levels for a certain period result in difference in quantity between groundwater recharge and groundwater run-off. As is described previously, an average change in groundwater levels at the coast from 1974 to 1981 was calculated at 12 mm in defect and it is equivalent to a volume decrease of 0.1 MCM.

Groundwater defect at the coast seems small, in comparison with the total quantity of storage, however, the groundwater levels should be kept at least one meter above mean sea level to prevent sea water from intruding into the aquifers. Permissible drawdown of the groundwater level at the coastal plain based on the concept of the sea water intrusion seems small because the average water levels for the last eight years of wells of AE-104, AE-142 and OA-2 are 1.1, 1.1 and 1.5 mamsl, respectively. Minor defected change in groundwater level of 12 mm mentioned above should not be underestimated.

The actual quantity of the groundwater run-off to the sea should be assessed by hydrological method. The following considerations are given in the estimation. Quantity of groundwater run-off at the time when the annual change in groundwater level shows zero meter above mean sea level is assumed to be the actual run-off, to the sea and the quantity obtained by recession curve for coastal wells in the dry month is also assumed the actual run-off. The annual actual groundwater run-off estimated in the above manners is about 8.0 MCM on an average.

g) Sea Water Intrusion

Qualitative assessment of the coastal groundwater can be carried out by comparing EC loggings of ILACO. As a result, the EC has not changed since 1974 at WSI-26 in the west of national highway, indicating almost stabilized conductivity with 600 - 700 micro mho/cm to the depth of 60 meter below ground surface. The EC logging at OA-2 in 1982, which is located only 600 m apart from the coast, detected interface between 900 micro mho/cm of the surface layer and 5,500 micro mho/cm of the second layer at 24 meter below ground surface (16 meter below mean sea level). Furthermore, a transgressional zone to the third layer of 50,000 micro mho/cm is detected at 42 meter below ground surface (34 meter below mean sea level). As is shown in Figure 3-8, the former interface shifts about five meters upwards from the location found in 1974, and the third layer detected 50,000 micro mho/cm instead of 18,000 at the same depth as the above.

The EC loggings at the wells of EA-1 and EA-2 in the gravel plain more than seven kilometers apart from the coast indicate almost stabilized conductivity of 500 - 600 micro moh/cm down to 80 meter below the ground surface. Changes in the EC in each depth are summarized in Table 3-7.

From the above table, the location of interface between fresh water and transgressional zone has been shifted about five meter upwards and the conductivity has increased. The relationship between the depth to interface of the fresh water and the salt water and the height to the fresh water table can be obtained by the following Ghyben-Herzberg formula with assumption that the densities of fresh and salt water are 1.000 and 1.025, respectively.

FIGURE 3 – 8 EC-LOGGING AT OA-2

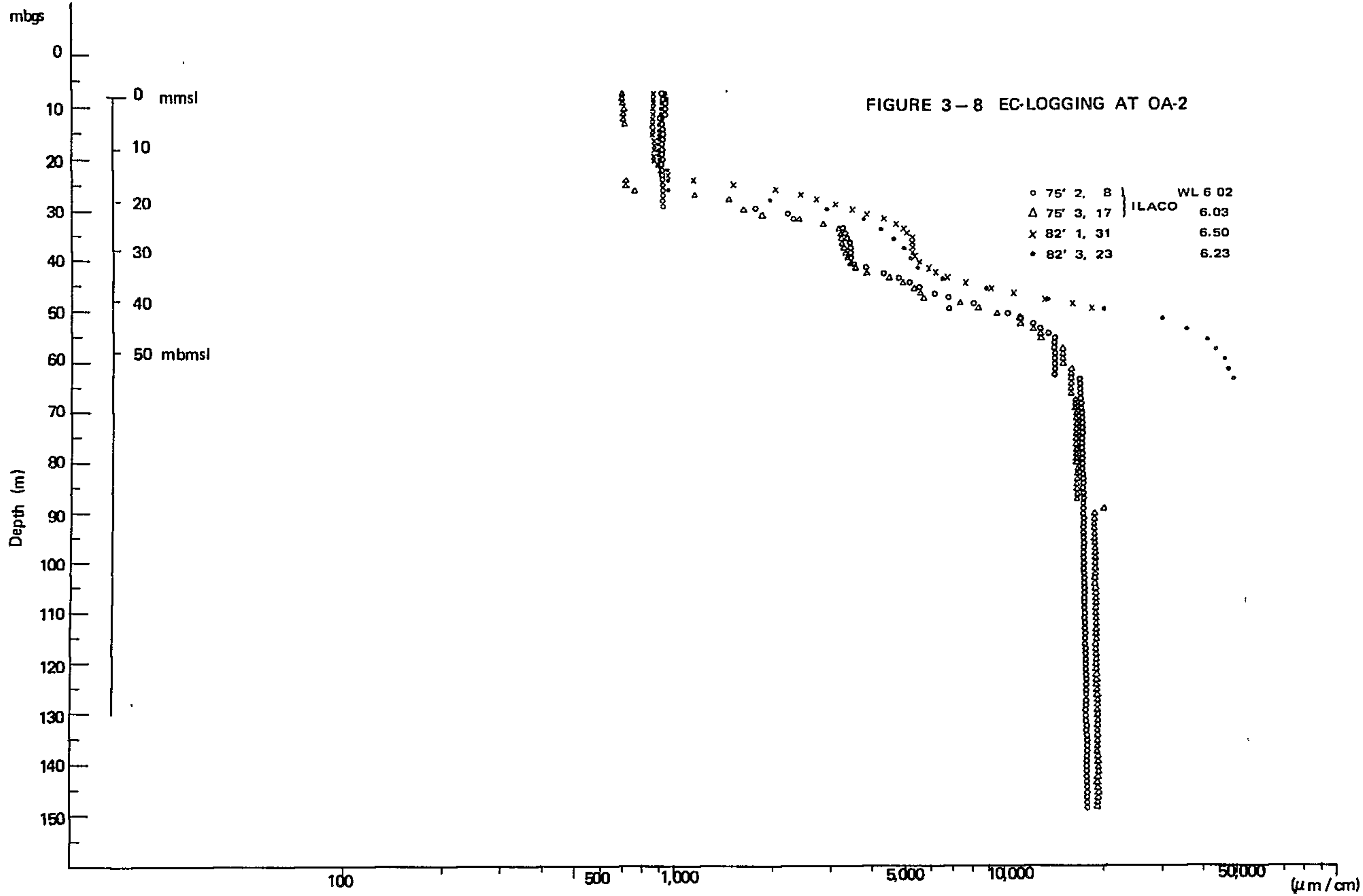


Table 3-7 Change of EC During 1974 ~ 1982 At OA-2

	Feb. 74		Mar. 82		Differences	
	Depth (mbmsl)	EC (μm/cm)	Depth (mbmsl)	EC (μm/cm)	Top of Layer (m)	EC (μm/cm)
1st Layer	~ 21	880	~ 16	900		+ 180
Transitional Layer	21 ~ 26	880 ~ 3,300	16 ~ 28	900 ~ 5,500	up + 6	
2nd Layer	26 ~ 34	3,500	28 ~ 34	5,500	up + 2	+ 2,000
Transitional Layer	34 ~ 55	3,500 ~ 17,000	34 ~ 55	5,500 ~ 32,000	down - 1	
3rd Layer	55 ~ 141+	18,000	55	50,000+	± 0	+ 32,000

$Z \doteqdot 40\ h$

Z : Depth to interface between fresh and salt water from mean sea level

h : Height to fresh water table from mean sea level

From the above formula, it can be assumed that the decrease in the groundwater table due to the from five meter rise of interface will be 13 cm. However, the actual water table in 1982 was about 20 cm lower than that of 1974, so that an increase in EC deserves more attention than the shifting of interface.

h) Groundwater Flow in View of Iso-EC Contour Lines

Distribution of EC at the surface layer of the groundwater along the Wadi Jizzi courses and their ideal section are drawn in Appendix C.

The Iso-EC contour lines are similar to the groundwater table contour lines and it is readily observed in the figure that the groundwater with 470 micro mho/cm at 25°C in the upper stream of the Wadi flows downwards solving saline materials. Also it is clear that the EC increase is moderate where the roundwater run-off is voluminous.

i) Chemical Quality of Groundwater

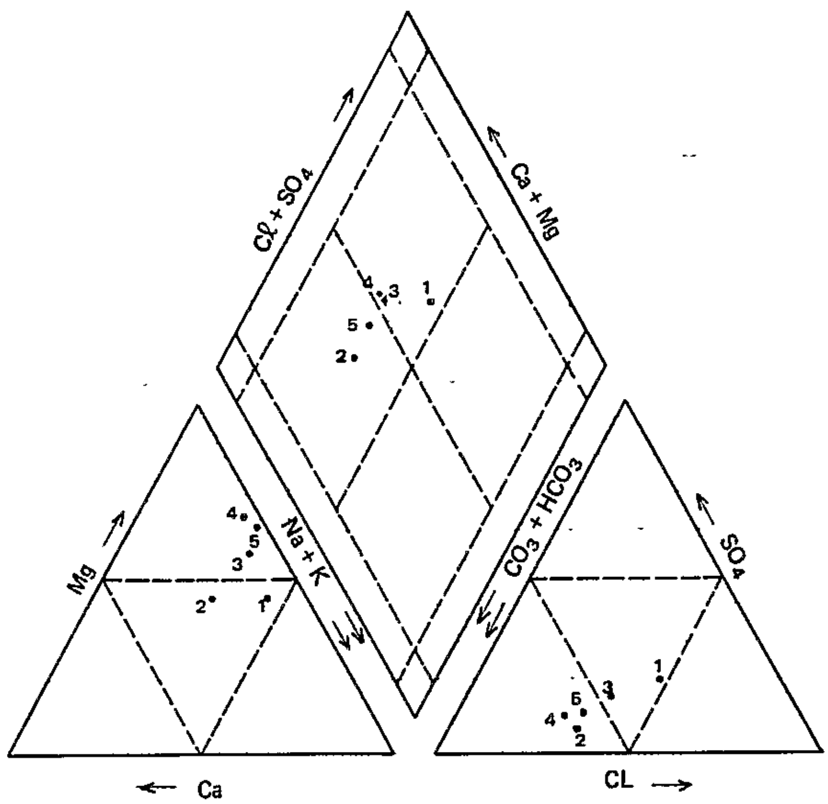
The result of chemical analysis of groundwater in the Project Area is shown in Table 3-8 and plotted on the key diagram of hydrochemistry in Figure 3-9. As is shown in the figure, the cations for all JA-wells are plotted in the Calcium-Sodium field; however, the plotted anions are spread to the Chloride-Sulfate-Bicarbonate field for the wells of JA-1 and JA-3 and to the Bicarbonate-

Table 3-8 Result of Chemical Analysis for Exploratory Wells

Sample No. Name of Well	Date, Analyzed	pH	EC (µmhos/cm at 25°C)	T.S.S (p.p.m)	Cations (me/L)					SAR	Anions (me/L)				
					Na^+	K^+	Ca^{++}	Mg^{++}	Total		$CO_3^=$	HCO_3^-	Cl^-	$SO_4^=$	Total
JA 1	24/3/1982	7.0	1,005.96	643.80	4.350	0.113	1.10	4.10	9.66	2.70	0.6	2.80	4.25	1.66	9.31
JA 2	24/3/1982	7.4	367.04	234.91	1.174	0.061	trace	2.50	3.74	1.05	0.6	1.45	1.10	0.16	3.31
JA 3	21/1/1982	7.6	518.00	331.50	1.552	0.074	0.40	2.80	4.83	1.23	trace	2.30	1.80	0.66	4.76
JA 4	24/3/1982	7.7	489.38	313.20	1.304	0.066	0.20	3.45	5.02	0.97	0.6	2.30	1.30	0.42	4.62
JA 5	24/3/1982	7.45	413.26	264.49	1.304	0.074	0.20	2.90	4.48	1.05	0.4	1.85	1.25	0.42	3.92

Note: Analyzed by Rumais Agricultural Research Station.

FIGURE 3-9 WATER ANALYSIS DIAGRAM FOR EXPLORATORY WELLS



Chloride-Sulfate field for JA-2, JA-4 and JA-5 wells. In general, groundwater plotted on Chloride-Sulfate-Bicarbonate field is characterized by hydrochemical signs of contamination by the sea water or fossil water. The deeper part of aquifers in JA-1 well is considered to indicate the sign of contamination by the sea water.

3.4. Land Resources

3.4.1. Introduction

Reclamation of the waste lands for increasing agricultural production with reasonable supply of irrigation water will be a prerequisite for the attainment of the national food security.

The surveyed area has been confined to the comparatively flat lands between the seashore and the alluvial plain below the gravel fan, extending from Majis to Wadi Khadaq, which is referred to as "Project Area" in this report.

The objectives of the survey are as follows:

i) to conduct a soil profile observation and a field analysis of the soil samples,

ii) to classify the soils into Soil Series - Soil Types with their extent in the Project Area, and

iii) to identify potentially the most suitable lands for agricultural development by classifying their suitability under irrigation through the evaluation of soil characteristics.

No systematic soil studies had been made for the northern Batinah of the Sultanate of Oman until 1973 when ILACO, a consultant of the Netherlands, initiated the water resources development project in the Batinah Coastal Plain, following the Oman Mountains and the Interior Plain development programs.

3.4.2. Soil Survey

a) Survey Method

For the survey of Wadi Jizzi Project Area, geographical maps at the scale of 1:100,000 and aero-photographs at the scale of 1:10,000 (BKS, 1978) were provided by the Omani Government, although the latter did not cover the northern-most part of the area near Amq.

The soil pits employs the reconnaissance survey and one pit was conducted per 400 ha with the depth of the pits being 80 to 120 m and a width of 100 cm.

A common hand auger (post-hole type) for finding the border lines among the Soil Types as well as for surveying the further lower layers of the pits.

The tests performed in the field survey are as follows:

1) Soil Hardness Test

The Tester was devised by Dr. K. Yamanaka for measuring soil hardness (compactness or strength), having been extensively used for the soil survey works in Japan. The Yamanaka's Tester has the similar mechanism to the cone penetrometers, equipped inside with a spiral spring durable up to eight kilogram strength (See Figure E-1, Appendix E).

Soil hardness is expressed by an index of cone penetration (mm) into the vertically cut column surface; the index value can be read as a resistance (kg/sq.cm) in the conversion table. The tester is portable and handy in the field works. Compactness of the soil layers is very important to investigate workability of lands for the potentiality classification as well as to identify the genetic differences in the soil classification.

2) Reagent Test

Reagent test is quite good for detecting special elements in the soils. It is often helpful to classify soils and their potentiality in the soil survey. Three reagents were used to assist the profile observation.

- Dilute hydrochloric acid: 1 N HCl solution. In profiles derived from calcium carbonate, effervescence with this reagent is visible in the order of carbonate contents.

- Benzidin solution: One percent solution of pp'-diamino-diphenyl salt in ten percent acetic acid solution. Oxidized manganese such as MnO_2 form contained in the soil materials instantly develops a dark blue color by benzidin oxidation reaction when sprayed on the profile surface.

- Dipyridyl solution: 0.05 percent solution of αα'-dipyridyl in ten percent acetic acid solution. This reagent reacts with ferrous iron (Fe^{++}) so sensitive that it can be used for its quantitative analysis in the laboratory.

The samples of soil and water taken during the field works were tentatively analyzed on some items at the base camp to check the soil properties.

3) Gravel Content and Bulk Density

Gravels separated after sieving the soil sample of less than two millimeters were sieved further by five millimeter-sieve.

4) pH and EC

In case of soil samples, 1:5 soil-water suspension was made for pH determination and its supernatant clear extract was subjected to EC meter. This soil-water ratio follows the National Standard of Soil and Water Analysis in Oman (1976) because of difficulty in preparing saturation extract of the soil in the field.

b) Survey Results

1) Soil Profile Survey

The field survey was conducted from the 1st to the 15th of April, 1981, basing a camp at the Oman Sun Farm. The Project Area including a water source zone is so vast that the soil survey was, due to the limited survey period, focussed upon the lands of existing or promising farming lands in Sohar area.

2) Scope of Survey and Sites

A topography unsuitable for irrigation, rocky or gravel plains, and heavily wadi-dissected lands were excluded from the survey. As a result, the objective area was defined as a nearly rectangular zone of about 13,850 ha lying along the coastal line from Majis to Wadi Khadaq of about 17 km long and 9.5 km wide, and the Project Area extends in the wadi detritus fan.

The location of 32 pits where the survey was undertaken is shown in Figure 3-10 together with well water sampling points. The profile

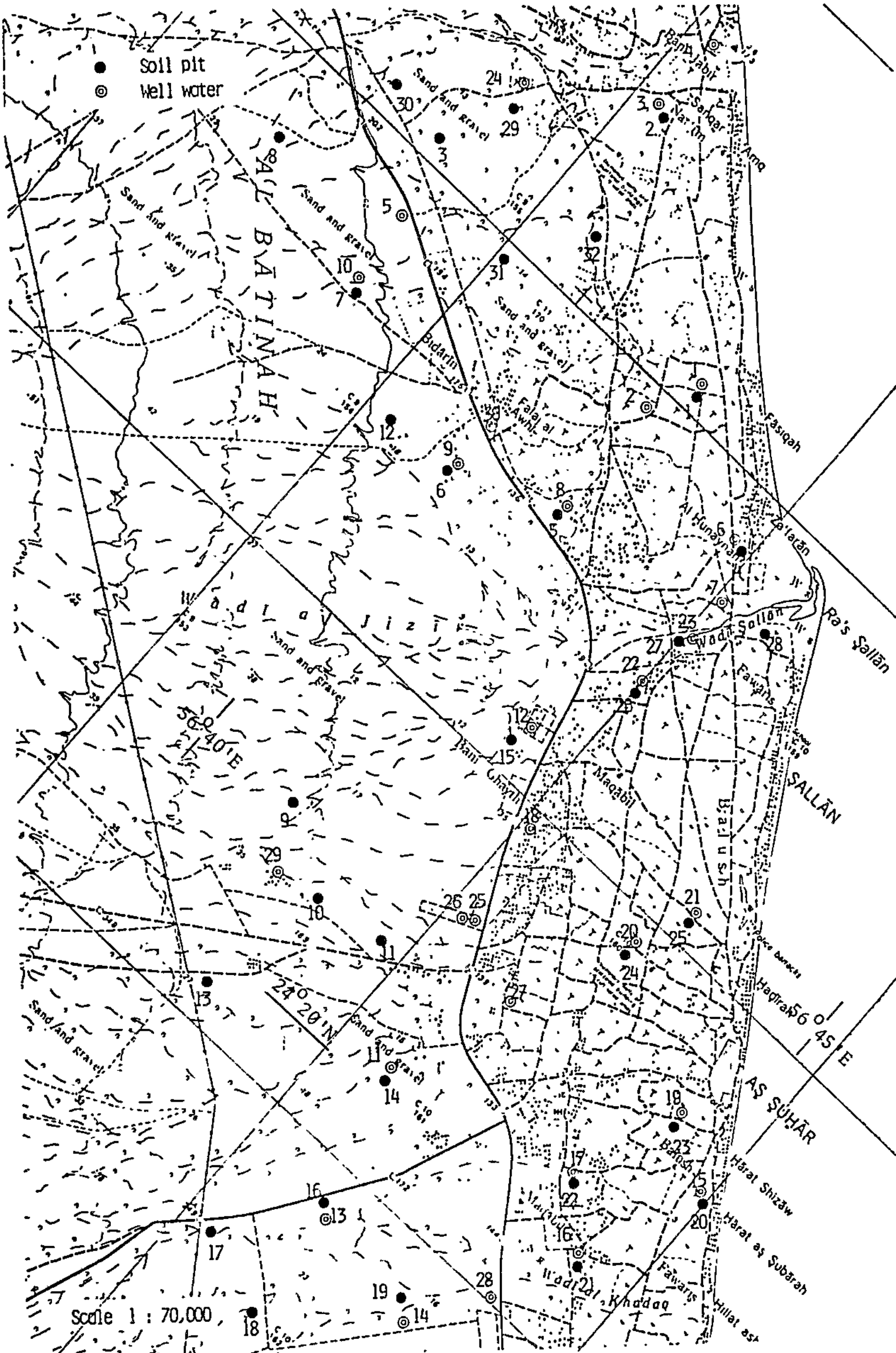


FIGURE 3-10 LOCATION OF SOIL PIT AND WELL WATER SURVEYED IN WADI JIZZI PROJECT AREA

survey density is thus one pit per around 220 ha within the survey areas as the reconnaissance level.

3) Profile Observation and Field Analysis

The results are summarized in Table 3-9 (Detailed data can be referred to Appendix E).

3.4.3. Soil Classification

The soil classification is normally made in the soil unit from great soil groups to smaller orders. This method is not necessarily applied to such a small area development plan as the Wadi Jizzi Project. The idea is particularly so in the agricultural area where almost all tracts of land have been under groundwater irrigation for long years and where irrigation is indefinitely needed to develop new farms. Under the circumstances, the classification will be focussed on the final step of the soil unit, that is, Soil Type from the view point of practical utilization of the lands.

a) Great Soil Group

According to the Soil Map of the World compiled by FAO-UNESCO (VII-1, 1977), the soils of the Project Area are classified as one Soil Unit of Haplic Yermosols. Since the map symbol shows the most dominant soil in the area, each soil unit is usually associated with and/or includes some other units.

