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REPORT ON CONSULTANCY MISSION TO THE MINISTRY OF REGIONAL MUNICIPALITIES AND ENVIRONMENT MUSCAT - SULTANATE OF OMAN

(During the period from 5 to 25 September 1992)

"THE ROLE OF WATER RESOURCES MANAGEMENT IN COMBATTING DESERTIFICATION IN OMAN"

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- The views expressed in this report are those of the author and do not necessarily reflect those of the United Nations Economic and Social Commission for Western Asia.

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In arid and semi-arid zones, developing countries are now, and will face in the future, more serious water related problems than ever before. The world's deserts are enlarging, and frequent intensive droughts are contributing to economic devastation of entire nations. The drought-stricken countries portray the difficult problems being faced by arid countries. In addition, factors of higher temperatures, less precipitation, limited water resources, and soil moisture, in such countries, could probably worsen the current critical problems of water supply. These adverse conditions and constraints, when combined with the heavy pressure on available water resources resulting from rapidly increasing water demand for different purposes, have resulted in serious water resources problems manifested by depletion of groundwater reservoirs, deterioration of water quality, soil salinization in areas irrigated with salinized groundwater, and consequently degradation of soil productivity. These features are all forms of the Desertification project.

Desertification is the man-made process of the degradation of land water and other natural resources so that they loses their capacity to provide economic returns under cultivation or grazing. In other words, desertification leads to the increase of the deserted area and the decrease of the fertile and productive land. Deserts are not always the sources from which desertification starts. Desertification may occur in areas which have been fertile and productive for decades.

The process has recently been recognized internationally as a world-wide problem with the United Nations Conference on Desertification held in Nairobi, Kenya in 1977. Accordingly, desertification commonly appears as the deterioration of land, water and other natural resources under ecological stress. Deterioration implies that activities in an area have been unsuitable or unbalanced either in degree or in kind with the capacities and potentialities of the natural resources. Such activities may have been pursued because of lack of environmental knowledge or experience, because alternatives were lacking or, in an attempt to maximize short-term gain at the expense of long-term productivity. Education, soil, technological and economic advancement and the adjustment of population growth to the development resources are the key elements responsible for initiation of desertification or successfully combating it.

Upon the request of the Ministry of Regional Municipalities and Environment in the Sultanate of Oman, and as follow-up for the first mission in March 1992, this second mission was undertaken for the preparation of a National Plan of Action for Combating Desertification.

The second mission included:

- Mr. Jafar Karrar, UNEP/ESCWA Consultant as the Head of the Team.
- Mr. Nour Eddin Gaddes, FAO/RNEA.
- Mr. Omar Joudeh, Regional Adviser/Water Resources U.N ESCWA.

The mission was undertaken between Sept. 5 & Sept. 26, 1992. Key persons in the different Ministries were met (see attached list) a number of field visits were undertaken.

This report would constitute one input to the proposed plan, and deals mainly with the water resources aspects of desertification. The report was based on the background report prepared by ESCWA/UNEP mission in March 1992, and on the additional information collected during the second mission through literature review, discussions with concerned to be initialized by the end of this year 1992.

The assistance provided by all persons met in the various Ministries during this mission was of great value to the preparation of this report and are highly appreciated.

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Summary and Recommendations.

Generally the Sultanate of Oman is characterized by high aridity, low annual rainfall,scarce water resources limited agricultural land area,sparce or and fragile natural vegetation cover.

The average annual rainfall over the country is 54 mm. compared to more than 2000 mm annual evaporation rate. The total natural renewable water resources are about 900 Mm3/yr which is mainly groundwater. The total present water use is about 1200 Mm3/yr with an overdraft of about 33% of the annual rate of replenishment. Areas where soil, is suitable for agriculture is about 0.7% of the total country area; About 0.15% of the total area of the country (54,000 hectar) is under cultivation. The natural vegetation in Oman coincides with the pattern of water resources availability. The natural vegetal cover is sparse and highly fluctuating according to a number of environmental factors especially the short term climatic changes and the increased human pressure on agricultural and range land.

Increased human activities and pressure on land, vegetal cover and water resources have seriously disturbed the natural balance between these resources. This disturbance is manifested in the field in the following forms:

1. Groundwater quality deterioration, mostly as increased salinization due to over pumping and sea water intrusion in the coasted areas such on Batinah, Salalah and sur plains, and due to return irrigation flow in the inland areas such as Wadi Al-Batha area.

2. Salinization of agricultural land due to the increased salinity of irrigation water, over irrigation, and inadequate irrigation and drainage practices. The result is the loss of soil productivity and suitability for various crops. A large number of farms have been fully or partly abandoned. Such problems have been observed in the Batinah plain, Sharqiya, and in Salalah plain.

3. Deterioration or loss of the natural vegetal cover. Over-grazing is the main reason in the Dhufar mountains. A secondary effect of this process is the increased loss of the natural soil which is already thin. Deterioration of the natural vegetal cover in the Wahiba sand dunes has reactivated these dunes and facilitated wind erosion and the advancement of the sand dunes into the adjacent agricultural land to the east and southeast.

These disturbances of the natural resources caused by human activities are forms of the desertification process taking place in the most developed and productive parts of the country. In Batinah plain, the most affected area in Oman, over 50% of the country's water resources occur and are threatened by serious salinization and depletion problems. About 60% of the national agricultural production comes from the Batinah plain. The most important socio-economic developments, other than oil production, are in the Batinah plain, which includes the capital area at its southern end.

There are different causes for the desertification process in Oman; the most important and effective of which are water related factors. Mismanagement of the water resources in Oman is a prime cause for desertification. On the other hand a wise, rational, and effective water resources management in Oman would be the most important factor for combating desertification. If water resources exploitation continues at the present pattern and rate, the cost, effort, and time for the recovery process may become prohibitive. Therefore action to combat desertification is urgently required. The integrated approach for managing the natural resources in general and the water resources in particular, should be adopted in the proposed action plan for combating desertification. This approach in water resources means the integrated and conjunctive use of traditional and non-traditional water resources.

As the agricultural sector in Oman is the major water user, greater emphasis should be given in the plan for conserving irrigation water through improving the irrigation, drainage and agricultural practices, and within the general framework of an integrated water resources management. Such water resources management should be the core of the national plan for combating desertification. The immediate goal of this plan would be to prevent and arrest the advance of desertification, and where possible, to reclaim desertified land for productive use. Meanwhile, the immediate objectives of the proposed water resources management plan would be to protect and augment the presently over exploited aquifers, both the quantity and quality, and to explore, assess and develop new water resources where possible.

The achievement of the above objectives is possible through implementing the proposed programme, projects, activities and corrective measures. Improvements in the water resources and reclaiming desertified lands are long-term processes which would take years to feel and observe the change.

1. INVENTORY AND POTENTIAL OF NATURAL RESOURCES OF OMAN

1.1 Location and Area

The Sultanate of Oman occupies the south-eastern part of the Arabian Peninsula and shares borders with the United Arab Emirates, Saudi Arabia and the Republic of Yemen. It extends along the Gulf of Oman and the Arabian Sea, with a coastline of about 1,700 km extending from the Straits of Hormuz in the north to the Yemeni border in the south (Figure 1). The country has an approximate area of 314,000 sq. km.

The Sultanate of Oman is divided into eight administrative regions as shown on Figure (1). The country is further divided into 44 administrative units called "Wilayat".

1.2 Physiographic Regions

According to the General Soil Map of Oman (MAF, 1990), Oman is divided into seven physiographic regions (Figure 2).

1.2.1 Arid Mountains

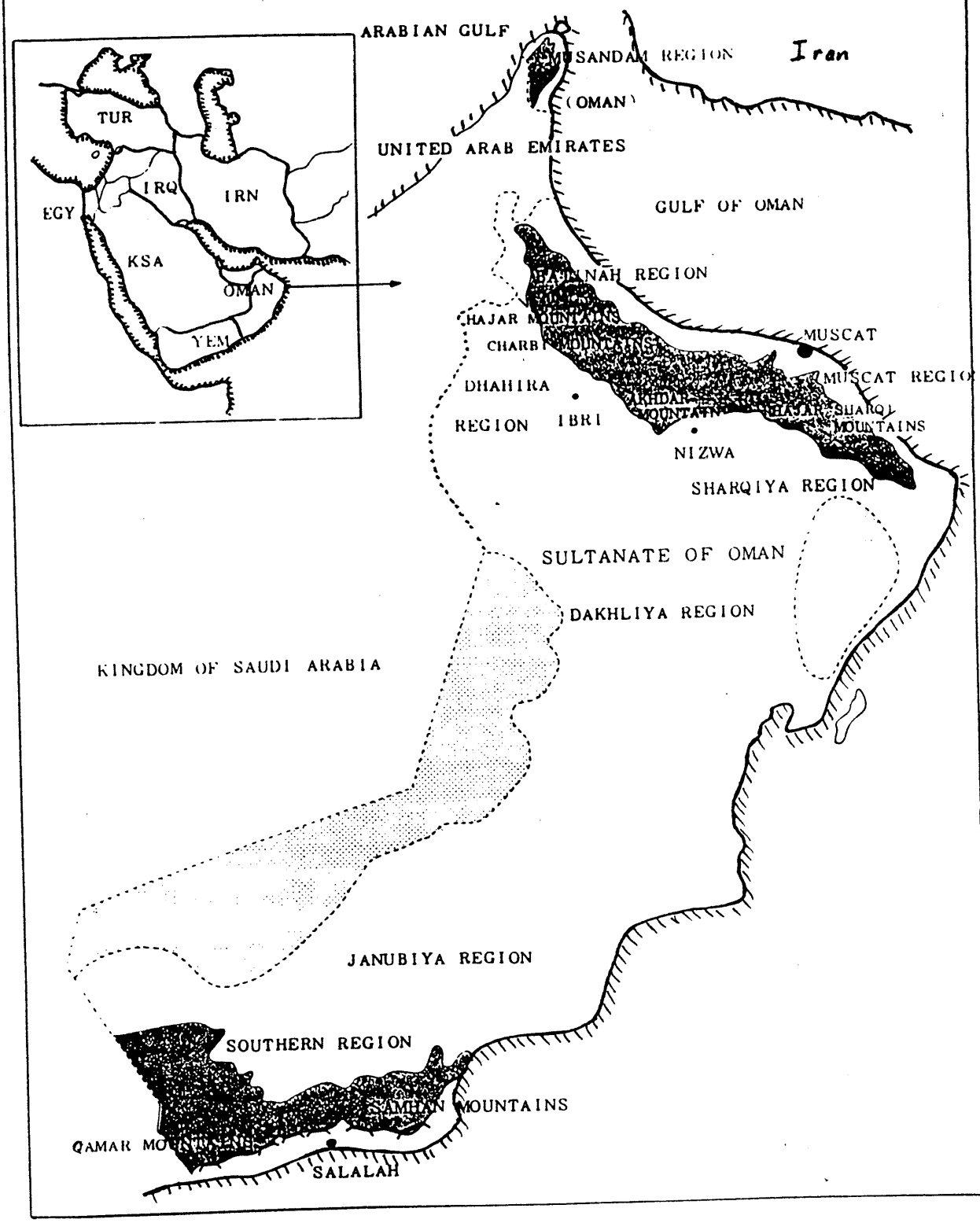
These are encountered mostly in the Hajar mountains, in northen Oman, including the Musandam peninsula. They also occur to a much smaller extent in the islands such as Masirah and Kuria-Muria. These mountains are mostly steep and barren formations of igneous and sedimentary rocks.

