- Fertilizer distribution (50%)
- Agro-chemicals distribution (50%)
- Agricultural materials distribution (seeds, plastic cover, nets, pumps, etc.; 50%)

The distribution of inputs in UAE for the last four years shows that pesticides have been a small decreasing trend while chemical fertilizers have been an increasing trend. There is no observed trend for seeds and seedlings. Concerning the amount of distributed inputs per hectare in 1993 the following was found : 1.8 kg. of seeds, 1 kg. of powder pesticide, 1.7 liters of liquid pesticide, 573 kg. of chemical fertilizers, 77 kg. of organic fertilizers, 2.4 productive tree seedlings (saplings), 6,204 vegetable seedlings.

The total number of extension officers in the whole country is 33. On an average, each extension officer takes care of 629 farms. Each extension officer made 373 farm visits on average. The main topics covered by the extension officer were: tree crop cultivation, soils/irrigation/fertilization, pest control, and vegetables and field crops.

2.4.7. Irrigation

(1) Irrigation and Water Sources

Because of the dry climate, with high evaporation losses and low supply of rainfall, agriculture in UAE is highly dependent on irrigation. The water source for the irrigation is groundwater, the traditional falajes are mostly dried-up and abandoned.

In 1993 there were a total of 32,376 wells in UAE. Out of those 3,887 wells were almost dry or providing negligible amounts of groundwater; 28,489 wells were in good production condition suitable for agricultural activities. The Abu Dhabi Region has the highest proportion of low-production wells; the Northern and Eastern Regions have the lowest proportion of low production wells.

(2) Traditional Irrigation

Traditional irrigation systems used in UAE mainly consist of two types as below:

Furrow irrigation : This system uses furrows and ridges placed alternately parallel and perpendicular to water supply channels. Furrows are divided transversely into convenient lengths of three to five m by earth cross ridges. Water is diverted into these sections up to about 3/4 of the furrow height and is then released to the section. This system is used for tomato, water melon, squash, onion, pepper, cabbage, cauliflower and cucumber.

Basin irrigation : This system consist of flat beds, bordered by small dikes which are filled with water and the water is then allowed to permeate into the soil. Water is usually conveyed to these basins by earth furrow from a central channel. Basins vary in area from six to 10 m^2 and are used for onions, pepper, alfalfa, cereals, and fruit trees.

(3) Modern Irrigation

MAF are aware of the clear advantages of using modern irrigation systems compared to the high levels of water consumption of traditional irrigation systems. Studies conducted at the Hamraniyah research station showed that the use of a trickle irrigation system could mean a saving of 82% of water compared with open earth furrow systems and a 45% saving on improved (lined and covered) furrow systems; labor savings of 75% to 88% could be expected.

At present, MAF is successfully trying to modernize agriculture by encouraging the utilization of modern irrigation systems which are more suited from the view of rationalization of water usage for agricultural purposes.

In the 1980s MAF started a irrigation modernization plan which has given the following results for 1993: out of total cultivated area in UAE of 66,682 ha, 40,453 ha (more than 60% of total cultivated area) is using a modern irrigation system. Within the area using modern irrigation systems, the drip system is the most used for 71% of total area under modern irrigation system; sprinkler and bubbler systems occupy 23% and 6%, respectively.

Table 2.2.1. Economic Indicators of UAE, 1990-1994

(Unit : Dh.X10^6 at current prices)

Economic Variables	Years					Growth Rates			
	1990	1991	1992	1993	1994	1990/91	1991/92	1992/93	1993/94
- Population (X10^3)	1,844	1,909	2,011	2,083	2,230	3%	5%	4%	7%
-Workers (X10^3)	694	738	799	856	907	6%	8%	7%	6%
-Gross Domestic Product	125,266	126,264	131,676	130,972	134,813	1%	4%	-1%	3%
-National Income	105,984	105,660	108,329	105,734	129,663	0%	3%	-2%	23%
- Disposable Income	98,822	88,079	105,974	102,784	108,343	-11%	20%	-3%	5%
- National Saving	31,985	15,572	25,261	15,441	9,450	-51%	62%	-39%	-39%
- Final Consumption Expenditure	66,837	72,507	80,713	87,343	95,793	8%	11%	8%	10%
a) Goveronment Final Consuniption	20,120	21,131	22,792	23,550	24,520	5%	8%	3%	4%
b) Private Final Consumption	46,717	51,376	57,921	63,793	71,273	10%	13%	10%	12%
- Gross Fixed Capital Formation (GFCF)	24,064	25,790	29,802	33,219	33,760	7%	16%	11%	2%
a) GFCF Government Sector	5,139	6,378	9,511	12,631	12,700	24%	49%	33%	1%
b) GFCF Private Sector	18,925	19,412	20,291	20,588	21,060	3%	5%	1%	2%
- Total Imports	42,510	51,104	64,328	72,495	80,400	20%	26%	13%	11%
- Total Exports	79,678	81,806	88,940	86,267	89,050	3%	9%	-3%	3%
- Surplus of Merchandise Trade	37,168	30,702	24,612	13,772	8,650	-17%	-20%	-44%	-37%
- Imports (Excluding Re-exports)	29,760	25,773	43,328	48,572	52,400	-13%	68%	12%	8%
- Current Surplus of Payments Balance	22,926	6,021	12,980	762	-4,690	-74%	116%	-94%	-715%
- Wages and Salaries	28,019	29,883	31,907	34,183	35,258	7%	7%	7%	3%
- General Consumer Price Index Numbers (1985=100)	109.4	115.4	123.6	127.8	135.0	6.0	8.2	4.2	7.2

Source : 1990-1993 :National Accounts for U.A.E. 1988-1993, Ministry of Planning
1994 : Annual Economic Report 1994, Ministry of Planning

Table 2.2.2. Economic Indicators per Capita, 1990-1994

(Unit : Dh.X10^3 at current prices)

ECONOMIC VARIABLES	Year					Growth Rates			
	1990	1991	1992	1993	1994	1990/91	1991/92	1992/93	1993/94
-Gross Domestic Product	67.9	66.1	65.5	62.9	60.5	-2.7%	-0.9%	-4.0%	-3.8%
-National Income	57.5	55.4	53.9	50.7	48.6	-3.7%	-2.7%	-5.9%	-4.1%
- Disposable Income	53.6	46.1	52.7	49.3	47.2	-14.0%	14.3%	-6.5%	-4.3%
- Final Consumption Expenditure	36.2	38.0	40.1	41.9	43.0	5.0%	5.5%	4.5%	2.6%
a) Government Final Consumption	10.9	11.1	11.3	11.3	11.0	1.8%	1.8%	0.0%	-2.7%
b) Private Final Consumption	25.3	26.9	28.8	30.6	32.0	6.3%	7.1%	6.3%	4.6%
- National Saving	17.4	8.1	12.6	7.4	4.2	-53.4%	55.6%	-41.3%	-43.2%
- Gross Fixed Capital Formation (GFCF)	13.1	13.5	14.8	16.0	15.1	3.1%	9.6%	8.1%	-5.6%
a) GFCF Government Sector	2.8	3.3	4.7	6.1	5.7	17.9%	42.4%	29.8%	-6.6%
b) GFCF Private Sector	10.3	10.2	10.1	9.9	9.4	-1.0%	-1.0%	-2.0%	-5.1%
- Total Imports (Excluding Re-exports)	16.1	18.7	21.5	23.3	23.5	16.1%	15.0%	8.4%	0.9%
- Total Exports	43.2	42.9	44.2	41.4	40.0	-0.7%	3.0%	-6.3%	-3.4%
- General Average of Wages	35.0	34.8	34.7	35.0	34.7	-0.6%	-0.3%	0.9%	-0.9%
- General Average of Labour Productivity	84.2	84.4	84.5	84.9	85.7	0.2%	0.1%	0.5%	0.9%

Source : 1990-1993 :National Accounts for U.A.E. 1988-1993, Ministry of Planning
1994 : Annual Economic Report 1994, Ministry of Planning

Table 2.2.3. Revenues and Expenditure of Federal Government , 1991-1993

(Unit : Dh.X10^6 at current prices)

Items	Year			Growth Rate	
	1991	1992	1993	1991/92	1992/93
Crude Oil Revenues	38,919	36,507	31,314	-6%	-14%
Other Revenues	8,886	10,895	7,856	23%	-28%
Total Public Revenues	47,805	47,402	39,170	-1%	-17%
Total Public Expenditure	56,509	45,735	45,206	-19%	-1%
Final Surplus or Deficit	-8,704	1,667	-6,036		

Source : Annual Economic Report 1994, Ministry of Planning

Table 2.4.1. Crop Production in UAE, 1993/94

Crop	Area Cultivated (ha)	Yield (ton/ha)	Production (ton)	Average Unit Price (Dh./ton)	Value (Dh.X10³)	Value/ha (Dh.)	Share in Total(%) Area	Value
I. VEGETABLES								
Tomato	4,131	58.77	242,753	1,650	400,542	96,962	7.58	16.58
Eggplant	1,061	63.30	67,147	1,100	73,862	69,635	1.95	3.06
Okra	133	16.22	2,149	3,100	6,662	50,279	0.24	0.28
Bean	70	11.02	766	3,751	2,873	41,338	0.13	0.12
Cowpea	67	12.31	820	2,800	2,296	34,474	0.12	0.10
Jews mallow	540	34.85	18,804	1,700	31,967	59,253	0.99	1.32
Chard	315	91.05	28,652	750	21,489	68,284	0.58	0.89
Squash	770	21.81	16,787	1,700	28,538	37,082	1.41	1.18
Cucumber	198	66.77	13,193	3,350	44,197	223,669	0.36	1.83
Cabbage	2,068	51.59	106,708	1,100	117,379	56,749	3.79	4.86
Cauliflower	387	23.28	9,002	1,350	12,153	31,427	0.71	0.50
Potato	174	20.33	3,545	2,150	7,622	43,704	0.32	0.32
Onion	636	12.55	7,976	1,150	9,172	14,430	1.17	0.38
Watermelon	236	17.18	4,058	1,400	5,681	24,052	0.43	0.24
Sweet melon	647	16.14	10,437	2,100	21,918	33,903	1.19	0.91
Lettuce	147	36.01	5,294	1,500	7,941	54,020	0.27	0.33
Radish	119	28.53	3,381	600	2,029	17,122	0.22	0.08
Parsley	152	12.45	1,892	1,500	2,838	18,671	0.28	0.12
Carrot	105	23.19	2,426	1,400	3,396	32,467	0.19	0.14
Pepper	325	19.22	6,242	1,975	12,328	37,967	0.60	0.51
Others	825	23.03	19,005	2,000	38,010	46,067	1.51	1.57
Subtotal	13,101	43.59	571,037	1,494	852,893	65,100	24.03	35.30
II. FRUIT TREES							0.00	0.00
Dates	28,860	8.18	236,135	3,500	826,473	28,638	52.94	34.20
Lime	934	20.85	19,485	2,500	48,713	52,133	1.71	2.02
Lemon (Adalia)	48	13.86	664	2,200	1,461	30,501	0.09	0.06
Grapefruit	39	30.30	1,194	2,200	2,627	66,675	0.07	0.11
Other Citrus	374	13.05	4,884	2,500	12,210	32,630	0.69	0.51
Guava	183	9.18	1,681	3,050	5,127	28,001	0.34	0.21
Mango	583	15.15	8,829	4,700	41,496	71,226	1.07	1.72
Indian Almond	38	7.65	289	799	231	6,111	0.07	0.01
Pomegrate	43	10.86	466	3,800	1,771	41,282	0.08	0.07
Fig	97	5.01	486	1,650	802	8,260	0.18	0.03
Grapes	24	2.64	64	4,000	256	10,579	0.04	0.01
Banana	17	8.26	138	2,297	317	18,982	0.03	0.01
Other	1,589	1.43	2,270	2,500	5,675	3,571	2.91	0.23
Subtotal	32,829	8.43	276,585	3,424	947,159	28,851	60.22	39.20
III. FIELD CROPS							0.00	0.00
Alfalfa	3,527	80.03	282,240	1,400	395,136	112,038	6.47	16.35
Green Fodder	4,281	45.19	193,462	1,100	212,808	49,712	7.85	8.81
Tobacco	61	9.74	592	1,801	1,066	17,533	0.11	0.04
Wheat	567	1.86	1,052	1,000	1,052	1,857	1.04	0.04
Other	147	42.16	6,177	1,000	6,177	42,164	0.27	0.26
Subtotal	8,582	56.34	483,523	1,274	616,239	71,810	15.74	25.50
Total	54,512	24.42	1,331,145	6,193	2,416,291	44,326	100.00	100.00

Source : Ministry of Agriculture and Fisheries

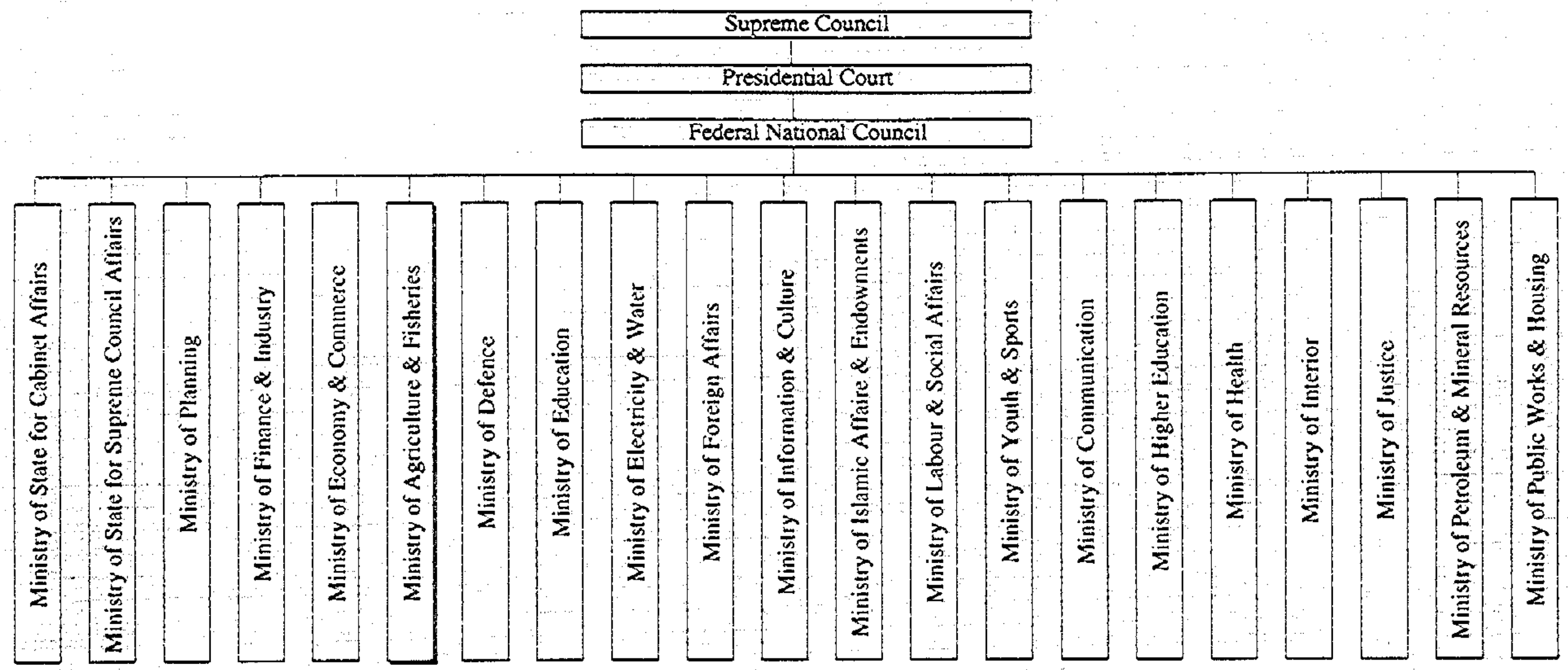
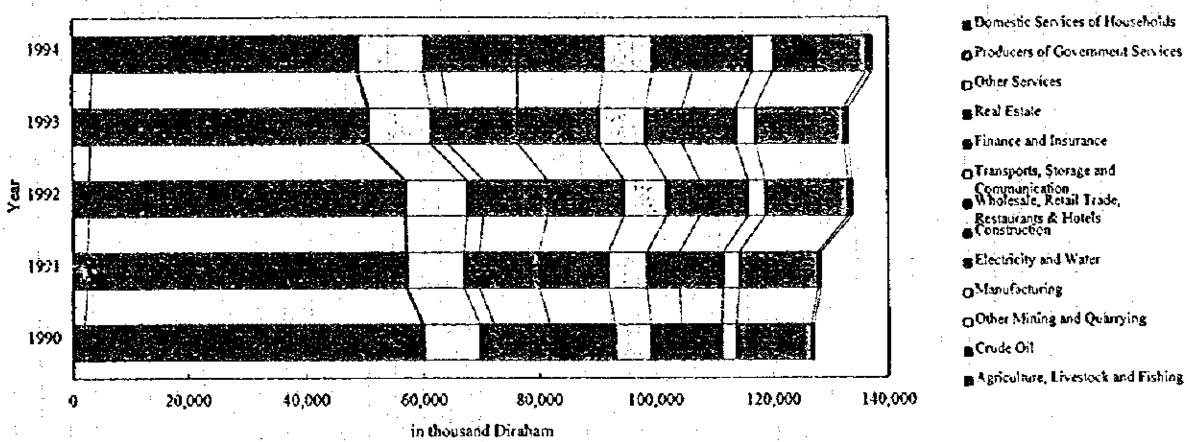
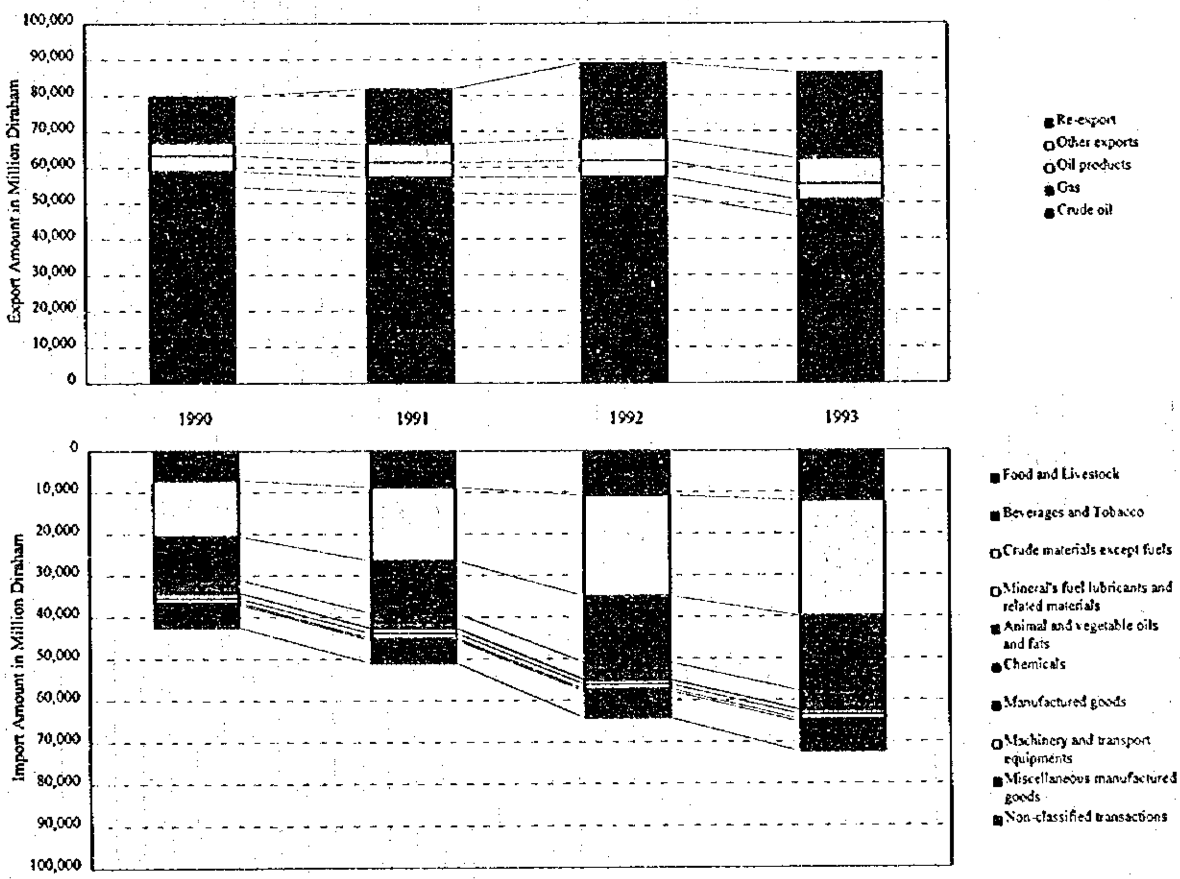


Figure 2.1.1. Organization Chart of Federal Government of UAE



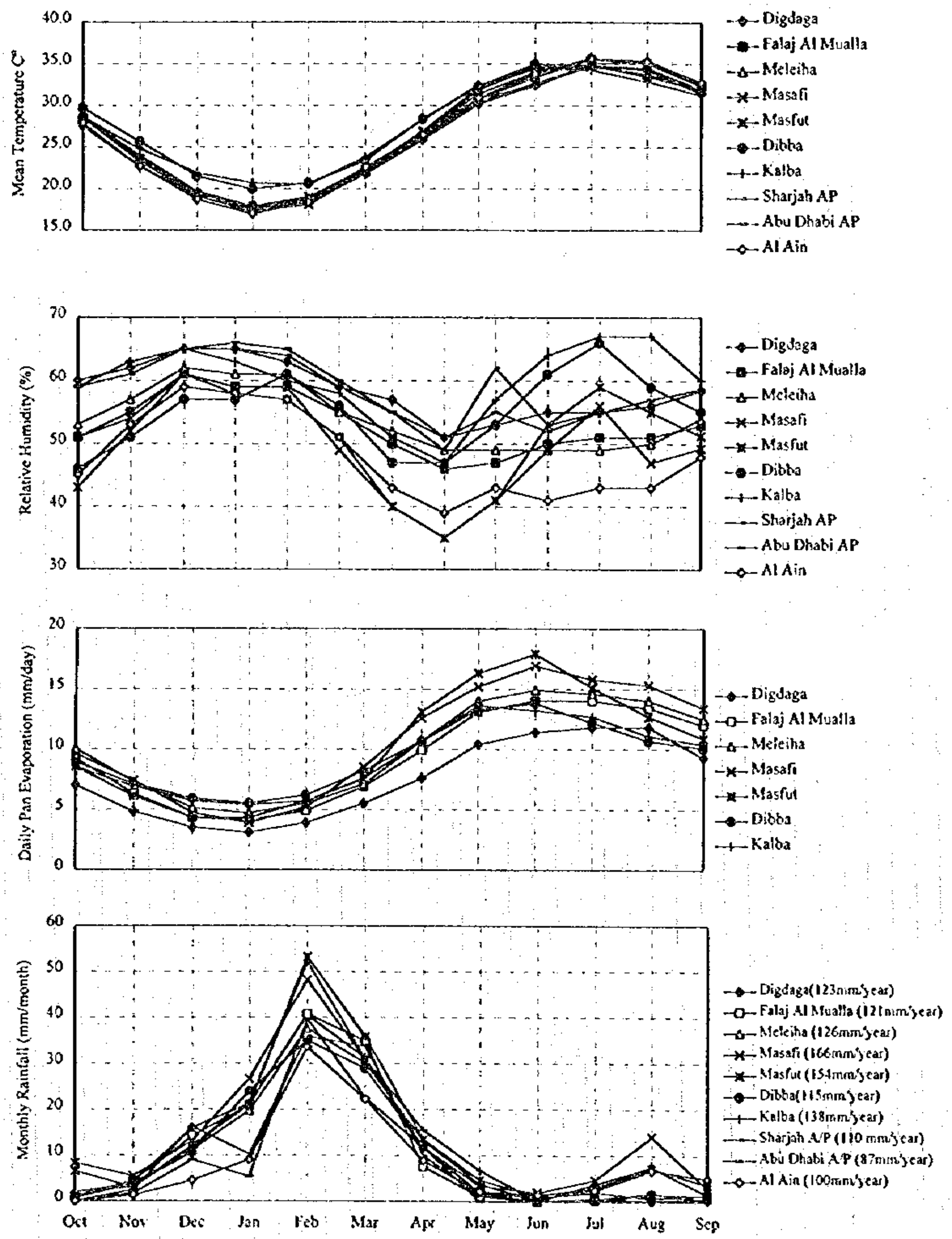
Sources : National Accounts for UAE 1988-199, and Annual Economic Report 1994, Ministry of Planning