Haplic Yermosols cover most part of the sea coast and peneplain areas. In the mountains Lithosols are dominant and associated with Yermosols in the north of Oman. The Yermosols on the Project Area are described as follows:

Table 3-9 Outline of the Soil Profile Observation and Field Analysis of the Samples Taken in Wadi Jizzi Project Area

Pit No (Elevation) (m)	Location and Land Use	Soil Type No.	Texture	Bulk Density	Gravel content 2-5 mm	Gravel content > 5 mm	pH (1.5)	EC (1:5) (mmhos)	EC of Well Water (mmhos)
1 (4.0)	Fasiqah, Farm (fallow)	1	SiL-SiL	1.4-1.2	trace-trace	0-0	9.6-9.6	6.7-1.8	1.8-1.3
2 (6.0)	Amq, Farm	1	SiL-SiL	1.0-0.9	8.9-trace	0-0	10.2-10.2	1.3-0.8	0.7-0.6
3 (13.5)	Amq, Unused	1	SCL-SL (SCL)	1.3-1.2	trace-trace	0-0	9.1-8.5	0.6-2	-
4 (5.0)	Al-Hushbah, few date palms	7	LS-S	1.8-1.7	trace-trace	0-0	8.3-8.6	0.1-0.1	1 7-4.6
5 (11.0)	Ibid, Farm (fallow)	2	SL-SL (SCL)	1.6-1.6	trace-3.3	0-7.2	8.8-9.0	0.1-0.6	0.7
6 (15 0)	Bidarin, fenced Land	2	SL-SiL	1.7-1.6	trace-0	0-0	8.2-9.0	0.1-0.1	0.4
7 (22.0)	Near Bidarin, Unused	7	SL-S	1.7-1.6	2.5-8.2	0.6-19.2	7.8-7.7	0.1-0.1	0.5
8 (23.0)	Bani Jabir, Unused	10	LS-S (G)	1.9-1.7	8.3-1.9	40-3.8	8.6-	0.1-	
9 (21.0)	Wadi bed, Unused	10	S-S (G)-(G)	-	15-15	40-45	-	-	0.6
10 (19.0)	Bahi Ghayth, Unused	10	S-S (G) (G)	2.0-1.5	14-6.2	57-6.9	-8.6	-0.1	1.2
11 (14.0)	Ibid, Unused	5	LS-SL	1.3-1.5	trace-trace	trace-0	8.6-8.6	0.2-0.1	0.6-0.7
12 (18 0)	Al-Obi, Unused	9	LS-S (G)	1.6-2.0	trace-7.8	40-48	8.5-	0.1-	-
13 (26.0)	Al-Mowaleh, Unused	10	LS-S (G) (G)	-	> 50	> 50	-	-	-
14 (16.0)	AL-Wagabeh, Unused	2	SL-SiL (SiL)	1.3-1.2	0-0	0-0	9.0-8.2	0.2-1.1	0.9
15 (10.5)	Near Maqabil, Unused	9	LS-S (G)	1.8-2.3	5.2-15.9	10.8-32	7.7-	0.1-	0 4
16 (21.0)	Ali Humod, Unused	4	SiL-SL	1.1-1.5	0-1.4	trace-1.2	8.7-8.9	0.2-0.1	0.8
17 (24.5)	Hibi Gravel Road, Unused	7	S-S (SiL,G) (SiL)	-	5-10	40-10	-	-	-
18 (22.5)	Butha Swahreh, Unused	7	S-S (SiL) (SL,G)	-	10-5	10-15	-	-	-
19 (16.5)	Al-Himbar, Unused	4	SiL-SL	1.3-1.5	0-0	0-0	8.8-	0.1-	0 8-1.1
20 (3.0)	Sohar Town, Unused	8	SL-S	1.5-1.7	0-0	0-0	8.9-9.5	2.5-0.3	2.1
21 (9.0)	Al-Himbar, Unused	1	SiL-SiL	1.2-1.0	0-0	0-0	9.4-10.1	2.2-3.1	0.9
22 (10.5)	Ibid, Farm (date)	1	SiL-SiL	1.0-1.0	0-0	0-0	9.0-9.3	3.7-4.2	1.6
23 (3.5)	Ibid, Farm (date)	2	SL-SiL (SiL) (SL)	1.2-1.1	0-0	0-0	8.6-9.3	0.8-1.6	2.9
24 (7 0)	Trafe, Farm (mixed)	5	SL-SL	1.5-1.4	0-0	0-0	8.8-8.9	0.1-0.1	1.1
25 (5.0)	Al-Mohmoodi, Farm (mixed)	2	SL-SiL	1.1-1.2	0-0	0-0	8.9-	0.5-	1.6
26 (6.0)	Al-Traif, Unused	2	SL-SiL (LS)	1.6-1.2	0-0	0-0	8.9-9.8	0.1-0.4	0.7
27 (5.0)	Near Wadi Sallan, Unused	4	SiL-SL	1.6-1.5	0-0	0-0	9.5-9.0	0.9-0.1	0.8
28 (5.0)	Ibid; Unused	2	LS-S (SiL) (SiL)	1.6-1.5	0-0.9	0-0	8.9-8.9	2.0-0.6	-
29 (11.0)	Al-Qabail, Unused	3	SL-SCL (G)	1.5-1.2	1.6-10.9	0-0	7.8-8.6	1.7-2.8	0.6
30 (16.0)	Near Wadi Suq, Unused	3	S-SiL (G) (L)	1.7-1.4	20-trace	33-0	8.0-9.3	0.1-0.5	-
31 (15.0)	Near Bidarin, Unused	6	LS-SL (G) (S)	1.5-1.2	9.7-0	9.7-0	8.3-8.8	0.2-0.2	-
32 (9.0)	South of Amq, Unused	2	LS-SiL (SiL) (SL)	1.6-1.1	0-0	1.6-0	8.2-8.8	0.2-0.3	-

Note: Value range shows dominant figure of upper 0-50 cm layers to lower 50-100 cm layers, but *for EC of well water means two places nearby.* Refer to Table 3-10 for Soil Types.

Map Symbol	Associated Soils	Inclusions
Yh 22-1 ab	Qc (Cambic Arenosols)	Rc (Eutric Regosols)
(Haplic Yermasols,	Yk (Calcic Yermosols)	Jc (Calcaric Fluvisols)
coarse textured,		Z (Solonchaks)
level to hilly)		

Yermosols are the so-called "Desert Soils" that are sandy, stony and mostly shallow, but deep, yellowish loams in some spots. "Haplic" is connotative of soils with a simple, normal, horizon sequence. The other cartographic representation can be found in Volume I and VII-1 of the above publication.

b) General Features of the Soils

The Project Area consists of coastal complex and accumulation plain of less than 25 m in elevation on the Batinah coastal plain. The former comprises coarse sandy soils on the sand-bars and saline finer-textured inland soils on the "Sebkhas". The latter plain has the average width of five to six kilometers and received sediments of loam of gravel size transported by wadi sheet floods; the soils are not saline but frequently shallow and gravelly immatured under the influence of the many braiding recent wadi channels.

Although many types of layer sequences are observed, the soils prevailing in the Project Area are in general coarse textured and have almost no organic matter and rather compact with very weak structures if developed; they are mostly alkaline with pH reaction of eight to nine, very calcarous with a strong effervescence with dilute HCl, and usually deficient in nutrients except for calcium and magnesium which would be derived from mother rock of the mountains being rich in serpentinized materials.

The soil colour varies little from 10YR 7/2 to 10 YR 5/3 dry with an increase in particle size; no mottlings were observed in inland areas while some weathered limstone fragments were incorporated into the strata often in the Sebkha area. Strong bubbling with dilute HCl solution appeared in almost all soil layers. This indicates a high content of carbonates which combine mainly with calcium. The color development with benzidin reagent was generally weak, showing a small content of active manganese. Reaction with dipyridyl solution which proves the presence ferrous iron was not entirely recognized with the profiles. It was very strong only in the silty or clayey subsoils around the lagoons.

No clear gypsum crystalline was detected in subsoils.

Vegetation is also quite characteristic of the arid soils with scarce rainfall and slightly high salinity. Well-growing Acacia arabica, Acacia tortilis, and low shrubs of Tamarix indica are commonly found in the gravel plains. In some places they make plant communities consisting of one or a few species which suit to the soil conditions there. The main species of more than 80 have been listed by Gibb and ILACO's soil survey report (1975) in Batinah and Interior Region of Oman. Vegetation is an useful tool for predicting soil species because it frequently provides a reliable indication of the local ecology including soil conditions.

c) Soil Type Classification

Soil classification for northern Oman area was attempted for the first time by Gibb and ILACO (1975). They divided the area soils into four great classes following the French C.P.C.S System (1967).

- Row mineral soil
- Slightly developed soil
- Calci-magnesic soil
- Sodic soil

The classes were further divided into groups, sub-groups, facies and series, successively, for each of which salinity, soil depth and erosion were considered as classifying factors. Finally 35 soil series were confirmed for the preparation of the soil maps.

In the present soil survey, the lower orders from Soil Series to Soil Types are adopted from the edaphological points of view and also for the following two reasons:

i) A comprehensive soil classification and mapping survey cannot be conducted in such a short time span as one month or so.

ii) A further detailed study for identifying the higher order classes is very difficult because of the scarce analytical data available in the Project Area.

Table 3-10 gives the classified soil Categories, Units, Series and Types. In view of the recent alluviums and their weak horizon formation, Calcaric Fluvisols were adopted for some of the soils. Although Solonchaks actually develop in the finer-textured soil near wadi mouth to the sea, a large part of the coastal sand dune area should be classified into the same Unit, too. Dystric Regosols cover most of the gravel plain and Haplic Yermosols occur in the intermediate zone.

The Series and Types were divided by the textural difference in the lower and upper soil layers, respectively, so as to allow direct evaluation of their land suitability. With these combinations ten Soil Types were taken up in total by investigating the results of profile examinations and sample analyses. Relative arrangement of these Types are simply illustrated in Figure 3-11 in terms of particle size, sequence of sedimentation, and topography.

Table 3-11 gives some characteristics of each Type, which are later used for classification and significant for land

Table 3-10 Classified Soil Types in Wadi Jizzi Project Area

Category	Unit	Series (Texture of Lower 50-100cm)	Type (Texture of Upper 0-50 cm)	Symbol No.	Location	Areas (ha)	Areas (%)
Solonchaks	Orthic	SiL	SiL	1.	Behind sandbars along sea coast, "Sebkha"	1,720	12.4
Yermosols	Haplic	SiL	SL/SiL	2.	Higher deposits than (1)	2,560	18.5
Yermosols	Haplic	SiL	S(G1-3)	3.	Along or nearby small wadis	210	1.5
Fluvisols	Calcaric	SL	SiL	4.	Deposits between wadis	410	3.0
Fluvisols	Calcaric	SL	SL	5.	Alluvial and aeolian Sandy areas around Wadis	1,050	7.6
Regosols	Calcaric	SL	S(G1-3)	6.	Nearby and along Wadis	370	2.7
Regosols	Calcaric	LS(S,G)	SL(LS)	7.	Sandy dunes behind sea coast and nearby wadi beds	1,180	8.5
Solonchaks	Orthic	LS(S)	SL	8.	Sea coast sandy areas	640	4.6
Regosols	Dystric	S(G3)	LS	9.	Between wadis and behind (7)	1,080	7.8
Regosols	Dystric	S(G3)	S(G3)	10.	Wadi beds of warse deposits	4,630	33.4
Total						13,850	100.0

Remarks : G1-3 give average gravel contents(0.2 - 7.5 cm) of 2 - 15, 15 - 50 and more than 50% of the profile, respectively.

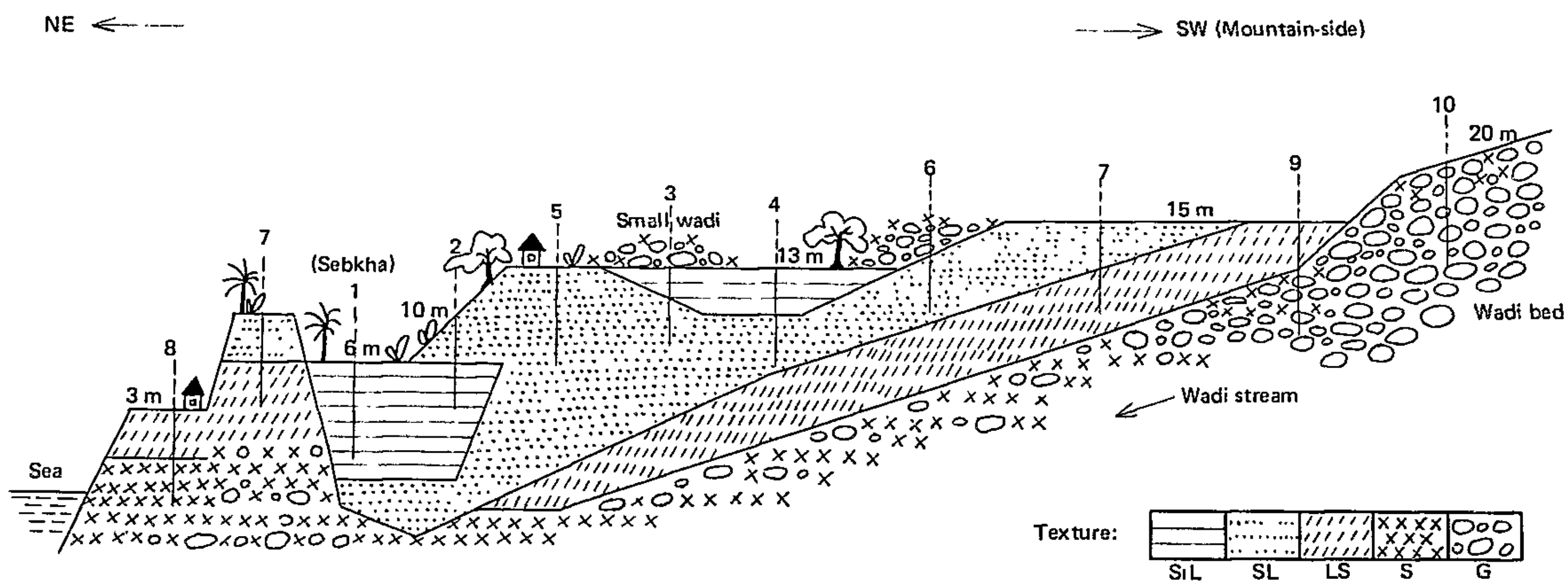


FIGURE 3 – 11 PARTICLE SIZE DISTRIBUTION AND TOPOGRAPHICAL POSITION OF THE SOIL TYPES IN WADI JIZZI PROJECT AREA

Tabel 3-11 Characteristics of Soil Types in Project Area in Relation to Land Classification

Soil Type No.	Texture (S) (Lower-Upper)	Gravel Content(v) (%)	Hardness[1/] (e)	Available Soil Depth(g) (cm)	Salinity (EC_s, n) (mmhos)	Topography (t)
1	SiL - SiL	0	10 - 30	> 100	1.5 - 4.0	Almost flat, "Sebkha"
2	SiL - SL/SiL	0	15 - 20	> 100	0.1 - 0.5	Almost flat (alluvial deposits)
3	SiL - S(G1-3)	10 - 50	5 - 18	30 - 50	0.3 - 2.0	Flood plain ridges, undulating
4	SL - SiL	0	10 - 30	> 100	0.2	Almost flat (alluvial deposits)
5	SL - SL	0	10 - 15	> 100	0.3	Almost flat (alluvial deposits)
6	SL - S(G1-3)	10 - 60	15 - 25	0 - 20	0.1	Flood plain ridges, undulating
7	LS(S,G) - SL(LS)	0 - 15	20 - 25	30 - 50	0.1	Sandy dunes, slightly sloping
8	LS(S) - SL	0	10 - 20	0 - 40	3.0 - 16.0	Sandy coast and dunes
9	S(G3) - LS	30 - 60	23 - 27	0	0.1	Almost flat (wadi edges)
10	S(G3) - S(G3)	50 - 100	25 - 30	0	0.1	Wadi beds, undulating

Remarks : For evaluation criteria of each item refer to Table E - 8.
1/; Figures show index values as measured by Soil Hardness Tester.

classification, as well. Soils of Type 1 to 3, mainly found on the Sebkha or similar natured areas, are reasonably saline due to their genetic formation.

d) Mapping and Area of Soil Types

Due to the repeated deflation and redeposition of alluvial, marine materials, and wind-borne deposition, the soils show very complicated features particularly along wadi bed, making it difficult to complete the precise soil map.

The extent of each Soil Type is outlined by checking the locations of the soil pits and their land forms which can be found on the topographical map scaled at 1:50,000. The soil map thus drawn is shown in Figure 3-12 the scale of which is reduced to 1:70,000 for convenience' sake in printing.

Acreages of the Soil Types are measured on the map by means of a linear planimeter taking the Gas Pipe Line as a southeastern boundary. These are listed in the right column of Table 3-10.

Nearly half of the area is occupied by Type 9 and 10, followed by Type 1 and 2 which are the finest-textured and saline, giving as high as 30 percent prevalence mostly in the inland Sebkha areas.

The respective soil types with respect to their characteristic features and distributions are detailed in Appendix E.

3.4.4. Land Suitability Classification

In order to reclaim and cultivate land economically and effectively, the lands should be subjected to the suitable crops and farm management according to their soil characteristics.

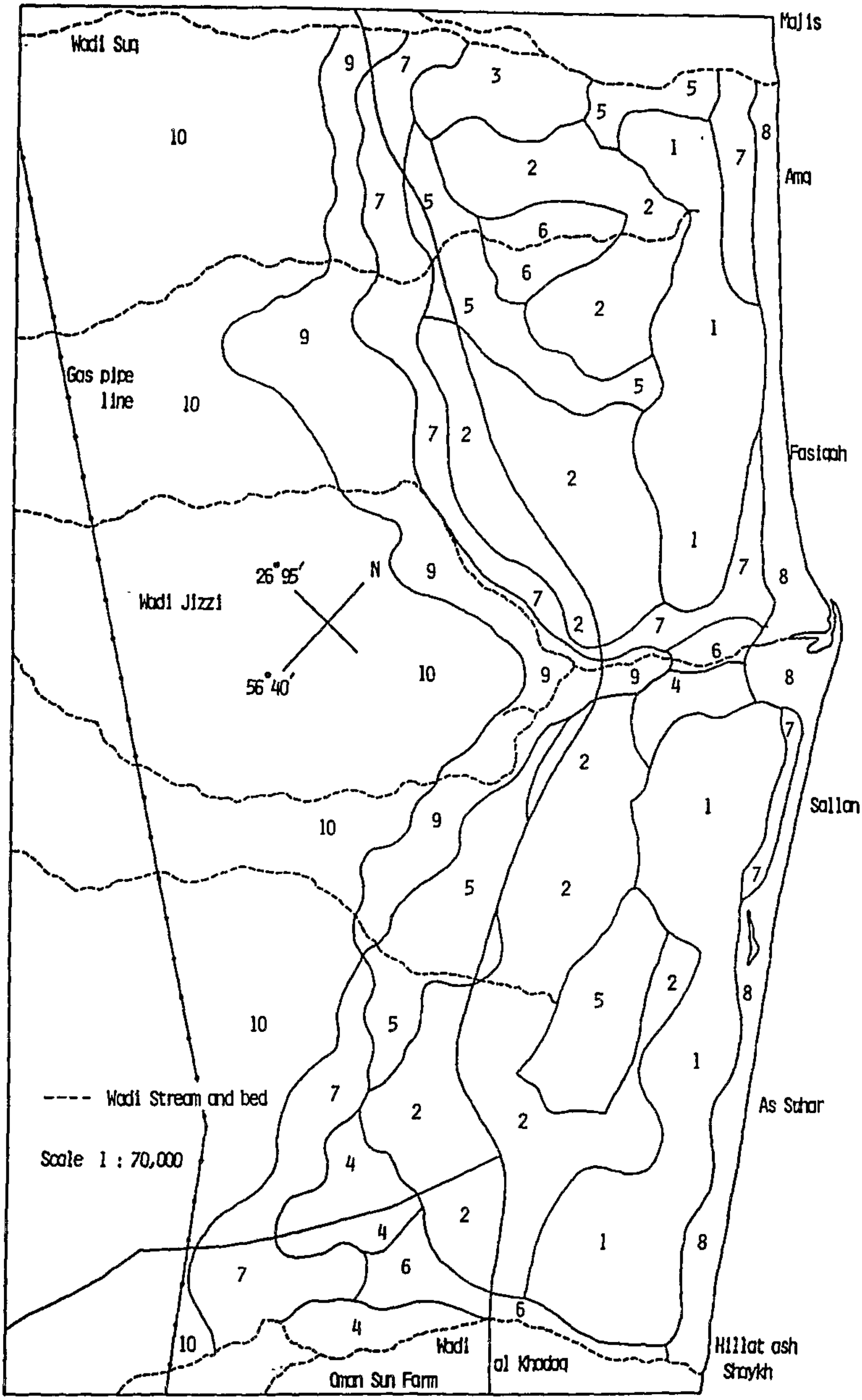


FIGURE 3-12 MAP OF SOIL TYPES IN WADI JIZZI PROJECT AREA

A land suitability survey for irrigated agriculture is vitally important to identify new areas suitable for implementation of agricultural projects as well as to investigate problems of land use in the existing farming. It is essential to take the best way of classification for successfully discriminating the classes among soil species found in the subject area.

a) Classification Method

Many processes of land suitability classification have been proposed in the agricultural development projects. In the present study, the first investigation was how to select the main limiting factors for irrigated agriculture. Secondly, it was attempted to decide land class by numerating evaluation of the limiting factors (Hazards).

1) Suitability Criteria

Five items of the soil characteristics are chosen as the limiting factors from the viewpoint of land utility in the Project Area:

a.	Texture	(Symbol s)
b.	Gravel content (%)	(Symbol v)
c.	Hardness	(Symbol e)
d.	Available depth	(Symbol g)
e.	Salinity	(Symbol n)

A special concern has been given to gravel content and hardness of the soils, both of which are considered to strongly affect the land use. Topography and drainage (permeability) are also important items, but these are omitted out of this report to avoid complication in the evaluation.

The criteria for each factor are summarized in Table 3-12. The said evaluation has five grades (values) from 0 to 4.

Salinity is the most important factor, especially in the Project Area where the saline problem has been involved, because of some degraded date farms being scattered along the coastal area.

The concentration of the soil salinity expressed by EC values is in general measured by the saturated water extract. In the present survey, 1:5 soil-water extract was used for EC measurement. This EC_5 value was estimated as low as about a seventh to a tenth of the saturation extract ECe. The criteria cited herein are thus scaled from 0.2 to 2.0 mmhos of EC_5, which are largely equal to the criteria generally adopted.

The soil profile should be examined on both depth of surface soils and subsoils; the surface salinity is related to the existing crop damage and the subsoils salinity may provide information on the future risk in agricultural production. Yet this time average value on the whole profile is adopted to make the process simple. The range from 1.0 to 2.0 mmhos which may correspond to around 8 - 16 mmhos of ECe has been assumed to be critical for normal crop growth.

2) Classification Process

Table 3-13 gives the results of classifying Soil Types on suitability for irrigated agriculture in the Project Area.

The process of land evaluation is as follows:

(1) First, read the value of each limiting factor on Soil Type,
(2) Total the values of respective Soil Types, and
(3) Decide the sphere of suitability with the total values considering relative importance among limiting factors.