The Hajar mountain range stretches northwest-southweast, along the Gulf of Oman, over about 700 km from Ras Al-Hadd to Musandam. Its width varies between about 30 to 70 km.

Bare rock outcrop and very shallow soils are dominant on sloping terrain, whereas very gravelly soils occur in valleys and alluvial fans. With summits nearing 3,000 meter above sea level in Jabal Al-Akhdar, the Hajar mountains intercept moist air masses, hence receiving relatively higher precipitation than surrounding areas. A dense network of wadis conveys drainage water north to the Batinah plain, and south and wouthwest to the interior of Oman.

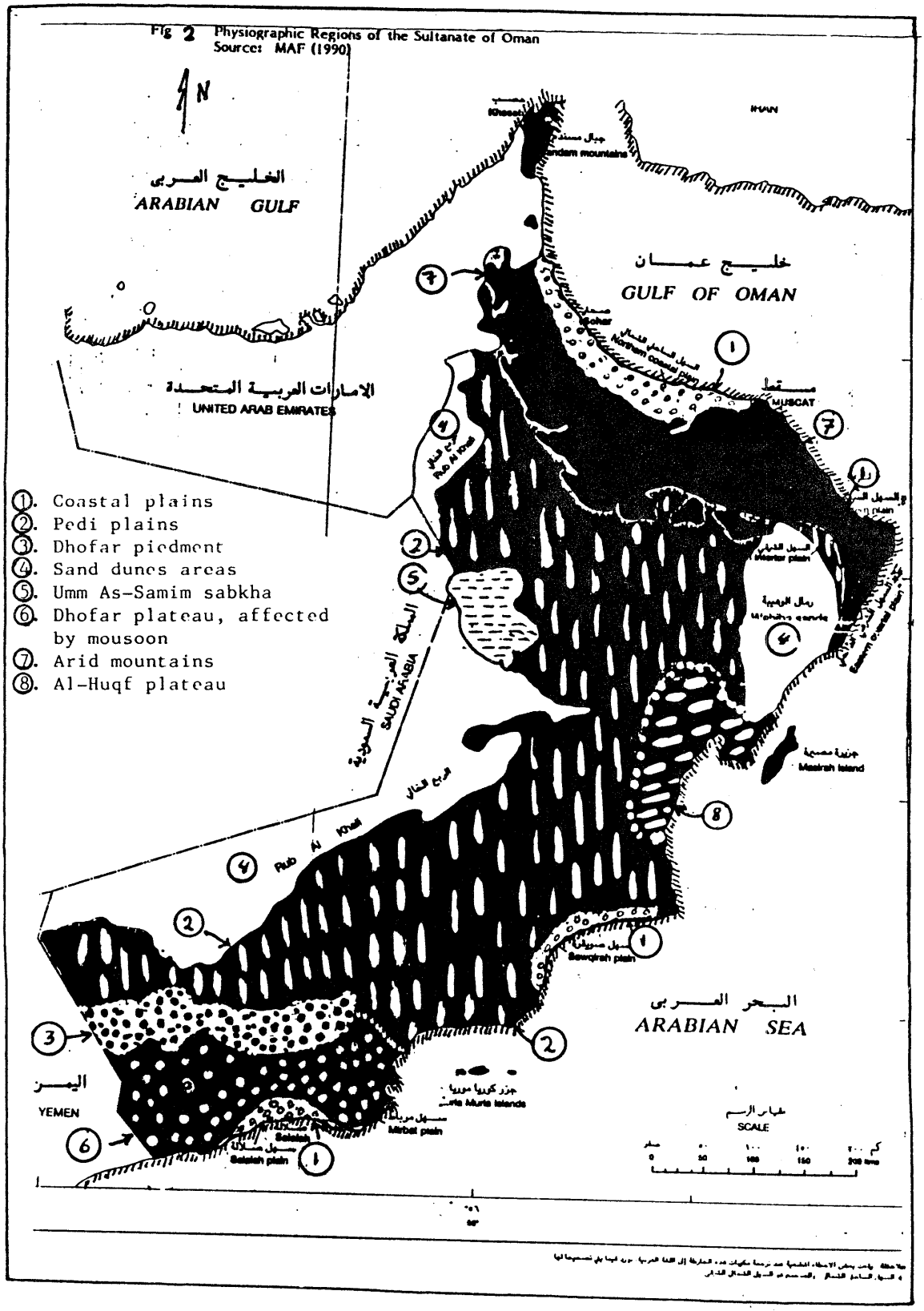
A large number of scattered oases, mostly using falaj irrigation systems, tap local springs or wadis underflow, to grow mostly date palm, limes, alfalfa and vegetables.

Fig. 1 : Map of Oman



Source: JICA (1990).

Fig 2 Physiographic Regions of the Sultanate of Oman
Source: MAF (1990)



1.2.2 Monsoon-affected mountains and plateaus

This kind of landscape occurs in Dhufar region. These areas are strongly dissected. A woody vegetation predominates on steep slopes and gullies, whereas grass and bushes, under heavey grazing, cover most of the relatively flat areas.

Soils are generally shallow in the grazed areas, suggesting that soil erosion is very active in the rangelands. Wooded slopes, protected from erosion by trees and bushes, generally have moderately deep soils.

Rainfed cultivation of beans and sorghum is done by some Jabali in very tiny plots during the monsoon.

1.2.3 The arid Dhofar plateau

The Dhofar plateau, which is gently sloping towards the north, is dissected by numerous wadis cutting deep and narrow incisions. Most of the area consists of sedimentary rocks.

Soils are mostly shallow and the meagre natural vegetation is under heavy grazing.

1.2.4 Accumulation plains

There are five accumulation plains in Oman: the Batinah plain, the Northern interior plain, the Sawqirah plain, the Dhofar piedmont and the Salalah plain.

All these plains are bajadas formed by the accumulation of three generations of alluvial fans and terraces. The Sawqirah plain differs somewhat from the other accumulation plains in that the rock floor outcrops in sizeable areas.

The soils are generally deep and very gravelly to extremely gravelly in all these accumulation plains. In the Salalah plain the soils are not gypsiferous, whereas gypsum accumulations occur in most soils of the other accumulation plain. The quantity of gypsum and the degree of cementation tend to increase with the age of the soils.

Cultivation is generally found in the lower alluvial terraces wherever adequate water resources exist. Most of these cultivated areas are in the Northern interior plain and the Batinah, because water resources are limited in the other accumulation plains.

Date palm, limes, alfalfa and vegetables are the main cultivated crops. Aflaj systems are the main source of irrigation water, but wells are expanding very quickly in and around the oases.

1.2.5 Accumulation/denudation plains

These are old accumulation plains where dissection of the landscape by stream erosion has exposed extensive areas of rock outcrop.

The Mirbat plain is mostly rocky, but two levels of alluvial terraces were found in its western part. They are mostly formed of loamy gravelly deposits. No trace of cultivation was seen in that area, probably because of the lack of adequate water resources.

The Northeastern plain in the Sharqiya region is less rocky, but the high alluvial terraces are extremely dissected. Soils are generally gypsiferous, but many of them have very strong salt accumulations. These salts seem to be deposited by droplets of sea water brought by winds.

Cultivation is very limited because of scarce water resources. Date palm and alfalfa are the main crops.

1.2.6 Coastal alluvial plains

There are only two such alluvial plains in the Batinah and Salalah areas. Before reaching the sea the wadis, originating in the nearby mountains, become braided and deposit their load of sand and finer particles in depressions behind coastal dunes before infiltrating into shallow aquifers.

These coastal plains have some of the best soils of the country and relatively important water resources.

Nearly half the cultivated area in Oman is in the Batinah coastal plain. Excessive expansion of the cultivated land has led to sea-water intrusion and salinization of the groundwater and the soils. Crops grown in the Batinah include date palm, limes, mangoes, alfalfa, rhodes-grass, and a variety of vegetables and minor fruit trees.