Figure 2.2.1. Gross Domestic Product by Sectors, 1990-1994



Source : Annual Economic Report 1994, Ministry of Planning

Figure 2.2.2. Foreign Trade of UAE, 1990-1993



Source : Climatological Data Volume 3, Jan. 1993, MAF

Figure 2.3.1. Monthly Average Climate Indicators in UAE

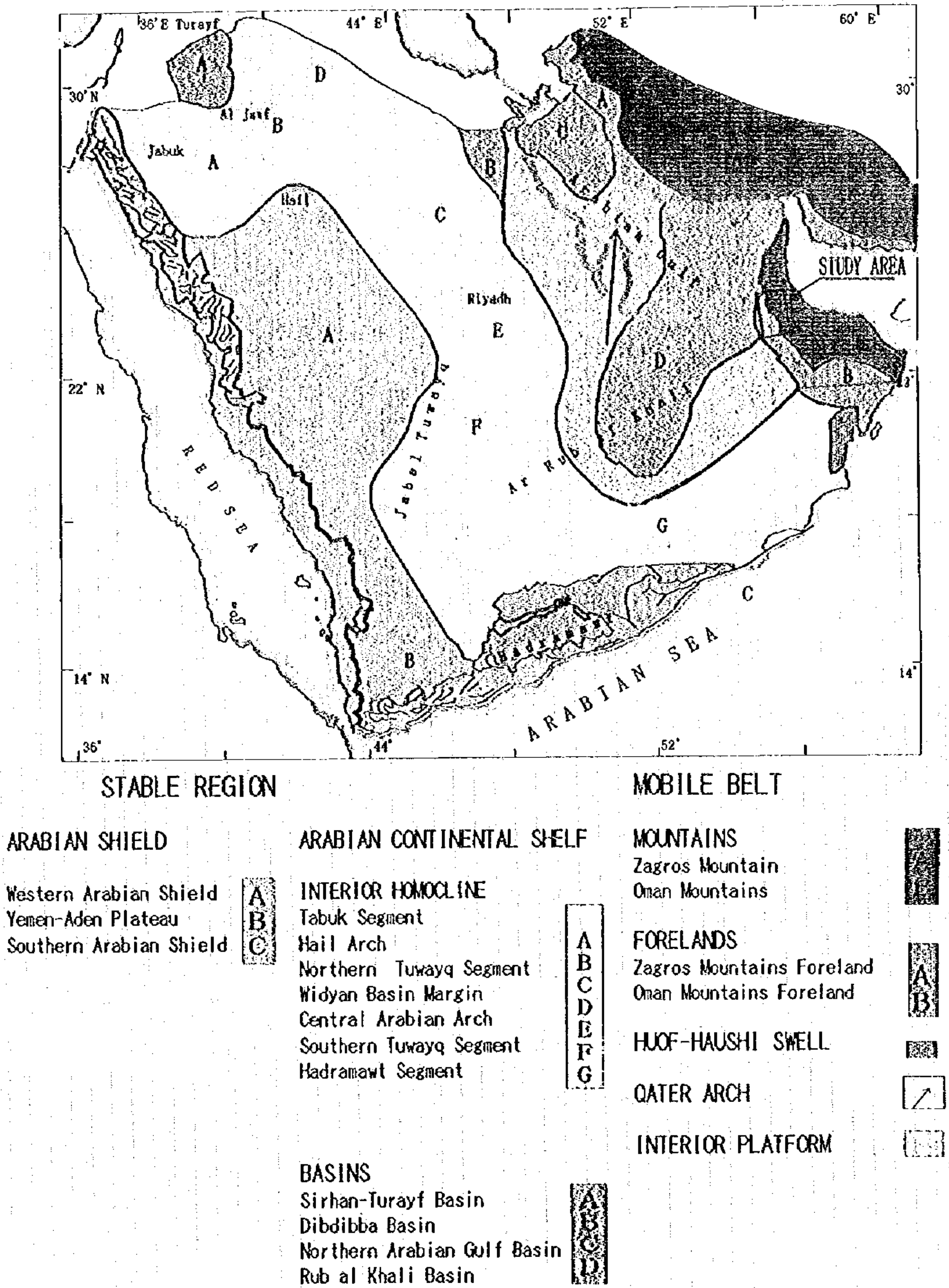
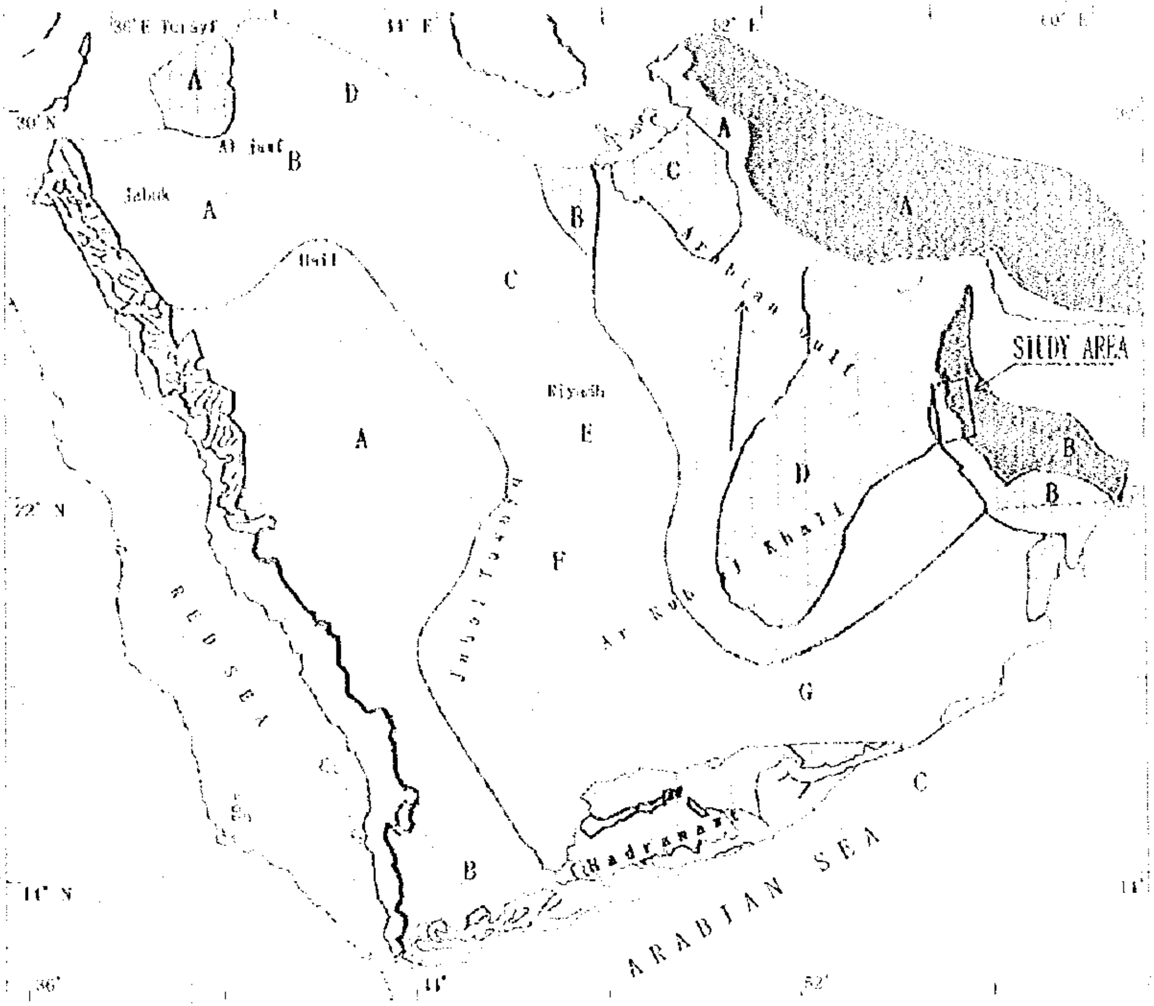


Figure 2.3.2 Geologic structure of Arabian peninsula



STABLE REGION

ARABIAN SHIELD

Western Arabian Shield A
Yemen-Aden Plateau B
Southern Arabian Shield C

ARABIAN CONTINENTAL SHELF

INTERIOR HOMOCLINE
Tabuk Segment
Hail Arch A
Northern Tuwayq Segment B
Widyan Basin Margin C
Central Arabian Arch D
Southern Tuwayq Segment E
Hadramawt Segment F G

BASINS
Sirhan-Turayf Basin A
Dibdibba Basin B
Northern Arabian Gulf Basin C
Rub al Khali Basin D

MOBILE BELT

MOUNTAINS
Zagros Mountain A
Oman Mountains B

FORELANDS
Zagros Mountains Foreland A
Oman Mountains Foreland B

HUOF-HAUSHI SWELL

QATER ARCH

INTERIOR PLATFORM

Figure 2.3.2 Geologic structure of Arabian peninsula

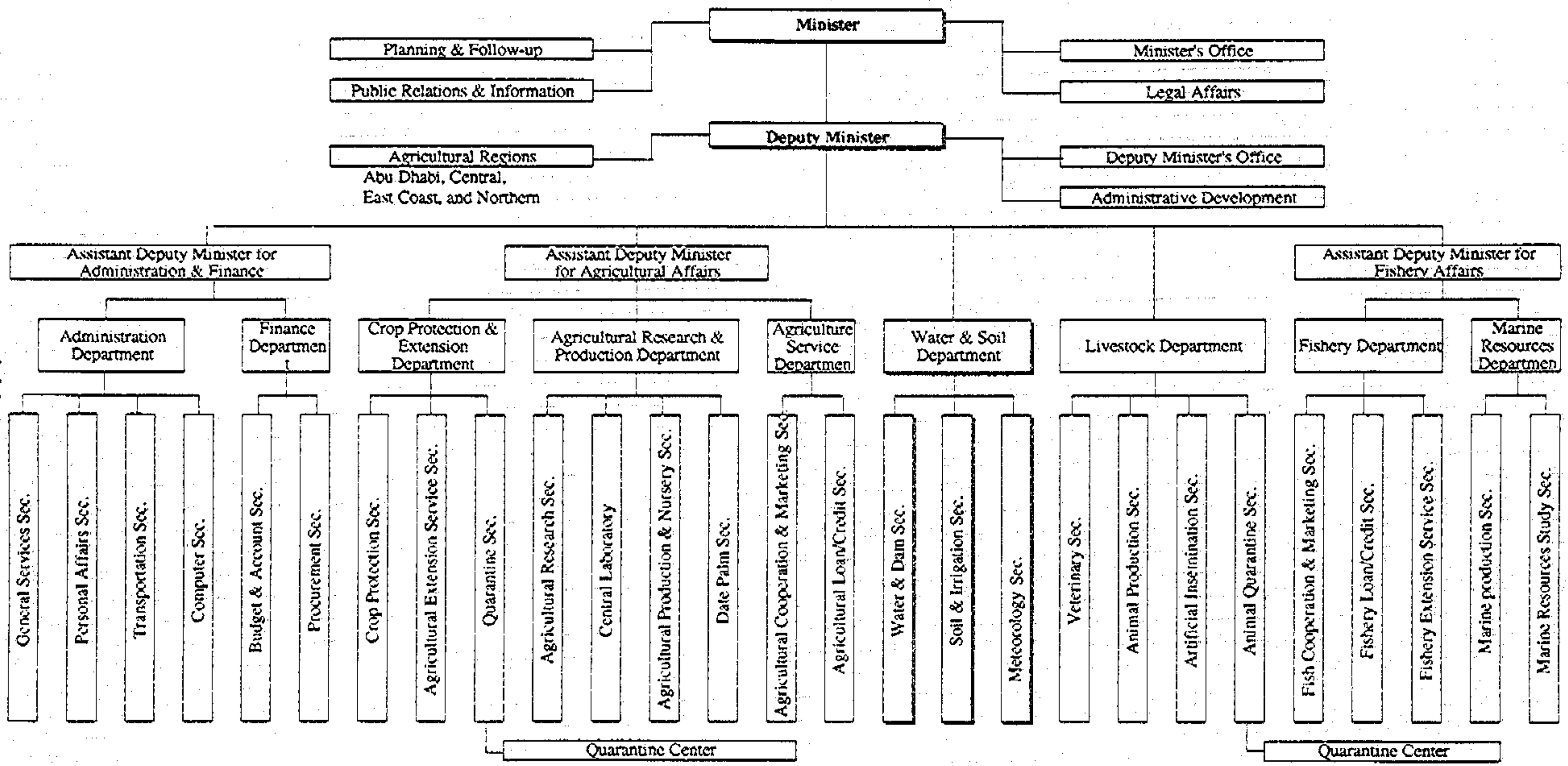
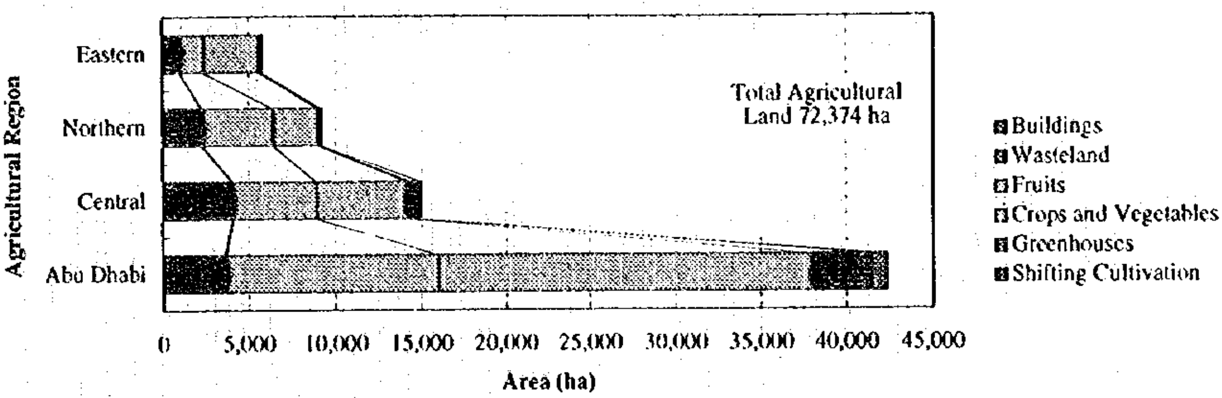


Figure 2.4.1. Organization Chart of Ministry of Agriculture and Fishery of Federal Government of UAE



Fugure 2.4.2. Land Use of Agricultural Land in UAE by Regions, 1993

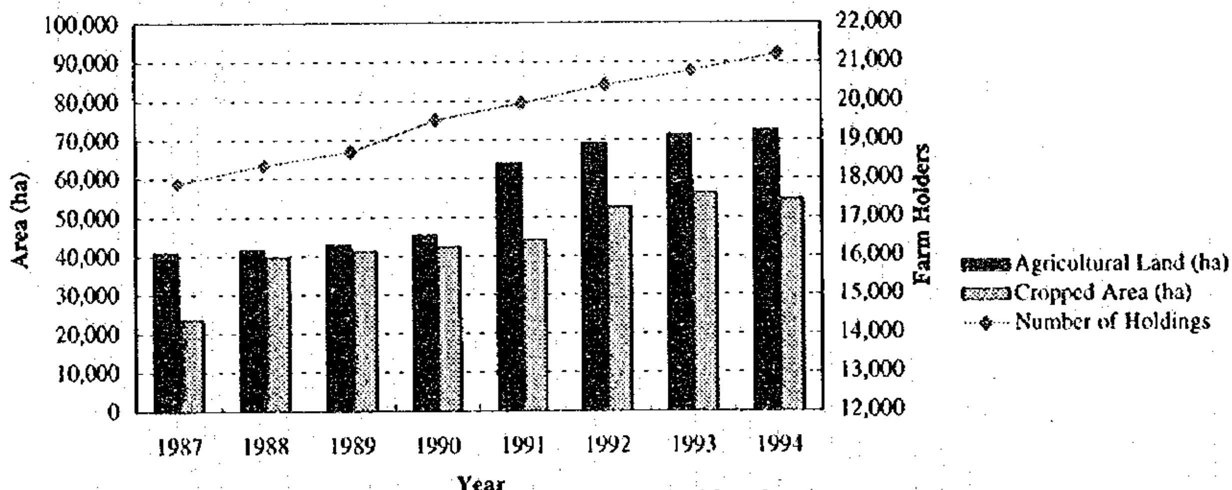


Figure 2.4.3. Number of Farm Holdings, Agricultural Land and Cultivation Area in UAE, 1987-1994

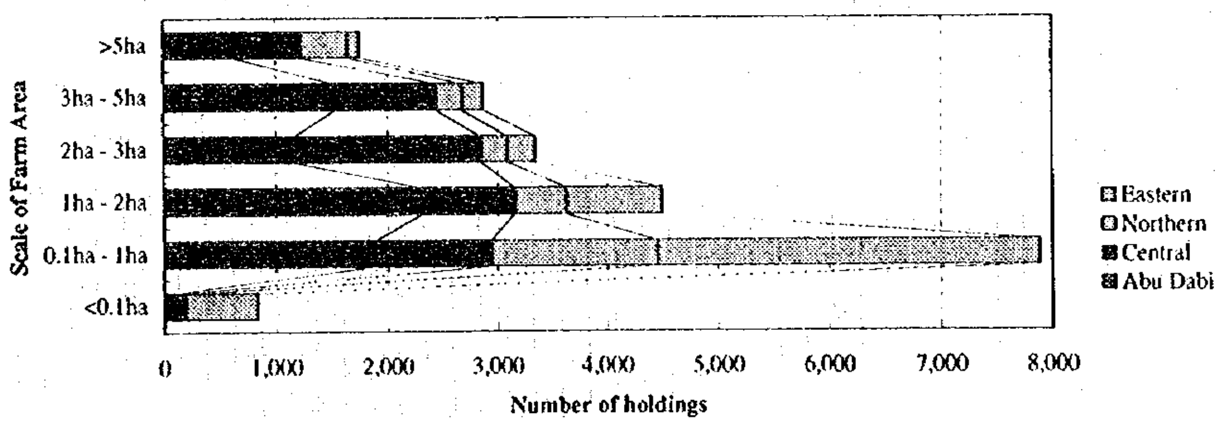


Figure 2.4.4. Scale of Farm in UAE by Regions, 1993/94

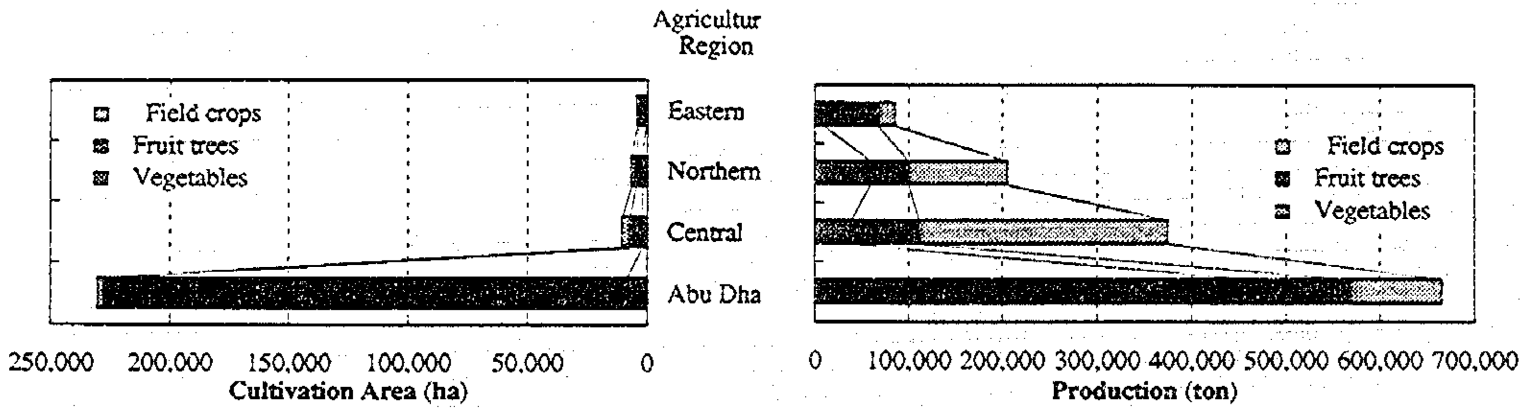


Figure 2.4.5: Cultivation Area and Production of Crops in UAE by Regions, 1993/94

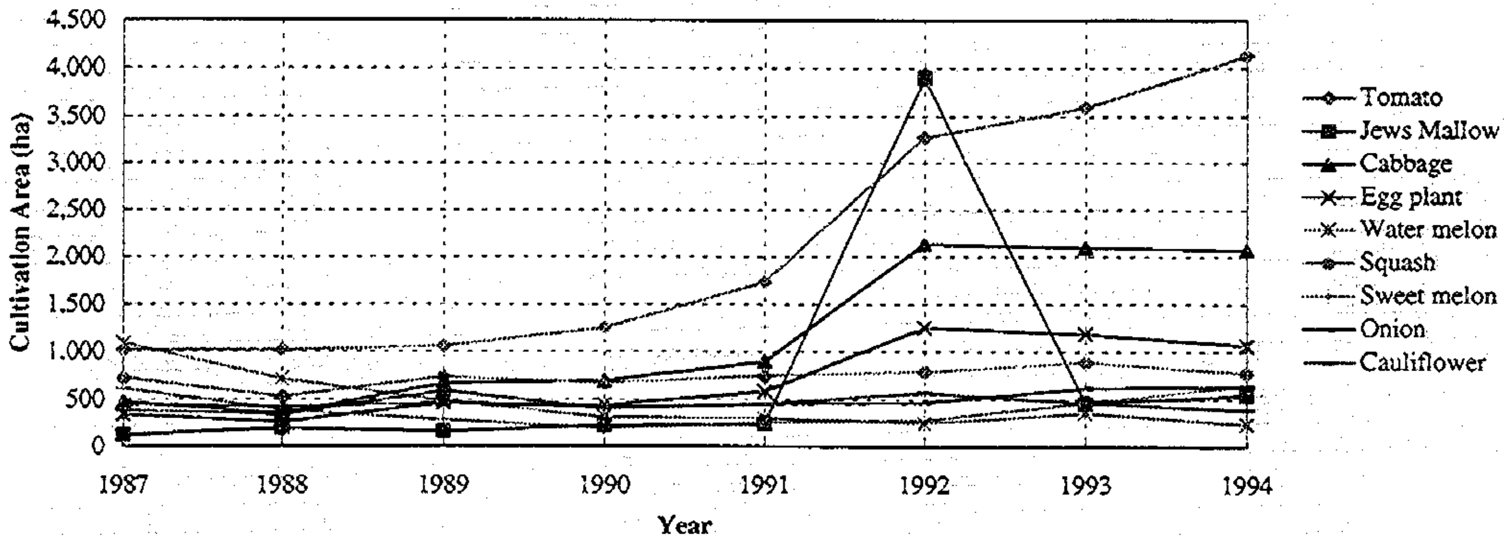


Figure 2.4.6. Cultivation Area of Main Vegetables in UAE, 1987-1994

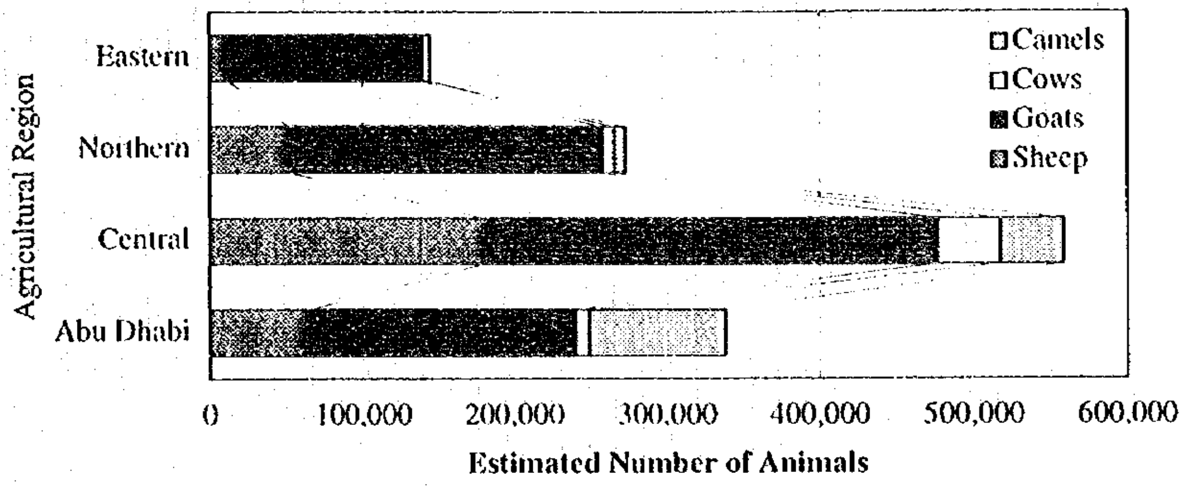
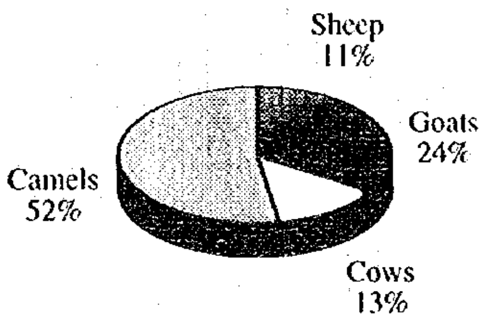