Table 3-12 Criteria of Soil Characteristics for Evaluating Land Classes of the Soils in Wadi Jizzi Project Area

Item	Value	Range	Remarks
Texture (s)	0	SiL - L (SiCL,CL)	Dominant texture within upper 50 cm depth
	1	L - SL	
	2	SL - LS	
	3	LS - S	
	4	S - S (Gl-3)	
Gravel Content (%) (v)	0	< 2	Average within upper 50 cm depth
	1	2 - 15	slightly gravelly
	2	15 - 50	gravelly
	3	50 - 75	very gravelly
	4	> 75	gravel
Hardness (mm, index of Tester) (e)	0	< 8	soft
	1	9 - 15	slightly hard
	2	16 - 22	hard
	3	23 - 28	very hard
	4	> 29	extremely hard (pan)
Available Depth (cm) (g)	0	> 120	Depth to gravel or coarse sand layer
	1	90 - 120	
	2	60 - 90	
	3	30 - 60	
	4	< 30	
Salinity (EC, mmho per cm at 25°C) (n)	0	< 0.2	Average within 1 m; determined with 1:5 soil water extracts
	1	0.2 - 0.5	
	2	0.5 - 1.0	
	3	1.0 - 2.0	
	4	> 2.0	

Table 3-13 Evaluation of Limiting Factors and Land Class of Soil Types

Soil Type No.	Texture (s)	Gravel Content (v)	Hardness (e)	Available Depth (g)	Salinity (n)	Total	Land Class (Symbol)	Order of Land Class (Map Symbol)
1	0	0	3	0	4	7	Marginally suitable (S3en)	2
2	0	0	2	0	1	3	Highly suitable (S1)	1
3	4	2	1	3	3	13	Permanently unsuitable (U2sgn)*	4
4	0	0	2-3	0	1	3-4	Highly suitable (S1)	1
5	1	0	1	0	1	3	Highly suitable (S1)	1
6	4	3	3	4	0	14	Permanently unsuitable (U2sveg)**	5
7	3	1	2	3	0	9	Conditionally moderatly suitable (C2seg)*	3
8	4	0	2	3	4	13	Permanently unsuitable (U2sgn)*	4
9	4	3	3	4	0	14	" (U2sveg)**	5
10	4	4	3	4	0	15	" (U2sveg)**	5

Note : * - **; These express grade of topographical limitations.

According to the FAO system, the land suitability class is arranged as follows:

Order	Class
S: Suitable	S1: Highly suitable S2: Moderately suitable S3: Marginally suitable
C: Conditionally suitable	C2: Conditionally moderately suitable C3: Conditionally marginally suitable
U: Unsuitable	U1: Currently unsuitable U2: Permanently unsuitable

The subclass is further divided by attaching symbols of each factor when its value exceeds 3.

As clearly learned from the table, numeration of total values is very convenient to decide each class and also to group the Soil Types belonging to the same class on the map by numbering in order of their suitabilities. Soil Type 6, 9 and 10 are only slightly different from Type 3 and 8 in sum of the values, and yet they are numbered by 5 because of the worse topographical conditions.

b) Mapping and Area of Land Classes

Land Classes expressed in the order number and subclass designation are mapped in Figure 3-13. The best Class, S1, distributes on the both sides of the National Highway.

The acreage of each land under subclasses is given in Table 3-14. Results of land evaluation for land improvement and potential suitability are summarized in the same table. Descriptions of each class are given in Appendix E.

c) Proposed New Extension Areas

Extension of new agricultural areas, which will be well-promised

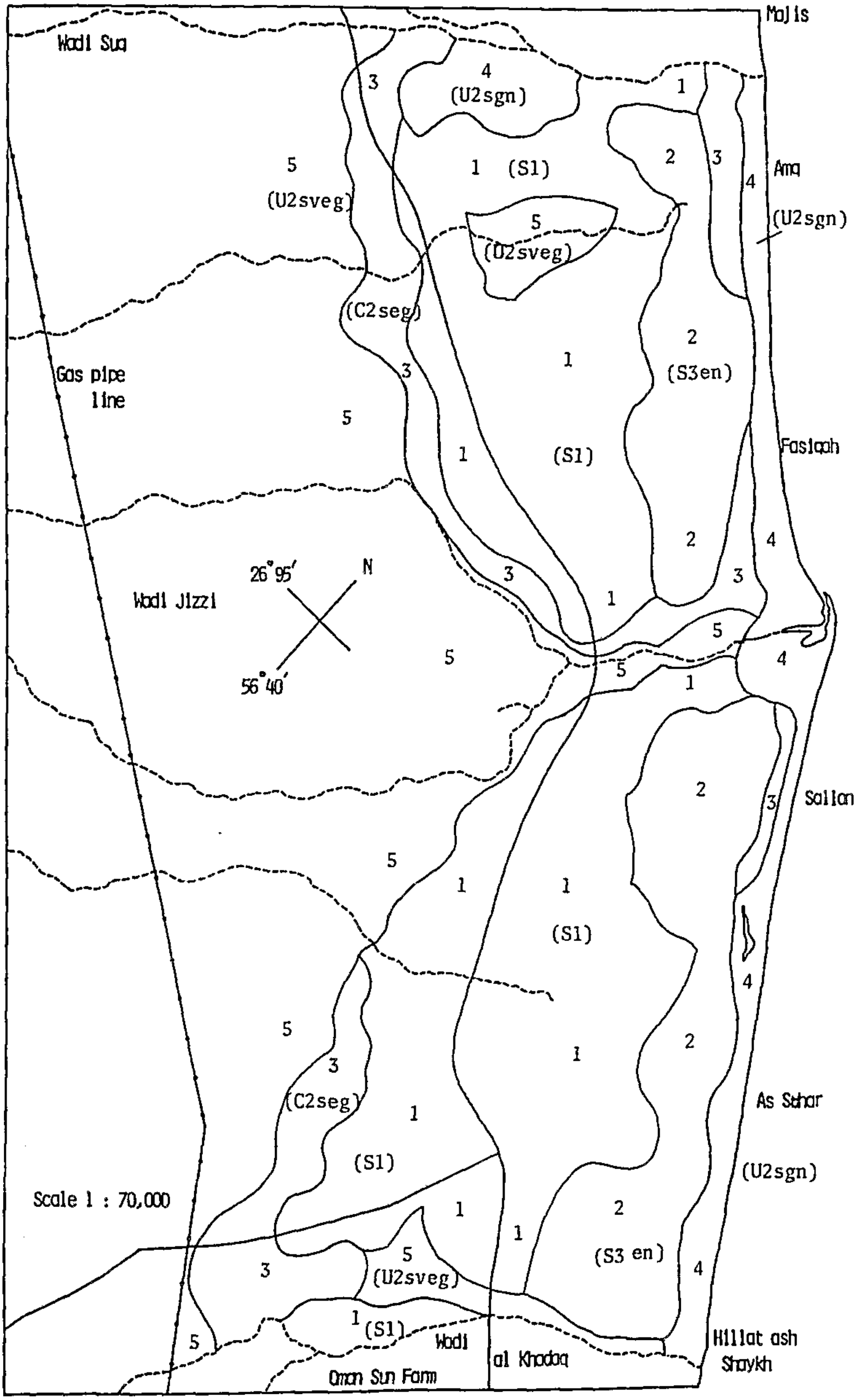


FIGURE 3-13 LAND CLASS MAP OF SOIL TYPES IN WADI JIZZI PROJECT AREA

Table 3-14 Area and Land Evaluation of Soil Types in Wadi Jizzi Project Area

Land Suitability	Class and Sub-class	Soil Type No. (Class order)	Area (ha)	Area (%)	Major land improvements required: Intensive levelling	Major land improvements required: Leaching of salts	Potential suitability 1/ Tree crops: Dates	Potential suitability 1/ Tree crops: Fruit crops	Potential suitability 1/ Field or forage crops	Potential suitability 1/ Vegetable crops
Highly suitable	S1	2,4,5 (1)	4,020	29.0			xxx	xxx	xxx	xxx
Marginally suitable	S3en	1 (2)	1,720	12.4		x	xxx	x	xx	x
	Sub-total		5,740	41.4						
Conditionally suitable	C2seg(t)	7 (3)	1,180	8.5	x				x	xx
Permanently unsuitable	U2sgn(t)	3,8 (4)	850	6.2						
	U2sveg(t)	6,9,10 (5)	6,080	43.9						
	Sub-total		6,930	50.0						
	Total		13,850	100.0						

1/ Remarks: x low; xx medium; xxx high

with the irrigation water sources has been a long cherished program in Oman to increase food production.

1) Existing Reports

O' the Sohar areas, the land suitability survey was carried out by ILACO as one of the serial works in the Batinah Coastal Plain for six months (1973 - 1974). The results were summarized in 1975 as shown in Figure 3-14. Taking the Wadi Jizzi as a center part, the area was divided into nine suitable subclasses, three conditionally suitable, and three unsuitable ones. In the following semi-detailed soil surveys, the area situated between two small wadis near Sohar town was subjected to pit borings at a rate of one pit per 50 ha. The total acreages surveyed were around 3,200 ha, out of which 1,600 ha of the uncultivated areas were evaluated as suitable classes for the future agricultural development.

In 1976 the FAO reviewed the data obtained by four consulting firms on the soils and the water management in Oman (Field Document No.4). In the document approximately 9,000 ha of suitable lands were identified to be developed; 4,000 ha on the Batinah coast in the Saham, Sohar, and Wadi Bani Kharus districts. In the Sohar district about 770 ha under Class S1 and 200 ha under Class S2 were expected to be developed according to the ILACO's report mentioned above.

Similarly, in 1977 a FAO's soil expert carried out a comprehensive soil study on the existing government production farms in the Batinah region, in which the expert evaluated the land suitability of the Sohar New Project Area. The relevant area is shown in lower part of Figure 3-15 together with the former objective area. Laboratory analyses of the soil chemical properties were also made at Rumais Agricultural Research Station. The report (FAO, OMA/77/001) paid special attention to farming practise and fertilizer dosage from the viewpoint of the nutrient status of soil and well water.

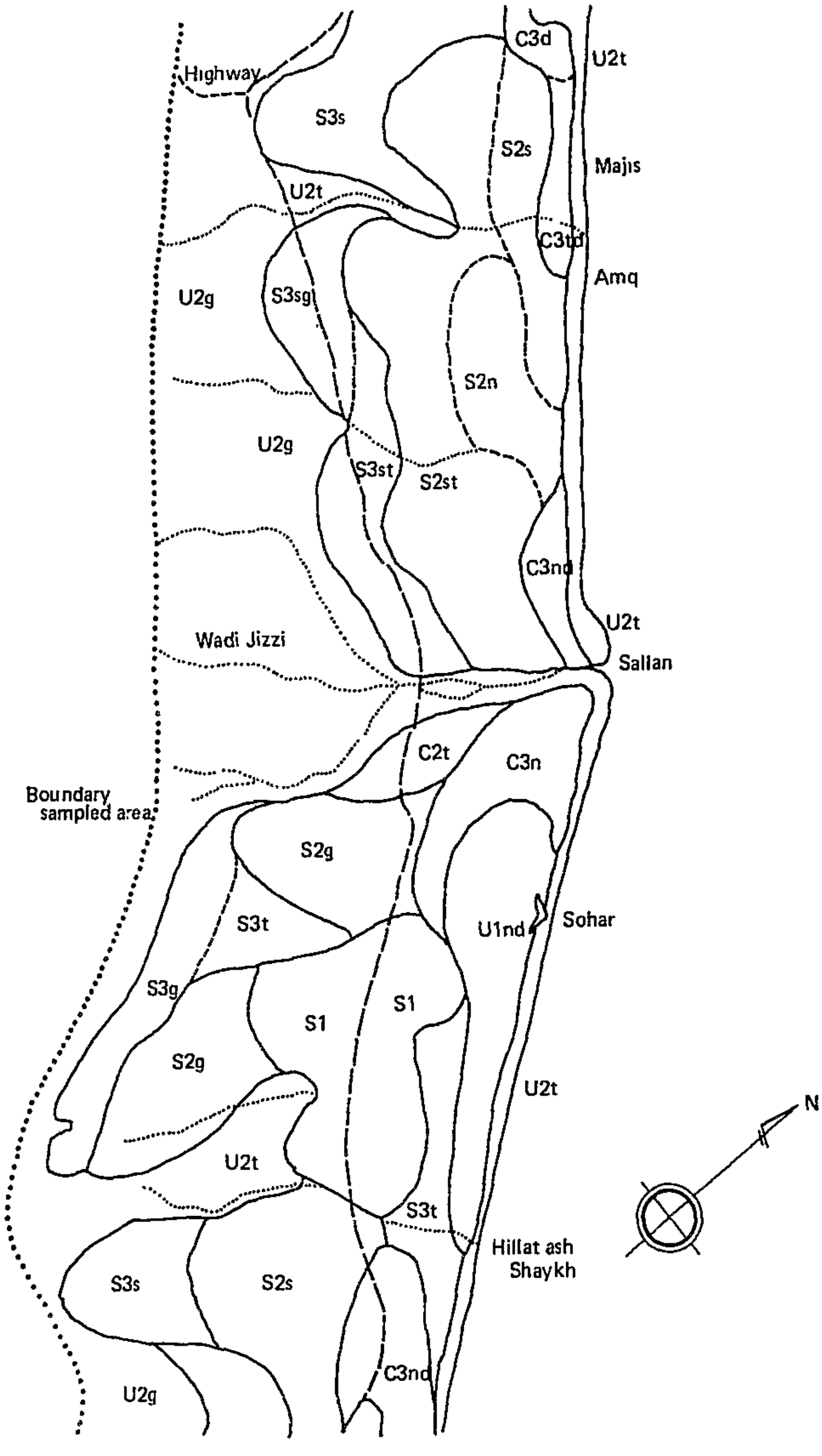
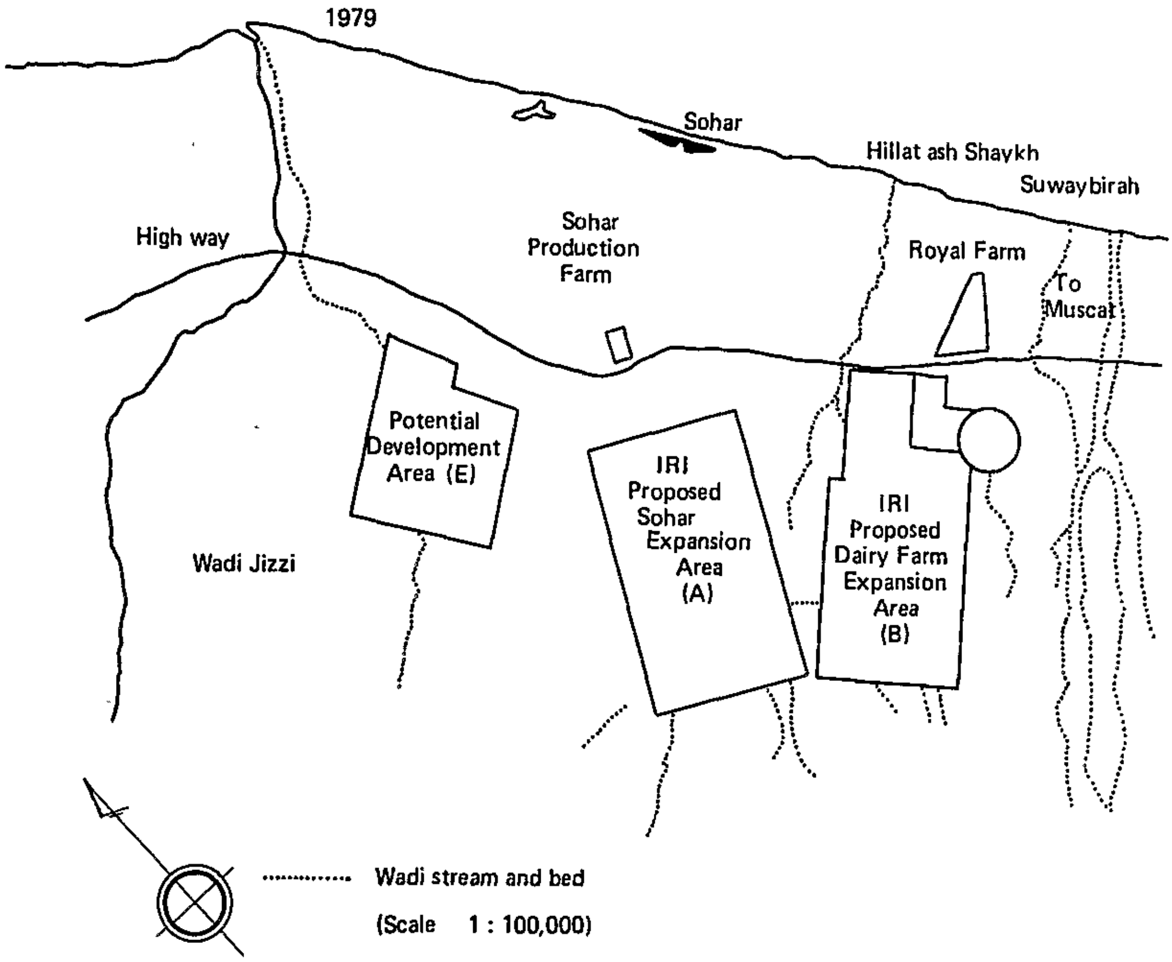


FIGURE 3 – 14 LAND SUITABILITY CLASSES FOR IRRIGATION REPORTED BY ILACO (1975)
– SOHAR AREA –



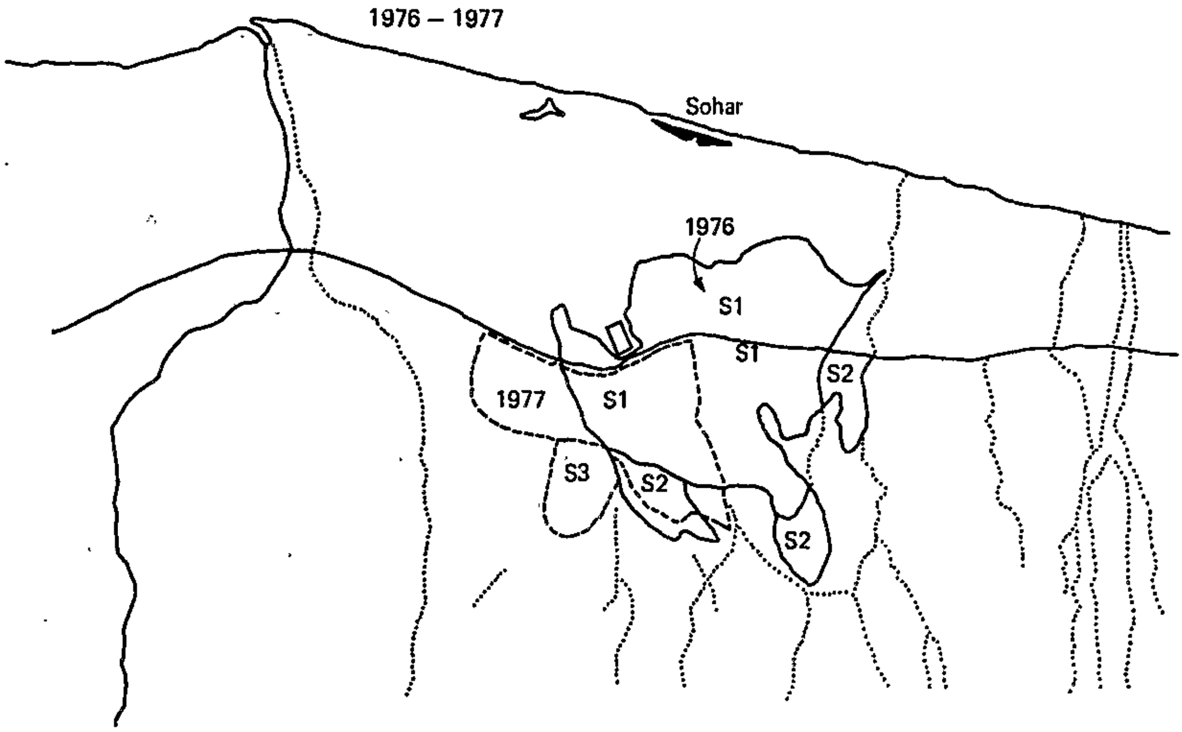


FIGURE 3 – 15 FORMERLY PROPOSED DEVELOPMENT AREA IN SOHAR DISTRICT (1976 – 1979)

More recently in 1979, the FAO Project (OMA/77/001, Field Document No.12) also presented a map of the proposed development areas in the Sohar district, and the document was compiled from the former reports as well. The areas are outlined in the upper part of Figure 3-15.

These soil survey and land development planning on the Sohar area have been thus focussed on the southern area of the Wadi Jizzi, crossing the National Highway (Muscat - Sohar road) and stretching up to the sites of the Oman Sun Farm and Royal Farm. In fact, the Oman Sun Farm has been expanded to 550 ha according to these recommendation.

2) Present Study

(a) Project Area

In the present study it is emphasized that the survey would cover the north of Wadi Jizzi upto Amq.

However, the net extent of the lands available for agricultural development is much less than expected since most of the lands under Class order-2 lands (S3en) and nearly a half of those under Class order-1 (S1) have been used for farms and houses. Only around 60 percent of the lands under Class order-3 remain undeveloped due to their gravel properties. Figure 3-16 illustrates these net lands to be available for development. Their acreages in four sections are measured and summarized in Table 3-15.

The most promising areas (S1) existing in groups are found both in the east and the west of the highway, being separated on the left and the right sides of Wadi Jizzi, respectively. These lands amount to 1,586 ha in total.

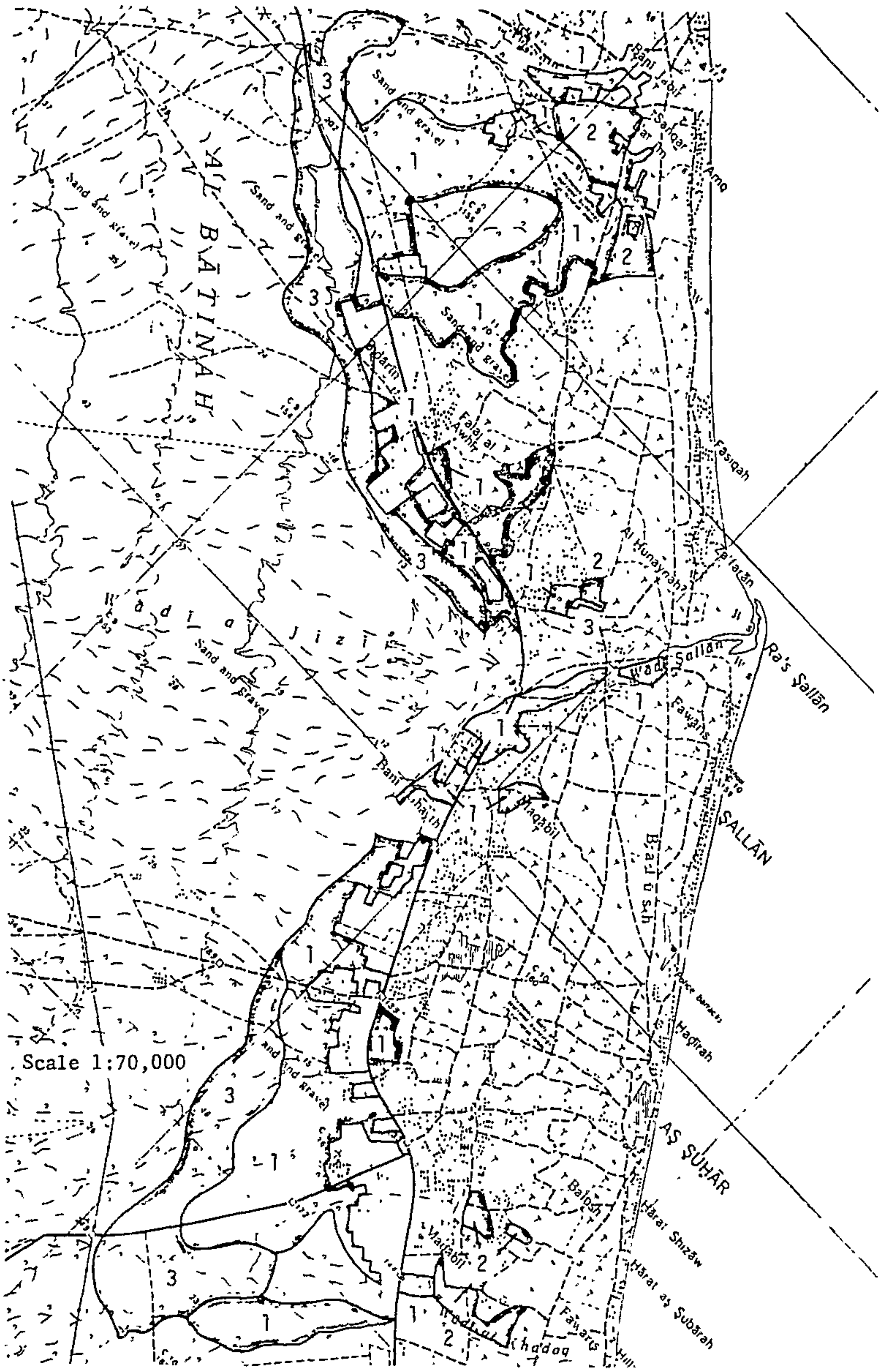


FIGURE 3-16 DISTRIBUTION OF SUITABLE CLASS LANDS YET-UNDEVELOPED IN THE PROJECT AREA

Areas are circled by grey color frame.
Numbers, 1-3, show the Class order.