In the Salalah coastal plain, the main crops are banana, coconut, papaya, vegetables and other minor crops.

1.2.7 Sabhka-dunes-rock outcrop complex

This landscape occurs extensively in Al-Huqf area in the Eastern coastal plain in the Sharqiya region. Hills of rock outcrop alternate with saline basins and sand dunes. Tidal flats are extensive along the coast.

Cultivation is very scarce due to the lack of suitable water resources.

1.2.8 The eastern pediplain

It is a nearly level monotonous rock plain made of hard carbonate rocks that resist erosion. There is a large number of small depressions caused by dissolution of the carbonates, under a past, moister climate. This landform is deeply incised by wadis near the sea coast.

Soils are generally very shallow and contain secondary lime. Cultivation is very scarce because of the lack of suitable water resources and soils.

1.2.9 The western pediplain

It is gently undulated and more dissected by streams. Sulphate rocks are more extensive in this area, leading to the concentration of gypsum in the soils which are generally moderately deep to shallow.

Cultivation is found in some areas like Dawka where good groundwater is available. Rhodes-grass, alfalfa and vegetables are the main crops.

1.2.10 Umm-As-Samim Sabkha

This is a large flooded depression collecting draingage surface water and possibly groundwater from the western part of the Northern interiorplain.

Soils and groundwater are extremely slaine, hence preventing any cultivation.

1.2.11 Sand dune areas

These are large areas of sand dunes. They occur extensively in the western part of the country in the Rub Al-Khali and in the eastern part as the Wahiba sands area.

Cultivation is very scarce because of unsuitable soils and sand blowing. Grazing is widespread, especially in semi-fixed dunes where a relatively dense bush and tree cover may occur.

1.3 Climate

Except for the Dhofar mountains which enjoy a tropical monsoon climate, the rest of Oman is a subtropical desert. The climate of Oman has a high variability both spatially and temporally. Two distinct seasons occur, winter (November to April) and summer (May to October). It varies, however, under the influence of three major phenomena, namely the prevailing winds over the region, the up-welling of cold coastal water, and the cyclones

The monthly average temperatures and rainfall recorded at selected meterological stations are illustrated in Figure 3.

1.3.1 Air temperature

Annual mean temperature ranges between 17.8C° and 28.9C° (MAF, 1990). Mountains areas like Jabal Al-Akhdar in the north and Jabal Al-Qairoon Hairiti in the south have the lowest average annual mean temperatures, 17.8C° and 21.6C° respectively. Salalah and Thumrait also have slightly lower mean temperatures than the national average which is 26.3C° because they are affected by the south-westerly monsoon winds during summer. In general the annual mean temperature increases from east to west.

The hottest months are June and July when the monthly mean maximum temperature ranges from 30.7C° in Saiq to 46.1C° in Fahud. The coldest month all over the country is January, with monthly mean minimum temperatures ranging from 9.4C° in Saiq to 24.0C° in Mina Raysut. Temperatures below zero are only recorded in Saiq where they occur every year (recorded minimum temperature of -3.6C°).

1.3.2 Rainfall

Only Dhofar mountains, in the southern region, and the Hajar mountains have regular rainy seasons with substantial preciption. Rainfall in the rest of the country is low and irregular. Heav y rains can occur, sometimes delivering all the precipitation of the year in one single storm, causing violent flash floods of high peaks and short durations.

Mean annual rainfall is less than 50 mm in the interior regions, covering two thirds of the country, and is around 100 mm in coastal areas. In the Hajar mountains rainfall ranges between 100 mm to about 300 mm (MAF, 1990). Parts of the Dhofar mountains, influenced by monsoons, receive between 200 mm and 260 mm of rainfall annually.

During September to November, very little precipitation is observed in the country (Figure 3).

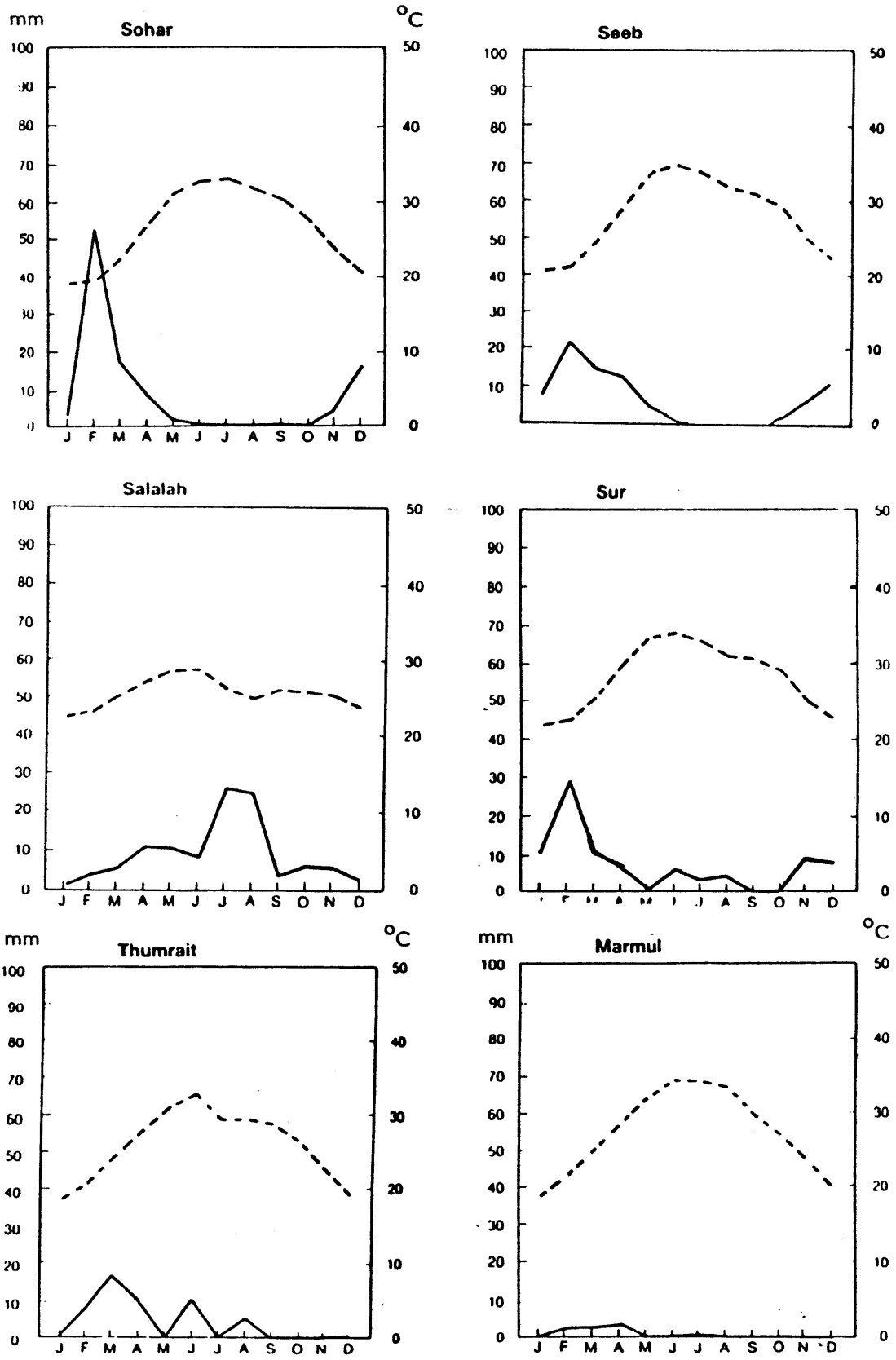


Figure 3: Average monthly Temperature and Rainfall at Selected Stations.

Rainfall, throughout Oman, shows not only geographical variations, but also high intra-annual variations. It is not uncommon to have years of very low or even no precipitation in some regions of Oman. This is evident from Fig.4 which shows annual rainfall at Muscat from 1894 to 1989 (MMDI, 1894 b).

1.3.3 Relative humidity

Monthly mean relative humidity is highest in coastal areas where it ranges from 50 to 90 percent. The interior areas are much drier and have mean relative humidity of less than 80 percent throughout four to five consecutive months. In these areas the absolute minimum relative humidity can be as low as 1 or 2 percent.

In the northern coastal parts of Oman, high mean monthly relative humidities are recorded in summer and in winter and the lowest values are recorded in May. In Salalah, on the contrary, the relative humidity value peaks in summer and bottoms out in winter.

In the past five years the minimum and maximum relative humidity values are shown in table 1. Maximum relative humidity reached 98 percent in Salalah for a nubmer of months and went down to 1 percent at Buraimi and Saiq.