Figure 2.4.7. Estimated Number of Animals in UAE by Regions, 1993



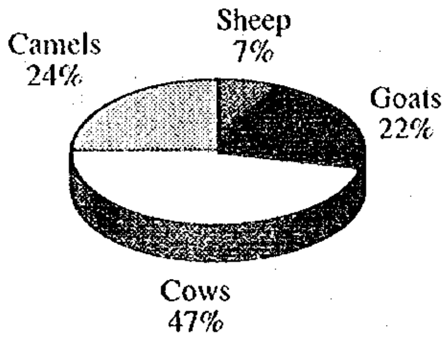


Figure 2.4.8. Meat Production in UAE, 1993

Figure 2.4.9. Milk Production in UAE, 1993

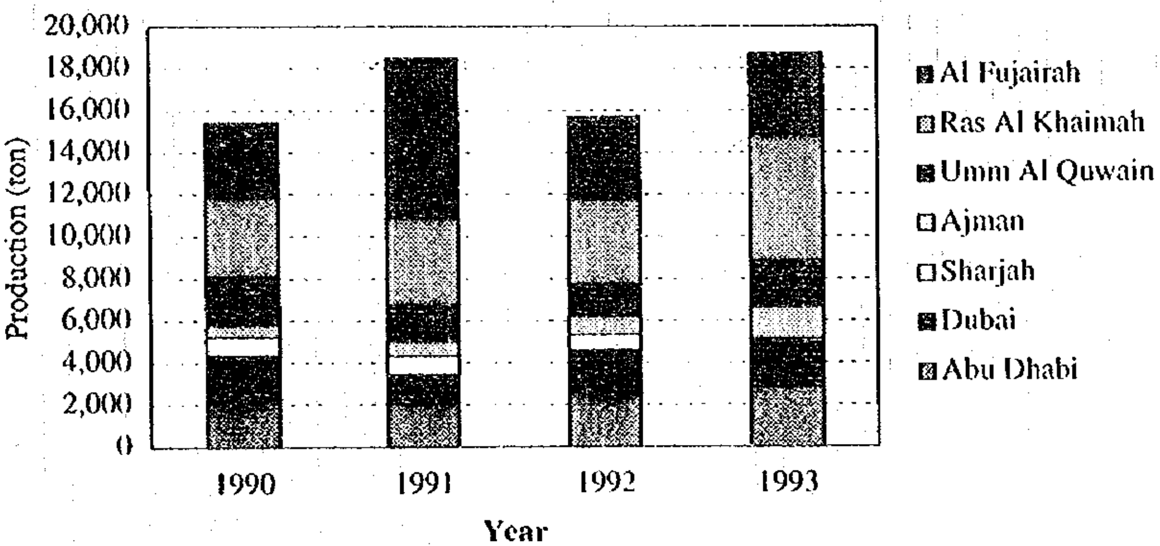


Figure 2.4.10. Poultry Production in UAE, 1990-1993

CHAPTER THREE : THE STUDY AREA

3.1. Natural Environment

3.1.1. Geography and Geomorphology

The northeastern part of UAE which includes the Study Area is categorized to be the Eastern Mountain Region, one of the geomorphologic units mentioned in the previous section. The actual landforms composed of the Oman Mountains and the marginal hills extend from the base of the mountains and the Bahada plain to the southwestern sand dunes, as well as to the Study Area. They sub-divide the Study Area into three the areas of: (1) Structural, (2) Fluvial, (3) Aeolian Forms.

(1) Structural Form

The Structural Forms inclusive of the Oman Mountains and Jabal Fayah are a folded structure due to climatic and sea level changes during the Quaternary period. The mountains rise higher than 400 m above sea level and exhibit the folded structural forms of parallel ridges and high-tilted beds. Many wadis cut down the mountains, forming narrow clefts, and there are also intermittent basins caused by the differential erosion. The terraces are developed in several levels which correspond to ancient sea level changes along the wadis. At the base of some wadis, karstic forms like small caves and solution features have also developed.

(2) Fluvial Form

The Fluvial Forms consist of wadis, wadi channels, the playa plains, and the Bahada plains. Wadis flowing from the Oman Mountains have spread out into several braided channels at the base of the mountains, forming the Bahada and playa plains. Due to the sand dunes at Jabal Fayah and Jabal Mileiha, the wadi courses have been diverted to the south-west, and they deposit silt in the tongue-shaped playa plain which lies between the dunes.

There are two types of Bahada. The first type was developed by wadis flowing from the Oman Mountains and was formed during the period from the Early Pleistocene up to the Holocene. The second type is of local origin, and was formed by wadis flowing from the local calcareous mountains such as Jabal Fayah and Jabal Mileiha. The earliest phase of Bahada, known as Pleistocene fan, may cover a wider area than that of the present, while their margins extend to the sea in the north of Ras Al Khaimah.

(3) Aeolian Forms

The Aeolian Forms extend westwards from the Bahada Plain, where linear dunes run NE-SW in a parallel, branching pattern. Their relative height reaches to more than 50 meters. However, the height decreases toward the south-east due to a decrease in sand supply and erosion caused by water occasionally flowing from the Oman Mountains. Some of the linear dunes are quite complex due to the development of rows of star dunes along the top of the their axes.

Inter-dune areas are covered by fluvial material which were laid down in the playas formed at the margins of the Bahada plain. Near the coast line, the dunes change their form to low flats of marine origin and their components are also dominated by bioclastic and quartz sands. Along the coast line in Ras Al Khaimah, sabkha, sand spits and lagoons have developed. These forms seem to have been developed over long periods of time as the sea level rose and receded.

3.1.2. Meteorology and Hydrology

(1) Meteorology

The Study Area has an arid to hyper-arid climate. There is only one narrow and elongated strip located at the eastern edge of the region that is under semi-arid and sub-humid climatic conditions. The sub-humid nature of the climate is manifested in relatively dense natural vegetation westward from Masufut. The mean monthly climatological parameters are shown in Figure 3.1.1.

a) Meteorological and Rainfall Stations

As shown in Figure 3.1.2., the meteorological stations operated by MAF in the Study Area are Falaj Al Mualla, which was installed and started recording in 1978, Mileiha, also installed in 1978, and Dhaid, which was installed in 1992. The stations at Falaj Al Mualla and Mileiha have recorded the most meteorological data, whereas for Dhaid station, rainfall records are only available from 1992. There is a total of nine rainfall stations in the Study Area, which include the catchment area of the wadis. They are: Falaj Al Mualla, Mileiha, Dhaid, Jebel Sharmas, Massafi, Siji, Fili, Sifuni, and Masabad.

b) Rainfall

Based on the climatological data obtained from Falaj Al Mualla and Mileiha stations in the Study Area, the average annual rainfall is around 127.2 mm in Falaj Al Mualla, while in Mileiha it is 133.6 mm. A major part of the annual rainfall is erratic and takes place during a few winter and spring storms which last for only a few hours.

c) Temperature

The temperature in the Study Area is high throughout a year. The summer is hot and the winter is warm. The mean annual temperature at Falaj Al Mualla Station is 27.0°C; the absolute maximum temperature is 49.0°C, the mean maximum is 35.3°C, the mean minimum is 18.6°C, and the absolute minimum temperature is 2.4°C.

d) Relative Humidity

At the Falaj Al Mualla and Mileiha Stations, the mean relative humidity is 51%; mean maximum relative humidity is 90% in Falaj Al Mualla and 85% in Mileiha; mean minimum is 16% in Falaj Al Mualla while in the Mileiha area it is 23%.

e) Wind Speed

The mean wind speed at Falaj Al Mualla station is 76.7 km/day. At Mileiha station it is 92.6 km/day. Generally, the wind between October and January is mild to gentle.

f) Evaporation

The mean pan evaporation is 9.4 mm/day in the Falaj Al Mualla area while at Mileiha it is 10.3 mm/day. Annual totals are estimated at 3,442 and 3,759 mm respectively.

(2) Hydrology

a) Drainage in the Study Area

The drainage system in the Study Area is divided into three major catchment basins: Wadi Ghyel and Lamaha, which flow from east to west and Thiqebah, which flows from north to south. These are shown in Figure 3.1.2.

i) Wadi Ghel Basin

The northeastern corner of the Study Area is under the Wadi Ghel basin with a catchment area of 79.4 km^2. The basin is a part of the Wadi Bih basin which flows northwestwards and drains into the Arabian Gulf when floods take place.

ii) Wadi Lamaha

Most of the Study Area is covered by the Wadi Lamaha basin. The basin is divided into six sub-basins: North Dhaid, South Dhaid, Siji, Khadrah, Shoukah and Hamdah. They originate from the elevated Structural Ridge and the Oman Mountains, and cross the Bahada gravel plain in a northwestwards direction to join the main trunk of Wadi Lamaha between Mileiha and Falaj Al Mualla. In that area, the wadi course changes from the northwest sharply to the north. It continues with approximately the same orientation to its mouth on the Arabian Gulf, to the south of Ras Al Khaimah city.

iii) Wadi Thiqebah

The southern part of the Study Area belongs to the Wadi Thiqebah catchment basin of 324 km^2, which is a part of the Wadi Guor (West) internal drainage basin.

b) Wadi Gauging Stations

A total of six wadi gauging stations were installed by MAF in the Study Area, in 1978. They are mostly located near the boundary between the Structural Ridge and the Bahada Plain. Their locations are shown in Figure 3.1.2., and summarized as follows:

Name of Wadi Basin	Name of Sub-basin	Name of Station	Location	Catchment Area (km^2)
Lamaha	Lamaha	WL - 1	Falaj Al Mualla	1,484.0
	Siji	WL - 2	Siji	86.6
	Khadrah	WL - 4	Sifuni Downstream	215.6
		WL - 3	Sifuni Upstream	137.9
		WL - 5	Ashwani	46.0
Guor (West)	Thiqebah	WG - 2	Jabel Fayah	

Source : Hydrology Vol. No. 3, [MAF (1983)]

c) Runoff at Gauging Stations

The characteristics and estimated annual floods of major drainage basins at wadi gauging stations in the Study Area are shown as follows:

Gauging Station	Catchment Area (km^2)	Average Slope (%)	Main Stream Length (km)	Concentration Time (min.)	Annual Flood (m^3/sec)
Siji	86.6	6.0	11.6	95	113
Ashwani	46.0	2.2	13.3	145	103
Sifuni U/S	137.9	4.5	17.5	123	123
Sifuni D/S	215.6	3.3	20.0	183	138

Source : Water and Soil Yearbook No. 2, [MAF, 1981], and Hydrology Vol. No. 3, [MAF, 1983]

The runoff coefficient in the Study Area varies from location to location and by flood, by a range of between 0.2% and 28%.

3.1.3. Geology

The northeastern part of UAE which includes the Study Area is geologically located in the Eastern Mountain Region, which includes two types of Allochthonous and Para-autochthonous units. They are both strongly influenced by the orogenic activity. The Allochthonous Unit contains Hawasina Group and Semail Series. The Para-autochthonous Unit mainly includes limestone facies from the Rus Al Jabal massif. These mountains are clearly divided into three tectonic lines (refer to Figure 3.1.3). They are the Diba zone, Wadi Ham line and Wadi Hatta zones.

The Diba Zone extends to the south of Diba and consists of a low-lying region dominated by a fault which cuts south-west through folded limestones and deep-sea argillaceous sediments along the chert, as well as volcanics belonging to the Hawasina Series. Thrust slices, outliers and exotic blocks of Limestones, ultrabasics and low grade metasediments are also to be found. Some are associated with the Semail Series and others with the sediments which form the Rus Al Jabal massif.

The Wadi Ham Line is a fault zone along Wadi Ham which extends NNW from the area to the west of Fujairah. It is divided into two areas of high ground formed from the basic and ultrabasic rocks of Semail Suit. Siliceous metasediments underlie the Semail rocks and are exposed in places in the fault zone.

The Wadi Hatta Zone lies in the south of the mountain region, north of Masufut. Extending WNW, the zone separates to two areas of Semail rocks and is similar in structure and lithology to the Diba Zone.

By controlling the above three structural zones, the northeastern Emirates lying within the Oman Mountains are divided into three regions: (1) the Rus Al Jabal massif, (2) Hawasina Series and Metasediments and (3) Semail Ophiolite Complex. In addition, (4) Upper Cretaceous Limestone is scattered around the base of the mountain to the Bahada Plain. The characteristics of these geological units are described as follows:

(1) Rus Al Jabal Massif

The Rus Al Jabal massif extends to the north of Diba Zone. It is dominated by carbonate and clastic sediments forming a broad, block-faulted region of asymmetrical folds which extend N or NNE. It has four major litho-facies; they are: Masundam Group, Elphinstone Group, Rus Al Jabal Group and Ramaq Formation (refer to Figure 3.1.3). Thrust faultings within the three main rock groups are common, particularly to the west of the massif. Thrust planes parallel to the main fold dip eastwards. A tectonic window reveals the thirsted relationship between the rocks of the massif and the underlying allochthonous sediments containing Semail and Hawasina debris. A thrust contact between the rocks forming the massif and those of the Diba Zone is assumed. Isolated blocks of predominantly carbonate sediments overlie the Hawasina series in the south of the massif, and it has been suggested that these exotic blocks, e.g. those containing rocks belonging to the Ramaq formation, share similarities with the Rus Al Jabal and Elphinstone groups. The Rann quartzite formation is categorized as par-autochthonous, the same as of the Ramaq unit.

(2) Hawasina Series and Metasediments

The Hawasina Series and Metasediments are distributed in the south of the Diba zone and are composed of sedimentary rocks (chert and clastics), metamorphic units and volcanic rocks. The sedimentary rocks occupy a strip along the Diba zone. The Metamorphic unit occupies a structural position between the Semail and Hawasina units. At Massafi, the metamorphics form a thrust slice in ultrabasic Semail Ophiolite. Tectonic windows related to either major faults or the core of the major anticlines expose the strongly sheared contact between the Metamorphic and the Semail units. The contact of the Hawasina with the overlying metamorphics has caused intensely foliated and sheared shale and schist. The contrast in the degree of re-crystallization between the two units and the abrupt change across the line of their contact indicates that the change of the Metamorphic unit preceded its emplacement.

(3) Semail Ophiolite Complex

The area to the south of the Diba zone is dominated by the Semail Suite of rocks comprising a layered sequence of basic and ultrabasic rocks with Ophiolite affinities. Ultrabasics, some serpentinized, are found in the west and are succeeded further east by a mixture of ultrabasic and gabbroic rocks. The upper rocks of the Semail Suite, volcanics and sheeted diabase, are found SSW of Khor Kalba. The level of erosion of the sequence compared to the rocks north of Wadi Ham suggests that the northern rocks have been uplifted in comparison with those in the south. The level of serpentinization varies, but, in general, it seems to be greater in the western mountain region adjacent to shear and fracture zones and it is also found near to the points of contact with underlying metamorphic rocks. Dikes and lensoid structures of granite or granodiorite take place in fracture and dilation zones in the gabbroic and ultrabasic rocks of Semail Suite.

(4) Upper Cretaceous Limestone

Along with the foothills of the Bahada Plain, the mountain rocks are overlain by autochthonous clastics and carbonate sediments which appear to be from the Maastrichian and Lower Tertiary ages. Similar sediments from northerly extending folds cored by allochthonous ultrabasic rocks are to be found at Jabal Al Fayah, which is west of the main mountain area. Superficial deposits from the Quaternary to Lower Tertiary periods cover the center of the Bahada Plain west of the mountains. Most of the surface is covered by Quaternary sediments, and also minor Tertiary carbonate, clastic sediments and evaporite crop out in the western aeolian dune. Quaternary fluviatile sediments dominate in the Bahada Plain. They are overlain by a layer of aeolian sands to the west which indicate various different ages. These widespread aeolian deposits, including some semi-consolidated miliolite from linear ridges, lie parallel to the coast. In Jabal Al Fayah, a series of roughly circular sand mountains extend in a northerly direction.

These superficial deposits, which are comprised of a series of post-Maastrichtian rocks, has not been mentioned in previous studies because of poor outcrops of these layers. Studies relating to them are described in the next Chapter.

3.1.4. Soil and Land Use

(1) Soils

a) Previous Soil Surveys

i) 1967 Survey

The major source of the soil survey data for the Study Area is the "Survey of Soils and Agricultural Potential in the Trucial State" [University of Durham, UK, 1967]. The survey concentrated on the gravel plains in the west of the mountain zone, but also included some selected areas in the Mountain and East Coast zones. Soil series and land capability maps were drawn for the gravel plain zone.

Soils on the gravel plains have been formed from outwash deposits derived from wadi discharges from the mountains. The texture of these soils becomes increasingly fine away from the mountains as the thickness of outwash sands and silt deposits increase. Aeolian sands encroaching from the west have covered most of the fine-textured soils, so that few of these soils are exposed. Soils in the gravel plain exhibit a high carbonate content because of the limestone parent material which is found to the north of the Diba line. Parent material is the dominant factor over all soils in the Study Area, and all are poorly-structured and immature. Nitrogen, Potassium and Phosphate levels are low, and deficiencies of trace elements have been observed, especially in the tree crops.

Major soil types recognized by the survey were sirerozems, non-saline alkali, and saline alkali soils. These types were sub-divided on the basis of texture and carbonate content. The gravel occurring within 50 cm of the soil surface was indicated on the soil survey map by suffix (g). The gravel content of the soil has a great effect on its land capability classification.

ii) 1982 Survey

In the study of the "MAF Dams and Recharge Facilities" [Halcrow (1982)], a soil survey was prepared covering the Study Area. The study recognized two further relevant soil types, namely saline non-alkali soils and wadi gravel soils.

iii) Atlas of UAE

The Soil map was prepared by the University of UAE in 1992 based on LANDSAT images and some field observations. The land in the Study Area is covered with fluvial and sand deposits, and soils are classified into: 1) Torrifluvents, torriorthends and outcrops, 2) Torripsamments-2 and calcirorthids, and 3) Rock outcrops torripsamments and calciorthids.

b) Soil Types

i) Sierozems

Sierozems normally occur in areas of less then 400 mm rainfall and are characterized by a lack of horizon differentiation, other than depositional. They have a weak platy structure overlying a sub-angular blocky structure. Top soil organic matter is usually less than 0.5% and carbonate and/or gypsum concentrations are commonly found below 30 cm. The overall texture is coarse though may become finer with depth, with the silt commonly exceeding the clay content. Top soil color is dark yellowish-brown (10 YR 3-4/4). On a saturation extract the pH varies between 7.8 and 9 and EC is less than 700μS/cm.

ii) Non-saline Alkali Soils

Non-saline Alkali soils are not found in the Study Area. These soils are generally accepted as containing large quantities of exchangeable sodium so that the ESP exceeds 15, although the EC remains below 4,000 μS/cm. These soils are toxic to plants and can often be recognized by the complete absence of vegetation.

iii) Saline Non-alkali Soils

Salinisation is the progress of accumulation of neutral soluble salts within the soil profile. This gives rise to soils with an EC of over 3,000μS/cm, an ESP of less than 15 and a pH usually below 8.5. These soils are associated with the use of saline irrigation groundwater and unregulated methods of irrigation.

iv) Saline Alkali Soils

These soils are formed by an accumulation of neutral salts in concentrations high enough to give an EC of over 4,000 μS/cm and sufficient sodium ions to give an ESP of over 15.

v) Wadi Gravel Soils

These soils are the most common soils in the Study Area. They represent the transitional phase between outwash cobbles and gravel and sierozemic soils. They are characterized by a sandy yellowish-brown to dark yellowish-brown topsoil up to 14 cm thick, often mixed with a fine gravel.

Horizons below this are depositional and therefore vary with location. However, while finer material may be present, it invariably consists of gravel and cobbles with a very low content of fine material. The organic matter content of the topsoil is less than 0.2%, pH values range between 7.5 and 8.5, and EC is generally less than 800 μS/cm.

(2) Vegetation

The Study Area lies in a dry but semi-humid climate, and therefore vegetation is relatively higher than in other areas. The nature of vegetation is sparse shrub with *Ornulaca leucacantha, Hammada elegans, Leptadenia protechnica, Orchradenus aucheri*, etc. with scattered trees of the *Acacia tortilis* and *Prosopis* species. The average height of acacia observed was 3 to 5 m. These rely on erratic rainfall and runoff from the mountain areas.

(3) Land Use

The land use in the Dhaid area is shown in the Atlas of UAE [UAE University, 1993]. According to the atlas, agricultural land occupies 3,392 ha and the area of abandoned farms is estimated to be approximately 374ha, which is shared among 115 abandoned holdings. There are 205 farms involved with the cultivation of dates. Though original data is not shown in the Atlas, it is presumed that the number of abandoned farms is increasing greatly at present.

3.2. Socioeconomic Factos

3.2.1. Administrative Jurisdiction

The Study Area covers parts of five emirates, namely, Sharjah, Umm Al Qaiwain, Ras Al Khaimah, Ajman and Fujairah. Sharjah emirate occupies the largest area of the Study Area (see Figure 3.2.1.).

There are 12 towns locate in the Study Area, as shown below. These are scattered throughout the desert/gravel plain.

Emirates	Name of Town/Village
Umm Al Qaiwain	Falaj Al Mualla
Ajman	Nasim
Sharjah	Suhelah, Dhaid, Wishah, Hamdah, Khuderah, Mileiha, Ikhedir, Bahayis, Fili
Ras Al Khaimah	Khadrah

The main towns are: Dhaid and Mileiha in Sharjah, and Falaj Al Mualla in Umm Al Qaiwain Fujairah Emirate does not have any towns in the Study Area, and occupies only a little waste land in the northeast part of the Study Area. Dhaid is the most important town in terms of regional economy.

3.2.2. Demography

In the Study Area, there was a settlement at Mileiha from around 300 BC that was heavily influenced by the ancient Greeks, and pottery from the island of Rhodes has been found. There are also some old forts and ruins in the Study Area. There is evidence that this area was already settled from prehistoric times.

The population of some major towns in and around the Study Area are as follows:

Town	Population			Percentage (1975=100)		
	1975	1980	1985	1975	1980	1985
Dhaid	5,000	8,160	15,780	100	163	316
Falaj Al Mualla	630	1,680	2,850	100	267	452
Manammah	1,430	900	1980	100	63	138

Note ; Manammah (AJN) is outside the Study Area.

Both Dhaid and Falaj Al Mualla have great rates of growth, as shown above. In 1985, the population of both towns increased more than three times from that of 1975. In Manammah, the population in 1980 was less than that in 1975, but it had recovered by 1985.

According to some unofficial estimates made by the Ministry of Planning, the gender ratio and age structure of the population in the Study Area roughly follow the same structure as the one for the whole country. The male population is greater than the female. The population is concentrated in the 20-35 age bracket.

3.2.3. Economic Conditions

(1) General

Sharjah Emirate, which occupies the largest part (about 65%) of the Study Area, ranks economically as third among the seven emirates. Its industrial production value in 1992 was Dh. 2.7 billion, of which 24% comes from the chemical and chemical products industry. Most of the industrial and commercial establishments are concentrated in the coastal and urban areas for the convenience of transportation and commerce [Government of Sharjah; Statistical Yearbook 1994].

(2) Agriculture

Main economic activity in the Study Area is agriculture which uses groundwater for irrigation. The value of agricultural production in Sharjah Emirate was Dh. 517 million in financial year

1992-93, with dates accounting for 33%, and alfalfa accounting for 30% of the total value. The total cultivated area was 7,848 ha in 1992-93, and the cultivated area around the Study Area in 1994 was 5,493 ha. This implies that the Study Area occupies about 70 % of the total cultivated area of Sharjah Emirate [Government of Sharjah; Statistical Yearbook 1994, MAF Statistics Section].