Table 3-15 Net Hectarages of Extensionable Lands in Wadi Jizzi Project Area

(Unit : ha)

Areal Section		Land Class 1 (S1)	Land Class 2 (S3en)	Land Class 3 (C2seg)	Total
Left Side of Wadi Jizzi Stream	Westward of the Highway	132	0	327	459
	% of Class Area	47.1	0	93.4	
	Eastward of the Highway	643	169	7	819
	% of Class Area	48.3	25.2	1.9	
	Area Total (ha)	775	169	334	1,278
Right Side of Wadi Jizzi Stream	Westward of the Highway	702	0	410	1,112
	% of Class Area	65.6	0	100.0	
	Eastward of the Highway	109	63	0	172
	% of Class Area	8.1	6.0	0	
	Area Total	811	63	410	1,284
	Area All Total	1,586	232	744	2,562
% of Total Class Area		39.5	13.5	63.1	37.0

Note : Net area is vacant land excluding those already used as farms and residences.

Considering the progressing land encroachment year by year by the construction of new farms and dwellings in this area, the agricultural development should be planned systematically without any delay. This is particularly so with the dwellings which have invaded the vacant land kept intact.

(b) New Extension Area

In the present study, the westward of the highway on the right side of the Wadi Jizzi is directed to a new extension area from viewpoint of the limited water resources, other technical problems, and social circumstances as well.

The area is scheduled to be provided is 100 ha, situated at Al-wagabeh along Hibi Gravel Road. According to the results of the past and present soil surveys covering the area where six pits and 10 bores have been examined around the site, distribution of Soil Types was mapped again. Figure 3-17 has the revised map scaled at 1:10,000. As a result, there are some changes seen in the border lines and newly set-up of Type 5 which is not shown in the general soil map of the area (see Figure 3-12). Land Suitability Classes of these Soil Types existing therein are as follows:

Soil Type No.	Land Class	Texture (Upper 50 cm)-(Lower 50 cm)	Sand or Gravel Layer (%)	Salinity
2	S1	SiL/SL - SiL	0 - 3	Slightly saline
4	S1	SiL - SL	0 - 3	Very slightly saline
5	S1	SL - SL/LS	0 - 10	Very slightly saline
7	U2seg	SL(LS) - LS(S, G)	0 - 10	Non saline

Although most of the soils are classified into S1, their properties are not always best in texture, permeability, and

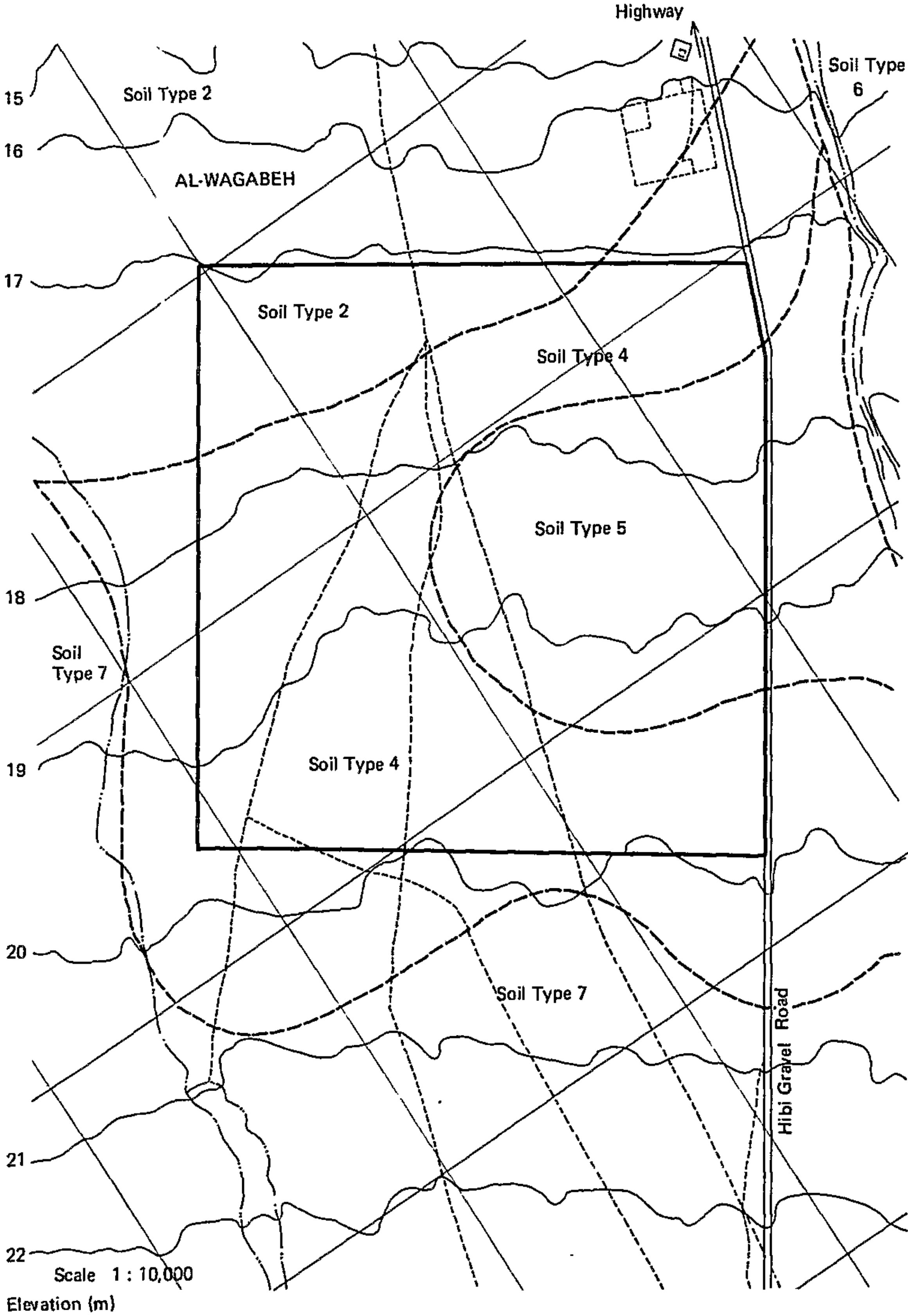


FIGURE 3 – 17 NEW EXTENSION AREA PROPOSED AND SOIL TYPES IN ITS VICINITY

fertility. These will be referred to in the next paragraph. An intensive survey must be carried out on the farm establishment including the correct distribution of the soils.

3.4.5. Problems and Recommendation

The soils of the Batinah Coastal Plain are in general infertile and more or less have a saline and/or alkaline property, since they have developed recently on the coarse alluvial deposits without any structural differentiation and any accumulation of organic matter under the supply of weathered products derived from basic rocks and the hot and arid climatic conditions. Those found in the Project Area are not an exception, being unable to escape from these problems.

a) Soil Salinity

As a result of the land classification (Table 3-13), Soil Types 1 and 3 have a fairy high salinity of the soils, prevailing on almost all existing farm lands. Poor growth of farm dates is in fact observed in some places near the sea coast, and among thick farm areas in the far inland whatever would cause the damage. In spite of lack of evidences, most of the survey reports have suggested the threat of saline intrusion which might result from local "upcoming" of the sea water, and the cause has been assumed to be over-exploitation and over-draft from the whole aquifer.

Since a high soil salinity was found in the coastal strip areas under long time cultivation, Gibb and ILACO concluded in their Final Report (1975) that a delicate equilibrium has to be maintained between the pumpage of groundwater and the penetration of sea water. They also suggested that the results of the soils and water resources studies would favour a future development in which irrigated farms are gradually relocated from the agricultural strip along the Batinah seashore to the new one a few kilometers inward. Such comment is questionable, however, from the following reasons so far as the present survey results are concerned.

i) Poor growth of dates was found only in the farms under unfavourable water management in the problem area.

ii) The soils of the well-managed farms do not show any evidence of salt accumulation even if high saline well water indicating more than 1.5 mmhos has been used for long time.

iii) Such high soil salinity as measured in the survey can be decreased to the level below the critical value (4 mmhos) by means of leaching procedure using sufficient well water under reasonable soil management.

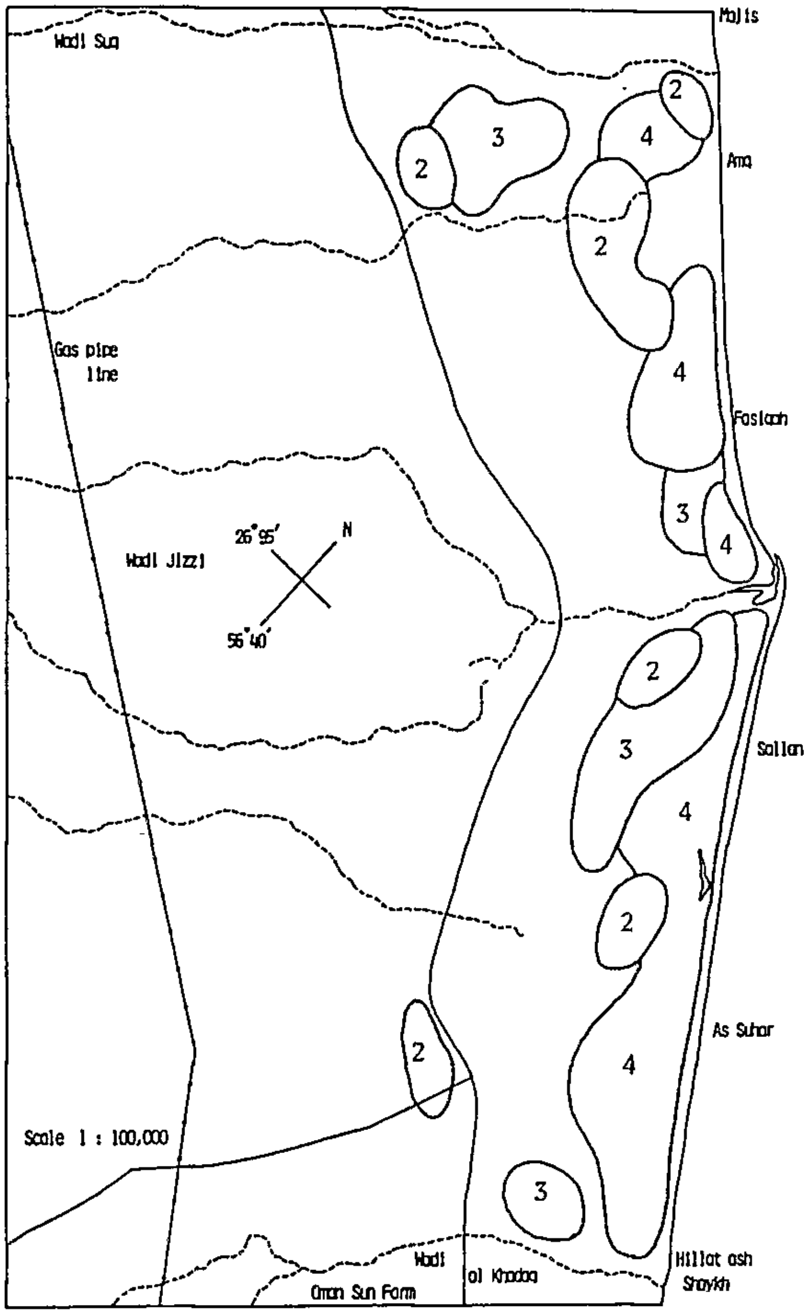
Reservation of the old farm lands is, therefore, of first importance because most of them had been reclaimed long before by farmers providing the best quality soils of fine textures. It is, therefore, quite necessary to obtain additional water resources by reserving the underground streams of the wadis.

It is hard to deny that the salt damage may be a potential danger along the Batinah coast. A periodical monitoring of the soil salinity by EC measurement, in extracting the water of the soils must be scheduled as has been carried on in the Rumais region.

The areas requiring intensive monitoring identified by the current study and ILACO's survey are shown in Figure 3-18.

b) Irrigation Water Quality

In irrigated agriculture, quality as well as quantity of the irrigation water is of the greatest significance. Similarly, as in the other areas in Batinah Region, the present agriculture and the future expansion can not change definitely the position of relying all of the water sources on wells and Aflaj from which groundwater



Legend: Grade EC, mmhos/cm at 25°c

Grade	EC, mmhos/cm at 25°c
1	< 4
2	4 - 8
3	8 - 16
4	> 16

FIGURE 3-18 DISTRIBUTION OF SOIL SALINITY TO BE MONITORED IN WADI JIZZI PROJECT AREA

has been obtained.

Almost all well water samples found saline to some degree according to the present survey. Especially in the coastal and "Sebkha" zones, the EC values frequently exceed 2 mmhos, far beyond the commonly accepted criterion of 0.75 mmho. In one farm at Al Zafarah, 4.6 mmhos was recorded of the well water, where very poor growth of date palms and other fruit trees were observed.

According to a rough estimation, the extent using irrigation water having the EC value over 0.75 mmho will amount to one third of the whole coastal zone covering most of the existing farms. On the wadi-gravel plains, west of the highway, salinity is very low except at the side of Oman Sun Farm probably due to the bigger pumping after its establishment.

Thus, unless continuous vigilance is taken, the deterioration of soils will be a threat to the expansion of agriculture. This also requires a monitoring system of irrigation water together with soil salinity. Simultaneously, sufficient linkage of the irrigation canals with the drainage systems must be facilitated.

The detailed chemical analysis of the groundwaters mostly taken from the gravel plain during the Second Stage Study has been reported in Appendix C, confirming moderately good quality for irrigation use. Their EC values range from 0.4 to 1.0 mmho. Cation status is characterized by the predominancy of magenesium followed by natrium. As a result, SAR values are very low, being from 1 to 3. The water quality is ranked at C2-S1 of USDA Criteria and presents no problem for long time irrigation so far as its source is gained from the groundwater running under the wadi bed area and the irrigation facilities are sufficiently equipped in newly extended farms.

c) Soil Alkalinity

So far as the surveyed soils are concerned, very high pH of more than 8.5 prevails all over the Project Area. This is quite remarkably observed in the Sebkha silt loamy area, often revealing extremely high pH of more than 10 in the subsoils. Particularly in the finer textured soils, sodium-rich water will react with their clay particles, cation exchange complexes, resulting in a high exchangeable sodium percentage (ESP).

Such cases have a close relation with the sodium status of the water, called sodium adsorption ratio (SAR) which classifies the water for possible alkalinity hazard. There are so many evidences reported on the other places of the world, where irrigated agriculture using high SAR water has suffered from the clay dispersion resulting in a poor permeability with subsequent lower productivity. Consequently, water quality should be analyzed chemically for each source, and alkalinization of the soil will be the second subject of monitoring survey.

d) Soil Fertility

Poor nutrient availability has been pointed out for the overall Oman soils. The soils of the Sohar area are not an exception. Although no national level survey was carried out, a few reports have dealt with laboratory analysis of the soil samples taken from several soil pits. These data are given in Appendix E.

Most of the analytical values pertaining to the fertility are rated low or medium except available potassium. The overall subsoils are poor in nutrients except for calcium and magnesium.

Such being the case, not only chemical fertilizers but also organic fertilizers such as compost and cattle manures are highly recommended. In case of chemical fertilizers, split application or combination of a drip or sprinkler irrigation must be practiced since the soils are in general very low in water and nutrient holding capacity and high in permeability due to the coarse texture and small cation exchange capacity (CEC).

Considering extremely high pH of the calcaric soils prevailing in the Project Area, physiologically acidic fertilizers like ammonium sulfate can be better used.

Another concern must be given to micro-nutrients which can be studied in the Research Stations. One problem is pointed out on their low content or scarce availability of zinc, copper and manganese due to the high alkalinity of the soils. Content of active manganese seems very small as estimated by the reagent test in the survey.

Excess of boron was, on the contrary, anticipated by El-Attar (1977) on the Sohar Production Farm where one of well water showed a high content of boron of more than one ppm, the inhibitory concentration to plant growth.

Study of micro-elements needs to be carried out in the near future for this area.

e) Soil Management

In the saline farms, a special care has been taken extensively as well as empirically in selecting crops based on their salinity tolerance. If surface soil salinity becomes over 16 mmhos, the field must be leached inevitably, being followed by intense and frequent irrigation.

With regard to the usual soil management, plowing should be done carefully after soaking the dry soil with an adequate humidity which may decrease the soil consistency. Frequent plowing is not recommended because it will destroy the weak structure and aggregates. Sometimes deep plowing is effective to improve permeability of the subsoils when they are silty and hard cemented.

3.5. Human Resources

Human resources are one of the key factors for the development of industry. In Sohar, the industry which employs a greater part of human resources is the agricultural sector. The stabilization of the annual productivity will support the farming population.

Because of little annual rainfall with heavy fluctuations, the agriculture in Oman does not rely directly on rainfalls, but on groundwaters. It is said that one or two comparatively wet years in five years can restore the groundwater which is decreased due to a little rainfall.

The traditional family farm in Sohar has been managed by family labor to maintain the standard of living. The surplus labor in the family has been supplied to other industries.

In general, as a result of the rapid expansion in the economic activity since 1970, the labor demand in Oman has exceeded the local supply of manpower. Consequently, the Oman industries have had to rely largely on imported labor. The number of work permits issued by the Directorate General of Labour Affairs indicates that the non-Omanis working in the private sector increased from about 87,000 persons in 1976 to about 130,000 persons in 1980, of which workers in agriculture and animal husbandry increased to about 6,300 from 1,100.

The similar observation has been made for the human resources in the rural area of Sohar.

On the other hand, the Omanis have been for centuries trying to work abroad to earn money. At present the Omanis leave their villages to serve in the army or work for the industries in the oil states of the Arabian Gulf.

3.6 Present Agriculture

3.6.1. Land Use

The Project Area, with Sohar as a center of the Area, i) comprises the farm lands extending five to three kilometers wide and about 17 km long along the coastal line from Majis in the north to the Wadi Al Khadaq in the south, ii) non-farm lands and iii) proposed reclaimed lands there-around. The Project Area covers the land area of about 3,830 ha.

As for the present land use in the Area, the lands extending in strip between the coastal line and the highway running north to south are almost covered with date palm trees, which have been growing for more than 30 years. Some farms have been growing vegetables in the spaces among those palm trees.

In the west side of the highway, there have been many new farm lands developed for growing vegetables and tree-crops.

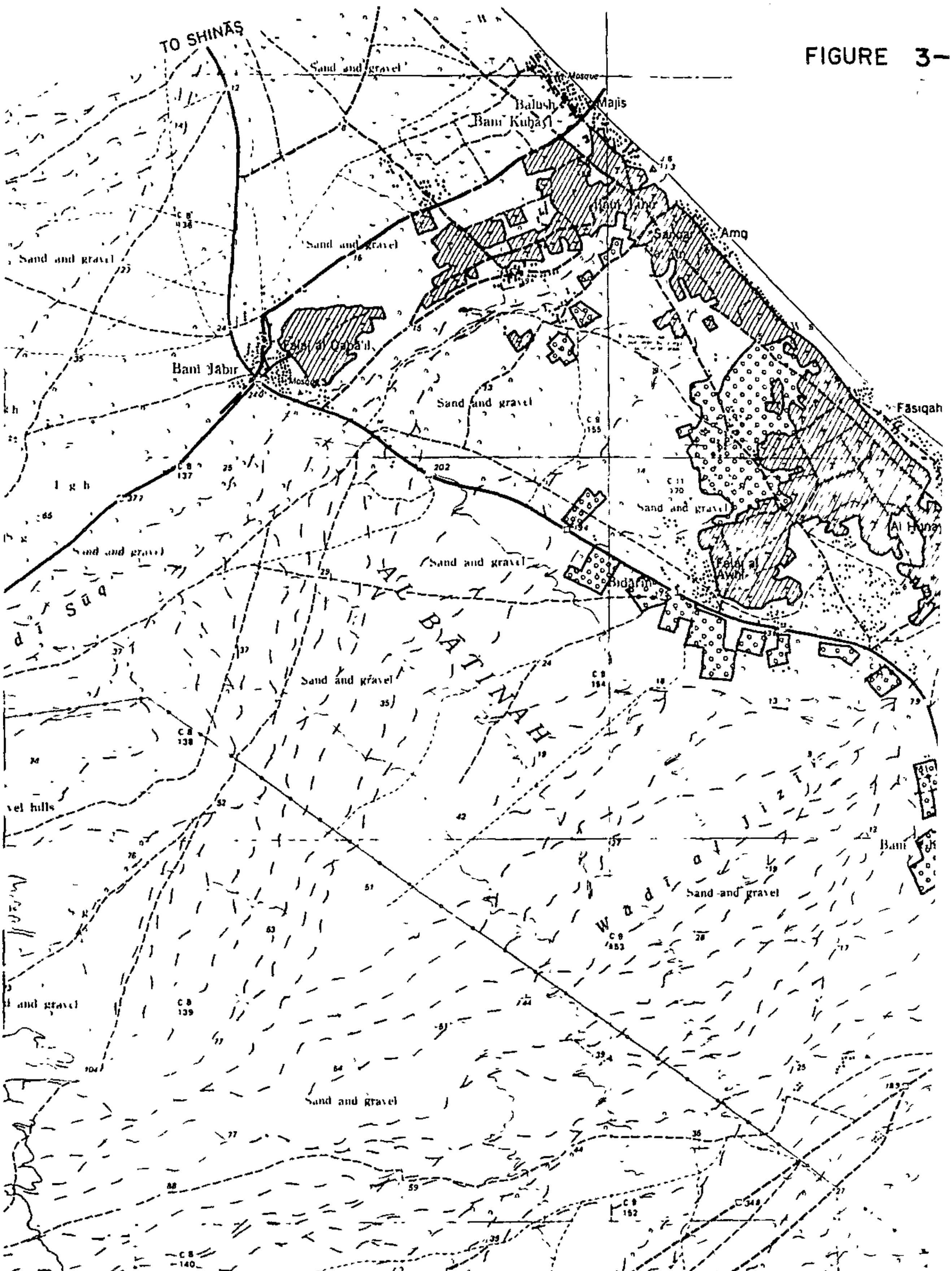
The present land use of the Project Area is classified as fallows, and this area was estimated on the basis of 1:10,000 aero-photographs prepared by B.K.S. in 1978 and 1:6,000 topographic map prepared by Ministry of Land Affairs and Municipalities.