Table 1: Maximum and Minimum Relative Humidity in Oman

Area	Humidity/Month Minimum	Maximum
Seeb	13% (May)	88% (August)
Sohar	39% (May	95% (September)
Sur	23% (July)	89% (January)
Salalah	27% (February)	98% (August)

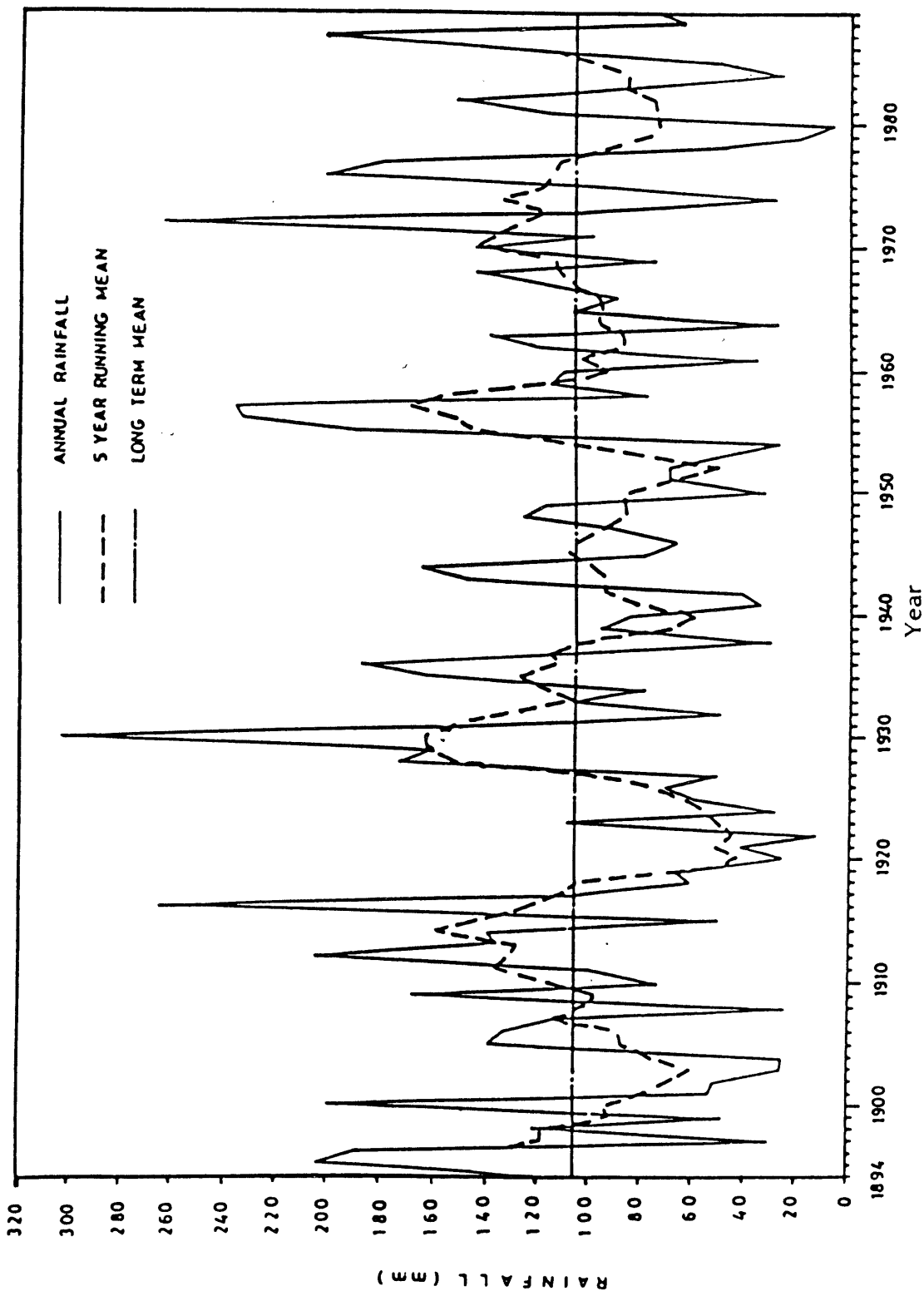


Fig. 4 : Annual rainfall in Muscat area during the period 1894 - 1989

Source: MMDI (1991_b) updated from Statistical Yearbook 1990.

1.3.4 Winds

Oman being located in a region between 16° 37'N to 26°30"N latitude, and between 51° 50'E to 59°40'E longitude, is under the influence of the equatorial convergence zone. This is a belt of converging trade wind systems that encircles the earth near the equator (JICA), 1990). In summer, this system reaches southern Oman and brings monsoon conditions to the Dhofar mountains from the south. In winter, the system moves south of the equator, and the predominant wind direction is from the north. Table 2, gives the average daily wind speed in selected areas in Oman.

Table 2: Average daily wind speed

Region	Wind Speed	
	Minimum	Maximum
Interior (Dakhliya)	0.6% (Dec.)	0.98% (June)
Batinah	0.45% (Dec.)	1.09% (June)
Sharqiya (Eastern)	1.6% (Dec.)	2.33% (June)
Jabal Al-Akhdar	1.97% (Dec.)	3.14% (June)
Al-Janubiya (Southern)	1.05% (Oct.)	2.47% (Jan.)

1.3.5 Evaporation and Aridity

In Oman, evaporation rates usually peak in summer season as temperatures and wind speeds are high and the relative air humidity is low, except in the southern region.

The annual open water evaporation rates are 1,411 mm in South Batinah, 2,360 mm at Al-Ayn, 2,216 mm at Ibra (JICA, 1990) and about 3,000 mm at Al-Wahiba sands (Jones et al, 1988). These evaporation figures are 10-30 times higher than the mean annual rainfall in the different regions of the country. The least amount of average monthly evaporation was, according to Gibb et al(1985), 168 mm for January (5.4 mm/day). This certainly highlights the degree of aridity the country is exposed to and the critical need for suitable water management systems in the agriculture sector.

1.4 Land Resources

1.4.1 Geological Regions

The geological formations in Oman range from Pre-Permian to Recent age, including igneous and sedimentary rocks. The predominant formations which have interest from water resources point of view are of the cretaceous and tertiary limestones and the Quaternary gravel and sand deposits.

Oman consists basically of two geological regions. The first is the Oman mountains and their adjacent areas in the north; and the second region is the desert area and the southern mountains. The difference between the two geological groups are clearly identified by topography and climate (JICA, 1990).

The Oman mountains form a part of the Alpine range and are located on the southeastern edge of the Arabian sub-continent, adjacent to the Gulf of Oman. Within these mountains, six major rocks sequences are found. From bottom to top, they are as follows (see also Figure 5):

(i) A basement of granites and gneisses, partly metamorphosed sediments and meta-volcanics.

(ii) The Hajar Super-Group and the Aruma Group a relatively simple sequence of mainly shallow-marine carbonates that range in age from the Middle Permian to the Late Cretaceous.

(iii) The Sumeini Group - local-thrust sedimentary sequences comprising mainly calcareous rocks that range in age from Permo-Triassic to Middle Cretaceous. These sequences are stratigraphically overlain by Middle Cretaceous rocks.

(iv) The Hawasina Group - a complex association of folded and faulted lithological sequences comprising quartz sand and carbonate turbidites, silicified limestone and radiolarian cherts containing fossils from the Triassic through Middle Cretaceous age, and shallow-marine limestone of the Permian and the Triassic ages that are either associated with deeper-water sediments or have a substrate of sheared basaltic pillow lavas.

(v) The Samail Ophiolite - a thick sheet of basic and ultrabasic rocks comprising periodotites, gabbros, diabases and spilitic lavas, which overlies the Hawasina nappes with intermittent contact.

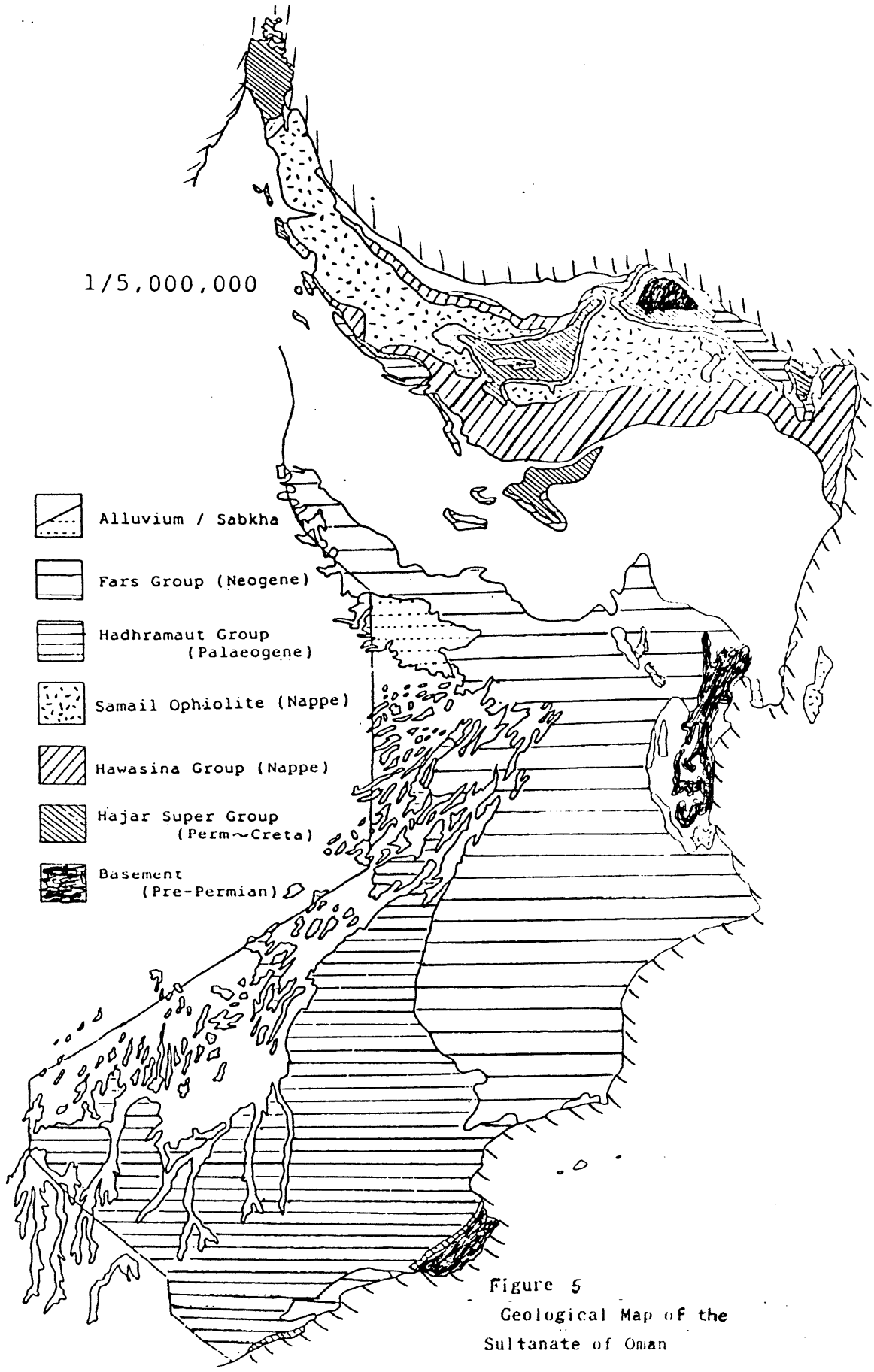


Figure 5
Geological Map of the
Sultanate of Oman

(vi) The Hardramaut Group and Fars Group - a sequence of mainly shallow marine carbonates, locally conglomeratic, which overlies all older sequences without conforming precisely to them.