(3) Other Economic Activities

Apart from agriculture, there are other activities such as livestock raising, beekeeping, retail business, quarrying and the manufacturing of building materials (concrete bricks, etc.). There are many quarry sites for gravel mining and many rock crushing plants in the Study Area. This means that skilled labor may be difficult to find for activities outside the agricultural sector. There are also some garment factories in Dhaid.

Data obtained from the Sharjah Chamber of Commerce & Industry shows that there are 479 shops in Dhaid. Of these, 100 shops do business related to agriculture, accounting for 20.9% of all business. According to the municipal office, there are about 150 shops in Falaj Al Mualla. Most of the other towns and villages have fewer than 10 shops, and people in those towns sometimes have to go to big towns such as Dhaid or Sharjah for shopping.

Garment factories are the most important industry in the Study Area based on their production value and salaries paid to workers. Their products are sold outside of the Study Area and some of them are exported. The second most important industry is bread baking. These products are sold not only in the Study Area but also in adjacent areas. The third most important industry is concrete block manufacturing. In order to supply the rapidly increasing demand for construction material, the concrete block manufacturing, including quarry mining, in the Study Area has increased rapidly of late. Because of dust from the factories and quarries along the main road in the Study Area, some factories and quarries have been banned or closed by local governments who are concerned about protecting the security of traffic and the environment. The other main industries are blacksmithing and carpentry related to agriculture, such as the building of greenhouses, and are operated on a small scale in the Study Area.

Local grocery stores sell local products, but during the summer season, when local production is low, imports substitute for local production. Flour and other grains are almost all imported.

(4) Public Works

Both municipal and federal governments do some public works in the Study Area. At present, low-cost houses are being built at Mileiha, Khadrah, and other towns. The construction of a dual carriageway between Dhaid and Mileiha is being carried out by Sharjah Municipality.

3.2.4. Social Infrastructure

(1) Water Supply

The Ministry of Water and Electricity supplies tap water for all parts of the Study Area, except for Falaj Al Mualla, where the water supply is the responsibility of the municipality. In general, the source of tap water is from well fields located individually in each town or village. Pumps lift up well water to an elevated water tank from where it is distributed to each house by gravity. In some areas, water supply service is not on a 24-hour basis, because it depends on the capacity of the wells and pumps in use.

According to the Ministry, the unit price of water is Dh.15 /1,000 gallons, but some people receive local government subsidies for tap water. In Umm Al Qaiwain, there are three unit prices. The price of Dh.7.5/1,000 gallons applies to UAE nationals, Dh.15/1,000 gallons applies to foreigners and Dh.30/1,000 gallons applies to establishments. Neither the Ministry nor Municipality offers water supply for any farms, so the farm employees who live on farms do not receive any tap water service. Usually, their daily water needs are supplied by wells on the farm. Also, bottled mineral water for drinking purposes is sold in shops in the Study Area.

(2) Sewerage and Sanitation Service

The houses of UAE nationals have underground septic tanks. The municipal vacuum trucks clean them, and the contents are spread in a treatment area in the desert.

Each municipality provides a garbage and trash collection service for residential areas. Trash is burned outside of the town or village. However, farm employees do not receive this service.

(3) Electricity

Most of the Study Area gets electricity from the Ministry of Water and Electricity. In the Study Area, there are three power stations. Al Dhaid Power Station is the largest. Moreover, an expansion project for Al Dhaid Power Station is now in progress.

The unit price for consumption of electricity is 7.5 fils / KWh for farm and UAE nationals, 10 fils / KWh for the government and 15 fils / KWh for foreigners and industrial use.

There are about 6,800 consumers in Al Dhaid and 1,500 in Falaj Al Mualla. In Al Dhaid, about 29% of all consumers (2000 people) use electricity for agricultural purposes.

(4) Education

Based on data obtained from Ministry of Education , there was a total of 16 public schools in the Study Area in 1989/90, eleven public preparatory and six public secondary schools. These are mostly concentrated in the Dhaid area.

There are also some adult schools in Al Dhaid, Mileiha, Falaj Al Mualla and Madam. Around 330 people who could not get education in the past are now studying almost the same as the ordinary curriculum in extension classes. About two-thirds of adult students are women.

(5) Medical Service

According to Al Dhaid Section, Sharjah Municipality, Al Dhaid has a public hospital which had 61 members of staff in 1993, and there are public clinics in Falaj Al Mualla, Mileiha and Manammah.

(6) Communications

In the Study Area, the telephone is a more popular communication method than the postal service. There is a post office and an ETISALAT (Emirates Telecommunications Corporation) office in Al Dhaid.

(7) Public Transportation

The road that passes through the center of the Study Area east to west is quite well developed and most of the sections are paved dual carriageways. Another main road that goes north to south is also paved, and a section of dual carriageway from Dhaid to Mileiha is now under construction.

There is no public transport system except for school buses. People usually use their own cars or private taxis.

3.3. Agriculture and Irrigation

3.3.1. The MAF Central Agricultural Region

Agriculture is the main economic activity in the Study Area. The MAF Central Agricultural Region, which covers the Study Area, is the third most important agricultural region after the Abu Dhabi and Northern Regions. The location and boundaries of the Central Agricultural Region are shown in Figure 3.3.1. The organization chart for the Region is also shown in Figure 3.3.2. As shown in Figure 3.3.1, the northeastern corner of the Study Area is under the Central Agricultural Region; also, the Eastern Agricultural Region is included near the Eastern border of the Study Area.

These areas are covered by sand dunes and no cultivation area or village exists. Therefore, for practical purposes the whole Study Area is considered to be under the Central Region.

3.3.2. Number of Farm Holders and Cultivated Areas

The Study Area is spread over the five emirates of Sharjah, Umm Al Qaiwain, Ras Al Khaimah, Fujairah and Ajman and four Districts: Al Dhaid, Al Mileiha, Khadrah and Falaj Al Mualla which come under the Central Agricultural Region. The number of farm holdings and cultivated areas in the districts are shown in Table 3.3.1.

The number of farm holdings and the cultivated area in the four districts concerned in the Study Area were estimated from village/town data and MAF's agricultural annual statistics. There were 2,018 farmers and 6,181 ha of farmland in 1994 with an average cultivated area of 3.1 ha per farm holding (Table 3.3.1).

3.3.3. Agricultural Production

There is no available official data published so far on agricultural production in the Study Area. However, the district (extension unit) data collected by MAF for the annual agricultural statistics database is available. Also, the number of farm holders and the cultivation data available on a village/town basis is in the MAF data. Agricultural production in the Study Area was estimated by using the following procedure:

1) estimate the share of the Study Area in each district, based on the number of farm holders and the size of the cultivated area as shown in Table 3.3.2.,
2) the average share of the Study Area in each district based on the number of farm holders and size of the cultivation area is multiplied by the agricultural production of each district as given by the data.

(1) Land Share of the Study Area in the Four Districts Concerned

In order to estimate existing agricultural conditions in the four districts in the Study Area, the share of the Study Area within each of the four districts with regard to the number of farm holdings and the cultivated area was estimated first. In 1994, 62% of people in the four districts within the Study Area were farm holders. Of these, 87% of people in Al Dhaid were farmers, 41% in Mileiha, 16% in Khadrah and 43% in Falaj Al Mualla. Furthermore, 68% of land in the four districts was cultivated, namely 92% of Al Dhaid, 36% of Mileiha, 31% of Khadrah and 46% of Falaj Al Mualla (Table 3.3.2.).

(2) Cultivated Area, Crops, Production and Production Value

Applying the average share of the Study Area in each district, the cultivated area and the production of crops in the Study Area are estimated as shown in Table 3.3.3. and summarized as follows:

a) Cultivated Area

The cultivated area in the Study Area was estimated as 4,584 ha in 1994; 1,158 ha (25.3%) for vegetables, 1,825 ha (39.8%) for fruit trees and 1,601 ha (34.9%) for field crops.

b) Cultivated Crops

The main vegetables cultivated in 1994 were: Squash (5.3% of the total cultivated area), Tomatoes (5.0%), Onions (2.4%), Sweet peppers (1.8%), Parsley (1.7%), and Eggplants (1.4%).

The main fruit trees were Dates (23.9%), followed by Lemons (5.9%), Mangoes (2.6%), Other Citrus (2.3%), and Guava (1.4%).

The main field crops are Alfalfa (21.2%) and Green fodder (13.6%) such as Rhodes grass, and what is locally called Missiblo, a species of elephant grass.

c) Crop Production

The largest crop production in the Study Area is of Alfalfa, of which 91,708 tons (46% of the total crop production in the Area) were produced, followed by Greenfodder (25%), Dates (11%), Squash (4%), Tomatoes (3%) and Lemons (2%).

d) Production Value

Alfalfa has the largest amount of production value in the Study Area; Dh. 128.4 million in 1994, which accounts for 40% of the total crop production value, followed by Dates (24%), Greenfodder (17%), Squash (3.9%), Tomatoes (3.3%), and Lemons (3.2%).

The production value per unit area is the highest for Alfalfa (Dh. 127,203/ha), followed by Cucumbers (Dh. 95,873), Greenfodder (Dh. 84,667), Dates (Dh. 67,293), Cowpeas (Dh. 61,848), Beans (Dh. 56,541), Potatoes (Dh. 50,758), and Squash (Dh. 48,697).

The yield of Alfalfa is 90.9 ton/ha of fresh Alfalfa, and the yield of fresh Greenfodder is 77.0 ton/ha.

3.3.4. Cultivation Methods

(1) Cropping

In the Central Region, generally, seeds for Tomatoes, Onions (both for storage and green), Peppers, Cabbages, Cauliflowers, Egg plants, Potatoes, Beans and Lettuce are sown September to October, and harvested from the end of December to the end of March, depending on the crop. Watermelon, Melon, Squash, Cucumber, and Okra are cropped twice a year (Figure 3.3.3.). Field crops such as alfalfa and greenfodder are seeded and renewed every four to five years.

(2) Greenhouse Cultivation

Greenhouse cultivation is expanding in the Study Area for such reasons as: control of the season of cultivation, water saving, a stabilized high yield, and the guarantee of a high quality product.

The total cultivated area under greenhouses in the four districts were 3.81 ha in Winter and 7.51 ha in Summer in 1994. The crops cultivated in the greenhouses are Cucumbers (3.00 ha), Squash (0.30 ha), Potatoes (0.3 ha) , Tomatoes(0.203 ha), Sweet peppers (0.005 ha) and Sweet melons (0.003 ha) in Winter, and Cucumbers (4.30 ha), Squash (1.40 ha), Sweet melons (1.40 ha) and Watermelon (0.40 ha) in Summer. Greenhouse cultivation is most popular in Al Dhaid, followed by Falaj Al Mualla and Mileiha, but greenhouses have not yet been introduced in Khadrah. During the last three years, the total area under greenhouse increased in the four districts by 10% on average.

3.3.5. Agricultural Extension Services

In the MAF Central Region, in 1993, there were 11 extension officers to take care of 2,911 farms. This meant that each officer had on average 265 farms to visit during the year. For the same year, the officers in the Central Region made a total of 3,104 visits. The visits dealt with vegetables and field crops, fruit trees, pest control, soil, irrigation and fertilization.

3.3.6. Irrigation

(1) Water Sources

In the Central Region in 1993, there were 843 dry wells and 8,187 productive wells. With the exception of Abu Dhabi, the Central Region has a relatively higher number of dry wells compared with the Northern and Eastern Regions; while in the Northern Region the figure is only 6% of the wells existing in that Region which are poor, in the central Region the figure is 9%. It is considered that the number of poor wells in the Central Region will have already increased in 1995 due a the drop in the groundwater table, especially in the Study Area.

On the other hand, the MAF Central Region had the second largest number of generators (6,585) and pumps (3,956).

In the Study Area, most farms operate one to four tubewells drilled on their own farms. Especially in the northern Al Dhaid area, sometimes the extracted water is conveyed by pipes for more than two km in places where the wells have dried up. Where this is not possible, the farms are abandoned.

There were three falajes in the Study Area: Falaj Al Mualla, Al Dhaid and Siji. They had no water flow during the period of the Study.

(2) Irrigation System

MAF and individual farmers are trying to minimize the amount of irrigation water through the introduction of modern irrigation methods using government subsidies, both in the Study Area and elsewhere.

Around 60% of the farms in the Study Area already use one or more modern type of irrigation. Sprinklers account for 33% of irrigation using modern methods, bubblers for 35% and drip irrigation for 32%.

Table 3.3.1. Number of Farm Holders and Cultivation Area by Towns/Villages in the Study Area, 1994

Emirate	Agricultural Region	District*	Town / Village	Number of Farm Holdings	Cultivated Area (ha)	Cultivated Area per Holding (ha)
Ajman	Central Region	Dhaid-1	Al Nasim	22	73	3.3
Sharjah			Suhelah	20	46	2.3
			Dhaid	570	1,601	2.8
		Dhaid-2	Dhaid	292	1,148	3.9
			Wishah	577	1,728	3.0
			Hamdah	4	15	3.8
		Meleiha	Meleiha	91	321	3.5
			Bahayis	141	427	3.0
			Ikhedir	17	35	2.1
			Al Ghili	53	99	1.9
		Khadrah	Melaiha Al Saqeera	38	92	2.4
Ras Al Khaimah			Khadrah	14	20	1.4
			Khudera	15	25	1.7
Umm Al Quwain		Falaj Al Mualla	Rashidiah	41	92	2.2
			Falaj Al Mualla	77	267	3.5
			Al Zarqa	25	104	4.2
			Al Nabkha	21	88	4.2
Total / Average				2,018	6,181	3.1

Source: Statistics Section, MAF
Note : * same as Extension Unit of MAF

Table 3.3.2. Number of Holders and Cultivation Area by Four Extension Units Concerned, 1994

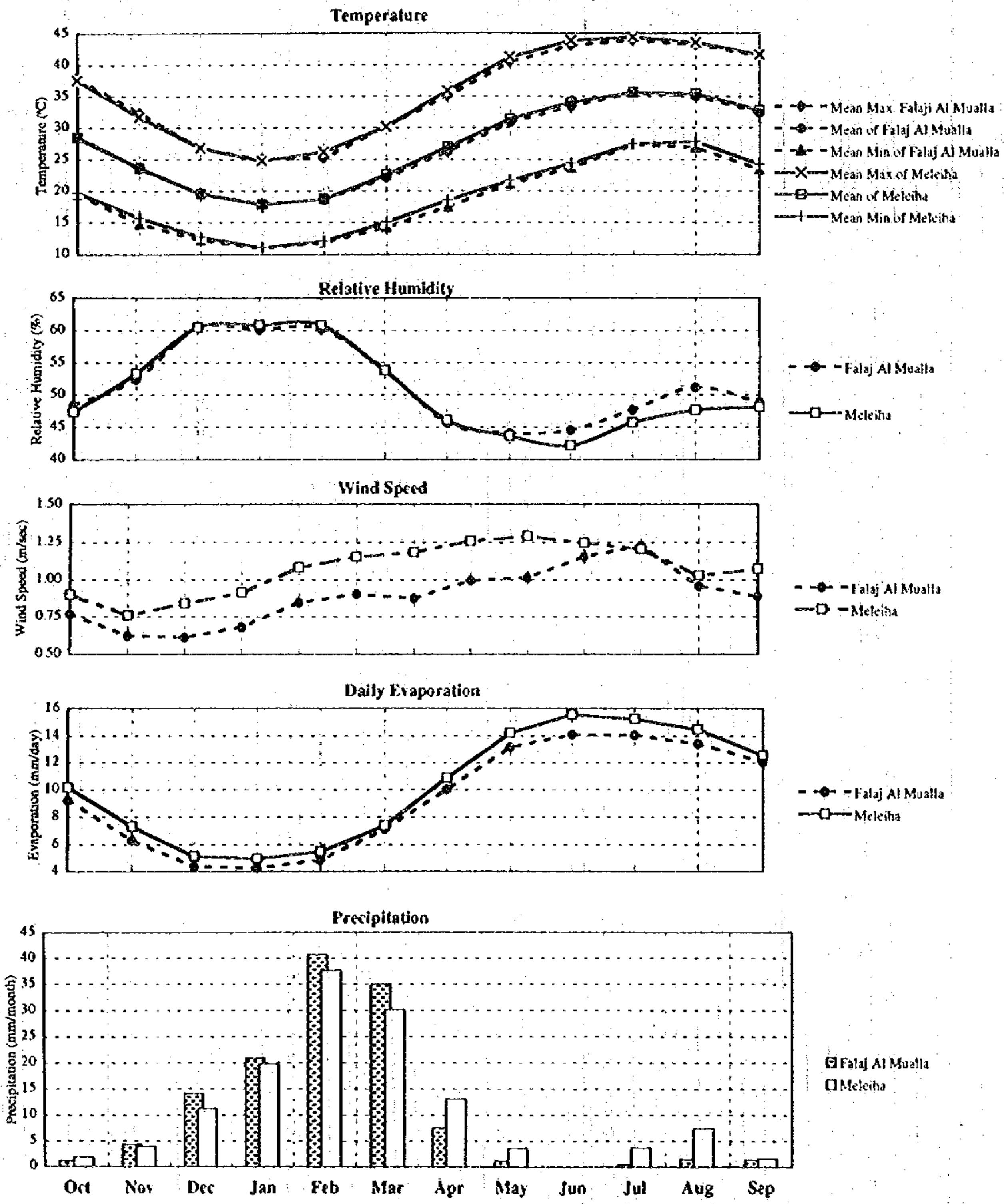
District*	Number of Farm Holders			Cultivated area (ha)		
	District Total	the Study Area Total	Share of the Study Area	District Total	Study Area Total	Share of the Study Area
Dhaid**	1,700	1,485	87%	5,024	4,611	92%
Meleiha	730	302	41%	2,456	882	36%
Khadrah	426	67	16%	440	137	31%
Falaj Al Mualla	378	164	43%	1,209	551	46%
Total	3,234	2,018	62%	9,129	6,181	68%

Source; Statistics Section, MAF
Notes : * same as Extension Unit of MAF
** including Dhaid-1 & Dhaid-2

Table 3.3.3. Crop Production in the Study Area, 1994

Crops	Area Cultivated (ha)	Area Cultivated Share in Total	Yield (ton/ha)	Production (ton)	Production Share in Total	Value of Products (Dh. X 10^3)	Value of Products Share in Total	Value/ha (Dh.)
[Vegetables]								
Squash	245.1	5.3%	28.6	7,248	3.7%	12,322	3.9%	48,697
Tomato	230.3	5.0%	27.0	6,353	3.2%	10,482	3.3%	44,617
Onion	108.1	2.4%	7.9	797	0.4%	917	0.3%	9,088
Sweet Pepper	82.9	1.8%	1.5	115	0.1%	219	0.1%	2,923
Parsley	76.4	1.7%	1.8	124	0.1%	185	0.1%	2,703
Eggplant	65.6	1.4%	38.0	2,492	1.3%	2,741	0.9%	41,770
Sweet melon	42.1	0.9%	20.6	900	0.5%	1,889	0.6%	43,250
Cabbage	32.8	0.7%	26.4	874	0.4%	962	0.3%	29,035
Okra	31.7	0.7%	10.6	331	0.2%	1,026	0.3%	32,842
Cauliflower	30.5	0.7%	22.2	701	0.4%	946	0.3%	30,000
Water melon	27.9	0.6%	21.2	572	0.3%	801	0.3%	29,677
Cucumber	22.2	0.5%	28.6	642	0.3%	2,150	0.7%	95,873
Bean	18.3	0.4%	15.1	292	0.1%	1,097	0.3%	56,541
Cowpea	14.0	0.3%	22.1	313	0.2%	877	0.3%	61,848
Radish	10.1	0.2%	19.6	208	0.1%	125	0.0%	11,764
Pepper	7.9	0.2%	10.4	95	0.0%	189	0.1%	20,583
Potato	6.7	0.1%	23.6	172	0.1%	371	0.1%	50,758
Jews mallow	4.9	0.1%	27.1	138	0.1%	234	0.1%	46,066
Carrot	4.6	0.1%	25.1	117	0.1%	164	0.1%	35,092
Turnip(Laft)	4.0	0.1%	30.4	123	0.1%	178	0.1%	44,144
Lettuce	3.7	0.1%	18.7	55	0.0%	82	0.0%	28,089
Other	87.9	1.9%	37.6	3,529	1.8%	-	-	-
Sub-total	1,157.8	25.3%	22.4	26,201	13.2%	37,957	11.9%	-
[Fruit Trees]								
Date Palm	1,095.4	23.9%	19.2	22,031	11.1%	77,109	24.1%	67,293
Lemon	270.5	5.9%	15.7	4,612	2.3%	10,146	3.2%	34,554
Mango	120.3	2.6%	6.4	794	0.4%	3,730	1.2%	30,104
Other Citrus	105.7	2.3%	11.8	1,318	0.7%	3,295	1.0%	29,558
Guava	62.9	1.4%	11.9	802	0.4%	2,445	0.8%	36,172
Fig	39.0	0.9%	4.8	196	0.1%	324	0.1%	7,881
Lime	23.1	0.5%	12.7	341	0.2%	852	0.3%	31,872
Grape fruit	14.3	0.3%	11.6	167	0.1%	366	0.1%	25,568
Pomegranate	12.7	0.3%	20.9	305	0.2%	1,160	0.4%	79,469
Grapes	9.0	0.2%	2.5	23	0.0%	93	0.0%	10,117
Almond	7.1	0.2%	3.0	20	0.0%	16	0.0%	2,357
Banana	3.6	0.1%	3.3	13	0.0%	29	0.0%	7,657
Other	61.7	1.3%	10.9	689	0.3%	-	-	-
Sub-total	1,825.3	39.8%	16.7	31,311	15.8%	99,567	31.1%	-
[Field Crops]								
Alfalfa	972.5	21.2%	90.9	91,708	46.3%	128,391	40.2%	127,203
Green fodder	625.7	13.6%	77.0	48,897	24.7%	53,787	16.8%	84,667
Tobacco	1.9	0.0%	8.7	24	0.0%	43	0.0%	15,661
Other	0.9	0.0%	20.0	18	0.0%	-	-	-
Sub-total	1,601.1	34.9%	85.4	140,647	71.0%	182,221	57.0%	-
Total	**4,584.2**	**100.0%**	**44.2**	**198,159**	**100.0%**	319,745	100.0%	-