Present Land Use

Items	Acreage
Orchards	2,340 ha
Uplands	300
Sub-total	2,640
Non-farm lands	1,190 (including proposed reclaimed lands)
Total	3,830 ha

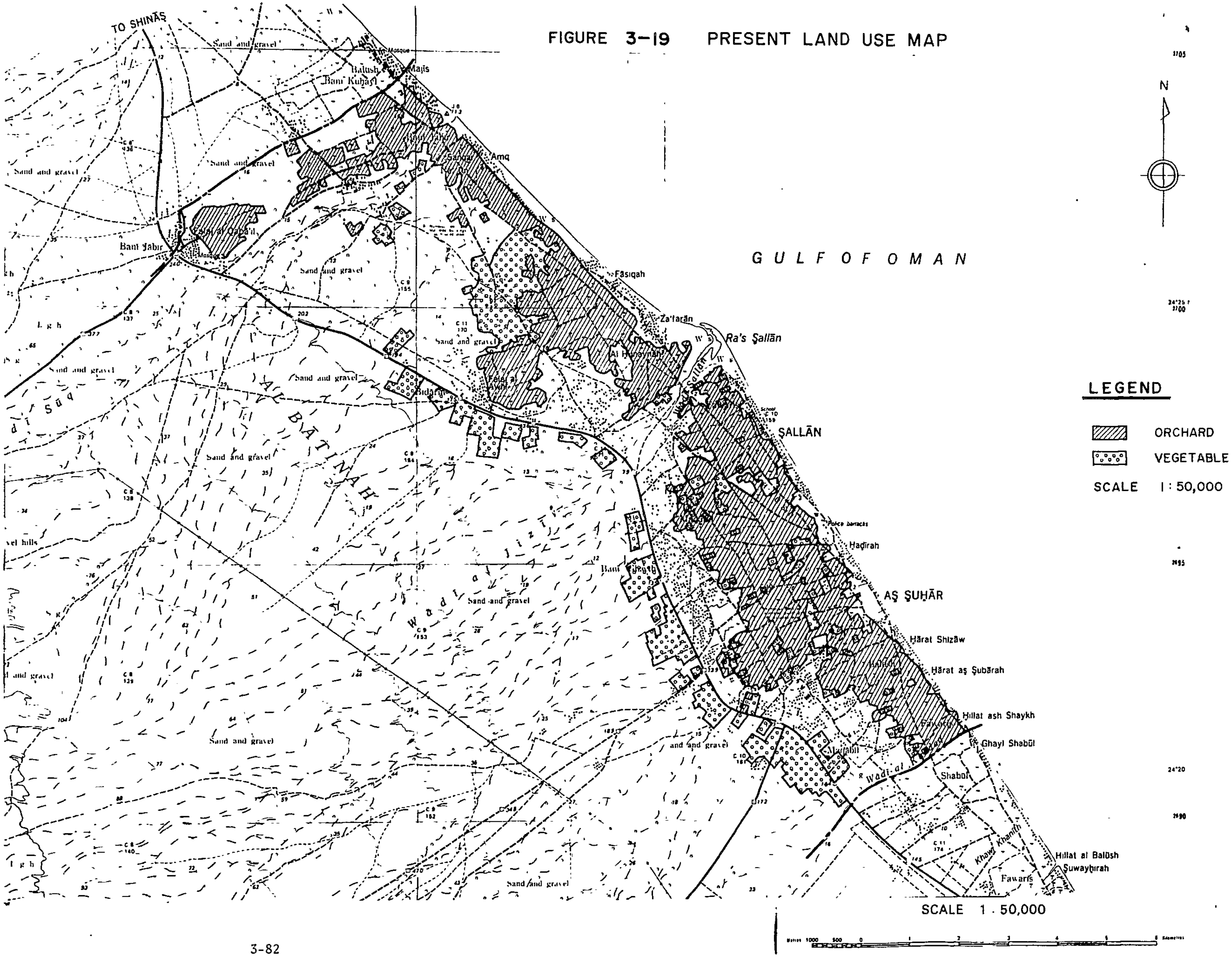
Figure 3-19 indicates the present land use in the Project Area.

FIGURE 3-



TO SHINAS
Sand and gravel
Mosque
Balush
Majis
Bani Kuhas
Amq
Bani Jabir
Mosque
Fasiqah
AL BATINAH
Wadi al Jizi

FIGURE 3-19 PRESENT LAND USE MAP



3.6.2. Water Use

a) Irrigation Condition

The existing cultivated areas in the Project Area were estimated at 2,640 ha out of the total cultivated area of about 4,420 ha in the Wilaya Sohar.

The prevailing irrigation methods in these areas are classified into the following three; i) basin irrigation, ii) border-strip irrigation, and iii) furrow irrigation. The basin irrigation is adopted for tree crops such as dates, limes and mangos, the border-strip irrigation for feed crops like alfalfa, misilba, and the furrow irrigation for vegetable crops. Besides these surface irrigation systems, pipeline, drip, and sprinkler irrigation methods are partly used for the vegetables or feed crops in the limited small area along the highway.

Under these circumstances, very low irrigation efficiency of 30 - 40 percent is considered as one of the most serious problems from the viewpoint of effective use of the very limited and precious water resources in the country. Most of the loss occur through deep percolation and evaporation partly due to poor canal conveyance systems and partly due to over-irrigation.

The annual irrigation demand for the areas of 2,640 ha was estimated at 21.1 MCM, taking into account the present cropping pattern, cultivated area and crop consumptive use of water estimated by theoretical method such as modified Penman and the modified Blaney-Cridle methods (refer to Appendix G-1).

b) Water Quality

The irrigation water quality was analyzed at Rumais Agricultural Research Station with water samples taken at five sites, the locations of which are illustrated in Figure 3-6. The results of the analysis are shown in the following table.

Results of Water Quality Analysis[1/]

Item		Analyzed Value
PH	:	7.4
EC	:	558.7 mhos/cm (at 25°C)
T.S.S.	:	357.6
Cations		
Na	:	1.93 me./lit
K	:	0.08 me./lit
Ca	:	0.83 me./lit
Mg	:	3.15 me./lit
Total	:	5.40 me./lit
S.A.R.	:	1.40 me./lit
Anion		
CO_3	:	0.55 me./lit
HCO_3	:	2.14 me./lit
CL	:	1.94 me./lit
SO_4	:	0.66 me./lit
Total	:	5.18 me./lit

Note: 1/ The values quoted herein are the averages of five samples

The detailed figures are shown in Table G-9, in Appendix G-2.

On the diagram of irrigation water classification (see Figure G-2 in Appendix G-2), the sampled waters belong to the classification of C2 - S1 and C3 - S1 with an average of C2 - S1 classification. Medium salinity water (C2) can be used for farming if leaching is conducted reasonably. Plants with moderate salt tolerance can be grown in most cases without any special practices for salinity control. On the other hand, with respect to Sodium, low-sodium water (S1) can be used for irrigation for almost all soils with little danger of the development of harmful level of exchangeable sodium.

Accordingly, it has been proved that the groundwater in the Wadi Jizzi Plain can be used for irrigated agriculture with most crops on most soil with little likelihood that soil salinity will develop, but some leaching will be required.

c) Drip Irrigation Practised in Oman

Drip irrigation, having only short history in Oman, is not so commonly used except for those farms of Remais Experimental Farm, Agriculture College at Nizwa, Experimental Station at Jebel Akhdar, Salalah and Qairaon Herithi farms, and Al-Wahaibi Farm in the Project Area.

In the Agricultural College at Nizwa the drip irrigation for tree-crops has started in this year 1982 with modern equipment of fertilizer mixing for liquid fertilizer dosing. The liquid fertilizer dosing device will be equipped with irrigation system for vegetable cropping.

The Al-Wahaibi Farm is the vegetable farm where the pipeline networks covering about 34 ha of lands are provided for the cultivation of melons, tomatoes, cabbages, cauliflowers, etc. And the detailed records and data of the survey/research on such irrigation practices have not been available yet.

The appropriate technology of the drip irrigation, however, is expected to be transferred and diffused to the farms through the graduates of the Nizwa Agricultural College.

3.6.3. Farm Household and Population

The number of farm land owners in Wilaya Sohar is about 3,500. This figure can be considered as the number of farm households in the Area. An average population per household is 7.1 persons. On the other hand, the average in Batinah region including the capital, Sceb, and eight Wilaya is 7.4 persons. The farm land area of holder in Wilaya Sohar is about 6,500 ha. The typical farm size per farm household in Sohar is 1.8 ha whereas 2.3 ha in Batinah region. But this farm land is not fully cultivated. The acreage cultivated with seasonal crops and perennial crops occupies 68 percent of the total farm land of about 6,500 ha in Wilaya Sohar while the equivalent figure in Batinah regions is 45 percent.

The farm population density in Wilaya Sohar is 3.9 persons per hectare for the total farm land and 5.7 persons per hectare for the cropping area. In Batinah region, the former is 3.2 persons and the latter 7.1 persons, respectively. This means that the supporting capacity of farming population in Sohar is larger than that in Batinah region.

3.6.4. Agricultural Production

a) Cropping Pattern

The Project Area has the two seasons of winter from November to March and summer from April to October. In winter temperature is low and most rainfalls in a year take place. Under the conditions, crops are grown in this season when rain water is available.

Dates, the major crop in the Project Area, are grown in about 69 percent of the total farm lands of the Area.

Other tree-crops grown in the Area are limes, bananas, mangos, etc. The date palm trees, some of which were planted as long as about 50 years ago, are growing in the area extending along the seashore where the groundwater table lies considerably high. The other fruit-trees are comparatively young in age.

Upland crops, inter crops of the dates cropping, are now raised in newly reclaimed upland fields with pumping facilities. Pumps have been introduced into Batinah since more than 25 years ago to facilitate irrigation water supply to upland crops like vegetables and feed crops.

In parallel with the development of upland fields, new orchards have been opened up to grow limes, bananas, etc. Bananas are commonly planted in the farm areas but rarely grown in the orchards.

Onions, garlics, tomatoes, etc. are the major vegetables grown throughout the year excepting the three hottest months of June, July and August, and generally single vegetable cropping in a year has been practised in the Project Area. Such low rate of land use night would have resulted from the shortage of irrigation water as well as of labor forces.

Alfalfa and sorghum are grown as feed crops for the silage use. Sorghum can be harvested two or three times a year.

b) Cultivation and Cultivated Area

The Project Area has an extremely high temperature with little precipitation in summer whereas a comparatively low temperature with a little precipitation in winter. The annual precipitation is about 90 mm on an average. The soils of the farm lands mainly consist of the silty loam and sandy loam.

Agriculture in the Project Area is under the administration of the North Batinah Office of the Department of Agriculture, and the extension division of this office is responsible for diffusion of the farming techniques. However, having a jurisdiction as large as about

13,300 ha, the office has not been able to render the sufficient and appropriate services to farmers.

The crop-wise Standards of Cultivation have been prepared by the office for successful guidance of farming techniques to the farmers. (see Table 3-16)

Each farmer purchases necessary farming inputs from the said office.

The statistical data prepared by the North Batinah Office revealed that the fertilizers used in the Area in 1978 were 256 tons of, ammonium sulphate 365 tons of compound fertilizer, and 112.1 tons of phosphate. The dosing amount of these fertilizers in total was estimated at 55.2 kg/ha, which is far below the amount prescribed in the above-mentioned standards of cultivation.

The plant protection, in principle, is carried out by the office in reply to the request of the farms. The pest-control, however, is not always made sufficiently and effectively due to the shortage of sprayers and labor, and about 30 percent of the farmers have sprayers and other necessary equipments purchased from the office or merchants so as to protect the plant by themselves.

As for date palm orchards, the Ministry of Agriculture carries out plant protection once a year by helicopter spraying free of charge.

The pumps are most commonly used to lift groundwater for irrigation, and some aflaj are used as the irrigation water sources. The basin irrigation has been employed for tree-crops and alfalfas while the furrow irrigation for the other crops except for the drip irrigation for some of them.

Since a considerable amount of water is required for the irrigation in the Area, the present irrigation method should be

Table 3-16 Standard of Cultivation

Crops	Seed (kg/ha)	Density	Fertilizer (kg/ha) Basal	Fertilizer (kg/ha) Topdressing	Plant Protection (per hectare)
Alfalfa	36	broadcast	manure	com.[1/]	Dimethoate 40EC 2.4^{ℓ} 12 times
			$10-20^{t}$	476 (4 times)	after cutting 10 days
Tomato	Seeding	0.6×0.9^{m}	$10-20^{t}$	com.	Diathane-M 45 3kg } mix 2
	0.6			1. 240 after 3w. after	Dimethoate 40EC 600cc single 1
	(pot)			2. 240 flowerings	Kafil 1^{ℓ} 2
				3. 240 small fruit	Dec. - Jan.
Watermelon	2.4 - 4.8	0.7×2.5^{m}	$10-20^{t}$	com.	Only Summer
				1. 240 3 - 4 weeks after	Pirimor 700cc 2
				2. 240 flowering	Omit 2^{ℓ} 1
				3. 240 small fruit	first time mix
Eggplant	Seeding	0.7×0.8^{m}	$10-20^{t}$	com.	
	0.83			1. 240 3 weeks	Dimethoate 40EC 2^{ℓ} 2
	(pot)			2. 240 flowering	Kafil 1^{ℓ}
				3. 240 small fruit	
Cabbage	Seeding	0.5×0.75^{m}	$10-20^{t}$	com.	
	3.6			1. 240 3 weeks after	Kafil 1^{ℓ} 3
				2. 240 4 weeks after	Pirimor 700cc 1
Redpepper	Seeding	0.45×0.7^{m}	manure	com.	
	830g		$10-20^{t}$	1. 240 3 weeks	Dimethoate 40EC 2^{ℓ} 2 times
				2. 240 flowering	Nov. Dec.
				3. 240 small fruit	
Dates		9×9^{m}	$10-20^{t}$	com.	
				1. 240 Jan.	Nogos 3.7^{ℓ} 1
				2. 240 Feb.	Oct.
				3. 240 Mar.	
Lime		7×7^{m}	$10-20^{t}$	com.	
				1. 240 Jan.	Dimethoate 40EC 3.6^{ℓ} 2
				2. 240 Mar.	Apr. Sep. - Oct.
				3. 240 May	
Banana		2.5×3^{m}		com.	
				1. 300 Aug.	Furadam 20kg 2
				2. 400 Oct.	Nemacur 34kg 2
				3. 300 Nov.	
				4. 300 Mar.	
Sorghum	10kg	$0.7-1.0^{m}$		com. 600 basin	
				Urea 150 after cutting	
				(2 - 4 times)	

1/ com. : compound fertilizer

improved to meet the requirements.

c) Farm Mechanization and Labor

The Sohar district has been provided with the farming machinery of about 6,000 in number, including lift-pumps. (see Table 3-17) The farm lands of 2,640 ha in the Project Area are cultivated by various machines and equipments.

Water pumps, power-tillers, tractors, and sprayers are the main farm machines and equipments employed in the Project Area.

The office of the Department of Agriculture renders the services of mechanized plowing, crop protection, etc. in reply to the request of the farm owners. Recently, however, the present capacity of mechanized farming cannot fully cope with the works of the whole farms in the Area due to an increase in farm acreage resulting from rapid agricultural development, and some farm owners engage in the crop protection works by their own machines and equipment.

The farms managed by family labor only occupy about 60 percent of the total farms, while the rest is managed by the hired labors including full-time workers, part-time workers and temporary workers.

The weekly working hours of those hired labors were estimated at 31 hours on the annual average basis. The chronic labor shortage prevails and some farms are not adequately operated.

d) Agricultural Production and Value

The agricultural statistical data based on the 1978/79 census cover only the crop-wise cultivated acreages, and three crops of wheats, tobaccos and dates will be surveyed on their productions from and onward. Under the circumstances, the unit yield of the respective crop was estimated following discussion with authorities

Table 3-17 Present Condition on Farm Mechanization

Machinery	Type of Ownership					Owned	Total
	Ministry	Coop	Rented from Others	Supplied by Owner	Owned by Holder & Other		
Water pump	22	-	22	44	154	2,772	3,014
Power plow	704	-	22	-	-	-	726
Animal plow	-	-	616	22	-	396	1,034
Power sprayer	44	-	-	-	-	-	44
Hand sprayer	990	-	88	-	-	220	1,298
Total	1,760	-	748	66	154	3,388	6,116

Source ; The Census of Agriculture 1978/79 concerned in the Ministry of Agriculture and Fisheries, the agricultural experimental farms, etc. The low unit yield is attributed to the low level of agricultural technology, and the shortage of various agricultural inputs, labor, and machinery.

The total agricultural production was roughly estimated to be about 9,600 tons from 2,640 ha of the land.

3.6.5. Animal Husbandry

The animal husbandry production in the Wilaya Sohar ranks high in the country. Particularly, the Oman Sun Farm (Sohar and Salalah station) is the largest ranch in the country with 1,000 ha of the grass land and feed-crop fields. The numbers of milking cows at Sohar and Salalah are more than 300 head. The number of cows is planned to be increased to 500 head in future. However, average number of animals kept by an ordinary farm is small; 0.05 head of camels, 0.6 head of horses, 0.7 head of cattle, 3.4 head of sheep, 4.3 head of goats, and 4.8 head of poultry (see Table 3-18). These small farms grow feed crops and the considerable part of hay in the country are exported to the U.A.E., and concentrated feeds have not been produced yet in the country. Some of these animals are raised for their meat and the others are as draft animals.

3.6.6. Marketing of Products and Input Materials

Trade of Foods

The cultivation areas in Oman total to about 41,000 ha which involve those in the Batinah including Capital Area and Oman Interior, accounting for 51 and 13 percent, respectively.

The Agriculture Census of 1978 - 1979 reveal that the crop area cultivated in Oman were about 20,000 ha of dates, 2,000 ha of limes, 3,700 ha of alfala, 540 ha of onions, 1990 ha of bananas, and 2,960 ha of mangos and others.

Table 3-18 Livestock

Livestock	Whole Country				Sohar				
	(1) Holdings (farm)	(2) No.of Feeding (head)	(3) (2)/(1) (head)	(4) 1/ (2)/All farm (head)	(5) Holdings (farm)	(6) No.of Feeding (head)	(7) (6)/(5) (head)	(8) 2/ (6)/Farm (head)	(9) (6)/(2) (%)
Camels	814	1,452	1.8	0.07	154	176	1.1	0.05	12.1
Horses	9,284	11,946	1.3	0.59	1,672	2,244	1.3	0.63	18.8
Cattle	9,702	18,062	1.9	0.90	1,364	2,486	1.8	0.70	13.3
Sheep	8,250	43,978	5.3	2.18	1,276	12,254	9.6	3.44	27.9
Goat	13,310	105,996	8.0	5.27	2,200	15,334	7.0	4.30	14.5
Poultry	11,308	81,488	7.2	4.05	2,112	16,962	8.0	4.76	20.8

1/ All farm ; No. of whole country farms, 20,130 farms

2/ Farm ; No. of farms at Sohar, 3,564 farms

Source ; The Census of Agriculture 1978/79

The amount of food and livestock imported was 42 million R.O. in 1978, 53 million R.O. in 1979, and 73 million R.O. in 1980 while the export was 3.3, 4.7, and 4.5 million R.O., respectively, according to the Statistical Year Book, 1980.

Market Channel

The agricultural market in Oman provides the three types of the channels, i.e., producers, state farms, and importers. The channel of the producers includes 83,000 farmers, the state farms consist of eight production farms and two extension farms, and the importers are made up of supermarkets and whole salers. In addition to the above, there are the Oman Sun Farm, the Royal Farm and other commercial large farm. In 1980, a FAO consultant surveyed the fruits and vegetables in the market to find that about 52 percent of the products was dealt with by producers, only one percent by state farms and 47 percent by importers.

In general, the lack of wholesale market, market information, market research, the handling of products by importers, insufficient storage facilities without effective packaging or labelling practices, etc. have all caused the unsatisfactory marketing.

Agricultural products in the Project Area are marketed to the different places as follows.

Local Market

Sohar has retail markets of agricultural products along the coastal area. The farmers in the Project Area transport vegetables and fruits by their own vehicles to sell to retailers. This market also deals with products imported from the other regions and countries. The population of rural and urban Sohar areas was estimated at 11,000 persons. The markets are crowded with people during the shopping hours. As this town is under the urban development project, the growth of population in future would contribute to the expansion of market.

Vegetable and Fodder Crops

The distance from the Project Area to Dubai, the U.A.E, is less than that to the capital area, Muscat. Besides, the export tariff on agricultural produces is free in the U.A.E. The import tariff on fresh fruits and vegetables in Dubai and Abu Dhabi and on fodder crops in Dubai are also free. Thus, a part of agricultural products is readily exported to the U.A.E. Some commercial farmers in the Project Area cultivate large areas with fodder crops and export them to Dubai monthly. The Oman Sun Farm also exports the pretty volume of hay to U.A.E, while the milk is marketed to the Capital area. It is considered that the farmers having large farms of vegetables and fodder crops forward their products to Muscat or to the U.A.E., while the farmers having small farms to local markets. A large scale transportation is more economical than a small one. The regular supply of products in a large quantity is more profitable to merchants in Mascut and the U.A.E. According to the result of the farm management survey, the transportation cost by truck was about 11.0 R.O. per ton from Sohar to Ruwi and about 7.0 R.O. per ton from Sohar to Dubai.

The technical secretariat of the Development council prepared a survey report on marketing of dry dates, alfalfa and limes, as follows;

Dry Dates

Marketing of dry dates has a long history of trade with India. Dry and preserved dates exported were 348,000 R.O. in 1978, of which 290,000 R.O. was exported to India. In old days, trading companies bought dates from growers directly or through agents.

The Government has taken over the trading of dry dates from the private firms since 1974. A new royal decree in 1977 gave the responsibility in trading to many ministries, one of which is the Ministry of Commerce and Industry. The subsidy is given to the farmers as an incentive to encourage them to grow more date palms and to produce more dry dates.