1.4.2. Soils of Oman

Information about soils of Oman could be extracted from two different soil maps. The first one "Soil Map of the World", which is based on FAO soil classification system. According to this map prepared at a scale of 1:500,000 the soils of Oman were classified in 1977 to two types of soil, Yermosols and Lithosols. Solonchaks and Regosols could, however, be found in certain areas. Haplic yermosols are spread in northern coastal areas, lithosols in the mountainous areas and calcic yermosols in the inland areas. In southern Oman, there are mainly calcic yermosols and some gypsic yermosols in inland areas.

"Agricultural Resources Map" was drawn up in 1988 utilizing LANDSAT imagery (JICA, 1990). Soils of Oman are classified accordingly to three classes, table 3.

Table 3: Survey of Agricultural Land

Region	Land Classes			
	S1	S2	S3	Total
Batinah	8,920	11,601	18,276	38,797
Dahirah	1,345	11,819	8,613	21,777
Dakhila	5,850	4,611	8,170	18,631
Sharqiya	1,000	22,000	17,000	40,000
Janubiya	28,340	46,582	72,022	149,944
TOTAL	45,455	96,613	127,081	269,149

source: calculated from data cited by JICA, 1990.

In a recent study (MAF, 1990) the soils of Oman were classified according to the Soil Taxonomy, the soil classification system of the United States of America (USDA-SCS, 1975), taking into consideration the Revised Legened of the Soil Map of the World (UNESCO-FAO-ISRIC, 1988) and using the same concept of the diagnostic horizons. Six diagnostic horizons were recognized in Oman during this soil survey, namely: Ochric Epipedon, Calcic horizon, Camic horizon, Gypsic horizon, Petrografic horizon and Salic horizon. Some more details about these horizons are given in Annex 1.

Out of the eleven orders that are defined by Soil Taxonomy, only three exist in Oman. These are the Entisols, Inceptisols and Aridisols. Some more details about the three soil orders existing in Oman are given in Annex 2.

The characteristics of the soils are presented below according to their presence in the main regions of Oman:

(1) North Batinah and South Batinah Regions

The Soils of the North and South Batinah are of alluvial types and represent the most suitable soils for agricultural activities. This area comprises yermosols of silt and fine sands. More than half of the cultivated areas in Oman are present in the Batinah plains and hence this region represents the most development potential for agriculture (JICA, 1990).

In areas nearer to the sea, salt accumulation is observed and the agricultural activities in some farms have been abandoned. This has pushed farmers to search for new farm lands towards the inland area in a search for better soils for agriculture.

Some of the gravel covered soils of the interfluvial plains are used for agricultural production despite their low suitability.

(2) Dhahira Region

The soils of the Dhahira region including those of Buraimi area are formed mainly by alluvial and eolian processes. Medium to fine textured yermosols, found on limestone alluvial fans, represent the most important soil type in this region.

(3) Interior and Wusta Regions

Alluvial plains in the north have yermosols derived from the limestone rocks and represent the agricultural areas in the region. Flood water brings weathered materials to the plains and forms the fine textured soils.

(4) Sharqiya Region

The soils of the Sharqiya region are formed mainly by alluvial and eolian processes. Yermosols represent the most suitable agricultural lands and are mostly under cultivation. Interfluvial plains with Arenosols are considered to have the highest potential for agricultrual development (JICA, 1990).

(5) Southern Region

Salalah plains with their yermosols represent the most important soils for agriculture in the Southern Region. The soils are derived from northern jabal. In the jabal areas, soils are of clay and silty type and have well developed structures. These areas are known as the main rangelands grazed by the livestock in the Southern Region.

1.4.3 Agricultural Lands

The latest soil survey (MAF, 1990) revealed that out of the total area of the country amounting to 31.427 million hectares only 2.223 million hectares are suitable for agricultrual activities or about 7 percent of the country area. In another recent study (JICA, 1990) based on analyses of 1982 LANDSAT MSS data, the land area suitable for agricultural activities was estimated to be only 0.269 million hectares,0.85%, (Annex II), located in 10 different regions of the country (Fig. 6).

Despite the surveys carried out and the series of investigations made, the present state of cultivated lands is not clear. The figures of land areas of irrigated agricultrual show considerable differences. Factors responsible for such differences include, according to MMDI (1991):

(i) Changes in areas cultivated due to expansion (3.3 percent annually for the period 1978-1988);

(ii) Boundary differences of regions at compliation;

(iii) Seasonal differences in coverage with crops; and

(iv) Differences in definition of agricultural lands.

The widely accepted figure for irrigated land area in Oman was estimated at 54.64 thousand hectares. This area was cultivated in 1988 to vegetable crops (6,040), field crops (9,647), fruit trees (32,303) and other crops(6,651).

The most common cultivated crop in the country is the date palm. (24,170 ha), about 44 percent of the entire irrigated area. The second largest crop area is cultivated to alfalfa, (8,770 ha) or about 16 percent of the total irrigated area of the country.

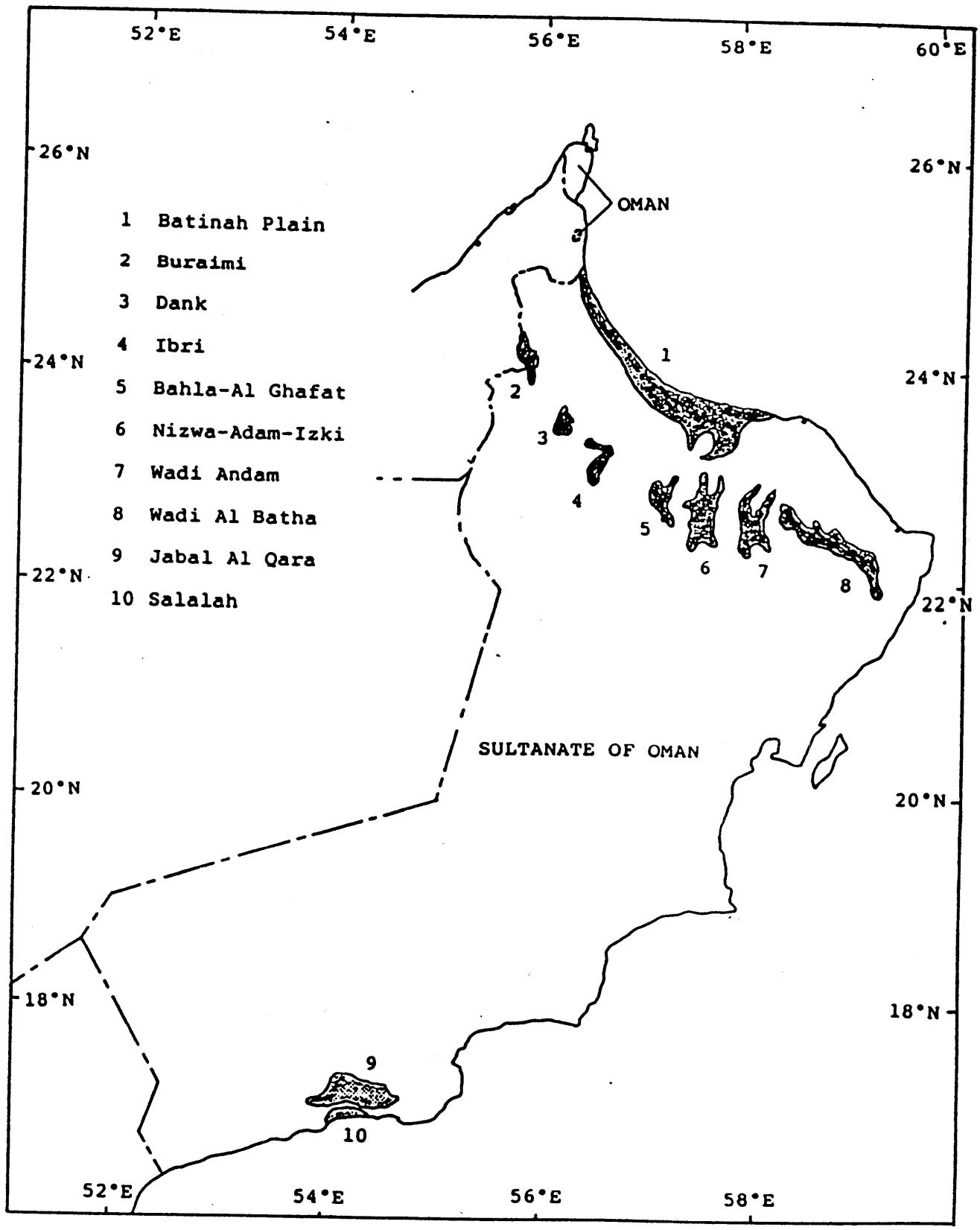


Fig. 6 : Areas with potential development for irrigated agriculture selected according to 1982 LANDSAT MSS data analysis.