Source; Statistics Section, MAF



Figures 3.1.1. Monthly Averages of Climate in the Study Area

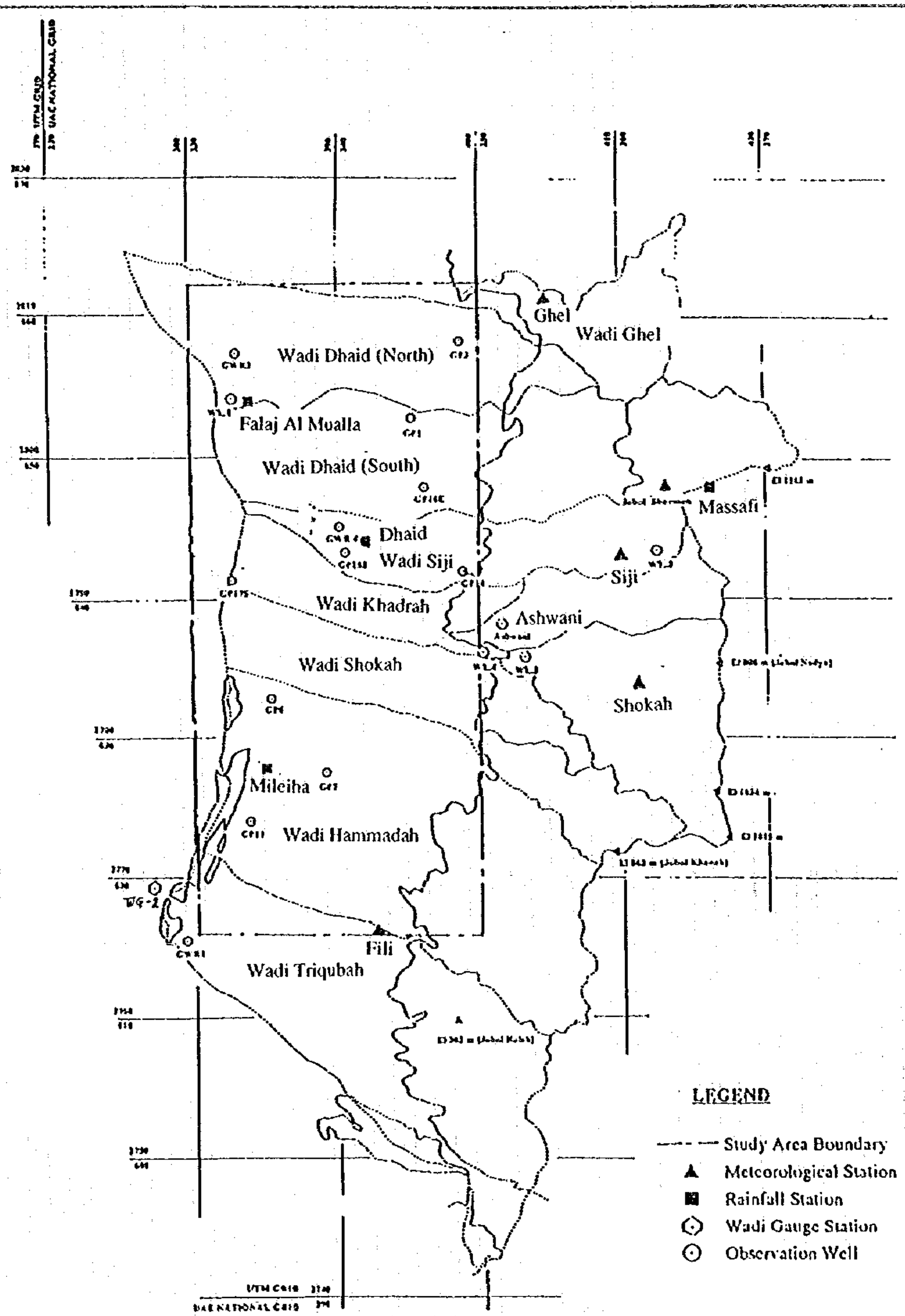
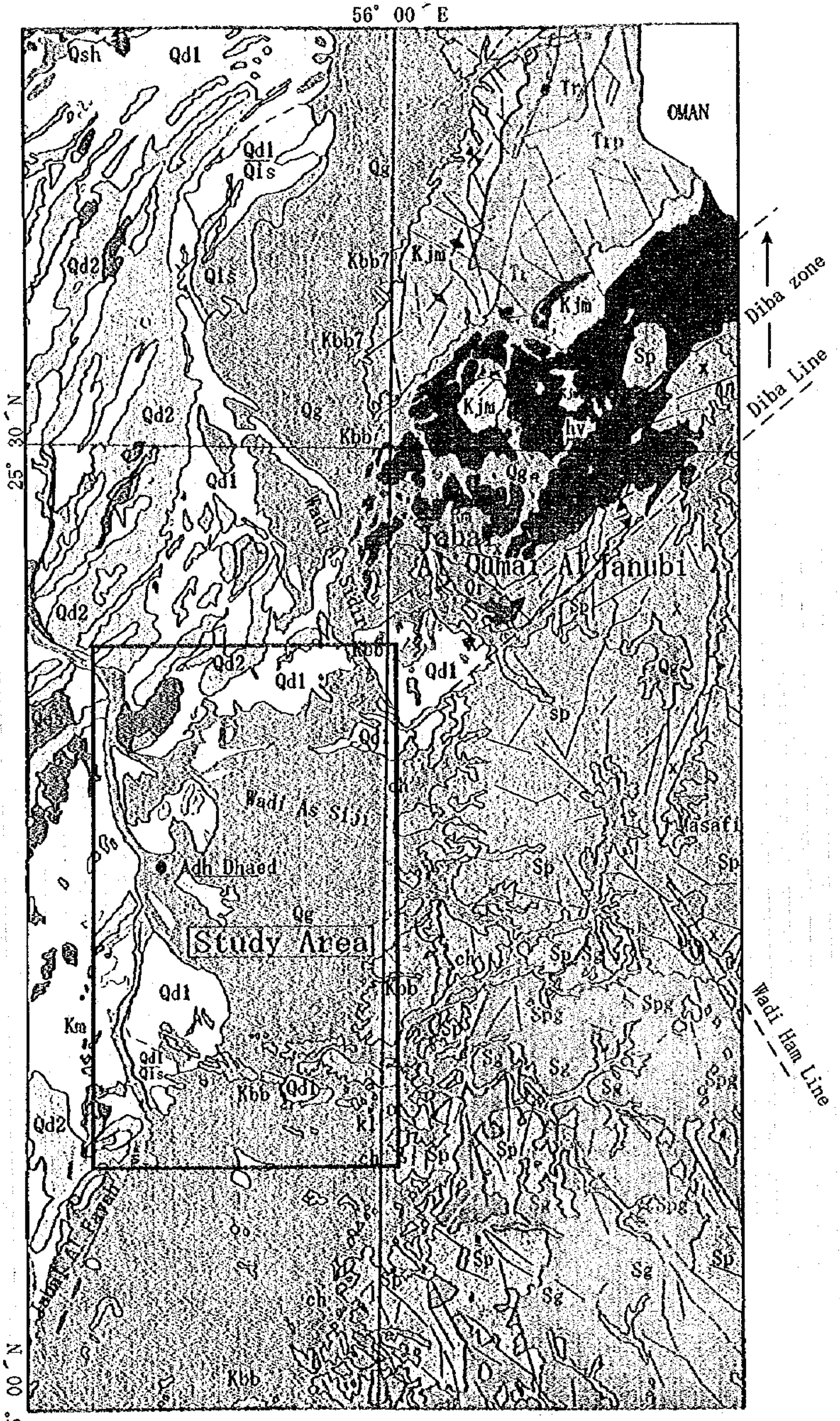


Figure 3.1.2. Location of Meteo-hydrological Stations and Observation Wells in the Study Area


56° 00´ E
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Jabal
Al Qumai Al Janubi
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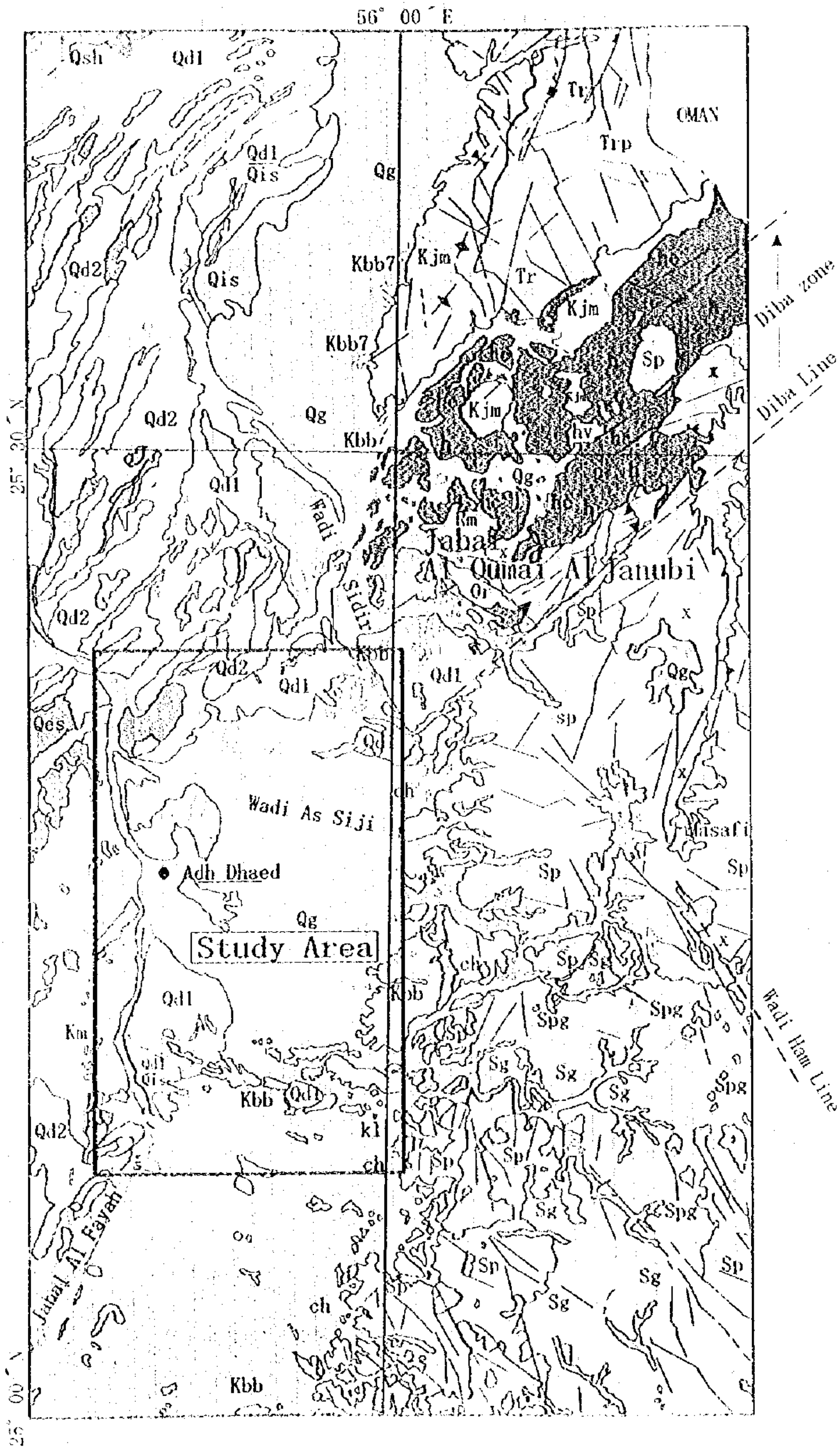
Wadi Ham Line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Wadi As Siji
Adh Dhaed
Study Area
Masafi
Wadi Ham Line
Jabal Al Fayah
Qsh
Qd1
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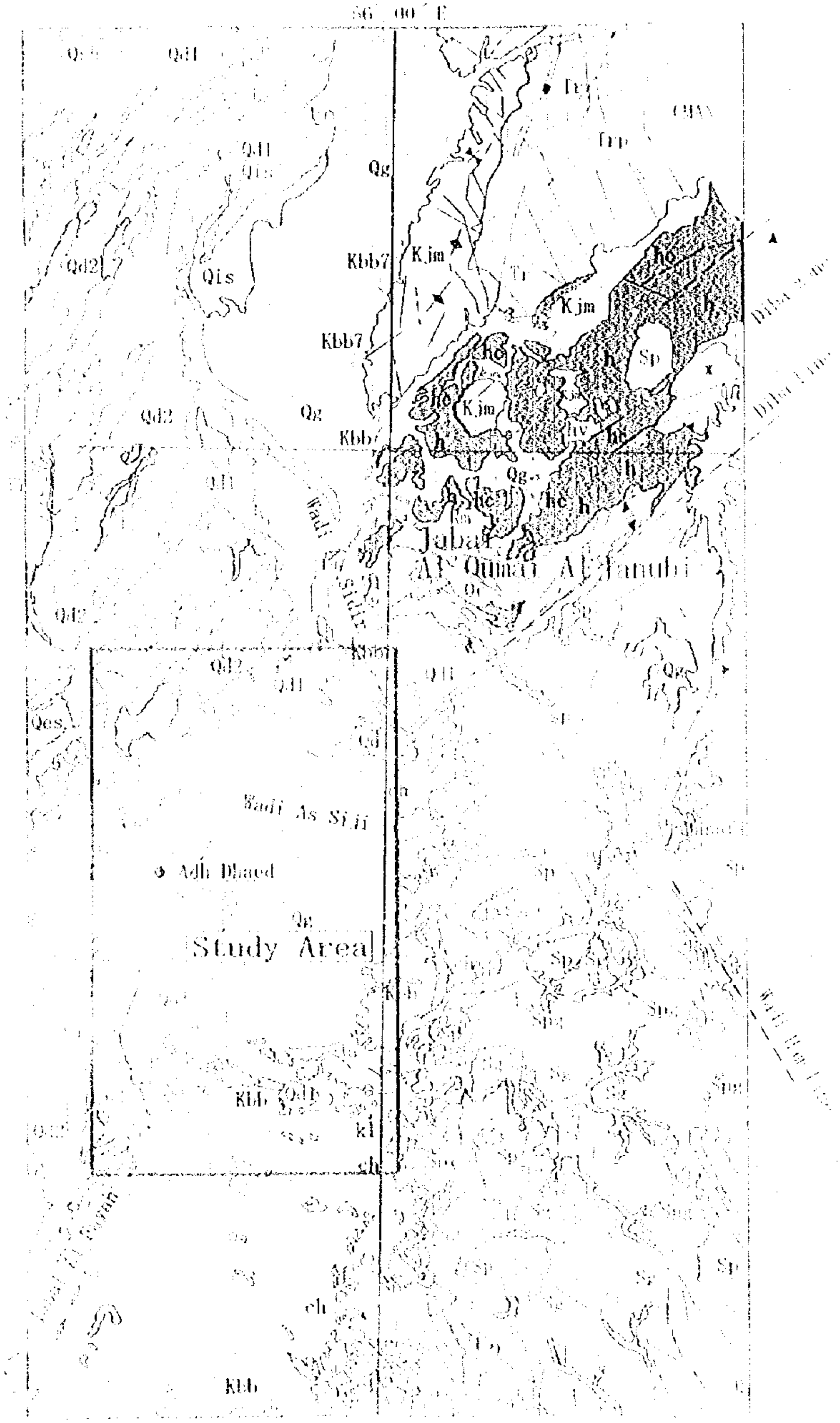
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ous and Par-Autochthonous units			
Fluviatile deposits	Boulders gravel,sand and silt in drainage Charnels and minor undifferentiated terrace deposits.Terrace and piedmont gravel beds,scree and outwash fans.Boulder to gravel size debris in a fine grained matrix,in places well cemented,local sand and silt interbeds	Holocene	QUATERNARY
Coastal sabkhah	Calcareous silt,muddy sand with considerable salt content, salt crusts,flooded by storm and spring tides	Pleistocene and Holocene	
Inland sabkhah	Silt and muddy sand,flooded by wadi or rising ground water		
Desert plain deposits	Lag gravels,locally sand or silt,from low-lying flat or gently undulating surface with isolated dunes.May include areas of thin eolian sand cover,sabkhah		
Eolian sand	Low dunes		
Eolian sand	High dunes		
Boulder beds	Pebbles,cobbles and boulders,principally of brown chert, gabbroic and ultrabasic rocks in a siliceous limestone matrix	?	
Limestone	White to buff,fine grained,porous,nodular weathering,contains fragments of chert,basic and ultrabasic rocks	Upper Cretaceous	JURASSIC to CRETACEOUS
Maastrichtian Limestone	Brown,purplish,grey and white fossiliferous limestone,locally with nodular varieties,limestone conglomerata and reef deposits. Occasional chert bands and nodules.Minor interbeds of marl,mudstone and shale.Local thich basal conglomerate in Jabal Al Fayah area		
Musandam Group	Grey,massive to well bedded limestones,locally oolitic, fossiliferous,dolomitic with chert nodules		
Elphinstone Group	Limestone,dolomitic limestone,dolomite,shale,marl, siltstone,sandstone,local chert and conglomerate(Ir)	Lower Jurassic to Lower Cretaceous	PERMO-TRIASSIC
Ru'us Al Jibal Group	Dolomite,dolomitic and argillaceous limestone and occasional shale(Irp)	Mid-Permian to Triassic	
Rann Formation	Limestone,dolomite,sandstone,marl and local shales outcropping in Jabal Al Qumar Al Janubi(Rm)	Ordovician	ORDOVICIAN
Rann quartzite Formation	Quartzitic sandstone and shale	Upper Cretaceous to Pre-Permian	
ious units			
Gabbros	Coarse grained leucocratic and melanocratic varieties, commonly layered and with minor serpentinite zones; breccias,microgabbroic and pegmatitic types occur locally		
Gabbros and ultrabasics	Complex zones of gabbro with intermixed ultrabasic rocks		
Ultrabasics	Peridotite,serpentinized peridotite and serpentinite, locally banded.Magnesite and thin chrysotile veins widespread. Serpentinite generally highly fractured.Silicified alteration products(ch)hatched		
series			
Metamorphics	Quartzite,quartz schist,quartz mica schist,chloritic schist, bands of brown,buff and White crystalline marble.Local calc silicate rocks include amphibolite and epidote schist		
Chert/limestone facies	Maroon and greenish grey chert commonly well bedded,grey brown and white limestone,occasional green/grey and maroon shale,local volcanics(h) Larger areas of chert(hc)		
Volcanics	Mainly dark green intermediate and basic lavas, vesicular, locally porphyritic and in places with pillow structures, agglomerate and ? tuff beds		

- Geological boundary
- Geological boundary,approximate
- Dip and strike of atrata
- Anticline
- Syncline
- Fault or fracture(mark on downthrow side)
- Fault or fracture,inferred or approximate
- Thrust fault(barbs point to overthrust rocks)
- Wadi
- Town