The yield of dates in Sohar is low mainly due to the lack of water, soil salinity, and shortage of labor. The quality is also low due to a high humidity in summer. Dates produced in Sohar are mainly brought to domestic markets only.

Alfalfa

According to the result of the farm management survey, the marketing of alfalfa in the Project Area is considered to be made in the following pattern. The traditional family farm, raising several head of livestock, cultivates some acreage with alfalfa. Alfalfa grown in the farm fields is mainly fed to the livestock bred by the family and some sold when surplus is secured. The newly settled farmers who raise no livestock grow alfalfa in large fields for commercial purpose to export mainly to the U.A.E.

Dried Limes

The marketing of dried lime is made in three stages. The first is the farmers, the second is the middlemen in the local markets and the third is the exporters. The harvest period of limes is from July to September. The farmers pick limes and dry them up for a month in summer. The dried limes are sold to the imiddlemen. In Batinah area, there is a traditional dried lime handling center for the export in Saham. The dried limes are all exported to the U.A.E. The exported value increased from 1.0 million R.O. in 1977 to 1.5 million R.O. in 1979.

Input Materials

Fertilizer supply in Oman fully depends upon import. The imports are classified into manufactured fertilizers and crude fertilizers according to the Statistical Year Book, 1980, Page 131 - 132. The latter is re-exported. The fertilizers are supplied by commercial companies under the control of the Director of Extension Service, the Ministry of Agriculture. The imported fertilizers are stored in the warehouse of sub-agents under commercial companies. The supplies are drawn from the sub-agents by farmers directly through requisition slips granted by the local extension centers.

Prices

The Omani Government publish in the Statistical Year Book the consumer price index of food, beverage, and tobacco of the capital area. These indices were estimated on the basis of the average prices the period July - December 1978. The trend of commodity price fluctuation was studied with these indices from March, 1979 to June, 1981.

The prices of fresh and dried vegetables indicate a typical seasonal fluctuation, i.e., reducing during February to April, whereas rising during October to December every year according to the results of study on price index mentioned above. The consumer prices of these vegetables have been rising in recent years. The rate of increase is 1.4 percent in 1980 and 5.2 percent in 1981, respectively as compaed with the lowest prices in March of the previous year. The prices of fresh and dried fruits rose in the latter half of 1979, and have been stabilized since March, 1980. The prices of frozen vegetables rose by about 20 percent during December, 1979 through December 1980, and thereafter stabilized.

The 1980 Statistical Year Book shows the values and quantities of fruits and vegetables traded during the three years of 1978 to 1980. The unit prices per ton of exported fruits and vegetables are higher in these three years than those imported as shown in the following table.

Comparison of Unit Prices of Fruits and Vegetables Traded

Year	Item	Value ('000 R.O.)	Quantity ('000 tons)	Unit Price (R.O./ton)
1978	Import	9,637	42.5	227
	Export	2,074.2	7.44	279
1979	Import	9,835	34.0	289
	Export	2,693.2	10.83	249
1980	Import	14,397	45.9	314
	Export	1,635.3	4.11	398

Note: The export values are totaled by Omani original exports and re-exports.

Source: Statistical Year Book, 1980.

The prices of crops sold by farmers in the Project Area were studied in the farm management survey conducted by JICA survey team in January, 1982. The prices of vegetables and fodder crops vary with markets. The prices of fruits such as dates, limes, mangos and bananas were surveyed on products from the Production Farm, Sohar. On the other hand, the retail prices of vegetables and fruits in the retail stores in Ruwi and Muttrah were surveyed.

The following table shows both of the prices mentioned above. It should be noted that the differences come from time lag.

Good	Selling Price by farmer in Sohar (Production in 1981) (Baiza/kg)	Retail prices in Ruwi & Muttan markets (21 January, 1982) (Baiza/kg)
Cabbage	250	350 to 500
Tomato	100 to 200	250 to 300
Cucumber	250	600 to 800
Onion	100	270 to 300
Okra	250	500

3.6.7. Farm Economy

The farm economy in Wilaya Sohar in future is expected to be expanded through the Government development policy. There are, however, several basic problems. The first problem is an increase in part-time farmers and an outflow of young laborers from family farm, etc. The second problem is stagnation in the marketing. The third is a comparatively low cropping intensity.

The typical farm size of 1.8 ha has to support the farm household with 7.1 persons per family. The farmers' living standard has been improving rapidly and continuously. The stagnation of farm income increase, however, will restrain the improvement of their living standard.

Farm income level was learned from the results of the farm management survey. However, it was difficult to know the standard level of income because of the small sample size and the lack of official data. The outline of the farm economy can be estimated as follows.

The majority of farmers in the Project Area are native. They are fruits farmers. They cultivate 80 percent of their total cropping area with the permanent crops. The farm management is carried out by Omani family farmers.

The cropped field of 1.24 ha per farm household is managed by one family laborer and hired laborer of 0.6 consisting of 0.4 full time laborer and 0.2 part time laborer. They also raise the livestock. The income sources are fruits, vegetables, fodder crops and livestock.

The gross income of the typical farm household was estimated at 1,860 R.O. per annum. The production costs consist of the costs of seeds and fertilizers, transportation fee, hired labor wages, tractor and pumping charge. The costs of seeds, fertilizers and tractor charge are subsidized. These costs total to 790 R.O. The farm income of the typical farm household was estimated at 1,070 R.O.

The living costs for family member of 7.1 persons are primarily covered out of the above farm income. The living costs consist of those costs for food and beverages, clothing, education, medicine, fuel and electricity, recreation, housing and others. When such income is assumed to be paid only to food, the costs of beverages and meal per one family per day is calculated at about 0.4 R.O.

The expatriate permanent farm laborers in the Project Area earn a monthly salary of 60 R.O. The expatriate workers are said to have remitted a half of their salary to their home countries. Therefore, one labor lives on one R.O. per day. The difference between 0.4 R.O. and 1.0 R.O. explains the migration young family labors.

3.6.8. Agricultural Supporting Services

a) Agriculture Cooperative

Twenty agricultural cooperative societies have been registered since 1976. By the end of 1980, the total number of membership and all the capital involved had increased to 2,561 and 70,715 R.O., respectively.

The distribution of 20 agricultural cooperatives is not even in the region. Cooperatives concentrate in and around Nizwa, and a few in Shinas, Sohar and Saham in the Batinah Coast.

The activities of these societies have three problems as follows; the first is that the Agricultural Cooperative Law has not been enacted yet although drafted in 1976, the second is that the Agricultural Cooperative Societies at present can not make use of the bank loan or credit because of the lack of basic relevant regulation, and the third is the shortage in staff. Some old societies in Sohar were established in 1976 but has been still inactive due to the above-mentioned three problems. Only the merit of the societies is that the member farmers can purchase the production materials at lower prices than non-members.

The price subsidy by the government, however, absorbs this merit, and the members can not enjoy the merit directly from the cooperative societies.

b) Agricultural Credit

To establish an agriculture and fisheries credit bank is one of the targets and policies of the second five-year plan for the agriculture and animal husbandry sector.

The Bank for Agriculture and Fisheries was established by a royal decree in May, 1981 for providing finance to agricultural and fisheries activities.

The loan conditions imposed by the Bank are summarized as follows.

Repayment periods:

i) 12 months at maximum for seeds, fertilizers, and chemicals;

ii) less than one to four years for small equipment depending upon its life;

iii) five years for heavy equipment like tractors; and,

iv) 20-year for buildings and reclamation works with five years of grace period and 12 years for tree-planting.

The interest rate applied to farmers' loan varies from 2.5 to 3.5 percent including 0.5 percent of commission. The interest rate of the commercial bank is 11.5 percent. The low interest rate of the Bank of Agriculture and Fisheries is due to a subsidy.

The credit regulations for the agricultural cooperatives have been not granted yet. This bank does not directly loan to the agricultural cooperatives, but to individual farmers or group farmers with collective responsibility.

The main office is located in Ruwi City. The construction of six branch offices is scheduled to be completed in 1982.

c) Agricultural Marketing Institution

The marketing institution on agricultural products is under the control of the Public Authority for Marketing Agriculture Produce. The Agricultural Marketing Corporation was created under the royal decree in 1981. This Corporation was formed for guaranteeing the minimum price of fruits and vegetables produced by Omani farmers and distributing at reasonable prices to consumers throughout the nation. This Corporation is plans to establish some networks of collection centres, warehouses, and selling outlets of the farm products.

d) Agricultural Extension Services

The Government provides the agricultural extension services through three levels of national, regional and local offices. The organization at the national level is represented by Director of Extension Services, the Ministry of Agriculture and Fisheries with some supporting staff. This organization arranges the agricultural input forecasts made on the national basis.

At the regional level, an extension office under the Director of Agriculture coordinates the works of the extension centres at the local level. At the local level, there are extension centres for a group of villages.

Thirty five extension centres are distributed in the country and the North Batinah has eight centres. The headquarter of the extension centres in the North Batinah is located in Sohar. This office manages the national production farm and controlled supply of seeds and fertilizers, rental services of farm machines, subsidizing services, and extension of modern techniques, etc.

3.7. Features of the New Extension Farm Land

3.7.1. Expected Arable Lands

Taking into account the results of the soil survey, topography, local conditions and governmental policy formulated for the Sohar urban development plan, the two sites which are deemed most suitable as the proposed new extension farm land were selected in the downstream basin of the Wadi Jizzi (see Figure 4-5). One, having an area of about 680 ha, lies upstream of the National Highway (Muscat - Sohar Road) and adjacent to the Oman Sun Farm, and the other lies downstream of the highway on the right bank of the Wadi Suq, having an area of about 700 ha.

The former is topographically very flat with an average slope of about 1/500 at an elevation of 16 m to 20 m above sea level and no vegetation is observed in this area at present. On the other hand, extending at an elevation of 10 m to 15 m, the latter is situated on the relatively rolling area with brush.

3.7.2. Socio-economic Environment

The new farm to be reclaimed is only 100 ha due to the limitation of water resources available.

Several socio-economic conditions are used as indices for the selection of the proposed site. A comparative study was made on the convenience in marketing of agricultural outputs, hauling of inputs, shopping of daily necessities, education of children and use of medical facilities.

The site lying in the upstream of National Highway adjacent to the Oman Sun Farm is more favourable in terms of the above convenience than the other site, and thus from the viewpoint of socio-economic environment, the former site has been proposed as the Project Farm.

Distance from Proposed New Extension Area

(Unit: km)

Location of Site	Extension Center	Sohar Market	Education Facilities	Medical Facilities
Upstream of Highway	3.5	5	2	2
Downstream of Highway	13	15.5	12	12

3.8. Related Activities to the Project

3.8.1. Oman Sun Farm

The Oman Sun Farm is one of the most famous and large-scaled commercial dairy farms in the country. Operation in the original farms at Sohar and Salalah started in 1973 by F.M.C. for the Government. The present Oman Sun Farm was established much later than 1973. About 150 dairy cows are raised. Feed grass is grown in the fields of 398 ha, of which 350 ha are irrigated by six sets of the centre pivot system and 48 ha by seven sets of the side-role system. Irrigation water is obtained from 16 wells of 200 feet deep with 25-HP pump facilities.

Milk produced in the farm is sold to the markets in Muscat. The price is 450 Baiza per litter at farm and 550 Baiza in Ruwi Market. Most of feed grass hay is exported to Dubai and Abu Dhabi. The farm gate price is around 1.5 R.O. per one bundle of 15 kg.

Green beans and potatoes produced in the winter season in 1981 were exported to Dubai and Abu Dhabi and re-exported to other countries. This business, however, is not profitable due to high machinery cost; therefore, these crops were not grown in the last winter season in 1982.

The new extension farm in this Project is adjacent to the Sun Farm. The settlement farmers in this Project will be able to make use of barnyard manure from the Sun Farm to increase the soil fertility of their farm lands.

3.8.2. Sohar Copper Project

a) The Agricultural Development Project and the Copper Project

The area of the Wadi Jizzi Agricultural Development Project is situated about 30 km to the east of the Sohar Copper Project area. The Project must enforce the copper project not to generate environmental problems such as the water contamination caused by the water released from underground or dressing ores and also the air pollution caused by exhaust gas or dust emitted from smelting plants.

However, the river water and air cannot be free from the influence of the mining works. Therefore, the copper project side (those concerned with the Project) should limit the operation within a permissible extent by the laws.

Considering the latent environmental problems to be caused by the copper project, the Project side should seek the measures by which these problems would not become too serious.

b) Copper Project of the Oman Mining Co., LLC.

The Oman Mining Co., LLC. has been developing three mines of Lasail, Bayda, and Aarja about 30 km west of Sohar and also engaged in the Sohar copper project including the establishment of a smelter plant which produces copper blister.

The outline of the project work directly related to the Wadi Jizzi Agricultural Development Project is as follows:

Three mines of Lasail, Bayda, and Aarja are the cupriferous iron sulfide mine in the mother rock of ophiolite.

The expected total ore reserve in the three mines is more than 12,000,000 tons. Bayda and Aarja mines are situated outside the Wadi Jizzi Agricultural Development Area.

Lasail mine has the biggest ore body of the three, and is situated at the right bank of the Wadi Jizzi.

The undergrounds of the mine are being developed with the sub-level caving method for mining and the trackless mining method (ramp access system) for transportation.

The developments have already reached the ore body and therefore, pumped-up water in the mine is acidic water containing heavy metals. Accordingly, copper is excluded in the treatment pound and neutralized.

Also under construction is a processing plant in which the crude ores supplied from the three mines are dressed and smelted. The crude ores supplied for dressing from the three mines amount to 3,500 (metric) tons x 6 days/week (Lasail mine produces 2,500 tons x 6 days/week). Content of copper at this moment is expected to be 2.13 percent.

The froth floatation method using the sea water will be adopted for dressing the crude ore of 3,000 tons x 7 days/week, producing the copper concentrate of 270 tons x 7 days/week.

Copper content at this stage is 25 to 28 percent with the expected actual receipt of more than 90 percent. Concentrates then are sent in a dry smelter in which they are pelletised, and through electric furnaces and converter, the blister of more than 99 percent copper content is expected to be produced 70 tons daily (20,000 tons yearly)

In addition, the Oman Mining Co., LLC. plans to conduct the electrolysis of copper. The copper production is expected to start in the mid 1982, but there seems to be some delay in view of the progress in construction.

According to the document entitled "Sohar Copper Project Water Requirement", which was prepared by Oman Mining Company and discusses the water demands by the dressing and processing plants and the project office, the total amount of water by 70 cu.m/hr, is required to be pumped up from the Wadi Jizzi, 50 cu.m/hr for processing plants and 20 cu.m/hr for the related facilities and accommodations.

3.8.3. Sohar Urban Development Plan

The Sohar urban development plan, the area of which extending from the Wadi Jizzi to the Wadi Al Khadaq, has been formulated under the direction of the Ministry of Land Affairs and Municipalities since 1975, and the plan has proposed positively the conservation and development of agricultural land within the area.

The proposed plan includes the following basic policy, especially on the agriculture;

i) The farmland lying to the east of the highway will be positively conserved, even the old dates palm orchards near the coast;

ii) The development of farmland extending to the east of the highway should not be permitted and will be eventually ceased as the number of farmers gradually declines

iii) Particularly, the vacant tract located between the highway and Sohar town will be developed for non-agricultural purposes; and,

iv) On the other hand, the area to the west of the highway will be reserved for a sole use of the agricultural development under the control of Ministry of Agriculture and Fisheries.

3.8.4. Water Supply Plan to Sohar

The study on the Sohar water supply project, which covers the Sohar urban development project area as mentioned above, started in 1978 under the Ministry of Electricity and Power, and two production wells with a depth of 70 m (WD 78 and 79) were provided in the Wadi Jizzi basin seven kilometers from Sohar town in 1978 and 1979. The distribution pipes (total length of about 45 km, diameter 500 - 300 mm) have been already placed and the water supply to the area is expected to commence in the beginning of 1982.

In the plan, the water demand for the area is forecasted as below on the assumption of population growth rate of four percent.

Item	1978	1985	1995
Population (head)	11,500	14,500	20,500
Water demand (MCM)	0.42	1.07	2.03

Source: Power and Water Supply Study, Phase 2, Water Supply to Sohar, 1978

3.8.5. Sohar Gasline Project

The Murayrat-Sohar gasline project under the Ministry of Petroleum and Minerals is an essential part of the industrial development along the Batinah coast, especially in Sohar area. This development of the area will be enhanced by the supply of natural gas through expanding the existing main gas transportation system from Murayrat to Sohar with 205 km long and 16 inch diameter pipelines. Being placed at a distance of approximately three to six kilometer from the highway in the Wadi Jizzi basin, the gasline was completed in September 1981.

A terminal with a simple manifold near Sohar is located at about one kilometer away from the bifurcation of the existing highway to Buraimi and will allow offtake to various areas around Sohar in future. One offtake point will be used for branch line to a power plant of the copper smelter site. Along the Murayrat - Sohar line, a number of offtake points will be provided for gas supply for the power generation purpose in the villages along the coast.

3.9. Annual Water Demand in Wadi Jizzi Basin

The major uses of water utilizing the Wadi Jizzi groundwater as the water sources is irrigation for the existing cultivated area, domestic water and industrial water, for Oman Mining.

The annual water requirement was estimated at 22.4 MCM as shown follows;

Irrigation Supply

Irrigation water requirement by the present cultivated areas was estimated as follows;

Irrigation Water Demands for Existing Lands

Land Category	Cropped Area (ha)	Water Consumption (MCM)
Dates	1,820	11.24
Orchard	520	2.98
Upland Crops	264	6.92
Total	2,604	21.14 (A)

Note: Detailed estimation is given in Table G-8, Appendix G-1.

Domestic Water Supply

Domestic water demands as of 1987 for the area between the Wadi Al Khadaq and Majis was estimated at 0.95 MCM/annum as shown below;

Total number of inhabitants	:	20,800 persons
Water consumption per head	:	100 lit/day
Total demand	:	0.95 MCM (B)1/

1/ inclusive of 25 percent of the water loss

In the above estimation, the following presumption was made; i) the population in the area will increase to about 20,800 by 1987 at an average growth rate of three percent, Agricultural Census, 1978/1979 reveals the population of about 16,000 and ii) water resources development exclusivly for domestic water supply shall be undertaken before 1987.

Industrial Water Supply

As mentioned in the paragraph 3.8.2. Sohar Copper Project, the water supply pumps for industrial purpose, having the capacity of 70 cu.m/hr, have been installed at two sites in the Wadi Jizzi basin.

The annual industrial water demand estimated at 0.31 MCM/annum as follows:

Plant site	:	0.22 MCM (50 cu.m/hr x 12 hr x 365 day)
Town site	:	0.09 MCM (20 cu.m/hr x 12 hr x 365 day)
Total		0.31 (C)

Thus, the total annual water demand is 22.4 MCM (A + B + C).

CHAPTER IV. THE PROJECT

CHAPTER IV. THE PROJECT

4.1. Objectives and Components of the Project

4.1.1. Objectives of the Project

The aforesaid study and evaluation of the present agriculture in Oman have revealed the following points;

The agriculture in the country is the major source of income for the majority of the population; however, its contribution to the Gross Domestic Product (GDP) is negligibly small. The agricultural production has been stagnating for recent years mainly because of the insufficient investment in water resources development and inadequate extension services. The total cultivation area in Oman has not changed significantly in recent years. The shortage in irrigation water is the major constraint in the expansion of agricultural lands. In Batinah coast, the uncontrolled pumping of groundwater from production wells has caused a high salinity of soils and groundwater, and helped lower the fertility of the existing arable lands.

Consequently, a careful attention should be paid to the future development and management of water resources.

Under the above-mentioned circumstances, the Wadi Jizzi Agricultural Development Project will serve as the initial project of water resources development involving the farm land development in the Sultanate of Oman. In order to generate the benefits from the water resources and agricultural development in the Project, efforts should also be made to firmly establish an extension services system.

The Project directly aims i) to increase the agricultural production through the water resources development by constructing the Wadi Jizzi dam, ii) indirectly to improve the existing farm lands for stable production of crops and the living environment for a better living of farmers, and also iii) to stabilize the Wadi Jizzi groundwater for various purposes of irrigation, industry, and domestic water supply.

To attain the goals of the Project, the following works shall be executed;

i) to construct a detention dam and the related structures,

ii) to construct a new extension farm land equipped with the pipeline irrigation systems; and,

iii) to establish an organization for strengthening the existing agricultural extension services.

4.1.2. Project Components

The Project includes the following components:

Wrter Resources Development

To develop the water resources in the Wadi Jizzi basin by constructing a detention dam and dispersion facilities in the middle reaches of the Wadi Jizzi.

Agriculture Development

To develop an new extension farm land supported by water resources facilities, irrigation systems, roads, and fully organized agricultural extension services.

4.2. Water Resources Development Plan

4.2.1. Alternative Studies

a) Objectives and Alternatives

In order to select the most applicable water resources development method for the Project, the following two alternative plans were drawn in the first stage of the Project formulation. A study inclusive of the cost estimate and economic evaluation was made for each alternative.

i) Storage Pond Method (Alternative-1)

The water resources development by the Storage Pond Method will be carried out in two stages, that is, the surface storage stage and groundwater recharge stage as described below;

Surface Storage Stage

In this stage part of flood discharge would be temporarily stored in the reservoir of the detention dam, and conveyed to a storage pond that would be constructed along the circumference of the new extension farm land. Accordingly, conveyance facilities will be necessary to connect the detention dam with the storage pond. The storage pond should have a sufficient capacity to meet the irrigation requirement of crops throughout the year.

Groundwater Recharge Stage

The above-mentioned detention dam would function to detain flood discharge and recharge groundwater even in the surface storage stage. The groundwater potential and yield in the wadi basin would be elaborately studied through surveys and investigations during the surface storage stage. Based on the study results, intake facilities such as production wells and pumps would be constructed to irrigate the new extension farm land with the groundwater to be recharged by the detention dam.

ii) Groundwater Recharge Method (Alternative-2)

A detaining and recharging dam would also be constructed in this alternative plan. The detained water in the dam would be released in proportion to the groundwater recharging capacity of the gravel plain. The groundwater so recharged would be supplied to farm lands through pumps or falaj systems.

b) Plan Formulation

1) Water Resources

i) Storage Pond Method

This method combines the above-mentioned groundwater recharge and the surface storage. The detention dam would have a storage capacity of 5.4 MCM. Part of the detained water in the dam would be released to the downstream through a conduit that will be embedded beneath the dam body. The other part of the reservoir water would be conveyed to the storage pond through a pipeline.

Table 3-3 shows an inflow to the reservoir, which was estimated from the daily rainfall data from 1974 to 1981. The dimension of the conduit is determined at 1,400 mm in consideration of the infiltration capacity of the downstream gravel plain. On the assumption of the simultaneous operation of the conduit and the pipeline for diverting the reservoir water, a study on the time required to completely release the reservoir water was made for various discharge capacities of the pipeline. The study results are illustrated in Figures 4-1 and 4-2.