Source: JICA (1990)

2. WATER RESOURCES

2.1 General

The Sultanate of Oman is mostly an arid area which is characterized by low, variable and unreliable rainfall, and high rate of evaporation which is several times the average annual rainfall.

Rainfall is the main source of the traditional sufrace and ground water resources. However, the above mentioned characteristics of rainfall have direct and significant impacts and implications on the resulting surface water flow and groundwater recharge.

Surface water flow consists mainly of the winter floods which occur in response to rainfall. Floods characterized by relatively high peaks and short duration (few hours to few days) occur in response to heavy rain storms. Perennial basflow in Oman is limited to a short reach in Wadi Dayqah, 70 km south of Muscat, and to few springs in the mountain regions.

Direct use of rainwater is limited to the relatively high rainfall mountain regions in the south and north where about 478 hectars are cultivated based on rain water; springs' water is used to irrigate about 120 hectars; while about 44,400 hectars (about 93 percent of the total irrigated area) are irrigated from the ground water, (67 percent from wells and 26 percent by Aflaj).

Direct utilization of the flood flow has not been practiced except recently for artificial recharge of groundwater. The adverse characteristics of flood flows, (short durations, high peaks, variability, and poor reliability) are the main reasons behind this fact.

However, these flood flows are important and potential sources for recharging the over developed aquifers all over the sultanate. This recharge process can be enhanced artificially by construction special facilities along the stream channels such as dams.

Under these circumstances of rainfall and flood flows, the groundwater in Oman has historically been, and will remain, as the most important water source for all purposes, particularly for irrigation which consumes about 91 percent of the total water supply in the Sultanate. The natural traditional water resources can therefore be equivalent to the groundwater resources.

Consequently great reliance has been put on groundwater resources to meet the increasing water demands for the different purposes, resulting in overdraft conditions in some basins or regions. As a result of this over exploitation, serious deterioration in the groundwater quality has been observed in different regions..

Deterioration of the water quality of this major and main water source for irrigation has resulted in soil salinization, which in its turn has resulted in serious degradation of the soil productivity for various crops. Ultimately such areas will loose its value as a productive agricultural land and will be deserted unless appropriate corrective measures are undertaken. It is the purpose of this study to recommend appropriate action plan to combact desertification in general, of which the degradation and loss of agricultural land as related to water resources constitutes a major and important component.

The increasing water demand for different purposes, and the scarcity and insufficiency of the converntional (traditional) water sources to meet these demands, have led to the use of desalinated sea and brakish ground waters for municipal purposes. In addition the treated sewage water has been partly used for land scaping in the capital area.

Finally, it is worth-mentioning, that some, unexploited groundwater aquifers still exist over the extensive undeveloped and scarcely populated areas in the Sultanate of Oman. However, sometimes, the constraints inherent in these resources are the reason while they are not yet developed.

The total water resources in Oman may be summarized as follows based on avaiable information till 1990:

Conventional Resources

Rainwater	5200
Surface Water (Floods)	929
Groundwater:	
Renewable	647
Non-renewable	Not determined Yet

Non-traditional water sources:

Desalinated Sea & Brakish Groundwater (DSW)	41
Treated Sewage Effluents (TSE)	25

It is clear that without adequate storage and recharge dams for regulating and controlling the flood flows, the only available water sources would be the underground reservior with its two components: the renewable (647 MCM/Yr) and the stock resources which comprises the stored groundwater reserve and this has not been properly estimated.

2.2 Surface water resources

Because of the scarcity of surface water resources, and their characteristics being confined to short durations of few hours or few days after heavy rainstorms, direct utilization of flood flows has had very little role in development. However, flood flows are of major importance for groundwater recharge. Recently some recharge dams have been constructed to augment groundwater resources by increasing their recharge.

The average total annual flood flows in Oman was estimated at 917 Mm^3/Yr. Its geographic distribution is given in table 4. This volume constitutes about 18 percent of the average annual rainfall over Oman. About 70 percent of this amount infiltrates along the lower reaches of the Wadi beds to recharge groundwater. The remaining is either lost into the sea or in the desert areas by evaporation.

The only perennial flow in Oman is in Wadi Dayqah (70 km south of Muscat), where it continues for about 30 km.

Perennial springs issue from limestone rocks in the northern mountains and in Dhufar Jabels (MMDI, 1991$_a$). The average annual flow for four major springs along the foothills near Salalah is about 9 Mm^3/Yr.

The accuracy in estimating the surface runoff for the different catchments is not that high, as it was not based on actual measurements, but on application of estimated run off coefficients. The adoption of different coefficients by the previous investigators is behind the large descripancy between their estimations. However, it is believed that the lower estimates of surface runoff are more reasonable.

Table 4: Surface Water Resources (Flood flows) in Oman

Region	Mean Annual Precipitation (mm)	MCM	Catchment runoff Ref.(1) MCM	JICA,1990 MCM
N. Batinah	137	666	180	266
S. Batinah	125	970	168	339
Dhahira	135	964	122	193
Dakhiya	168	719	143	216
Sharqiya	105	1,112	186	278
Al-Janubiya:	156	570		142
- Salalah			68	
- Nijd & Dhafar			27	
Musandam	255	177	23	35
Total	133	5178	917	1470

Ref.1: Country paper presented at the Symposium on Water Resources and Water Utilization in the Arab World, held in Kuwait, 17-20 February, 1986.

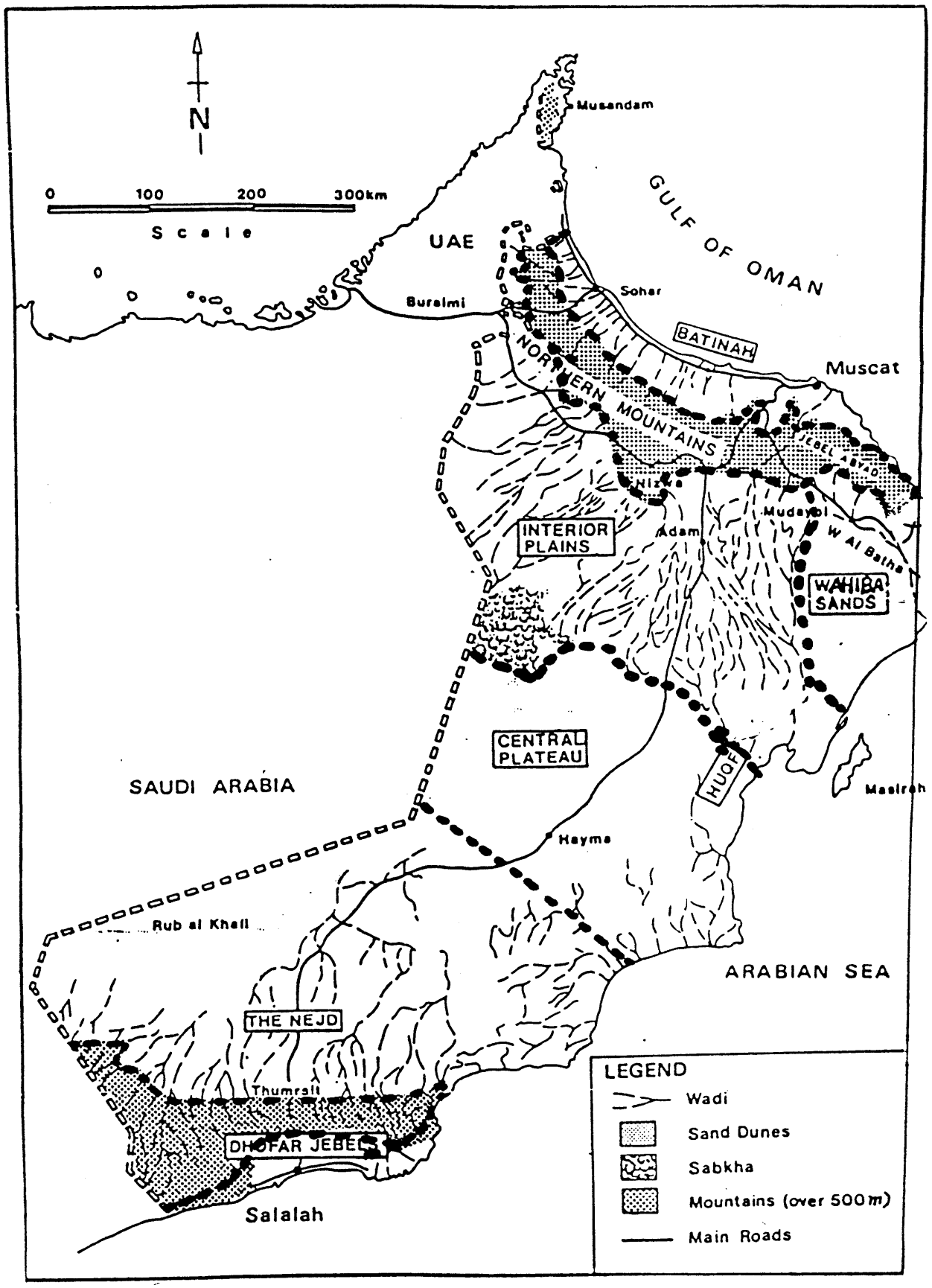
2.3 Groundwater Resources

Groundwater in Oman occurs in three main aquifers types or formations: The alluvial aquifer, the Umm-Raduma aquifer, and the tertiary limestones. The sand dunes with their high permeability also provide favourable hydrogeologic conditions for direct recharge from local rain storms, and from flood flows. These sand dunes stretching along the southern and eastern edges of Rubu Al-Khali and in the Wahiba sands area may provide local water sources for oasis and natural vegetations.