Figure 3.1.3. Geologic Structure of the Study Area

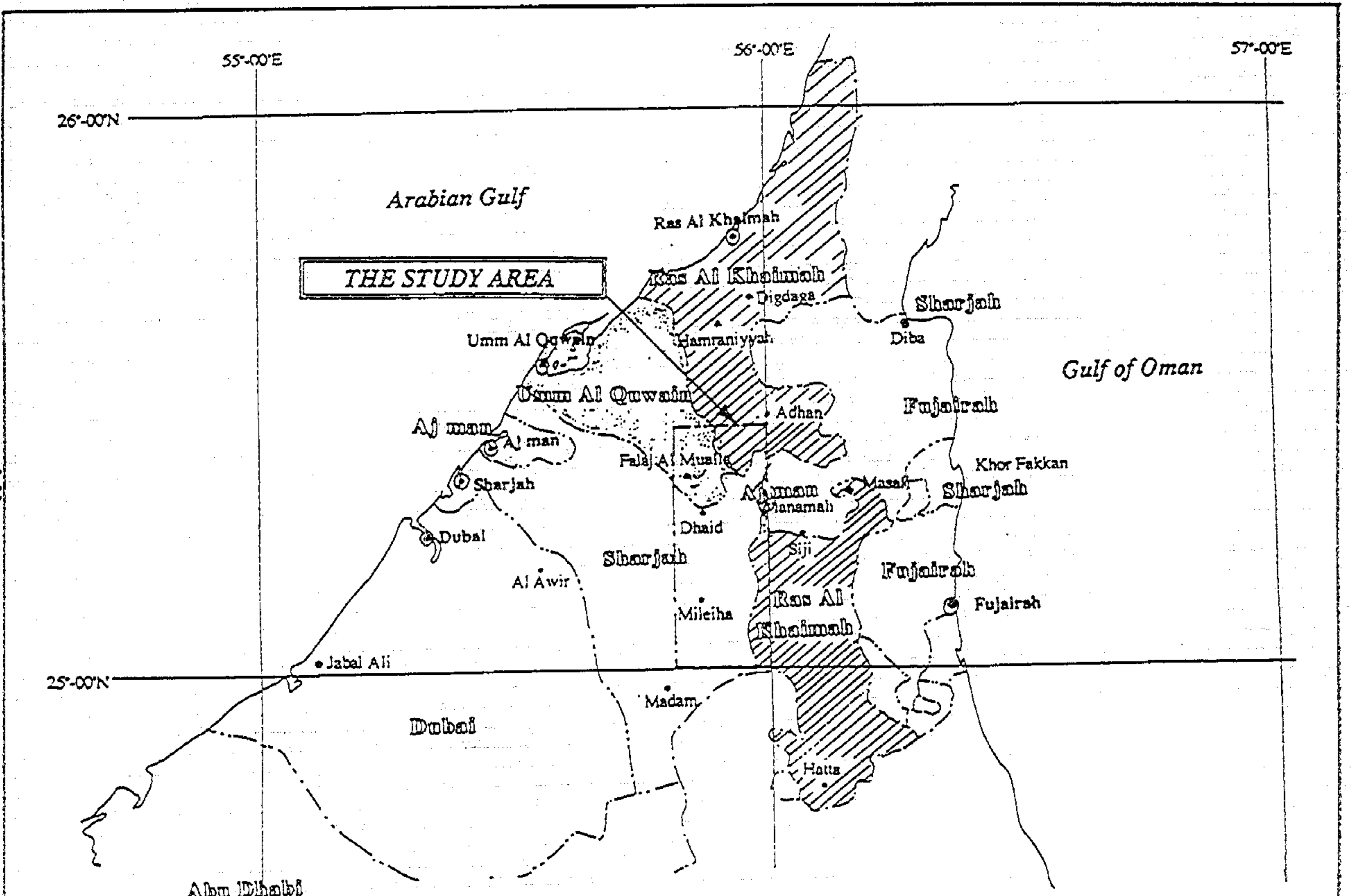


Figure 3.2.1. Administrative Boundaries of the Study Area

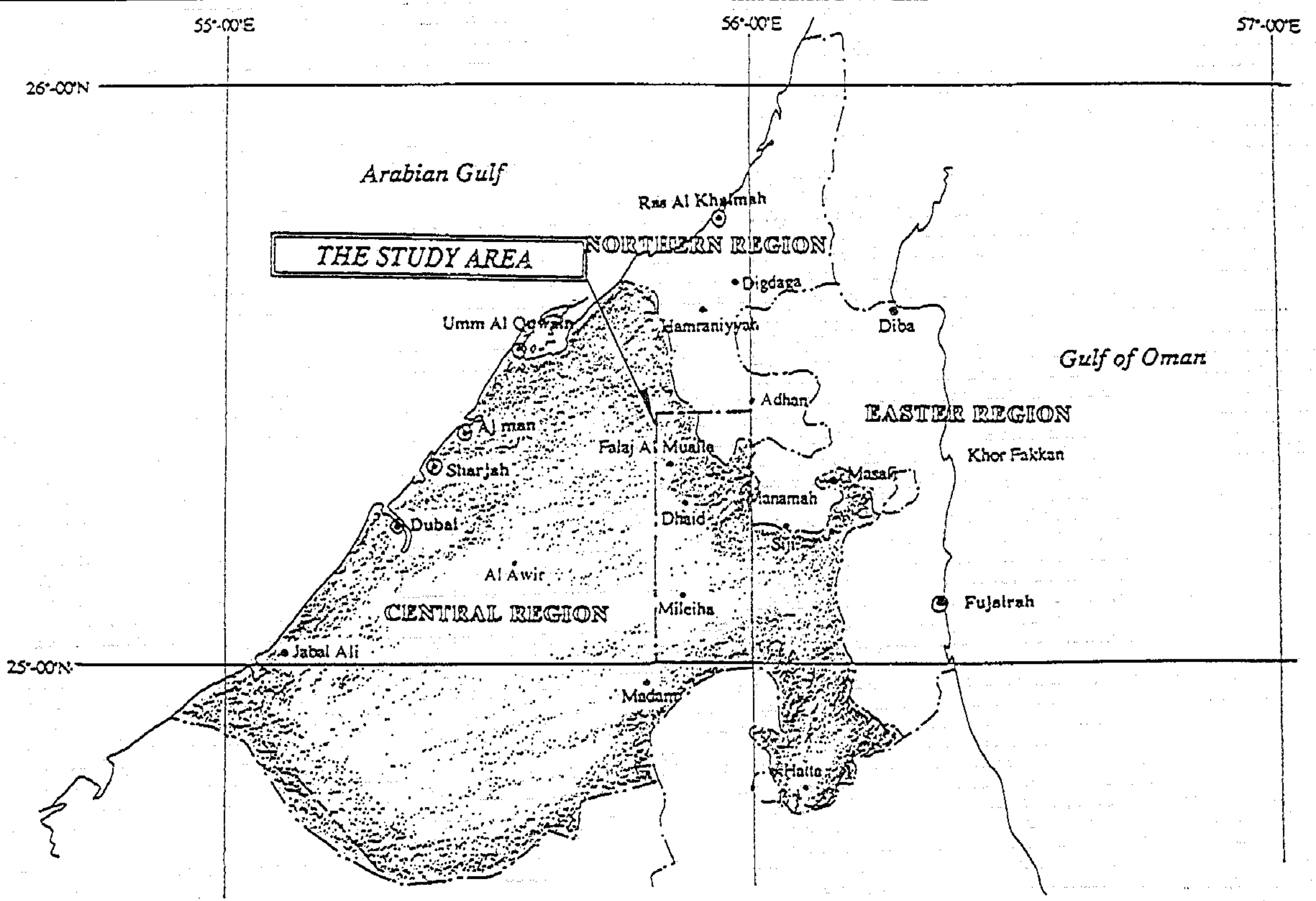


Figure 3.3.1. Agricultural Regions of MAF

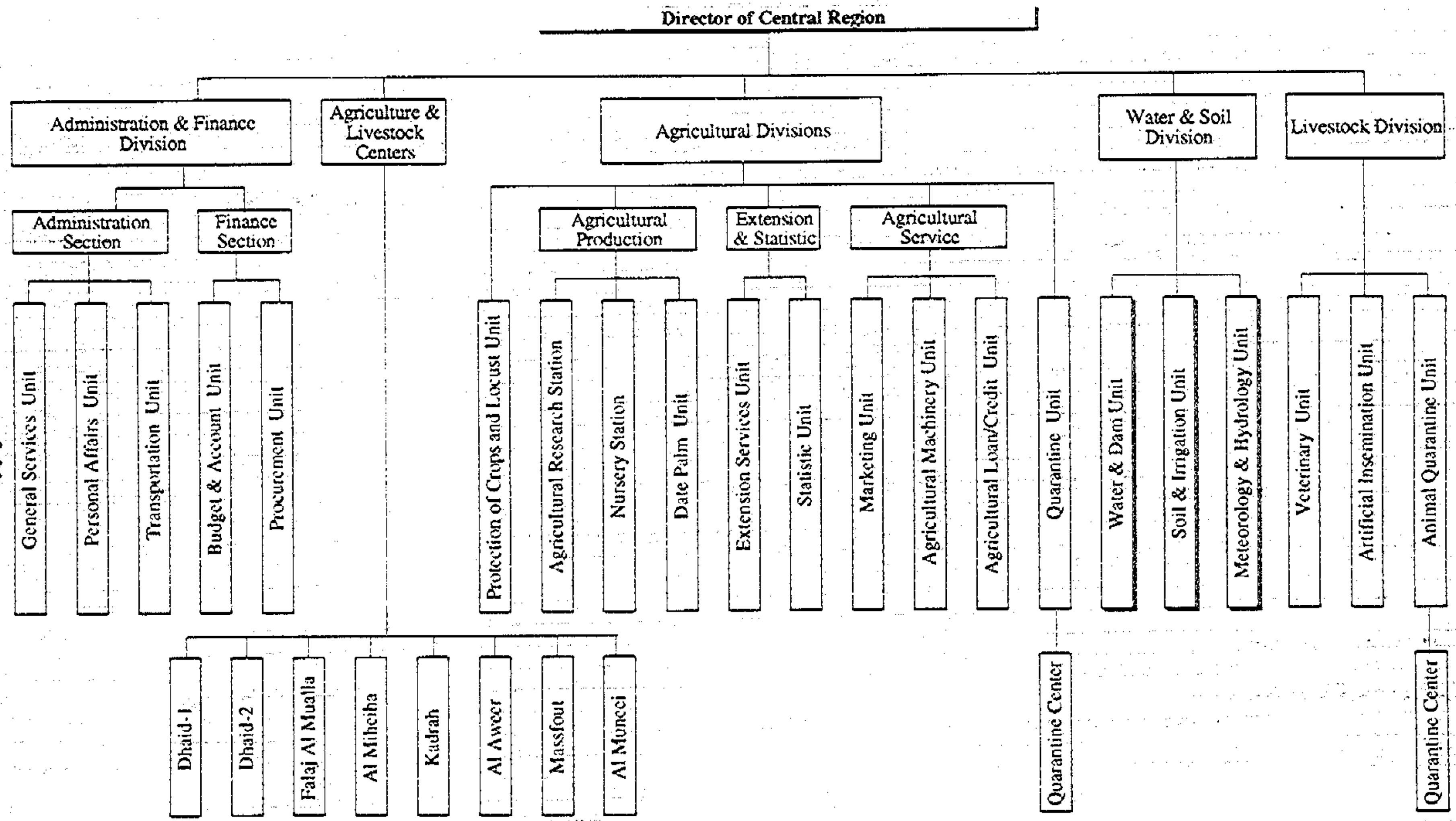
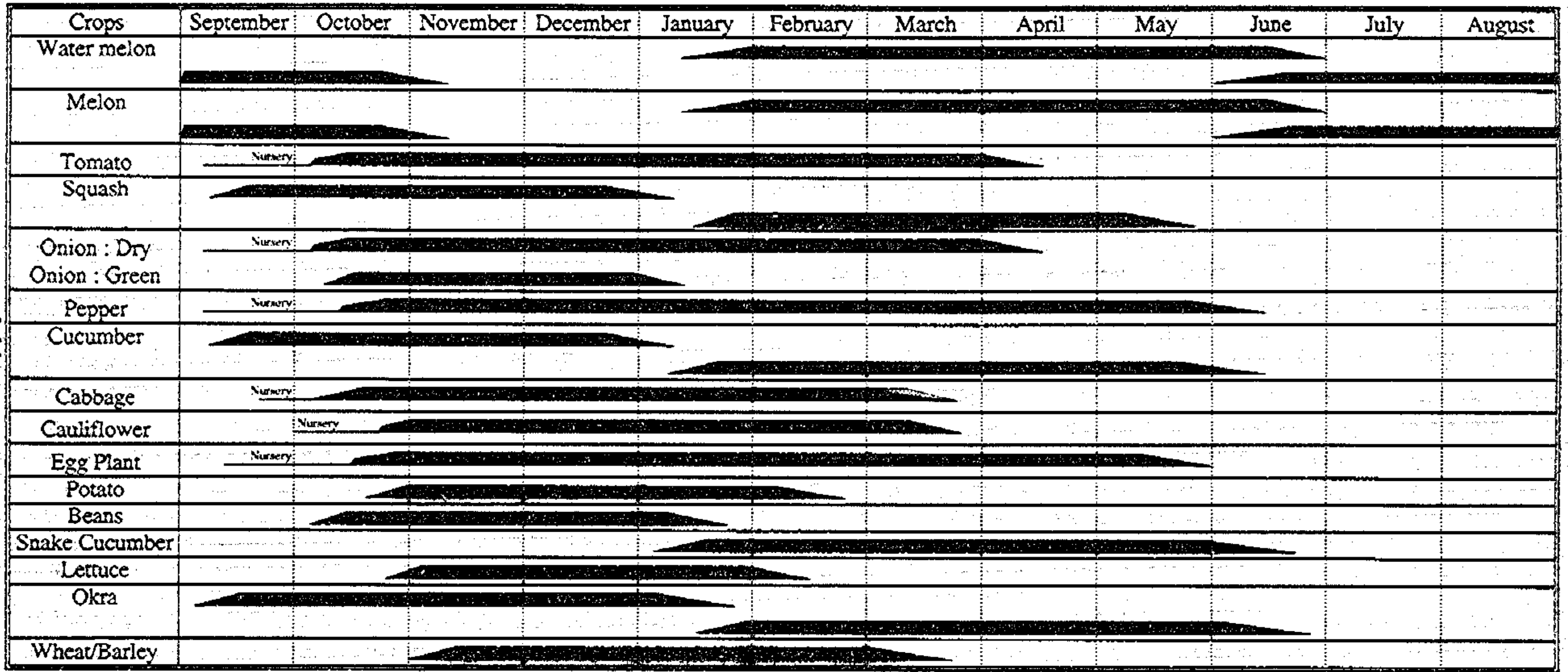


Figure 3.3.2. Organization Chart of Central Agricultural Region of MAF



Source : FAO Technical Report 3, Cropping Pattern and Irrigation Requirements Central Region, UAE, May 1978

Figure 3.3.3. Cropping Calendar of Main Vegetables in the Central Region

CHAPTER FOUR : THE SURVEY AND STUDY

4.1. Introduction

The Study consists of five stages: preparatory work, the Field Survey (I), the Homework (I), the Field Survey (II) and the Homework (II). During the Field Survey stages, the following works were conducted:

-Topographical Mapping

Orthophoto mapping by aerial photography (consigned to a local company)

-Agricultural Survey

Farm inventory survey (consigned to a local consultant)
Aerial-photography interpretation
Soil survey and soil sampling
Laboratory analysis of soil (consigned to a local consultant)
Intake rate test

-Socio-economy Survey

Farm and well inventory survey (consigned to a local consultant)
Survey of absentee farm owners
Supplemental agricultural survey

-Groundwater Survey

Well inventory survey (consigned to a local consultant)
Supplemental groundwater survey and groundwater sampling
Water quality analysis (MAF)

-Geologic and Hydrogeologic Survey

Geological reconnaissance survey
Geophysical survey (study team)
Core-boring and geophysical logging (consigned to a local contractor)
Aerial photograph interpretation
Test-well drilling, geophysical logging and pumping test (consigned to a local contractor)
Infiltration experiment (consigned to a local contractor)

-Environmental Survey

In addition to the above work, the collection and review of data and information related to the Study were carried out in close collaboration with MAF and other governmental agencies.

The analyses, studies and master plan formulation were made during the Home Work stages. The results obtained through the said surveys and studies are described in the following sections.

4.2. Farm and Well Inventory Survey

4.2.1. Introduction

(1) Implementation

It is very important to collect details of agricultural activities, livestock, household economy, water uses and the well conditions of individual farms. These surveys were conducted by a sub-contractor under the supervision of the Study Team. Interviewing methods were adopted for this Inventory Survey. The team also determined the on-site measurement of wells for temperature, electrical conductivity and pH. The survey was conducted in the Summer, and the fieldwork for the survey was almost completed by the end of July 1995.

For the survey, two survey teams were employed. One team was composed of two investigators (including at least one fluent speaker of the Arabic or Urdu language), and usually went to survey two farms within a normal working day. One of the team members questioned the farm owner or worker, while the other recorded the information regarding farm size and type, as well as details regarding production and the wells.

(2) Selection of Sample Farms

According to the existing data regarding MAF Central Region, about 2,000 farm holdings are estimated to be in the Study Area. It was impossible to survey all the farms in the Study Area within the limited survey period of the Study. Through discussions with the staff of the Central Agricultural Region, including consultants, it was decided to sample 200 farms (equivalent to 10% of total farms estimated). These were selected from five districts (extension units of the Central Agricultural Region), Falaj Al Mualla, Khadrah, Dhaid-1, Dhaid-2 and Mileiha, in accordance with the number of existing farm holdings and the farm size category as recorded by MAF. Numbers of farms in each category in each of the five districts are as shown below:

District (Extension Unit)	Number of Existing Holdings	Number of Sampled Holdings by Farm Scale				
		Large	Medium	Small	No Answer	Total
Dhaid	1,485	58	41	0	1	100
Mileiha	302	42	17	0	1	60
Khadrah	67	6	5	3	1	15
Falaj Al Mualla	164	16	7	1	1	25
Total	2,018	122	70	4	4	200

Note : Dhaid includes Dhaid-1 and Dhaid-2

The locations are shown in Figure 4.2.1.

(3) Farm Survey Questionnaire

The Study Team prepared a draft form of a questionnaire for the Farm Inventory Survey. In order to modify the draft form to a final form to meet the practical conditions, a pilot survey of 20 sample farms was conducted by a joint team composed of members from the Study Team, extension officers from the MAF Regional Office, and local consultants. The major items in the final form of questionnaire were:

- **respondence details** : position (owner/family/employee).
- **owner details** : name, ethnic/tribal group, full-time farmer/part-time farmer, location, address.
- **family members** : adult (number of male/female/total), children (number of male/female/total), family members engaged in agriculture (number of male/female/total), employee family status (number of persons in the family, nationality).
- **farm details** : year opened, total acreage of farm, area available for cultivation, area cultivated, area of land owned.
- **cultivation; production, consumption and sale of products** : acreage and number of trees by crop, season of cultivation season (month of seeding/harvesting) by crop, production by crop, home consumption by crop, amount of sale by crop, average unit selling price by crop, total selling price.
- **marketing** : marketing channel of the products (wholesaler, retailer, intermediary, cooperative, government marketing board, local market, others).
- **cropping input/resources** : fertilizer/pesticide/herbicide used (kind, amount, cost), labor input by crop, production cost by crop.
- **livestock details** : number of livestock used for breeding, livestock production, home consumption and sale of products, breeding cost of livestock.
- **farm household economy** : total annual expenditure, total annual income.
- **farmers' intentions** : schemes, farming intentions, water source, irrigation, cost of irrigation.
- **water uses** : irrigation facilities installed, irrigation practices, cost of irrigation.
- **water/well inventory** : well details, pump details, static water table, water quality at the time of survey, major use of well, problems with well.

The questionnaire for the farm inventory survey is attached in Appendix 2-1.

4.2.2. Results of the Farm Inventory Survey

(1) Farm Owners and their Families

In the inventory survey, the farmers were notified of the interviewer's visit one day in advance, but only 17 farm owners (8.9%) could be interviewed. Based on the data obtained from general farm details, most (35%) of farm owners in the Study Area are from Sharjah Emirate, followed by Abu Dhabi Emirate (22%), and Dubai Emirate (18%).

Much of the data about the owner's family is invalid, because most respondents were farm employees, not owners, and it is considered that the majority of them do not know their owner's family, especially children or babies, who live far from the farm. The average number of people in a farm owner's family is 8.76 persons. This figure is composed of 5.94 adults and 2.82 children below 14 years old. The number of children is shown to be smaller than the number of adults, and it varies from 1.44 in the Dhaid-2 area to 5.64 in Khadrah. The number of adults in each family varies on a smaller scale than that of the children, between 5.13 and 6.90.

(2) Farm Workers

The average number of farm employees is 3.46 overall. The largest number of farm employees is in Falaj Al Mualla, at 4.39 employees, and the smallest one is in Al Dhaid II, 3.17 employees. This may be due to the farm land and cultivation area in question.

In the Study Area, Pakistani employees are the most numerous, representing around 47.2% of the total of as surveyed in the data, followed by Bangladeshis (26.6%), Indian (11.6%), and Egyptian (8.7%). In Falaj Al Mualla, Indian employees are predominant, but in the other four areas, Pakistanis predominate.

The average monthly salary for a farm employee is Dh. 814. The highest salary is found in Dhaid-2 at Dh. 882. On the other hand, the lowest is found in Mileiha at 783.72. The salaries vary widely; Dhaid-2 shows both the highest at Dh. 1,600 and lowest at Dh. 400.

Farm employees work 9.6 hr/day on average, but the average of each sub-area varies from 8.5 to 11.2 hr/day. The longest daily working period, 18 hr/day, was in Mileiha.

(3) Farm and Cultivation Area

The average cultivated area is 40.39 donums, which is a higher figure than in MAF statistical data, where it stands at 3.1 ha (Table 4.2.1.).

(4) Crop Production

The total cultivated area was 519 ha, of which 60% was occupied by orchards, 30% by pasture crops and 10% by vegetables (Table 4.2.2.). The largest cultivated area is Dates, which occupies 37% of the total cultivated area, followed by Alfalfa (16%), and Rhodes Grass (9%).

Based on the cultivation area, the main vegetables are Squash and Tomato followed by Eggplant, Watermelon, and Cauliflower. The main tree crops are Date palm, Lemon and Mango, while the main field crops are forage crops such as Alfalfa, Rhodes grass, and Methapleon (local name is Misiblo).

c) Consumption of Products

As shown in Table 3.3.4., 80% of the vegetables produced were sold by 70% of the farms and 22% of the pasture produced was sold by 7% of the farms. However, almost all the total amount of fruit produced was consumed at home. As a whole, more than half of the products were consumed at home. The number of farms who did not sell any crop products at all amounts to nearly 60%.

d) Production and Efficiency

Production and efficiency in the 200 farms as estimated from the inventory survey is shown in Table 3.3.5. The total crop production in the 200 farms amounted to 19,599 tons with an average of 98 tons per farm in 1994.

81% (15,830 tons) of the total produce were pasture crops and the rest (19%) was evenly shared by vegetables and fruit trees.

The total net income in the 200 farms amounted to Dh. 10,488,263, with Dh. 52,441 per farm, earning an average of 71% of this amount from pasture crops, 22% from fruit trees and the rest from vegetable crops. Crops such as Eggplant, Sweet melon, Beans, Cabbage, Pumpkin, Watermelon, Courgette, Green beans, Orange, Chico, Pomegranate and Grapefruit, however, showed a loss.

Production, production value, production cost and net income per unit area of each of the crops cultivated on the 200 farms are as shown in Table 3.3.5.

The highest production was obtained by Methapleon with an average yield of 154,028 kg/ha, followed by Rhodes grass (100,915 kg/ha), Cucumber (99,981), Alfalfa (91,551), Tomato (48,908) and Squash (46,496).

The highest gross income was made from Alfalfa (Dh. 97,113/ha), followed by Cucumber (91,061), Methapleon (74,072), Tomato (73,851), Okra (54,088), Carrot (49,440), Rhodes grass (42,846), Lime (41,184) and Cauliflower (38,422), while production cost was highest for Egg plant, which amounted to Dh. 39,516/ha, followed by Sweet melon (37,971), Methapleon

(34,863), Courgette (32,884), Alfalfa (28,634), Squash (26,483), Rhodes grass (25,071), Watermelon (23,475) and Tomato (23,312).

The details of the production cost are shown in Table 3.3.7. The main production cost was shared between labor costs and the purchase of manure.

The labor requirement was largest in vegetable cultivation, accounting for 9 times that of fruit cultivation and 1.5 times that of pasture cultivation (Table 3.3.8.).

Manure is one of the most important materials purchased for desert agriculture, especially in the case of vegetable cultivation.

The total production cost was highest for vegetable cultivation, amounting to more than twice that of fruit tree cultivation. Looking at each crop, Jews mallow, Sweet melon, Watermelon and Tomato required large amounts of labor, which was mainly allotted to watering (Table 3.3.9.).

(5) Livestock

Goat is the most common livestock in the area, with 6,675 heads being bred on 54% of the farms in 1994, followed by Sheep (5,720 heads, 45% of the farms), Chicken (2,144 heads, 20%), Cattle (1,191 heads, 35%), and Camel (757 heads, 18%) (Table 4.2.3.). An average number of head per livestock farm is estimated to be 67 goat, 69 sheep, 19 cattle, 58 chicken and 23 camels.

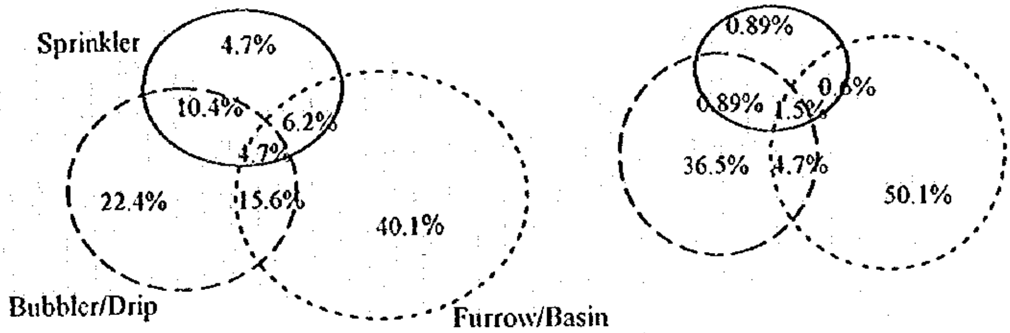
Almost all livestock are consumed at home; 33% (22 heads) of the total heads of goat, 49% (34 heads) of sheep, 27% (16 heads) of chicken, 23% (4.3 heads) of cattle and 6% (1.5 heads) of camel was consumed on the farm where they were raised.

(6) Irrigation

The summary of the irrigation conditions clarified in the Farm Inventory Survey is as follows:

- Most of the farms have tubewells for irrigation. Even though they have open wells they are not productive because of depletion of the water table. Falajes are no longer used because of they have dried up. A farm has on average 6 tubewells, but operates only 55% of them. There are 22 open wells, mainly in the Mileiha area, but only 32% of them are operational.
- Modern irrigation methods are installed in the Area. 50% of farms use bubblers to irrigate their tree crops, while 20% of farms use sprinkler and drips to irrigate their other crops, as shown below. The Dhaid area shows a high installation ratio of modern irrigation systems, but related irrigation apparatus such as sand filters and liquid injection tanks have not been completed.

[Installed] total farm 192 [in Use] total farm 182



- Most of the farms surveyed are facing a shortage of irrigation water, and farms except those in the Dhaid area are damaged by groundwater salinity.
- The survey period was Summer, when only the field crops and tree crops were irrigated. These were irrigated during the cooler morning and afternoon, but a few farms irrigated during the hot daytime too.

(7) Farm Household Economy

Vegetables account for 7.3% of the net income of a farm, tree crops account for 14.1%, and field crops for 78.6%, as shown in Table 4.2.2. The total net income of 196 farms is estimated at Dh. 6.8 million, and an average per farm householder is Dh. 35,000. Alfalfa shows the highest share of net income by crop at 63%, followed by Methapleon (8%), Rhodes grass (8%), Dates (8%) and Tomato (7%).

(8) Supplemental Farm Survey

a) Greenhouse Cultivation

A detailed survey on greenhouse cultivation, from which a high yield and the benefit of watersaving could be expected, was carried out by the Study Team on cucumber, sweet melon and Jews mallow in the Study Area and Al Ain. The results are shown below:

Crop	Production (kg/ha)	Net Income (Dh./ha)	Net Income / Water Consumption (Dh./ha/m^3)
Jews mallow (Dhaid-1)	9,259	22,465	11.89
Cucumber (Dhaid-1)	69,444	122,691	64.57
Cucumber (Al Ain)	113,280	225,185	47.02
Sweet melon (Dhaid-1)	50,000 pcs.	103,056	28.10

These results also confirmed that greenhouse cultivation can obtain a high yield as well as save water.

b) Alfalfa Cultivation

In order to confirm the yield of alfalfa and practices regarding its harvesting, a survey was conducted at two farms in Khadrah. The results are summarized as follows:

Farm-A cultivates 3.9 ha of alfalfa. The net cultivation area, after subtracting the farm ditch, farm road and canal area, is 2.6 ha (about 68.6% of the cultivated area). It harvests 13.6 times a year, at which time the unit yield in green alfalfa becomes 171 ton/ha for the net cultivation area and 117 ton/ha for the gross cultivation area.

Farm-B cultivates 3.7 ha of alfalfa, and the net cultivation area is 2.3 ha (about 62.8% of the total cultivated area). It harvests 13.6 times a year. In this case, the unit yield in green alfalfa becomes 167 ton/ha for the net cultivation area and 105 ton/ha for the gross cultivation area.

Unit yields of alfalfa in both farms showed a higher than average yield compared with MAF statistics at 90.9 ton/ha. Annual gross income was estimated at Dh. 69,088/ha for the net cultivation area and Dh. 43,366/ha for the gross cultivation area. Because of different selling prices (A farm at Dh. 0.50/kg, B farm at Dh. 0.38/kg and MAF statistics at Dh. 1.40/kg), gross income per unit area showed a quarter of MAF statistical data. These are caused by the conditions of sale contract set at the pre-harvesting stage on an area-by-area basis, in addition to which the involvement of middlemen further increases the price.

4.2.3. Well Inventory

The survey items in the Well Inventory, excluding those related to the aforementioned Farm Inventory Survey were as follows:

- Well Location (area, coordinates, Date of survey)
- Well Construction (construction firm, Date of construction, drilling method, depth)
- Casing/Screen Details (installed or not, material, type, size, depth)
- Pump Details (installed or not, type, size, position, output Hp)
- Hours of Pump Operation (survey Date, operating hours in Summer and Winter)
- Total Yield (survey Date, yield in Summer and Winter)
- Static Water Head (survey Date, water head in Summer and Winter)
- Water Quality (Ec, Temperature, pH, ORP)
- Uses of Well (domestic, animals, irrigation, others)
- Problems with the Well, Redemption Measures and Other Comments

The number of wells surveyed in the Study is summarized as follows:

Area	Number of sampling farms (No.)	Number of sampling wells (No.)	Number of Wells in a Farm (No, Min.-Max.)	Number of Wells in a Farm (Avg.)	Well Depth (No., Min.-Max.)	Well Depth (Avg.)
Dhaid	100	496	1-18	4	30-609	250
Mileiha	60	306	1-24	4	24-350	80
Khadrah	15	140	1-8	3	9-200	50
Falaj Al Mualla	25	192	1-17	6	30-365	130
Total	200	1134	-	-	-	-
Average	-	-	-	4	-	130

Well construction has been underway since the 1960s. Its peak came in the 1980s. The life of a well as estimated by the abundant wells is seven years. Most of the wells were constructed uncased, with neither a screen nor casing installed. The pump position is ordinarily set up to an average depth of 100 m. The majority of the pumps are submersible types with a capacity of 0.5 to 5.0 l/sec (outlet size is 1 to 3"). The water quality measured in the inventory survey indicated a wide range of EC from 500 to 10,000 micro-S/cm. The salt-damage to soil, especially in Mileiha and Falaj Al Mualla, caused by pumped water has been reported previously. There was also some concern regarding depletion of the water head and a decrease in the well yield.

4.3. Hydrology and Groundwater

4.3.1. Geomorphology

The mountain part of the Study Area is covered by Ophiolite. Moreover, the area from the base of the mountain to the Bahada plain is composed of Carbonate Rocks, such as limestone, chalk, dolomite, and dolomitic mudstone. The Bahada plain is occupied by Fluvial Deposits (see Figure 4.3.1.).