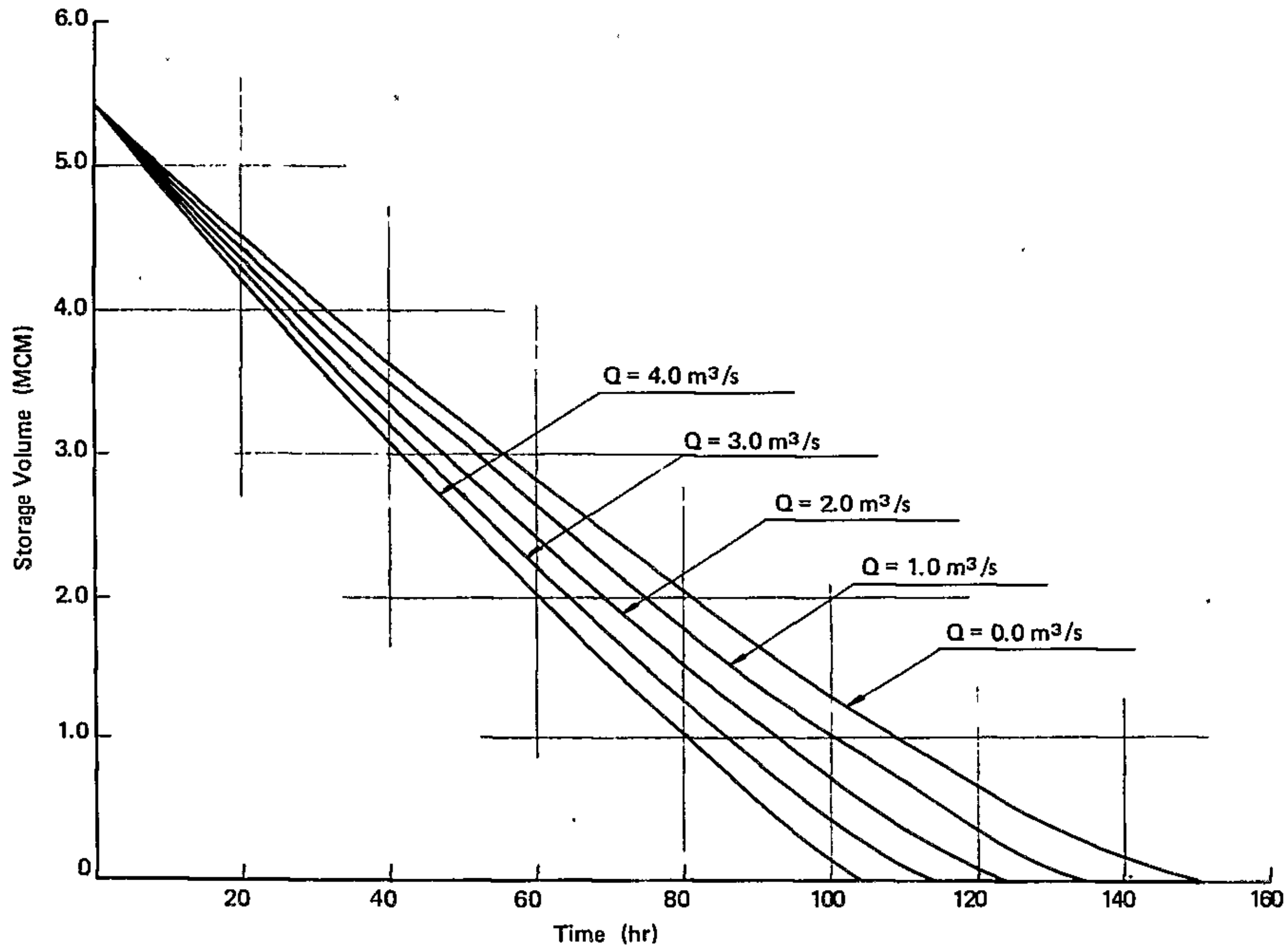


FIGURE 4-1 RESERVOIR-EMPTYING TIME IN VOLUME

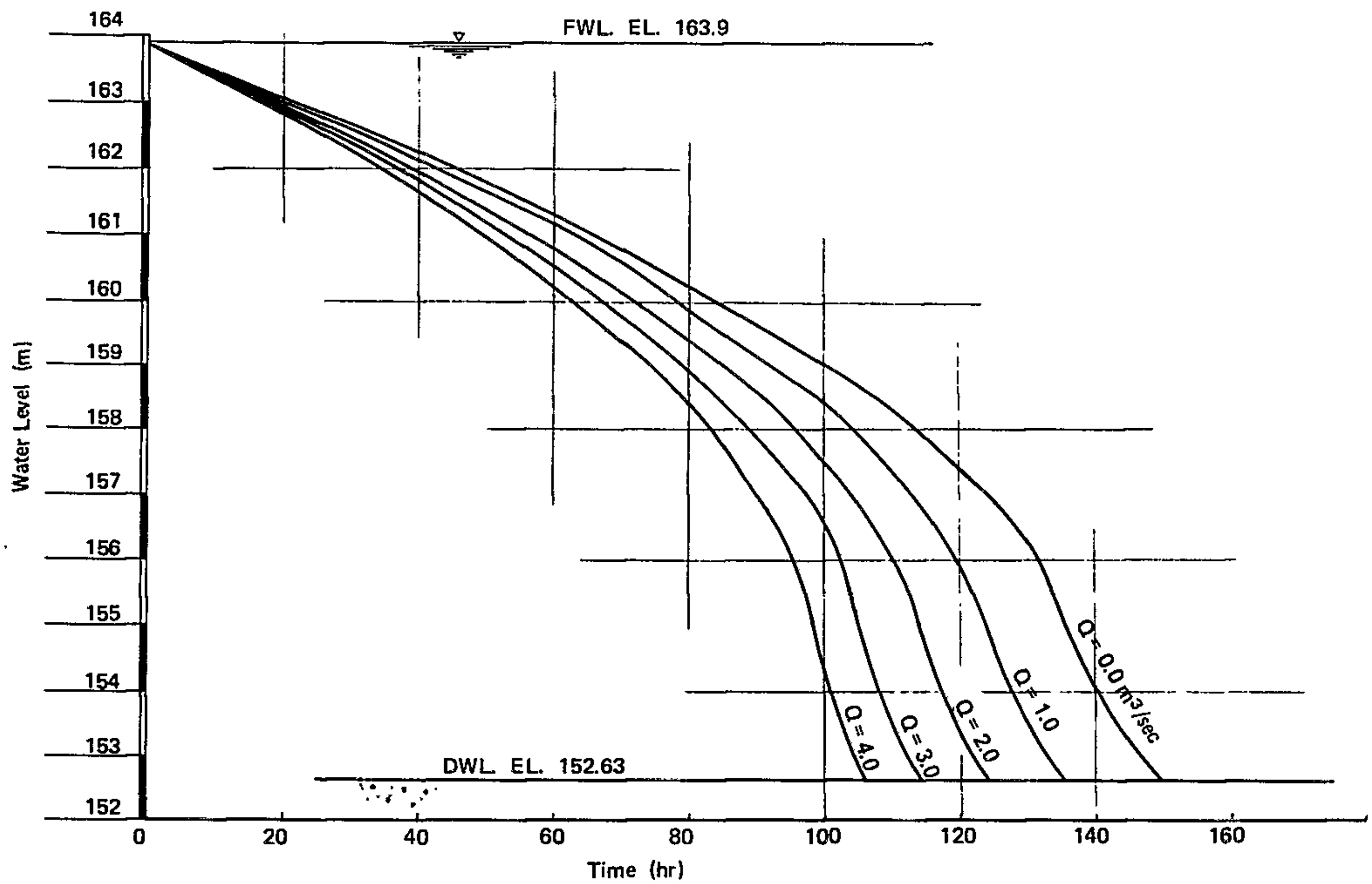


FIGURE 4-2 RESERVOIR-EMPTYING TIME IN WATER LEVEL

Tables F-1 to F-4 of Appendix F-1 show the reservoir water to be monthly released through a pipeline with a discharge capacity of 1.0, 2.0, 3.0 and 4.0 cu.m/sec. Table 4-1 shows the reservoir water to be annually diverted through the above-mentioned pipeline as well as the corresponding irrigable areas. At least irrigation water to meet the irrigation water requirement in a half of the irrigable areas should be secured for the effective use of the new extension farm. Therefore, a pipeline with a discharge capacity of 3 cu.m/sec should be installed. In this case, an averaged irrigable area is estimated at 46 ha out of the proposed new extension irrigable area of 85 ha with an annual water consumption of 0.73 MCM.

ii) Groundwater Recharge Method

The water resources to be developed in the basin only consist of flood water flowing uselessly into the sea at present. A flood sporadically takes place due to heavy rains in a short time. The flood water uneffectively flowing into the sea was estimated at 2.5 to 3.6 MCM on an annual average during the eight years from 1974 to 1981. The only way to utilize such flood water is to retain it by a detention dam. The dam would have two functions of storage or detention and dispersion. The stored flood in the reservoir of the dam could be conveyed downwards for utilization through an canals or pipelines and through aquifer as groundwater. Dispersed flood would recharge groundwater in the same way as the detention water. The latter way is a groundwater recharge method.

The groundwater development plan is deemed to be adaptable to the Project because stored groundwater in the coastal basin is sustained for a few seasons even flood does not occur. Furthermore, a distance between the recharge areas and the extraction areas does not affect groundwater tables in the latter areas due to a large storativity and unconfined conditions of the aquifer.

Table 4-1 Annual Intake Volume and Irrigable Area

Year	Intake Discharge Q = 1.0 cu.m/sec		Intake Discharge Q = 2.0 cu.m/sec		Intake Discharge Q = 3.0 cu.m/sec		Intake Discharge Q = 4.0 cu.m/sec	
	Intake Volume V(MCM)	Irrigable[1/] Area,A(%)	Intake Volume V(MCM)	Irrigable Area,A(%)	Intake Volume V(MCM)	Irrigable Area,A(%)	Intake Volume V(MCM)	Irrigable Area,A(%)
1974	0.21	15.7	0.37	27.6	0.52	38.8	0.62	46.3
1975	0.47	35.1	0.84	62.7	1.16	86.6	1.40	100.0
1976	2.38	100.0	4.39	100.0	6.05	100.0	7.32	100.0
1977	0.73	56.0	1.34	100.0	1.83	100.0	2.19	100.0
1978	0.30	22.4	0.53	39.5	0.76	56.7	0.87	64.9
1979	0.07	5.2	0.11	8.2	0.16	11.9	0.17	12.7
1980	0.13	9.7	0.22	16.4	0.30	22.4	0.34	25.4
1981	0.10	7.5	0.17	12.7	0.23	17.2	0.26	19.4
Average	0.55	31.5	1.00	45.9	1.38	54.2	1.64	58.6

Note: 1/; Annual percentage of irrigable area = Intake volume/Annual total demand
Annual total demand : Irrigation requirement for 85 ha: 1.34 MCM

Needless to say, the groundwater table at the extraction areas should be kept above mean sea level since it is prerequisite for the prevention of sea water intrusion into the aquifer. The flood water would recharge groundwater at the gravel plain. To keep the groundwater table above mean sea level, detained water in the dam will be released to meet the recharge potential of the gravel plain. The recharge potential of the gravel plain is 15 cu.m/sec. In addition, the construction of dispersion facilities at 3.3 km downstream of the detention dam has been proposed in order to further increase the recharge of groundwater. The dispersed flood of take the course of the wadi that has been filled up by old floods to an elevation slightly higher than the recent wadi platforms. The groundwater recharging by the dispersion method is estimated at 7 cu.m/sec in rate.

A groundwater balance study conducted in the Study has revealed that 85 ha of the lands could be irrigated by the groundwater.

2) Physical Plan

The required structures for alternative plans are summarized as follows;

Structures	Storage Pond Method	Groundwater Recharge Method
Recharge structure	o	o
Water supply facilities		
Conveyance facilities	o	x
Storage pond	o	x
Wells	x	o
Deep well pumps	x	o
Irrigation and farm land facilities	o	o
Farm and related facilities	o	o

Note: o : needed

x : not needed

The descriptions of these facilities are given hereinafter.

(a) Storage Pond Method

(1) Recharge Structure

The detention dam with a storage capacity of 5.4 MCM has been planned as a recharge structure. As a result of a comparative study or five potential dam sites, the site located at 23 km upstream of the river mouth of the Wadi Jizzi has been proposed.

This dam will help to reduce the peak of floods, to store temporarily flood discharge, and to recharge groundwater. In this way, the flood discharge uselessly flowing into the sea at present could infiltrate into the aquifer and be utilized in the downstream area.

The temporarily stored water in the detention dam would be released through the intake tower with an outlet conduit. The tower would be located at the left abutment of the dam site to convey the water to the storage pond through a pipeline.

The main components of recharge structures such as the dam, spillway and outlet facilities are shown in Drawing Nos. D-1001 to 1008, and the major dimensions of these structures are summarized as follows;

Catchment area	812.0 sq.km
Detention capacity	5.4 MCM
Specific sediment discharge	100 cu.m/sq.km/year
Full water surface level (F.W.S)	EL 163.90 m
Reservoir water surface area at F.W.S	1.25 MSM
Dam crest elevation	EL 168.0 m
Dam crest length	1,005 m
Dam height from trench base	17.0 m

Design flood discharge of spillway	1,890 cu.m/sec
Spillway crest length	169.2 m
Overflow depth of spillway	3.30 m
Max. discharge of outlet facilities	12.15 cu.m/sec
Max. discharge intake tower	9.45 cu.m/sec

(2) Water Supply Facilities

The water supply facilities for the Storage Pond Plan consist of conveyance facilities and a storage pond as follows;

Conveyance Facilities

A 21.1 km long pipeline would be provided to convey the diverted water from the detention dam. Its design capacity has been determined at 3.0 cu.m/sec. Reinforced concrete (RC) pipes would be used for the pipeline with three energy dissipators.

Storage Pond

Water conveyed from the detension dam would be stored in the storage pond which will be constructed around the new extension farm land.

The storage pond would have a trapezoidal shape with 20 m bottom width and 1:1.5 side slope, and the storage capacity would be about 1.1 MCM with the maximum water depth of eight meters. This storage capacity corresponds to the irrigation requirement in a nine-month period from March to November.

The watted perimeter of the storage pond would be paved with thin concrete, and a cover would be stretched over the water surface so as to prevent evaporation from the pond.

The structural details of conveyance facilities and the storage pond are shown in Figure F-1 of Appendix F-2.

(3) Irrigation and Farm Land Facilities

The irrigation and farm land facilities consist of terminal i·rigation facilities, distribution pipelines, delivery pumps, the fırm pond and so forth. The major dimensions of these are shown below:

Terminal Irrigation Facilities:

Drip irrigation:		(for vegetable and fruit crop)
Manifold capacity:		q = 6.58 lit/sec - 8.16 lit/sec
		h = 24.84 m - 39.85 m
		L = 235 m (vinyl chloride pipe)
Driphose	:	L = 45 m (polyethylene pipe)
Sprinkler irrigation:		(for feed crop)

D stribution Pipelines:

Irrigation networks	:	Link system (L = 3,470 m)
Pipe	:	ø75 - ø300 mm (vinyl chloride pipe)

D. livery Pumps

Number of pump site	:	2 places
Peak discharge	:	Q_1 = 190.6 lit/sec,
		Q_2 = 95.3 lit/sec
Totı l head	:	H_1 = 50.5 m, H_2 = 49.0 m
Motor capacity	:	P = 45 kw x 6 units
Pump type	:	Horizontal volute pump[1/]

1 A kird of centrifugal pump which dose not provide the guide vane is celled volute pump.

Farm Ponds

Number of ponds : 2 places

Capacity : V_1 = 3,100 cu.m,

V_2 = 1,600 cu.m

Farm Land Facilities

Road:

Main road : L = 7,000 m (B = 5.0 m)

Farm road : L = 8,500 m (B = 4.0 m)

Windbreak: : Eucalyptas, casuarina equestifolia

Flood protection works : L = 4,000 m

(4) Farm and Related Facilities

The following facilities would be constructed in parallel with the construction of new extension farm land:

Building

Settler's house : 20 houses (150 sq.m x 20 houses)

Sorting and packing center : 200 sq.m

Pumping station : 2 places

Water and Electricity Supply : lump sum

The typical layouts of irrigation, farm land, and related facilities is shown in Drawing Nos. F-1010 to F-1013.

(b) Groundwater Recharge Method

(1) Recharge Structure

As to the recharge structures by the groundwater recharge method, a detention dam with a storage capacity of 5.4 MCM and dispersion facilities would be necessary in order to fully utilize the water resources in the Wadi Jizzi basin.

The roles, location and dimensions of the detention dam are similar to those of the dam in the storage pond method. The structural details of the detention dam are shown in Drawings Nos. D-1001 to D-1008.

In the groundwater recharge method, an intake tower with an outlet conduit similar to that of the storage pond method would be necessary as the emergency outlet.

The dispersion facilities will be constructed on the wadi course about 3.3 km downstream of the detention dam site. The location and structural details of the dispersion facilities are shown in the Drawing, No. D-1009.

(2) Water Supply Facilities

The water supply facilities for the groundwater recharge method consist of the production wells, pumps and conveyance pipe, major features of which are summarized below:

Wells

Number of wells	:	3 wells (SE-1, SE-2, SE-3)
Location of wells	:	Upper limit of proposed area with more than 600 m spacing
Depth of wells	:	50 m - 56 m
Diameter, casing	:	250 mm
Diameter, hole	:	275 mm more

Material, casing	:	Steel, same as API or JIS quality
Screen	:	Wire wrapped, the same type as Johnson's
Aperture, screen	:	2 - 3 mm, equivalent to Slot No. 100 - 120
Length, screen	:	10 m

P·oduction Pumps

Three production pumps (No.1, No.2, No.3) will be installed at each of the above-mentioned wells.

Name of Well	Pumps	Q (cu.m/hr) 1/	H (m)
SE-1	No.1	132.5	30.0
SE-2	No.2	46.5	23.0
SE-3	No.3	90.0	22.0

Q : design well yield (peak discharge for irrigation)

H : total head of pump

All of the pumps are of a vertical turbine pump with electric motor.

(3) Irrigation and Farm Facilities

The irrigation, farm land, and their related facilities are of tl e same kind and type as those proposed for the storage pond method.

c) Cost Estimates and Project Implementation

The Project cost inclusive of the price escalation was estimated for the alternative plans by separating into foreign and local currency portions as summarized below:

Item	Storage Pond Method 1/ ('000 R.O.)	Groundwater Recharge Method 2/ ('000 R.O.)
Foreign Currency	24,819	8,468
Local Currency	2,891	1,522
Total	27,710	9,990

1/ : Details are given in Table F-6, Appendix F-2.

2/ : Details are given in Table J-1, Appendix J-1.

The construction schedule for each plan is shown in Figure 4-3. The proposed construction period for the Storage Pond Method is determined at three years from 1984 to 1986 in consideration of a large amount of construction works especially for the conveyance facilities and storage pond. On the other hand, the construction period for the Groundwater Recharge Method is proposed to be two years from 1984 to 1985.

d) Project Evaluation

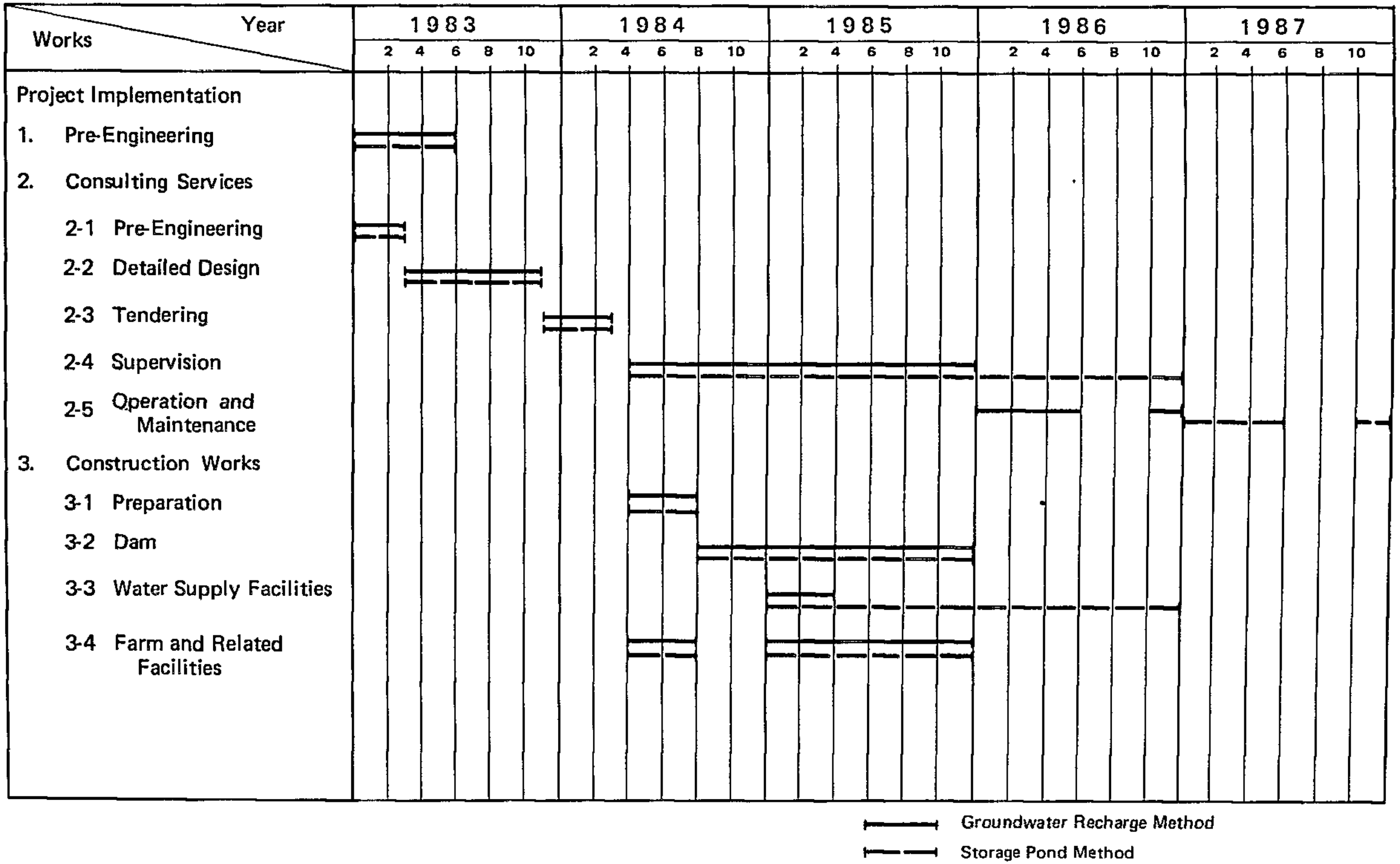
Four kinds of benefits could be expected from the Project, that is, the incremental products, protection of flood damages, protection of salt damage, and domestic water supply. The evaluation of benefits to be brought about by the above-mentioned alternatives was carried out for the four specific benefits. The beneficial area of the new farm land is 46 ha in Alternative-1 and 85 ha in Alternative-2.