Based on the prevailing hydrogeologic conditions in Oman, the country was subdivided into eight groundwater areas as shown in Figure (7) (MMDI, 1990$_a$). These areas are:

- The Northern mountains
- The Batinah plain
- The Interior plains (Dakhila)
- Wadi Al-Batha and Wahiba Sands
- The Nejd
- The Dhufar mountains, and
- The Salalah plain.

Fig. 7 : Physical Features and Hydrogeological Regions of Oman



Source: MMDI (1991_a)

Groundwater in these areas may be found in one or more of the above mentioned three aquifers. A brief description of the hydrogeologic conditions of the aquifers in the various groundwater areas is given in the following sections.

2.3.1 The Main Aquifer Systems

The Alluvial Deposits:

The Alluvial deposits from the most important and exploitable aquifer in Oman. This aquifer occurs under two conditions:

(a) In the stream channels at the flanks of the northern mountains and in the interior plains of Sharqiya, Dhahira, and Dakhliya.

(b) In the coastal plain of Batinah and Sharqiya regions.

Recharge for these aquifers comes mainly from infiltration of the flood flows following major rain storms. Direct recharge of rainwater over the coastal plain is insignificant as rainfall is mostly less than 100 mm per year on the average.

Natural groundwater discharge from these aquifers takes place as sub-surface outflow to the sea in the coastal aquifers or by evaporation and evapotranspiration in the internal Sabkhas and oasis.

The high variations of rainfall, in time and space, reflects on the groudwater recharge to the alluvial aquifers. In addition, the short duration of flood flows following rainfall events also reflects on the quantity of recharge. The high variability of these factors makes the potential yield of the alluvial aquifer highly unreliable and variable.

In addition, the limited areal extent of the alluvial deposits along the stream channels, and the relatively limited thickness of these deposits, make the storage capacity (volume) for groundwater to be limited. Two exceptions for this situation occur in the Batinah coastal plain where the thickness of the alluvium reaches 600 meters in some areas and constitutes one of the major aquifers in the country. The other exception is in Wadi Batha and in the Wahiba Sands area but to a much lesser extent than in the Batinah region.

The water quality in the alluvial aquifers are generally good except near the coast where they have been affected by sea water intrusion, such as what is happening in the Batinah coastal plain. Deterioration in the water quality of the alluvial aquifer has also taken place because of contamination from the irrigation return flow in areas of shallow water table such as the areas of Al-Wafai and Al-Kamil in the Sharqiya region. The shallowness of these aquifers and their high vertical permeability makes them subject to contamination from agricultural activities.

The alluvial aquifers in the Batinah coastal plain is the most important groundwater reservior in Oman. It forms the main water supply for irrigation and to a lesser extent for domestic water supply. However, over exploitation in this region has led to serious water quality deterioration and depletion of the aquifer storage.

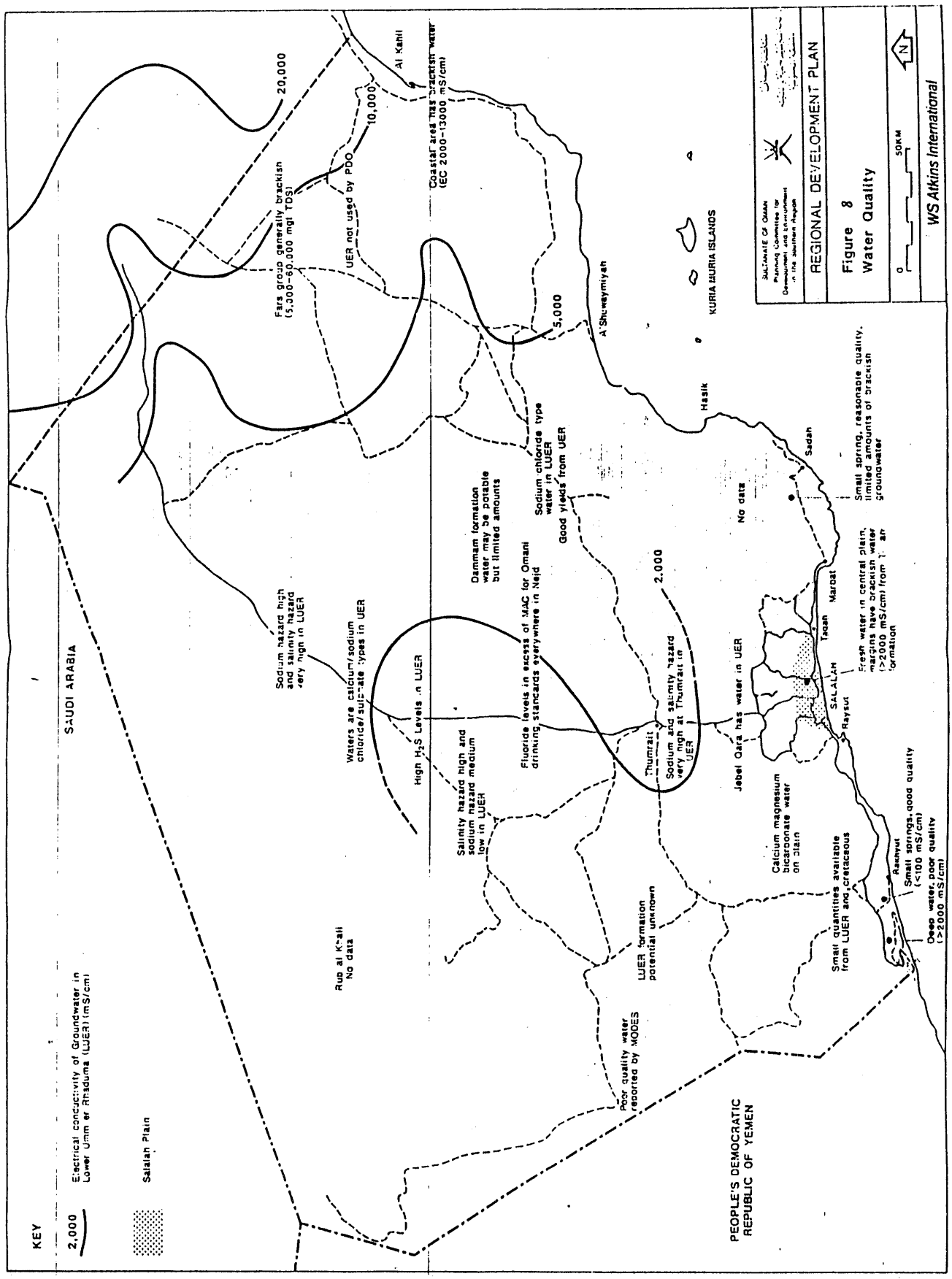
The alluvial aquifers in the other regions are mostly limited to the alluvial channels, and consequently have smaller lateral extents and consequently less regional significance. However, they provide the only water supply sources for the internal regions.

Most of the alluvial aquifers in Oman are fully developed by wells or by aflaj. Various levels of overdraft, sometimes local, have been identified in the various regions of Oman. However, because of the permeable nature of these aquifers, and occurrence, and connection to the surface runoff drainage network, their recharge from flood water can be artificially increased by various means and facilities, and consequently their potential yield can be augmented.

Areas suffering from overdraft conditions such as the coastal plains of Batinah are in urgent need for corrective measures to maintain and conserve this ground water supply source and sustain the existing agricultural and social developments.

The groundwater systems in the alluvial aquifers in the Batinah plains and in the interior plains, have regional significance. However, other alluvial aquifers are significant only at the local levels.

Generally, the groundwater potential in the alluvial aquifers can be increased in the future by constructing artificial recharge dams and facilities. However, this might not be taken as additional water supply source in areas where groundwater is presently over-developed; but it should be looked at as an important step towards protecting such over-exploited groundwater sources and to improve the existing negative water balance of these aquifers.


KEY
2,000
Electrical conductivity of Groundwater in Lower Umm er Rhaduma (LUER) (mS/cm)
Salalah Plain
SAUDI ARABIA
PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN
20,000
10,000
5,000
2,000
Al Kahil
Coastal area has brackish water (EC 2000-13000 mS/cm)
Fars group generally brackish (5,000-60,000 mgl TDS)
UER not used by PDO
Sodium hazard high and salinity hazard very high in LUER
Waters are calcium/sodium chloride/sulphate types in UER
High H2S Levels in LUER
Salinity hazard high and sodium hazard medium low in LUER
Rub al Khali No data
Poor quality water reported by MODES
LUER formation potential unknown
Small quantities available from LUER and cretaceous
Small springs, good quality (<100 mS/cm)
Deep water, poor quality (>2000 mS/cm)
Calcium magnesium bicarbonate water on plain
Jebel Qara has water in UER
Fluoride levels in excess of MAC for Omani drinking standards everywhere in Nejd
Dammam formation water may be potable but limited amounts
Sodium and salinity hazard very high at Thumrait in UER
Thumrait
Sodium chloride type water in LUER
Good yields from UER
A'Shuweymiyah
Hasik
KURIA MURIA ISLANDS
No data
Sadah
Small spring, reasonable quality, limited amounts of brackish groundwater
Fresh water in central plain, margins have brackish water (>2000 mS/cm) from the formation
Taqah
Marbat
SALALAH
Raysut
Rashyut
SULTANATE OF OMAN
REGIONAL DEVELOPMENT PLAN
Figure 8
Water Quality
0
50KM
N
WS Atkins International

Umm-Raduma Limestone Aquifer

This aquifer is of importance in the Nejd, Dhufar mountains and along the escarpment foothills in Salalah plain. It is recharged from infiltration of rain water over the Dhufar mountains. Part of the groundwater flows to the north and northeast into the Nejd and the Central regions, and part of it flows southward to the Salalah coastal plain, where a number of high-yielding, good quality springs issue along the escarpment foot hills.