The Bahada plain, characterized by a monotonous terrain with minor relief, is divided into several landforms consisting of a river bed (active wadi bed), alluvial fan, terrace, and dunes. The active wadi bed, periodically flooded by heavy rain, is covered by very poorly-sorted gravel. The terrace and old fan form a relatively high tableland and both are classified by their scale and topographical shape as it lies in the Study Area. Both landforms were formed in Pleistocene age, which is characterized by heavy rain and high sea level, and are wider than that of the Alluvial fan.

In the Study Area, there are six watersheds; namely, Wadi Tiqubah, Wadi Hamdah, Wadi Shoukah, Wadi Khadrah, Wadi Siji, Wadi Dhaid. Wadi Gyle is located in the south of the Study

Area. All wadi courses which flow to the Bahada plain often branch off into small streams several kilometers from the base of the mountain. This topographical feature indicates that groundwater recharge takes place in this zone, especially at Wadi Khadrah and Wadi Siji, which is where the most active groundwater recharge takes place. This is because both wadis have the widest watersheds in the Study Area. Furthermore, this productive zone is situated near Dhaid, so that all water recharged will serve as a water source for irrigation in the Dhaid area.

In other areas such as the terraces and dunes, not so much groundwater recharge has taken place. Most of the rainfall retained in the impervious layer interbedded in the lower part of the dune is lost by evapotranspiration in the dry season.

4.3.2. Geophysical Survey

The primary objectives of this survey were to detect the layer composition and the fault and fracture zones. Secondary objectives were to clarify the aquifer structures to delineate the impervious basin in the Study Area.

For this purpose, the method applied was the transient electromagnetic method, often referred to as TEM, and the Natural Gamma Ray Survey. The survey line was selected at appropriate points either to cover the whole area or the existing test wells (IWACO, 1986). 131 stations were surveyed by TEM method and 805 were serveyed by Natural Gamma Ray Method (refer to Figure 4.3.2.).

TEM measurements were made at spacings of approximately one kilometer along the five profiles spanning the Study Area. Four of these profiles are approximately parallel and run from west-northwest to east-southeast across the Study Area. The fifth line is a longer north-south profile line through the center of the Study Area. Five Natural Gamma Ray Survey lines (Lines GA to GE) were set along the TEM lines, based on preliminary TEM results. The measurements were made at 20 m intervals along each line.

When data processing commenced, automatic one-dimensional data inversion was performed to generate 19-layer resistivity models for each of the data sets. The thickness of the layers increase with depth and these models extend to a depth of 600m from the surface. This data was used to produce resistivity sections and resistivity contour maps and to estimate initial model parameters for interactive one-dimensional inversions. The layer analysis was completed based on these initial models of the horizontal four layer model. Three to five layers were analyzed as the final model interpreted from all the geological data obtained from the boring log and the test wells. The data from the Natural Gamma Ray Survey was analyzed graphically and largely qualitatively. The four gamma-ray count values and the two count ratios which were recorded were plotted along survey lines. Mean values (M) and standard deviations (S) for each count and count ratio were also calculated for each survey line. With these mean values and standard deviations, the two threshold values, M + 2S and M + S, were calculated and used to determine anomalous zones along the lines.

The TEM result commonly shows the high-low-high series of resistivity layers which was analyzed as being a four layer model at most of the stations. The first and second layers were analyzed as Upper Aquifer. The third layer was thought to be a clay layer (Aquiclude). The fourth layer corresponded to the Lower Aquifer. With the result of the Natural Gamma Ray Survey, 50 anomalies were also detected in the Study Area. Several stations out of these coincided with the vertical structure indicated by the resistivity pattern obtained by the TEM survey.

4.3.3. Core-boring and Test-Well Drilling

Core-boring and Test-Well Drilling were completed during the Study period. Core-boring was made to determine the stratigraphy in the Study Area, as well as the physical and hydraulic properties of the rocks encountered. The Test-Well Drilling was carried out to detect the extent, scale and hydraulic property of each aquifer. In addition, the stations for Core-boring were selected based on these conditions: (1) the stations were to cover the whole geological structure using a minimum number of wells to maximum effect, (2) analysis of the survey was to be made with the existing geological and hydrogeological data obtained from the previous geological survey, and (3) the survey result was to be correlated with the TEM result. Among the most appropriate stations, two geophysical stations set on the C-Line intersected in the center of the Study Area and were selected as the Core-boring sites.

On the selection of Test-Well sites, the conditions were: (1) the stations located at the productive aquifer, as supposed from the existing data, (2) the stations would be used as an observatory for the monitoring system in the future, and (3) the stations would penetrate into the Lower Aquifer. The location and depth of the Core-boring and Test-Wells are summarized as follows:

Core Boring Test Well	Type of Holes or Wells	Location	UTM (N)	UTM (E)	Depth (m)	Elevation (m)
B1	Core-boring	Ikhedir	2778548	393803	200	180.00
B2	"	Mileiha	2780638	389518	300	154.00
PW1	Pumping Well	Dhaid	2793594	397342	600	182.60
PW2	"	Khadrah	2785600	394300	150	177.86
OW2	Observation Well	Khadrah	2785600	394300	70	177.96
PW3	Pumping Well	Mileiha	2782369	391000	300	162.52
OW3	Observation Well	Mileiha	2782369	391000	250	162.32
OW4	"	Falaj Al Mualla	2805856	386558	300	110.00
PW4	Pumping Well	Manammah	2802981	391257	350	131.55
PW5	"	Fili	2771060	387299	300	178.10

From the results of drilling, the stratigraphy in the Study Area was divided into four layers. The first layer, composed of mainly loose sand and gravel, occupies the area from the surface to a depth of between 20 m and 100 m. The second layer is mainly composed of semi-consoliDated to consoliDated gravel. The third layer consists of marl, clay, shale and claystone. Lastly, the fourth layer, or basement, is comprised of limestone and dolomite mixed with gravel and Ophiolite.

In the drilling survey, the Lugeon Test in the borehole and pumping test in the Test-Well were conducted for detecting the hydraulic properties of each layer. A general value of one Lu was obtained from the borehole, excluding un-testing stages, due to a collapsing at the bottom of B2 and the top horizon, due to a very loose facies of the sand and gravel. This value is equivalent to a permeability coefficient of $k = 1 \times 10^{-5}$ to 10^{-7}, which correlates to that of the aquiclude, or the impervious layer, intercalated in the Aquifer.

Transmissivity was observed to have a wide range, from impervious to highly permeable in nature, up to a maximum of 290 m^2/day. The storage coefficient was estimated at $s = 2$ to 3×10^{-3}. The aquifer coefficients obtained from the Test-well in addition to the existing observation wells are given in Table 4.3.1.

Geophysical Logging was carried out in both the boreholes and the Test-wells by applying Formation and Groundwater Logging procedures. Formation Logging consists of Caliper, Gamma, Sonic, Density and Neutron Logs. Groundwater Logging consists of Temperature, Electric Conductivity, Dissolved Oxygen Content and Redox Potential Logs. The former was conducted for a comparison with the geophysical result, and the latter was used to grasp the groundwater quality and to determine the type of groundwater. Based on the results of the Geophysical Logging, the porosity of layers was inferred as being between 5 to 40 %.

4.3.4. Geology

The correlation of the geological members and litho-facies with the general stratigraphy established in UAE was made by summarizing the overall results from the Geophysical Survey, Core boring, Test-well and the Existing Well Survey. The correctional table among those results in the Study Area is given as follows:

	Geological age	Stratigraphy	Major stratum	Resistivity layer	Aqui
Quaternary	Holocene	Superficial Alluvium Talus	Gravel layer, Sand and gravel layer and Sand and gravel mixed with sand and clay (Partly consoliDated sand and gravel layer)	1st resistivity layer (Avg. 100 ohm-m)	Upper Aquifer
	Pleistocene	Post-Fars Formation	ConsoliDated clay layer, Limestone layer	2nd resistivity layer	
Tertiary	Neogene	Upper-Fars Formation Razzak Formation	Marl layer, Calcareous gravel layer and Calcareous sand layer	(Avg. 50 ohm-m)	
	Palaeogene	Umm al Radhuma Formation Qahlah Far Formation Fars Formation Fars Formation (Eocene shale)	Shale, Limestone layer, Marl layer, Sandstone layer and Dolomitic layer	3rd resistivity layer (Avg. <10 ohm-m)	Aquiclude
Mesozoic	Upper Cretaceous	Aruma Group (Juweiza Formation, Fiqa Formation and Muti Formation)	Melange layer or Carbonate rocks with serpentinites, Gravely layer, Marly and Shalely layer and Dolomitic layer	4th resistivity layer (Avg. 20 ohm-m)	Lower Aquifer
	(Maastrichtian – Santonian)	Semail Ophiolite complex	Ophiolite, Basic rock and Ultrabasic rock		

As a result of TEM survey, the resistivity layer division largely coincided with the changes of litho-facies and local stratigraphy in the Study Area. By correlating these layers, the geological characteristics of each unit were recognized as follows:

Holocene Sediments (1st. Resistivity Layer): The layer widely covering the Study Area, with an average thickness of 20 m, overlays deeper along the old channel east of Wadi Dhaid and Wadi Mileiha.

Pleistocene Sediments (2nd. Resistivity Layer): This layer consists of gravely facies with some clay intercalation.

Neogene Sediments (2nd. Resistivity Layer): This layer is made up of semi-consoliDated to consoliDated gravel and minor marl and sandstone layers with a maximum thickness of 200 m. The basement of this unit is isolated by a rise existing in the center of the Study Area and divided into two parts: the north (Dhaid district) and the south (Mileiha district). The layer corresponds to the Upper Aquifer.

Paleogene Sediments (3rd Resistivity Layer): This mainly consists of the impervious layer of shale, marl, claystone and dolomite. The layer decreases in thickness from the central to the southern parts of the Study Area located between the Oman Mountains and Jabal Mileiha, while in the northwest of the Study Area, the thickness abruptly increases up to 300 m. This Paleogene Formation acts as an aquiclude layer in the Study Area.

Pre-Cretaceous Sediments (4th Resistivity Layer): This corresponds to the Aruma Group and Semail Ophiolite Complex. The litho-facies observed in the Test-Well differed from hole to hole based on its vertical structure. The Aruma Group are composed of autochthonous sediments, represented by a conglomerate in Juweiza Formation, and other coarse sediments originating from the shallow-sea environment. The Melange facies characterized by these included Ophiolite Complex, and take the shape of Allochthonous units in this layer. The structure is pronounced by the major trends of NNE-SSW with secondary faulting along a NE-SW line.

The Juweiza Formation was represented as the main aquifer in the previous survey. The detail members and constituents of the aquifer were not, however, clearly described, and even the stratigraphical position was not categorized. Although the Juweiza Formation was often found in the cutting samples taken from the well drilling, the outcrops needed to allow a description of the litho-facies were not observed. A detailed description of the above layer was made during the Core-boring to clarify the regional extent of this layer. Through correlation of the results of the Core-boring, Test-Well and Geophysical Surveys, the litho-facies distribution was delineated in the subsurface map, as were the geological sections given in Figures 4.3.3. and 4.3.4.

4.3.5. Hydrogeology and Groundwater

Based on the geological conditions identified by this Study, the aquifers were classified into Upper and Lower Aquifers. The Upper Aquifer consists of a sand and gravel layer dating from the Holocene and Pleistocene eras. The Lower Aquifer is composed of conglomerate and limestone facies from the Upper Cretaceous. The Aquiclude, which is formed by Paleogene shale, is interbedded in between these aquifers.

Upper Aquifer: This aquifer, interpreted to be Holocene sediment, acts as an unconfined aquifer. However, the lower part, which is cemented by calcareous and dolomitic material with a higher content of clay toward the lower horizon, behaves as a semi-confined aquifer. The storage coefficient and permeability show a larger value than those of the lower aquifer. Transmissivity (T) = 85 m^2/day and Storage Coefficient (s) = 0.004 were the results obtained from the pumping test.

Aquiclude: This layer contains an impervious shale layer ordinary which is ordinarily comprised of an alternation of shale, limestone and dolomite. The permeability coefficient was measured as (k) = 1×10^{-5} to 10^{-7} cm/sec. At the Falaj Al Mualla, located on the Paleogene sedimentary basin, the thickest shale layer to be found in the Study Area was observed. Consequently, the Lower Aquifer is not found in this area within the designed depth of the test-well drilling.

Lower Aquifer: The conglomerate layer consisting of assorted gravels interbedded among limestone and dolomite layers forms the most productive aquifer in the Lower Aquifer. However, the thickness of this layer was detected as being relatively thin compared with that of other layers and was observed to be only several to several tens of meters thick. Therefore, the potential of the aquifer, depending on the existence of this conglomerate layer, was represented by an average Transmissivity (T) = 51 m^2/day and Storage Coefficient (s) = 0.0028.

To clarify the regional extent and shape of the aquifers classified above, a structural contour map was made for respective aquifers, as shown in Figure 4.3.5. The behavior of the groundwater head of each aquifer was delineated by a contour map of the water head as well as by a contour map of the difference in groundwater head over the last decade, as shown in Figures 4.3.6. and 4.3.7.

The existence of fissure water was also recognized in the Study Area due to very large amounts of specific yield as compared with that of ordinary aquifers. Transmissivity (T) = 776 m^2/day and Storage Coefficient (s) = 0.024 were observed in this type of aquifer. Their occurrence, however, is scarce in the Study Area, having been detected at only three locations: the fault zone near the Jabal Mileiha, an extended zone from the Diba Line and the fault zone at the margin of the Oman Mountains. A summary of Aquifer Coefficients in the Study Area is shown in Table 4.3.1.

4.3.6. Hydrochemistry

The general condition of the hydrochemistry of the groundwater in the Study Area can be understood from the distribution of electric conductivity (EC). The EC measurement varied widely, from 1,000 to 10,000 micro S/cm, as shown in Figure 4.3.8. The low EC observed in the area of the Mountains becomes high EC towards the Western area, which is covered by sand dunes. The area occupied by low EC in the Upper Aquifer, traced in a tongue-shape from the mountain side, is located along Wadi Hamdah and Wadi Tiqubah, while in the Lower Aquifer, the areas detected as having low EC were at Wadi Khadrah, Wadi Siji and Wadi Dhaid.

The vertical distribution of water quality was observed in the hydrochemical log completed in the boreholes and Test-Wells. There were clear changes in water quality, with a higher EC and lower dissolved oxygen content and Redox potential being measured at the deeper horizon.

In order to grasp the hydrochemistry of the Study Area, the chemical components were displayed as a Piper Diagram and Stiff Diagram (refer to Figures 4.3.9. and 4.3.10.). Although most of the samples were categorized in the Non-carbonate Alkali type, some samples which were obtained from the mountain area indicate another chemical type plotted as being in the Carbonate Hardness type. Consequently, the groundwater in the Study Area is categorized by following two types in Piper Diagram:

A Group (Carbonate Hardness) : This group comprises stored-water in the Ophiolite Complex because most of the samples were taken from the mountain and its adjacent area.

B Group (Non-carbonate Alkali type) : This group comprises recharged water directly from the Bahada plain because the distribution was limited only to the Bahada plain.

The evolution of groundwater quality, both groups A and B, can also be seen in the Piper Diagram, with an intermediate composition between both.

The water samples tested for potability give unfavorable results, namely, that the content of chemicals in some items exceeds the guidelines set out by WHO. Not all the samples were tested. Only three samples taken from the Central to Southern part in the Study Area (3 wells of PW 2, 3, 5) exceed the WHO standards, especially the water samples taken at Khadrah (PW2) and Mileiha (PW3), which show high contents of fluoriDate, to a maximum of 14 mg/l. Taking the international standard for fluoriDate (0.1 mg/l) into account, this level seems to be considerably high. High chromium content was also detected at Khadrah (PW2). Furthermore, a high concentration of lead was found in the South (PW5). Since all these samples were obtained from the mountain area, these metals are contained in the groundwater stored in the Oman Mountains. In regard to the background components of the groundwater in the Oman Mountains, the chromium and lead samples were considered to be ordinary. Otherwise, the samples taken in the north of the Study Area (samples from PW1, 4) show a safety quality within allowable levels for drinking purposes.

4.4. Infiltration Experiment

4.4.1. Site Testing

(1) Location of Test Pits

The Study Team carried out field experiments to determine the actual infiltration rates of the wadi-bed on the Bahada plain. The site for the field experiments was selected as a point on the gravel plain where the mountain wadi runs off. These selected wadi areas are on the east end of the Study area. The experiment sites, DW1 on the Wadi Siji, DW2 on the Wadi Khadrah, and DW3 on the Wadi Shoukah, are shown in the Figure 4.4.1. The groundwater table of these sites (15 to 35 meters below ground level) are relatively shallow. Also, the selected sites are situated on the major groundwater recharge districts in the Study Area.

(2)Setting Up and Methodology

a) Water Source

Because there is no water supply system at the experiment sites, the water was supplied by tanker from the wells on the nearby farms. At the site, two water tanks with a total capacity of $22m^3$ were installed, together with one additional tanker as a standby, and provided water in the amount of $30m^3$ for each test. To maintain a constant hydrostatic pressure on the water flowing into the test pits, a multi-stage centrifugal pump with a delivery of up to 1.13 m^3/min. was installed directly after the water tanks. Water volume from the tanks was calculated by the gauge readings at each period.

b) Test Pit Layout

The test pits had square dimensions of 1.5m×1.5m. Three pits were excavated to the different depths of 1.5 m, 3.0 m, and 6.0 m and backfilled with a natural filter gravel with a grain size not exceeding 3/4".

c) Experiment Program

Water discharge and tank gauge were recorded each time the pump began to supply water to the pit. When the water level in the pit reached a certain height, the pump was adjusted to maintain a constant water head in the pit.

4.4.2. Infiltration Rate

(1) Result and Analysis

The following table shows the results of the experiments. In the table, "Steady State Infiltration Rate" is infiltration rate at infinite time, which is found on the x-y plotted graph of infiltration rate-squared time period.

The Result of Constant Head Test

-Infiltration Rate and Head-

Infiltration Pit	Depth of Test Pit (m)	Steady State Infiltration Rate (m^3/sec)	Infiltration Rate : (m^3/sec)	Head (m)
DW1-1	1.5	0.0089	0.0100	1.15
DW1-2	3.0	0.0183	0.0175	1.67
DW1-3	6.0	0.0259	0.0270	4.20
DW2-1	1.5	0.0017	0.0017	1.09
DW2-2	3.0	0.0040	0.0040	1.43
DW2-3	6.0	0.0029	0.0029	2.22
DW3-1	1.5	0.0005	0.0015	1.07
DW3-2 (T1)	3.0	0.0031	0.0031	1.20
DW3-2 (T2)	3.0	0.0023	0.0110	2.47
DW3-3	6.0	0.0165	0.0165	3.49

Both steady state and infiltration rate were increased by the water head in the pit. Most cases followed this tendency, except for DW2-2. The table implies that the infiltration rates of DW1 site were relatively large and the rates of DW3 were small as compared with the rate in equivalent heads.

At the wadi-bed of the experiment site, several layers were composed of gravel, sand, and silt. Therefore, the site must be of an anisotropic nature. The isotropic hydraulic conductivity was, however, calculated initially, and is shown in the following table:

Isotropic Hydraulic Conductivity: K(m/sec)

Wad		Depth of Test Pit (m)			Ave. by Site
		1.5	3.0	6.0	
Siji	DW1	0.00004487	0.00014497	0.00018623	0.00012536
Khadrah	DW2	0.00000536	0.00002050	0.00001858	0.00001481
Shoukah	DW3	0.00000346	0.00003118	0.00022442	0.00007234
	DW3*		0.00003029		
Ave. by Depth		0.00001790	0.00005674	0.00014308	0.00007099

* Result of an additional test of depth 3.0m in DW3.

The above table shows that the differences in hydraulic conductivity for the same site implies the anisotropy of the infiltration on the wadi bed. The result of the experiments does not describe the infiltration rate in both the vertical and horizontal directions. Assuming that vertical-infiltration is the flow from pit bottom and horizontal-infiltration is the flow from pit wall, however, the infiltration of both directions can be obtained. Based on the table below, the horizontal-infiltration rate of a 6.0 m pit is two to five times larger than the vertical-infiltration rate.

Comparison of Vertical and Horizontal Infiltration Rate

Infiltration Pit	Infiltration Rate (m^3/sec) Vertical Q_V	Horizontal $Q_H=Q-Q_V$	Vertical/ Horizontal Q_V/Q_H	Compared with Rate of 1.5m Pit Vertical Rate	Horizontal Rate
DW1-1	0.00010590	0.00879410	1.20%	100%	100%
DW1-2	0.00010863	0.01819137	0.60%	103%	207%
DW1-3	0.00012328	0.02577672	0.48%	116%	293%
DW2-1	0.00001245	0.00168755	0.74%	100%	100%
DW2-2	0.00001259	0.00398741	0.32%	101%	236%
DW2-3	0.00001298	0.00288702	0.45%	104%	171%
DW3-1	0.00000840	0.00049160	1.71%	100%	100%
DW3-2(T1)	0.00000857	0.00309143	0.28%	102%	629%
DW3-2(T2)	0.00000939	0.00229061	0.41%	112%	466%
DW3-3	0.00001081	0.01648919	0.07%	129%	3354%
Ave.	0.00004130	0.00836870	0.49%	107%	566%

Based on the above vertical and horizontal infiltration rates, the infiltration rate of a Recharge Trench which was designed with dimensions of 1.5 m width, 6 m depth and 1,000 m length, was estimated. The following table shows the infiltration of the Recharge Trench in each wadi bed.

Infiltration Rate of 1,000 meter Recharge Trench

Wadi	k (m/sec)	Recharge Trench (m) Width	Depth	Length	Infiltration Rate (m^3/sec)	(m^3/day)
Siji	0.00018623	1.5	6.0	1,000	2.5141	217,218
Khadrah	0.00001858	1.5	6.0	1,000	0.2508	21,669
Shoukah	0.00022442	1.5	6.0	1,000	3.0297	261,766
Ave.	0.00014308	1.5	4.5	1,000	1.9315	166,884

This table shows the maximum infiltration capacity of each Recharge Trench. If a simulation was applied to floods over the past 19 years, the average annual infiltration rate of the three trenches may reach 0.77 MCM, as shown in the table below:

Annual Recharge of Three Trenches

year	Infiltration (m^3/year)		
	DW1(w.Siji) site	DW2(w.Khadrah) site	DW3(w.Shoukah) site
1977	188,600	0	122,700
1978	42,700	0	27,800
1979	195,600	0	133,100
1980	0	0	0
1981	0	0	0
1982	2,012,800	210,200	2,034,600
1983	84,000	0	55,500
1984	0	0	0
1985	0	0	0
1986	0	0	0
1987	523,800	0	354,600
1988	1,116,100	229,300	1,015,300
1989	476,200	0	381,000
1990	979,700	130,000	927,900
1991	0	0	0
1992	0	0	0
1993	1,190,200	108,400	1,101,100
1994	0	0	0
1995	527,900	0	371,400
Ave.	386,189	35,679	343,421

4.5. Groundwater Augmentation

4.5.1. Introduction

The rainfall on the Bahada Plain does not contribute to the groundwater recharge due to water retention in the surface layer and the large loss due to evapotranspiration. Meanwhile, the floods generated in the mountain wadi flow concentrately down wadi channels in the Bahada Plain, and seem to recharge the groundwater substantially. Remarkable flood records observed by MAF indicate that the mean annual flood runoff from the major mountain wadis (Wadi Siji and Wadi Khadrah) in the Study Area during the 15-year period from 1975/76 to 1989/90 ranged from 1.5 to 2.1 MCM/a. From the specific runoff (0.0107 MCM/a/km^2) and the total mountain catchment area (983 km^2), it may be estimated that the mean flood runoff generated from all the mountain wadis in the Study Area is around 11 MCM/a. If this flood water could be forced to permeate into the ground at the foot of the mountain, the groundwater may be augmented by several MCM/a.

Measures for such augmentation are proposed as below:

-Recharge (Flood-Detention) Dam;

The function of the scheme is to store the major part of a flood in a reservoir in order to prevent the unnecessary discharge of water from the basin, releasing stored water in line with the infiltration capacity of the wadi channel below the dam, and to augment groundwater recharge within the basin. A number of such recharge dams have been constructed in UAE and Oman.