The internal economic rate of return was computed as follows:

	Alternative-1	Alternative-2
IERR	2.9%	11.5.0%

Alternative-2 is economically more justifiable than Alternative-1.

FIGURE 4-3 IMPLEMENTATION SCHEDULE OF THE PROJECT



e) Selection of Proposed Development Plan

The results of studies so far made are summarized in Table 4-2, and reveal that the plan of the Groundwater Recharge Method is recommendable as the Project plan from the technical and economic viewpoint. Consequently, the Project plan for the water resources development will be described hereinafter by focussing on the Groundwater Recharge Method.

4.2.2. Development Plan

The basic concept of the water resources development is to augment the groundwater recharge to the alluvial aquifer by constructing a detention dam at D-2 site as stated in the previous paragraph.

a) Surface Water

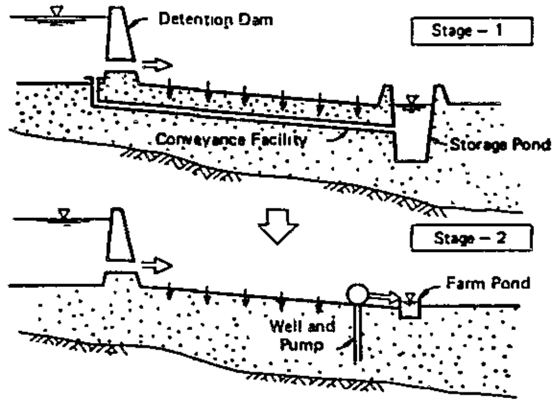
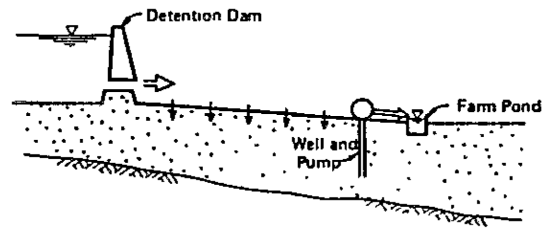
1) Design Flood Volume

The continuous observation records of floods in the Project Area are not available. Only the rainfall records from 1974 to 1981 are available for estimating the frequency of floods. The 20 percent excess probability is adopted for the design flood volume. As already mentioned in the Section 3.3.1., the frequency analysis of single event flood volume was made. The flood volume with 20 percent excess probability was estimated at 5.4 MCM.

2) Capacity of Reservoir

A reservoir capacity should be so decided as to retain the run-off of the single design flood and is usually based on a water balance study on the inflow to and outflow from the reservoir through the conduit. However, the total design flood volume is adopted as a design capacity of the reservoir for the safety because of the lack

Table 4-2 Result of Alternative Studies on Water Resources Development

Description	Storage Pond Method	Groundwater Recharge Method
1. Diagram of the plan		
2. Proposed Structures – Dam; – Water Supply Facility Stage – 1; Stage – 2; – Farm and Related Facility	Function: Detention dam (Rock fill dam) Capacity: 5.40 MCM Conveyance facility: L = 21.1 km (RC pipe) Q = 3.0 cu.m/sec Storage pond: V = 1.1 MCM Wells and pumps: 3 wells and pumps New extension farm: 100 ha (net area 85 ha)	Function: Detention dam (Rock fill dam) Capacity: 5.4 MCM Wells and pumps: 3 wells and pumps Farm pond: 4,700 cu.m (2 places) New extension farm: 100 ha (net area 85 ha)
3. Project Evaluation – Technical Aspects – Cost and Economic Aspects Project Cost Internal Rate of Return	Average irrigable area: 46 ha (10 ha ~ 85 ha) No accuracy to obtain the water could be observed in dry year. 27.7 million R.O. (277) 2.9%	Irrigable area: 85 ha Safty groundwater could be obtained 10.0 million R.O. (100) 11.5%

of complete hydrograph. Thus, the storage capacity of the detention reservoir is decided at 5.4 MCM.

3, Design Peak Flood

The maximum possible flood for design of the spillway was estimated at 1,890 cu.m/sec by the rational formula, as described in Appendix B-2. The value is larger than 1,283 cu.m/sec estimated by the Creager's equation where the coefficient is 20.

4) Annual Flood Inflow

The relationship between single flood volume and rainfall was as described in the Section 3.3.1. Surface Water. From this relation, a flood discharge volume was calculated based on the areal rainfall from 1974 to 1981. The annual flood inflow to the reservoir is shown in Table 3-3.

5) Design Discharge Rate of Release Flow

The discharge rate of release flow through the conduit of the dam should be so decided as to ensure the maximum possible infiltration in the downstream of the Wadi course. The maximum discharge rate was estimated at 15 cu.m/sec. A 1,400 mm diameter conduit will be embedded beneath the dam body. The conduit will function without any mechanical device.

Reservoir-emptying time was estimated on the assumption that there would be neither seepage loss nor evaporation loss. Starting from the full water elevation and neglecting further inflow above the spillway crest, estimated reservoir-emptying time through the conduit is illustrated in Figure 4-1 and 4-2. Stored flood water at the full water level will remain in the reservoir for seven days.

b) Groundwater

As mentioned above, the proposed development plan aims at the groundwater recharging in the gravel plain under natural conditions. The reservoir water will be released to the Wadi course in proportion to the recharge potential of the gravel plain. The recharge potential was estimated at 15 cu.m/sec. The dispersion facilities to supplement the recharge potential are planned. The facilities will be located at 3.3 km downstream of the detention dam.

Dispersed floods will take the course of the old wadi which was filled up with the flood sediments to raise the elevation slightly higher than the recent wadi platforms. Additional recharge caused by the dispersion facilities was estimated at 7.0 cu.m/sec in rate. A quantitative assessment for the plan was conducted in the following manners.

1) Quantity of Exploitable Water Resources

A quantitative assessment of the existing groundwater is essential to estimate exploitable groundwater resources since the groundwater is only dependable water for the people in the Area. The present status of groundwater can be assessed through the well-hydrograph, water balance calculation, groundwater contour mapping, and iso-EC contour mapping.

Average variation of the groundwater levels at wells AE-104, AE-142, and OA-2 for the last eight years was estimated at 12 mm in deficit as mentioned before, and that is equivalent to 0.19 MCM/annum in deficit for the areas of 317 sq.km in the coast. It is natural that the groundwater in the basin will be in deficit if on an average amount of rainfall does not take place.

On the other hand, groundwater contour line, at zero meter above mean sea level which is an indicator of the sea water intrusion, extends one kilometer wide and five kilometer long in the coastal plain around Sohar town in the drought months.

The Iso-EC contour line of 3,000 micro mho/cm, which is equivalent to about 1,000 mg/lit of chloride content, is located at the same point of groundwater contour line at zero meter above mean sea level, indicating chemical contamination of the groundwater by the sea water.

The results of the above assessment are summarized in Table 4-3. As described previously, the flood discharge is only the exploitable water resources. It was estimated at 2.5 to 3.6 MCM/annum by the hydrological analysis and groundwater balance calculation. Actually possible extraction for the Project was estimated at 3.5 MCM inclusive of water to compensate the coastal deficit amounting to 0.1 MCM. On the other hand the estimated consumption of domestic water and industrial water by the year of 1987 is 0.95 and 0.31 MCM/annum, respectively. The said amount may be subtracted from 3.5 MCM; therefore, the possible quantity for the Project is finally calculated about 2.24 MCM as shown latter.

2) Groundwater Recharge Potential

A recharge potential at the downstream Wadi course of the dam was estimated to get the optimal recharge for the development plan. A discharge was observed at Mulayyainah on February 15, 1982 with a currentmeter for estimating the recharge potential of the gravel plain when the flood discharge ceased in the mouth of Wadi Sallan, the river mouth of the Wadi Jizzi.

Table 4-3. Assessment of Water Balance in the Basin (Year Applied 1974 - 1981)

Method	Applied Parameter	Assessed Parameter	Results, Assessed
Well-Hydrograph	Water table	Storage	- 0.6 mm in basin; - 0.19 MCM for 3.7 km^2 in storage
Water Level Map	Water table	Area of sea water intrusion	Area enclosed by Zero mamsl water table line is extending near Sohar with 1 km width and 5 km length.
Iso - EC Map	EC	Contamination of groundwater	Area enclosed by more than 3,000 μmho/cm/25°C (equivalent more than 1,000 mg/ℓ chloride content) is extending same area of Zero mamsl water table line.

The measured discharge and the estimated potential recharge are shown below;

11.01 cu.m/sec ..... measured discharge at Mulayyinah

11.01/654 sq.km (for Mulayyinah) x 812 sq.km (for dam site)

= 13.6 cu.m/sec.... converted discharge at dam site

11.01/654 sq.m x 893 sq.m (for outlet of catchment)

= 15.0 cu.m/sec ... converted discharge at outlet of catchment

The calculated figures are considered as the recharge potential at the respective sites. The design volume of possible released flow was decided at 12.15 cu.m/sec including the safety factor. The potential recharge at the outlet of the catchment comes to 1.3 MCM per day. As mentioned in the following paragraphs, 7 cu.m/sec, an incremental recharge by dispersion facilities will create another recharge volume of 0.6 MCM per day. The total recharge created by the detention dam and the dispersion facilities will reach 1.9 MCM per day.

3) Recharge Method

The flood, on February 14, 1982, caused from the rainfall of about 103 mm in total at Sohar was estimated with a return period of about twenty years. The loss to the sea analysed based on the gauging records available in the Wadi Sallan was calculated at 3.83 MCM in total. The size of flood is similar to the one that took place in March 1976 (76/3) in terms of loss to the sea at 4.16 MCM. As mentioned in Appendix C, the flood of 76/3 could be controlled by the proposed detention dam and dispersion facilities in the Project.

The total length of the dendric form wadi courses was estimated at 200 km. The potential recharge rate at the unit length is calculated as follows;

13.6 cu.m/sec/200 km = 0.07 cu.m/sec/km
= 0.1 cu.m/sec/km

where 13.6 cu.m/sec is discharge at the dam site

The measured Wadi course, ordinary course of recent floods, is composed of unconsolidated sand and gravel with thickness of 5 to 40 m. The wadi course bed for the dispersion of flood water is composed of partially cemented sand and gravel on the platform of the terrace which has been eroded during the transgression in the post-glacial age. Permeability in the wadi course was estimated to be less than that of the recent wadi beds because flood activities on them do not usually occur. With the infiltration test the rate of potential recharge for both of the courses in the recent wadi and terrace wadi is assumed 3 mm/min and 2 mm/min, respectively.

As a result of the above assumption, an increased recharge by dispersion was estimated as follows;

An increased recharge by dispersion

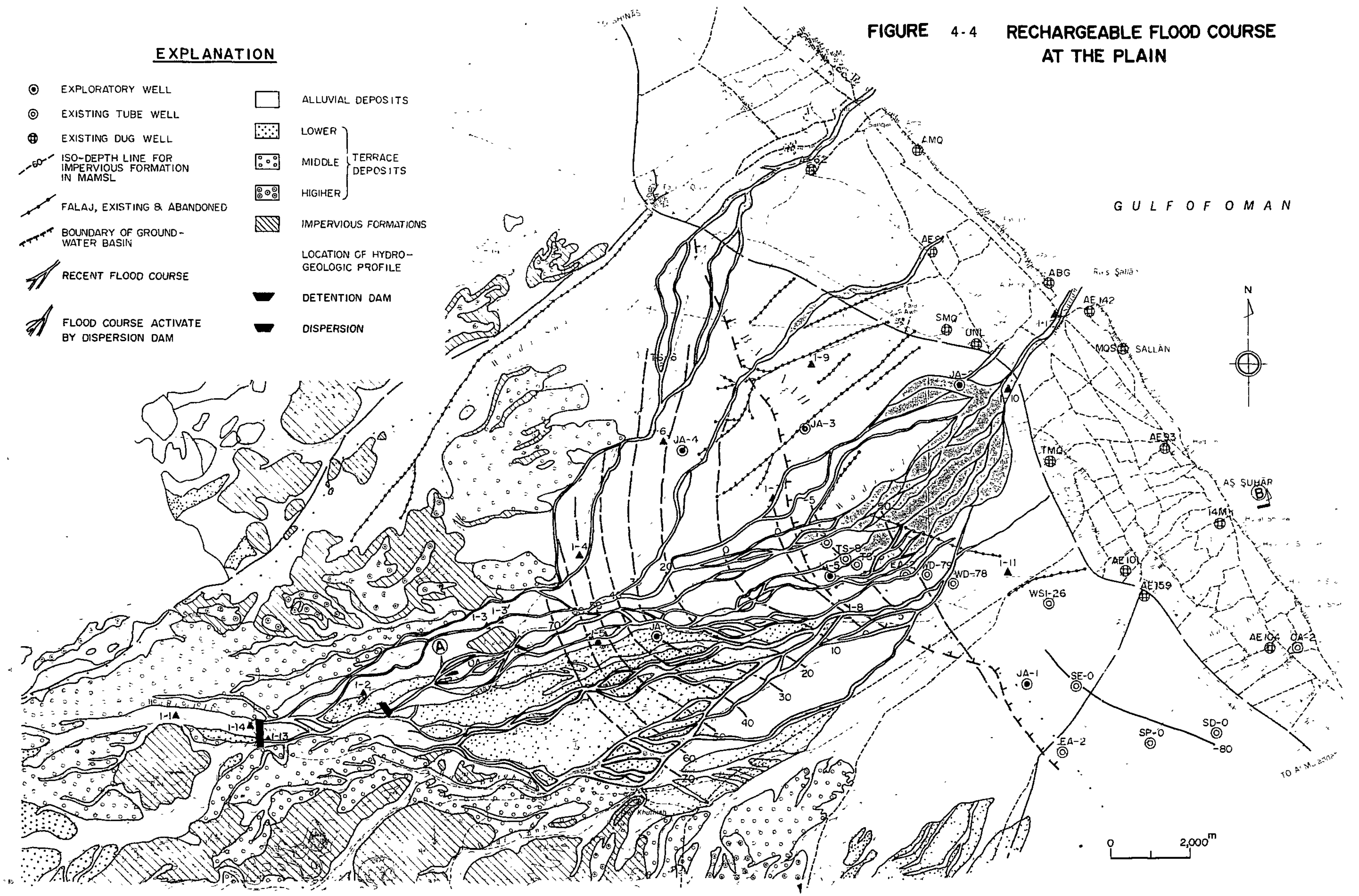
= Increased length of wadi courses x Potential recharge at unit length x 2/3
= 100 km x 0.1 cu.m/sec/km x 2/3
= 6.7 cu.m/sec
= 7.0 cu.m/sec

The additional wadi courses which flood water will be scattered from the dispersion facilities are shown in Figure 4-4.

4.2.3. Water Allocation

Based upon the results of the present water balance study in the basin, the water resources developed by the Project and the proposed water demand for irrigation, domestic and industrial water uses, the water allocation in the basin is summarized as follows;

FIGURE 4-4 RECHARGEABLE FLOOD COURSE AT THE PLAIN



- Developed groundwater : (+) 3.60 MCM/annum
- Present water balance : (-) 0.10
- Water demands for domestic and industrial water uses 1/ : (-) 1.26 (at 1987)
- New extension farm : (-) 1.34
- Water balance surplus : (+) 0.90

Note: 1/ Sohar domestic water supply : 0.95 MCM
Sohar Copper Project : 0.31

4.3. Water Supply Development Plan

4.3.1. Location of Groundwater Collecting Facilities

Production wells should be located closest possible to the Project Area from the economic point of view; however, their relations with recharge schemes and with drawdown permissible in terms of the sea water intrusion into the aquifer should be taken into account. In a recharge scheme, it has been pointed out that the flood water scattered by the dispersion facilities can be subjected to recharge in an immediate upstream area of the Project. According to the specifications of the proposed dispersion facilities, about 50 percent of the released flow can be diverted to the dispersing wadi courses when the total volume of the released flow exceeds about 15 cu.m/sec. It reaches 1.25 MCM on an annual average based on the floods from 1974 through 1981, and covers 93 percent of the annual water requirement of the new extension farm.

As mentioned in the previous chapter, it is natural that deficits of seven percent should be compensated by the recharge at the Wadi Jizzi main course without any hydrogeological problems. Therefore, the proposed location of the production wells in the eastern edge of the gravel plain is consistent with the recharge scheme.

In connection with the permissible drawdown, the concept of safe yield for preservation of groundwater basin should be taken into consideration in production pumping. The report by IRI Research Institutes Inc. (hereinafter referred to as IRI) proposed a general guide for the safe yield in production pumping at Sohar Expansion Farm as follows;

i) Quantity should not exceed 50 percent of groundwater flow in the area; and,

ii) Water level in the aquifer is to be kept more than one meter above sea level.

The proposed production rate at Production Wells SE-1, SE-2, and SE-3 were 4,750, 2,500 and 5,000 cu.m/day, respectively. The permissible drawdown in the gravel plain was considered from the safe yield point of view. The proposed water requirements at Production Wells SE-1, SE-2 and SE-3 were estimated at 2,523, 858 and 1,665 cu.m/day at maximum, respectively, and these all full within the realm of 33 to 52 percent of the proposed production rate of the IRI.

The estimated drawdown by production pumpings was obtained by applying the non-equilibrium equation. The applied parameters for the calculation are shown as follows;

Transmissivity	:	33,000 sq.m/day
Storativity	:	0.05
Pumpage, total	:	14,600,000 cu.m/year
Pumpage, wells	:	50 percent for SE-1, 17 percent for SE-2, 33 percent for SE-3
Pumping time	:	300 days
Well loss	:	75 percent

Calculated drawdown with accumulated interferences at each wells are;

SE-1 ; 0.3 m SE-2 ; 0.1 m SE-3 ; 0.2 m

The water levels at the end of December, 1981 (drought month), at SE-1, SE-2, and SE-3 were 2.4, 2.2 and 2.2 meters above sea level, respectively. Therefore, water tables at the end of production pumping at SE-1, SE-2 and SE-3 are 2.1, 2.1 and 2.0 meters above sea level, respectively. The production pumping will make the interface between fresh and sea water based on Ghyben-Herzberg assumption come to about 80 meter below mean sea level which is more than 40 m below the bottom of the wells.

4.3.2. Alternative Plans of Groundwater Collecting Method

Many methods are available for collecting groundwater. The selection of a particular method is made in due consideration of the depth to groundwater, geologic conditions, the quality of water required, and economic factors.

The following methods can be considered for the Project;

- Falaj
- Caisson well with radial collectors
- Tube well

a) Falaj

Falaj, the traditional water collecting facility in the Sultanate of Oman, attracts special interests. The locations of Aflaj in the Wadi Jizzi basin are shown in Hydrogeological Map (see Figure 3-7). Aflaj which terminate at Qabail and Awhi are assumed active at present. As easily found in the Map, the sources of Aflaj are located where the impervious formations upheave nearly to the ground surface. Aflaj collect groundwater on the impervious formations where a constant quantity and water table can be secured.

Discharge patterns in quantity and time of Aflaj are very similar to those of the base flows. Collecting potentials at the unit length of Falaj Qabail and Awhi are estimated at 2.5 lit/sec/km on an average since their total length is 12 km.

In case of adopting Falaj for the Project, its source is to be located four kilometer from the proposed new extension farm site where the impervious formations can be found near the ground surface. Eventhough discharge of Falaj could be sustained to meet the Project requirements, the water table in the farm is expected to be more than 20 meter below ground surface; therefore, pumping facilities as well as the tube wells are required. Falaj is deemed unsuitable for the Project because the merit of Falaj is considered to be the groundwater collecting facility without any pumping.

b) Caisson Well with Radial Collectors

In general, caisson wells are adopted where groundwater table comes to the surface with high permeability as well as water table relectively high. In this method, a large amount of water is expected to be extracted. However, adopting the caisson wells for the Project is not advisable since the estimated construction cost is much higher than that of tube wells.

c) Tube Well

Adopting tube wells is more recommendable for the Project than the other two methods. Tube wells have the following merits in groundwater extraction.

i) Tube wells can cope with heavy groundwater level fluctuations.

ii) The location of adequate aquifers can be easily selected prior to casing installation.

iii) The construction cost is lower than the others.

4.3.3. Designed Well Yields

The annual water demand for irrigation in the Project was estimated at 1.34 MCM. However, the peak requirement should be applied to designing of wells and pumps. The estimated peak requirement for the Project is 70.1 lit/sec for 85 ha in the month of July. On the other hand, the report of IRI indicates that the well yield Sohar Expansion Farm are 45 cu.m/hr/m.

The possible well yields can be calculated to be 90 cu.m/sec or 2,150 cu.m/day with two-meter permissible drawdown at maximum.

The necessary number of production wells was calculated in the following procedures;

Number of necessary wells = Peak requirement/possible well yield
= 70.1 x 86.4/2,150
= 2.8
= 3 wells

In case of using the production wells of Sohar Expansion Farm for the Project, Wells No.1 (SE-1), No.2 (SE-2) and No.3 (SE-3) could be utilized in view of their respective locations. The design yields of each well can be assigned based on their own well potentials to minimize differences of drawdown. As mentioned above, the shared yield of Wells No.1, No.2 and No.3 is 50, 17 and 33 percent of total pumpage with the corresponding peak requirement of to 35.1, 11.9 and 23.1 lit/sec, respectively.

It is recommended that aquifer tests at the production wells of Sohar Expansion Farm will be conducted again in the next stage of study since these wells have not been used since 1978.

In case of the construction of new wells, the design yield and expected drawdown of the wells were estimated at 25 lit/sec and 1.4 m at the peak requirement based on the data available at the production well No.1 of Sohar Expansion Farm.

4.4. New Extension Farm Land Plan

4.4.1. Area of New Extension Farm Land

The groundwater resources to be recharged by the Project was estimated at 3.6 MCM/annum as mentioned in the previous paragraph. Of this volume, the water resources available for the irrigation of new extension farm land were estimated at 1.34 MCM/annum, after subtracting total 1.26 MCM/annum for those who gain the new vested water right (0.95 MCM for the Sohar Water Supply Project, 0.31 MCM for the Sohar Copper Project) and 1.0 MCM for the existing farm lands.

On the other hand, an annual irrigation water requirement per hectare, which was estimated at about 15,700 cu.m, based on the proposed cropping pattern, (refer to Paragraph 4.5.3.). Therefore, the area of 85 ha will be possibly developed as cultivated land in the Project. The required lands for public facilities such as roads, windbreaks, villages, and buildings were estimated at 15 ha as below. The total farm land area amounts to 100 ha.

Cultivated land		:	85.0 ha
Others			
Roads;	Main roads	:	3.0
	Farm roads	:	4.7
Windbreaks		:	4.6
Buildings:	Housing	:	2.2
	Sorting and Packing center	:	0.5
	Sub-total		15.0
	Total		100.0