-Recharge Trench

The permeability of the sedimentary layer in the wadi beds and Bahada Plain is much larger in the horizontal direction than in the vertical direction. A drastic improvement in the total infiltration capacity of the wadi bed may possibly be made by installing a trench of a certain depth and width. Consequently, the trench is to be refilled with filter gravel, and river training works are necessary to some extent. A remarkable effect in groundwater augmentation may be expected if such trenches are constructed along the base of the mountain in the Study Area.

-Underground Dam

A water-storage dam constructed on the surface cannot avoid evaporation loss from the water surface, nor can it avoid silt sedimentation in the reservoir bottom. Due to the high intensity of these phenomena, the construction of a storage dam on the surface is, in many cases, not feasible in an arid area.

However, a water-storage dam and reservoir could be constructed under the ground where appropriate conditions prevail. Many advantages may be expected from the underground dam scheme in that no evaporation loss nor sedimentation take place. The groundwater is stored in the shallow area of the upper reaches in order to prevent loss to the lower reaches. Some potential sites for underground dams are available in the Study Area.

4.5.2. Recharge Dam (Flood Detention Dam)

In this Study, three recharge dams on Wadi Siji, Wadi Khadrah, and Wadi Shoukah were proposed. The dimensions, cost estimation and the effects of such a dam were studied. As described in Chapters Two and Three, these three wadis have catchment areas in the mountains which are located on the east of the Study Area. When a flood occurs in these wadis, it crosses the gravel plain on the east part of the Study Area, passes the agricultural area in the middle of the Study Area, and flows towards the north-west of the Study Area. To contribute to groundwater recharge, proposed recharge dams are to be located on the wadis at the entrance to the gravel plain at the east end of the Study Area, or located at the wadis on the mountainside. The location and scale of the proposed recharge dams are as follows:

(1) Location of Proposed Recharge Dam

Locations of proposed recharge dams are shown in Figure 4.5.1. The proposed recharge dam at Wadi Siji is close to the wadi gauge which was constructed on the mountainside. The proposed dam site on Wadi Khadrah is located to the east of Khadrah village, while the proposed dam site on Wadi Shoukah is located near the quarry site located on the edge of the gravel plain.

The catchment area of each proposed dam is shown in Table 4.5.1. Khadrah dam has a relatively large capacity. However, several farms are inunDated when dam storage reaches its full capacity of water. On the other hand, both Siji and Shoukah dams have less capacity and bring no inundation to the farming area.

(2) Flood Runoff

MAF has collected runoff data on the floods since the installation of wadi gauges on Wadi Siji, Wadi Khadrah, and two branches of Wadi Khadrah (Wadi Ashwani and Wadi Shifuni) in 1977. MAF has constructed 9 rainfall stations in the Study Area and its catchment area, and collected rainfall records for 20 years. As described in Chapter Three, a relationship between rainfall and flood runoff was found in the long-term data (monthly or yearly).

However, no relations between rainfall and flood runoff can be found in the daily data because the number of rainfall stations is insufficient to determine rainfall on the mountainside using the Thiessen-polygon method. Also, 19-year flood records are not enough to determine the design flood discharge by a statistical process. In this case, flood magnitude and volume for different return-periods, which were shown in HYDROLOGY, published by MAF, was applied to determine dam and spillway capacities. This magnitude and volume are based on the MAF survey and the flood return-period determined using rational formulas.

In this Study, 25 and 10,000 year return periods are applied to determine both dam and spillway capacities. Table 4.5.1. summarizes the catchment area, dam capacity with flood volume of a 25 year-return period, surface area of dam storage, and full water level for each proposed dam. Flood discharge at dam sites is estimated by the specific discharge and catchment area. Full water level is designed in consideration with the sedimentation volume which was obtained from the annual sedimentation volume in HYDROLOGY.

Spillway capacity, which has the magnitude of flood discharge of a 10,000 year-return period, was shown in Table 4.5.2. The maximum flows of spillway in Siji and Shoukah dams are designated as being 500 m^3/sec, while the maximum flow of spillway in Khadrah dam is 700

m^3/sec. With settings of 1.5 m overflow depth and 2.5 m of freeboard, the design flood level, dam height, and spillway dimensions are as shown in Table 4.5.2. The spillway is made out of concrete with a trapezoid cross-section. The discharge coefficient is 1.81, which is based on hydraulic formula for the discharge coefficient. The surface storage area, taking flooding into account, of Khadrah reservoir is 1.2 km^2 and the surface area of Siji and Shoukah reservoirs are 1.0 km^2.

(3) Groundwater Augmentation

A simulation made by Synthetic Storage Model with a recharge dam in operation and run-off data from the mountain wadis (1977 to 1995) was carried out to determine how it would contribute to the groundwater recharge. As a result, it was found that peak-cut and constant discharge headed downstream does not contribute to groundwater recharge, but instead increases evapotranspiration. In certain years, negative effect on groundwater recharge was found. In this simulation, the design discharge capacity was set to discharge full storage within 10 days.

(4) Estimated Construction Cost

The proposed recharge dams are a homogeneous embankment dam with a concrete spillway and discharge conduit. Figure 4.5.2. is the standard cross-section of an embankment. The embankment volume for each dam increases in proportion to the dam height. The construction cost based on UAE market prices and the embankment volume was estimated as shown in Table 4.5.3. The cost of Siji dam is the most expensive, followed by Shoukah and Khadrah. The cost per unit storage water of Khadrah dam was highest, followed by Shoukah and Siji. The construction of Siji dam includes a larger excavation for a spillway than the others.

4.5.3. Recharge Trench

The following are the dimensions and estimated construction costs of the proposed recharge trenches on Wadi Siji, Wadi Khadrah and Wadi Shoukah.

(1) Dimension of the Recharge Trench

The location of the proposed recharge trenches are as shown in Figure 4.5.1. Each trench has dimensions of 1.5 m width, 6.0 m depth and 1,000 m length (Figure 4.5.2.). The construction of a trench would follow the course of the river, and a revetment would be constructed using gabions (0.5 m × 1.0 m × 2.0 m). These works are necessary to guide the water flow along the trench and to keep the trench filled with water.

Although deterioration of the infiltration rate of a trench by siltation is feared, it may not be serious because of a muddy stream on the proposed site which brings in silt, occuring at the beginning of a flood and changing to clean stream later. It is supported by the fact that the surface of the wadi bed has less siltation on the site at present. Moreover, the sites are considered to be appropriate because three of them are far from farms. There are no farms that have to be evicted in the proposed site.

(2) Estimated Construction Cost

The construction cost for a recharge trench with the dimensions described above is estimated to be US$ 1.43 million or Dh. 0.39 million. Table 4.5.4. shows the breakdown of the construction costs. The cost and dimension of the trench for all three sites are the same.

Computer simulation made by Synthetic Storage Model implied that the annual total recharge would increase to 0.30 MCM/a.

4.5.4. Underground Dam

(1) Location of Proposed Underground Dam

The proposed location of the underground dam is shown in Figure 4.5.1. The site is located on the north-east of Khadrah village and the storage area is located between two hills that run east to west.

A cutoff wall is located on a line between the east end of two hills. Extension of the cutoff wall is 1.8 km and the average thickness of an aquifer used for water storage is 70 m. If the aquifer has a storage coefficient of 2%, this underground dam has a storage capacity of 9 MCM. The probable discharge of a 25-year flood cycle is 3.3 MCM, and an average annual discharge at the runoff gauge of Wadi Khadrah (upper stream of the storage area) is 1 MCM. Therefore, the storage capacity of the dam is large enough to catch wadi flood in this site even if 100 % of flood discharge was recharged. As described in the previous section (4.4. Infiltration Test), this underground dam cannot work efficiently because the infiltration rate is low without any recharge facility.

(2) Estimated Construction Cost

An estimated cost of construction for the underground dam was US$ 1.40 million or Dh. 0.51 million. Since the installed cutoff wall was maintenance-free, the water cost is only US$ 14/m^3, with a life period of 50 years. For the actual operation of the underground dam, an intake facility, which includes production wells, water transport and a distribution pipeline system are required. Therefore, the unit water price on a farm site is much higher than the raw water cost. Also, an organization of water users should be established to maintain and operate these facilities.

4.5.5. Summary

The underground dam operates on a different concept from the detention dam and recharge trench. It is basically constructed with the following objectives in mind: (1) to ensure sufficient water storage, and (2) to stabilize water production, while the detention dam and recharge trench have the function of producing groundwater recharge by restricting evapotranspiration and surface runoff.

Based on the studies made so far, the underground dam is not appropriate in the Study Area from the viewpoint of hydrologicalal balance. The water balance in the Study Area is constantly negative or insufficient. This means that the surplus water to be allocated to the underground reservoir is not enough to operate the dam aiming at the stabilization of water source. As a new method for solving this difficulty, this dam may be utilized as a local reservoir for the desalinated water transported into the Study Area.

Although the detention dam aims to promote the groundwater recharge by detaining the flood water and by preventing the invalid runoff from the Study Area, this dam alone may not be effective in the Study Area due primarily to the high rate of evaporation. The groundwater recharge newly produced by this facility would be very small because most of the flood water soaks into the Bahada Plain naturally under the present circumstances. Furthermore, the observed value of 0.4 MCM/a at the lowest reach of the Study Area does not coincide with the rainfall pattern in the Mountain area. Consequently, the flood which arises at the lower reaches is mostly coming from rainfall on the Bahada Plain. Under such conditions, a detention dam constructed on the mountain may not be appropriate. Constructing the dam in an area where space is limited, such as where floods constantly flow down into the sea or dune area, is the only way this kind of dam could be effective.

The recharge trench has a clear advantage over the other two facilities because it directly infiltrates water into the ground. The effectiveness of this facility is expected by (1) prevention of evaporation loss at the surface by a steady movement of water down to the ground, and (2) the decreasing of evapotranspiration when water is infiltrated. The advantage of the recharge trench is substantially pointed out by its ability to prevent evapotranspiration loss, and it plays its role well against such high evaporation potential, which is large as 3,700 mm/a in the Study Area. To fulfill its functions in the Study Area, however, the difficulties of (1) high permeability at the surface, (2) the wide space needed to set up the trench, (3) effective measures to prevent silting and (4) a management plan shall have to be resolved.

Under this study, there are three proposed groundwater augmentation schemes; (1) three recharge trenches and (2) three recharge dams in combination with three trenches, both of which were examined by the Synthetic Storage Model computer simulation.

This computer simulation of the three trenches plan, namely the trench construction in Wadi Siji, Wadi Khadrah and Wadi Shoukah showed an additional yield of 300 thousand m^3/year. Total construction cost of the three trenches are US$ 4.29 million or Dh. 016 million (US$ 1.43 million×3) and the unit water cost is estimated at US$ 2.05/m^3.

On the other hand, the plan which calls for a combination of three sets of recharge dam and trench yields some 1.97 MCM/a of water. In this plan, a buffer function of the dams extends the full water period of the recharge trench. The computer simulation using runoff from the past 19 years shows that total infiltration volume of plan (2) is 4 to 10 times larger than that of plan (1). The average annual infiltration of combined dam and trench for is 1.58 MCM/a for Siji, 0.4 MCM/a for Khadrah, and 1.28 MCM/a for the site at Shoukah. The unit water cost of plan (2) is US$ 2.87/m^3, which is 1.4 times larger than that of plan (1). The developed water volume of plan (2) is 6.6 times larger than that of plan (1). Therefore, plan (2) is deemed to be sufficiently effective to supply supplementary water for the "Option-1 Plan".

4.6. Hydrologicalal Balance and Groundwater Resource

4.6.1. General

When the groundwater development in the Study Area is established, it is necessary to examine the following requirements:

1) Whether the groundwater use level at the current situation is appropriate, and whether continued use of groundwater is possible;
2) Whether the use of groundwater is economical;
3) Whether the water quality of groundwater is suitable.

In addition to the above items, the following requirements are needed in terms of a broad and long-term perspective:

4) Whether a sharp drawdown in the groundwater head will occur in the future;
5) Whether the groundwater resources will be depleted in the future; and,
6) Whether the water quality of groundwater will be maintained in the future.

Item (1) above relates to the "amount of groundwater resource". As regards the formulation of a development plan, an examination of "the hydrologicalal property of the catchment area" and "hydraulic property of the aquifer", such as composition, distribution, scale, productivity, and storage coefficient of the aquifer will be needed.

Item (2) relates to "economy of use of underground water", and its examination is to be made through comparison between the convenience of groundwater usage and the facility cost which includes construction, operation and the maintenance cost of intake facilities. This item is closely related to the above-mentioned "hydraulic property".

Item (3) relates to the "chemistry of underground water". If the water quality is poor and requires any treatment, the cost-effectiveness will be affected.

Items (4) and (5) are related to "amount of the resource of underground water". The groundwater has renewable resources within a certain limit of its hydrologicalal cycle. A sustainable development is possible as far as it is within the recharge potential.

Therefore, groundwater recharge has the same meaning as "amount of groundwater resource". An understanding of the "hydrological behavior of underground water" is essential for this evaluation. This perception is also important to determine a plan for "groundwater resource management" and "environmental influence evaluation".

Item (6) may take place when saline water intrudes into the development area from an adjacent source. This relates to Items (4) and (5) above. However, this often occurs secondarily as a result of a sharp drawdown of the groundwater head or the exhaustion of groundwater resources.

In any case, Items (4) to (6) will influence the environment, which includes elements of the natural environment such as the eco-system and soil contamination as well as the socio-economic environment (i.e. existing water rights).

As per Items (1) and (2), the construction of a simulation model is indispensable to dynamically reproduce the recent hydrologicalal phenomena in the Study Area. The model thus constructed could then be used to forecast the state of the groundwater in the future, and for groundwater management purposes.

A so-called "Synthetic Storage Model" was adopted to examine all the above items concisely, to reproduce the hydrologicalal phenomena pertaining to the Study Area, and to put the groundwater development plan into operation.

4.6.2. Simulation Model

(1) General

The simulation model to produce the current situation was constructed by integrating the parameters mentioned above into the computer model, and then conducting trial runs to match the computed value with the verification parameters of flood data and groundwater head. Forecasting was done by using the present model, internalizing the condition related to the groundwater draft and using it to compute hydrologicalal cases under given conditions. This study was basically made by comparing the present situation with one of the forecasts. The difference between the two cases was considered in the Study. The outline of this model and identification parameters are described below.

(2) Synthetic Storage Model

The Synthetic Storage Model was developed by Sanyu Consultants to enable the simulation of a hydrologicalal cycle under given circumstances.

The model is a mathematical one that simultaneously deals with the basin-wide hydrologicalal balance of surface and sub-surface systems in an unsteady and quasi three-dimensional state. In regard to the groundwater system, any analysis is possible not only for unconfined aquifers which relate to the surface system, but also for confined multi-layer aquifers which include aquicludes. Consequently, this model can be applied to solve such phenomena as multi-phase density flow, underground dams, substance balance, and so on.

The concept of this model is explained below:

The basin is divided into sub-basins in arbitrary rectangles, based on the characteristics of the topography, drainage system, hydrogeology, water and land uses, and so on. The upstream and downstream relationship of the surface flow system in neighboring sub-basins have to be defined in advance.

For the groundwater system, the aquifers and aquicludes are grouped based on the hydrogeological conditions and the water drafts from aquifers at different depths. The aquifer groups at the same level in the neighboring sub-basin also have to be defined in advance.

The surface system is represented with an exponential serial depletion model, known as the "Tank Model," which explains the concept of the inflow, storage, and outflow of water in a container (tank) with orifices. The lowest orifice in the lowest tank plays the role of the groundwater recharge.

Groundwater storage takes place at the uppermost unconfined aquifer and confined aquifers separated by the leaky aquicludes.

In a common hydraulic analysis which applies potential solutions such as FEM and FDM, the water head is initially defined while the water storage is defined secondarily. This model initially defines the change in storage (balance) of an aquifer in a sub-basin, and the water head is derived through the relationship between the water storage and head which have been previously defined. This methodology was the most specific part of the model and from which the model name has been derived.

The balance of storage capacity in an aquifer of a sub-basin is the sum of the recharge from the surface system, the leakage through contacted aquiclude(s), the inflow and outflow from/to the aquifer at the same level in neighboring sub-basin(s), and the draft. The components, except for the recharge and the draft, are estimated by Darcy's Principle; that is, the product of permeability of an aquifer or aquiclude, the seepage area, and the hydraulic gradient.

The model constructed is identified through trial runs to meet with the actual hydrologicalal behavior, observed by a time-series hydrograph, of the surface runoff for the surface system, and groundwater head at each aquifer for the groundwater system. Needless to say, the artificial drafts from each aquifer must be determined as precisely as possible in order to identify the model. Figures 4.6.1. and 4.6.2., present the concept of storage model and the division of sub-basins in the Study Area.

(3) Identification of Parameters

To complete the model construction, all the parameters, not only the aforementioned two input and verification parameters, but the overall parameter to define the model configuration, should be determined. There are two kinds of model parameters: one for the overall model and one for each sub-basin model. The overall parameters contain the number of sub-basins, total number of years across which the model extends, beginning year and month, and the parameters on rain and draft.

The sub-basin parameters include the basin area, cumulative basin area, surface connection, subsurface connection, surface tank structure, parameters on rainfall/evapotranspiration/draft, structure of the groundwater system, and so on. Trial runs modify these parameters one by one until the simulated runoff or groundwater movement match the verification data. The parameters of the sub-basins, which have no verification data, are applied from neighboring or similar sub-basin data.

4.6.2. Input and Verification Parameters

(1) Input Parameter

The meteo-hydrologicalal parameters to be input to the model are rainfall, evapotranspiration potential and groundwater draft. The daily rainfall of the Massafi station during the 19 years from 1977 to 1995 were recorded. Furthermore, the rainfall observed at the mountainous stations was different from that on the Bahada Plain. Therefore, a Rainfall Coefficient (Rc) was introduced to each Sub-Basin (Rc: 0.83 to 1.11).

The input parameter of rainfall per sub-basin was the daily records from Massafi multiplied by Rc of each sub-basin.

Taking the rainfall data modified by the Thiessen Method from eight observatories in the Studs Area into consideration, the Rc was determined by giving an area rainfall of 155 mm/year across the whole Study Area. For the evapotranspiration potential, the monthly mean value of pan-evaporation at the Mileiha station was applied, namely 3,760 mm/year. Moreover, the amount of present groundwater draft was assumed by analyzing the well inventory data and the aerial photographs. The amount of the present groundwater draft in the whole Study Area in 1995 was taken to be 45 MCM, comprising 12 MCM for the Upper Aquifer and 33 MCM for the Lower Aquifer.

(2) Verification Parameters

The parameters which verify the model is the "groundwater hydrograph" of each aquifer for the sub-surface system and the "flood record" for the surface system. The verification for the sub-surface system was made by daily data processed from original charts obtained from six observatories in the Study Area. Six were selected out of 12 existing MAF records as parameters by omitting the unsuitable properties and inadequate changes of the groundwater head for the Simulation Model which resulted from fissure water. Out of six records, four were obtained from the Upper Aquifer and the remainder from the Lower Aquifer. The period of the verification was about 10 years from 1986 to 1995 for which all observation records can be obtained.

For the wadi flow, the four records at Wadi Siji, Wadi Sifuni, Wadi Ashuwani and Falaj Al Mualla stations were selected as the verification data. The catchment areas of these stations were, however, different from that of the applied sub-basin of the Model. The specific runoff was, therefore, calculated by the observation record, and the flood amounts for each sub-basin were corrected in their dominant areas. The records of Wadi Sifuni and Wadi Ashuwani were combined together and taken to be the data for Wadi Khadrah. Three sub-basins comprising the two mountain basins located on Wadi Siji and Wadi Khadrah, and one groundwater basin on Falaj Al Mualla far downstream from the Study Area were then used for verification. The period of the verification was set to be the 19 years from 1977-1995.

4.6.4. Hydrological Balance

In the Study Area, the current hydrological balance was analyzed during the 19 years from 1977 to 1995. The period of analysis was divided into two parts consisting of the first 9 years from 1977 to 1985 and the second 10 years from 1986 to 1995. In the first period, only the flood record was used for the model identification, while in the second period, both the flood record and groundwater hydrograph were used. The following describes the model identification and the present hydrologicalal balance:

(1) Identification of Model

Identification of the model was carried out through comparison between the computed value and the verification data. Both results in the Surface and Sub-surface Systems mutually coincided within a certain measure of success as shown in Figures 4.6.3. and 4.6.4. In the Surface System, there was little difference between both values. Therefore, the model precision was determined to be sufficient to reproduce the flood pattern by means of the rainfall record. In the Sub-surface System, although the computation was not precisely in accord with such abrupt changes as could be seen in the real groundwater hydrograph, it was also thought to well represent the hydrologicalal balance in the Study Area.

(2) Hydrological Balance in the Current Situation

The hydrologicalal balance reproduced for the period 1977 to 1995 is presented in Table 4.6.1. and Figure 4.6.5.

A Summary of curent hydrologic balance in the comparison with the previous IWACO study (1986) is shown in the following table.

Summary of Current Hydrologic Balance made by JICA and IWACO

Study Team	JICA			IWACO		
Duration (Year)	average of 1977-1995			1985		
Basin Area (km^2)	1,826			4,290		
	Depth (mm)	Volume (MCM)	(%)	Depth (mm)	Volume (MCM)	(%)
Basin Rainfall	155.1	288.3	100.0	112.6	483.0	100.0
Evapotranspilation	143.3	261.6	92.4	104.9	449.1	93.2
Surface Runoff	0.2	0.4	0.1	2.8	12.0	2.5
GW Recharge	11.9	21.7	7.7	5.3	22.7	4.7
GW Runoff	10.4	19.0	6.7	1.7	7.2	1.5
GW Draft	14.8	26.9	9.5	55.6	238.7	49.4
Balance	-13.5	-24.7	-8.7	-57.7	-246.7	-51.2

a) Hydrological Balance in the Surface System

Prior to estimating the groundwater balance, all parameters in the surface system were identified and set, and the surface hydrologicalal balance in the Study Area during the 19 year period 1977-1995 was calculated based on the rainfall data. During these 19 years, the total basin rainfall was estimated to be 155 mm/a. From this, 143 mm/a was lost by evapotranspiration. The remaining 12 mm was allocated to the other items, including 0.2 mm for surface runoff, 12 mm for groundwater recharge and -0.3 mm/a for storage balance in the Surface System. The variation in annual rainfall was large; Hence the drought which influenced the shortage of the groundwater recharge, and the surface runoff which also often took place. In a wet year, however, or even in a drought year followed by a wet year, large evapotranspiration which often exceeded the amount of rainfall took place. The ratio of groundwater recharge to rainfall was estimated as being up to 10 % in a wet year.

b) Hydrological Balance in Sub-surface System

The groundwater recharge was calculated as being an average of 12 mm (22 MCM) for the 19 years. In contrast to this value, a groundwater draft of 15 mm (27 MCM), and a groundwater runoff of 10 mm (19 MCM) from the Study Area were calculated. This expenditure, totaled with the groundwater draft and the groundwater runoff, reaches twice the amount of the groundwater balance. Consequently, the negative amount was compensated by the loss of groundwater storage. The groundwater storage during this 19 year period decreased 412 MCM, that was in a rate of 22 MCM/a. To this end, a remarkable reduction of groundwater resources arose in the final five years of the period, from 1990 to 1995. It has continued in rainy years, so that groundwater recharge has increased compared to before. However, the amount of groundwater draft drastically increased in this period and has reached twice the level of what it was before. Accordingly, the negative balance and large loss of stored water has continued.

c) Comparison with the Previous Study of Hydrological Balance

IWACO consultant made a groundwater balance study for the Northern Emirates inclusive of the Central Agricultural Region in 1985. The result of study for the Central Region is summarized in the table above with that of JICA's study.

The area under the IWACO's study was covered an area of 4,290 km^2 inclusive of Structural Plain upto Gulf coast, Bahada Plain and the related mountain catchment in all the Central Agricultural Region. Whereas, the area under the JICA's study covers an area of 1,826 km^2, only Bahada Plain from Falaji Al Mualla in the north to Fili in the south and its mountain catchment within the Central Region

IWACO estimated the groundwater abstraction of some 62 MCM for the domestic water supply within their study area inclusive Awir, Bidai, Shunuf, Tawi Rashid, Manama and others which are out of JICA's area. While, JICA study team estimated that in its area at 2 MCM inclusive of Falaj Al Mualla, Dhaid, Mileiha and others.

A significant discrepancy in both studies was taken place in the estimate of groundwater abstraction for irrigation. IWACO's estimate at 179 MCM/a in 1985 was drived based on the total gross farm area of 7,674 ha, a crop water requirement of 3.2 mm/day and an irrigation efficiency of 0.45. The JICA team estimated that at 52 MCM/a in 1995 based on the total net