This aquifer could also be a great important supply source for brakish groundwater, to be used for desalination and as drinking water supply sources, in the Central region.

Umm-Raduma aquifer is the most important groudwater source in these four regions. Although the annual recharge rate is limited, however, the large volume of stored water in this aquifer offers significant possibilities for development based on mining the non-renewable portion of this resource.

The groundwater quality in this aquifer is good in the Dhufars' mountains and along their foothills neighbouring Salalah plain. It is also good in the Nejd region. The water salinity increases with the direction of groundwater flow towards the north and northeast (Figure 8). It is about 500 micromhos in the Dhufar mountains and increases to about 2000 micromhos near Thumrait, and to about 5000 micromhos some 100-150 km northeast of Thumrait. The water salinity then rapidly increases in the same direction to exceed 20,000 micromhos in the Central region.

The groundwater in the Umm-Raduma aquifer is only partly exploited mainly for irrigation. It has a good potential for further development in the future in the Nejd area. More field studies are needed in order to come to a reasonable assessment of the renewable and the stock components of this groundwater system. However, the collection of all needed information on this aquifer would require few years. Development of this important groundwater source need not be delayed till the completion of this lengthy exploratory and assessment study. The available information is adequate to locate 2 to 3 well fields for pilot irrigation projects, where up to 5 MCM/yr can be pumped from each well field for an experimental pumping period of 3 to 5 years. During which close monitoring of the groundwater levels and quality should be done. Such practical and actual information would provide the best means for the assessment of the aquifer potential and response to exploitation. Based on this assessment, the optimum future extraction rate and pattern can be determined using a mathematical model which will be culibrated with the collected data.

The Tertiary limestone aquifer

This aquifer is found in the Salalah plain, in the Dhufar mountains, Nejd region, the Central region, the Interior region (Dakhliya), and in the Northern mountains.

Inspite of this wide occurrence of the tertiary sediments, they do not form any regional aquifer or flow system in proper. These sediments form local groundwater systems with local significance.

In the Northern mountains groundwater occurs in fractured limestones, which are the sources of several important springs and aflaj. Water quality is generally good, but highly alkaline springs are associated with certain horizons within the ophiolites.

Whilest these sediments, in the northern mountains, are important sources of water to many existing communities, they do not appear to offer scope for further large scale development.

Near potable groundwater may be found locally in this tertiary limestone in the central region in connection with the orelying alluvial sediments, and in the nothern parts of Nejd in connection with the sandunes in some oasis.

In Salalah plain the upper limestone member of the Taqa formation forms the important fresh water aquifer in the area. This broad tongue of fresh water extends accross the plain from the mountains to Salalah. To the east and west of Salalah, groundwater is mostly brakish.

Signs of brakish and salt water intrusion can be seen in figure (9) along the interface between fresh and brakish groundwater.

In the other regions where Tertiary aquifer occurs, Nejd, the Interior, and the Northern mountains, this aquifer contains brakish groundwater.

A summary of the groundwater conditions for the different aquifers in the different groundwater areas is given in table (5).

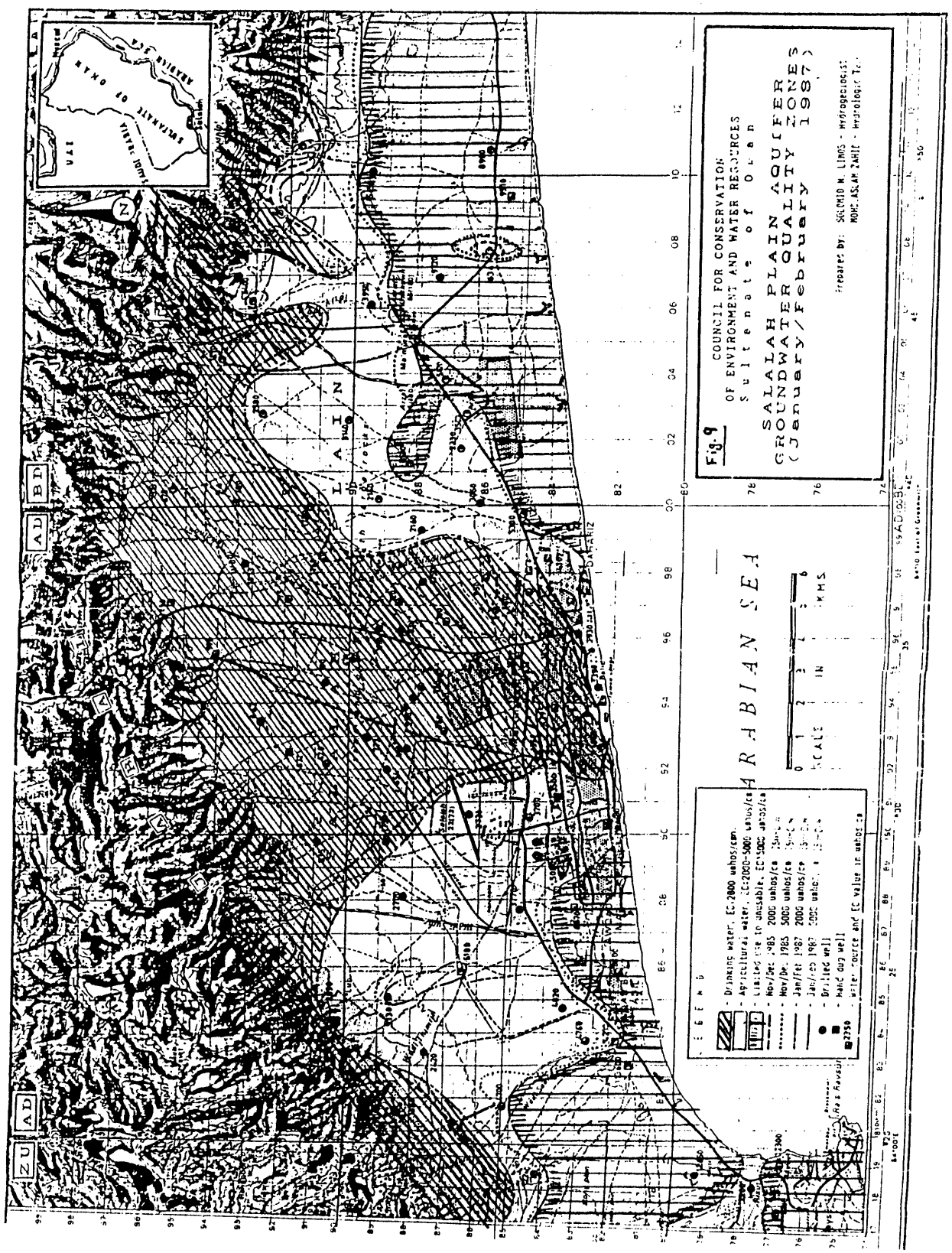


Fig.9
COUNCIL FOR CONSERVATION
OF ENVIRONMENT AND WATER RESOURCES
Sultenate of Oman
SALALAH PLAIN AQUIFER
GROUNDWATER QUALITY ZONES
(January/February 1987)
Prepared by: SOLOMID M. LIMOS - Hydrogeologist
MOHD. ASLAM ZAHIT - Hydrologist
LEGEND
- Drinking water, EC<2000 umhos/cm.
- Agricultural water, EC=2000-5000 umhos/cm
- Limited use to drinkable, EC=5000-10000 umhos/cm
- Nov/Dec 1985 2000 umhos/cm
- Nov/Dec 1985 5000 umhos/cm
- Jan/Feb 1987 2000 umhos/cm
- Jan/Feb 1987 5000 umhos/cm
- Drilled well
- Hand dug well
- Water source and EC value in umhos/cm
SCALE 0 1 2 3 4 5 6 KMS
ARABIAN SEA
SALALAH
SAUDI ARABIA
YEMEN
SULTANATE OF OMAN
ARABIAN SEA

Table 5: Main Groundwater Features in the various Regions in Oman

Region/Area	Aquifer(s)	Recharge	Storage	Water Qality	Exploita -tion	Further Potential
* Northern Mountains	1. All	Y	Limited	Good	FE	N
	2. TLST.	Y	Limited	Good	FE	N
* Batinah Plain	1. All	Y	Large	Good except Near the coast	OE	N
* Interior	1. All	Y	Limited	Good	FE	Y,??
	2. TLST.	N	Limited near mountains	Brakish	NE	N
* W. Batha& Wahiba Sands	1. All	Y	Moderate	Naturally good to fair, Deteriora- tion has occured	PE	Y,?
* Central Region	1. U.R.	N.	Large	High salinity 12000ppm	NE	Y,?
	2. All,TLSE	Y.	Small locally	Fair to Good	NE	Y,?
* Nejd	1. U.R.	Y	Large	Good,fair, Brakish	NE	Y
	2. TLST & Sand dunes	Y	Small	Fair-Brakish	PE	Y
* Dhufar Mountains	1. U.R.	Y	Large	Good	NE	Y
	2. TLST	Y	?	Good	PE	Y,?
* Salalah Plain	1. TLST	Y	Moderate	Good to Poor.	FE	N

Explanations:

Aquifers: All: Alluvial deposits, U.R.: Umm Raduma, TLST: Tertiary limestones.

Recharge & potential: Y: Annual recharge Occurs, Further potential for development occurs; N: means the opposite.

Exploitation: FE: fully exploited, PE: partly exploited, NE: not exploited, OE: over exploited.??? not presicely known.

2.4 Desalinated Water

Desalination plants are at present limited to Muscat area, Salalah and the Kuria-Muria Islands. Small-scale desalination plants have been installed in some rural areas. The total amount of desalinated water is about of 41 Mm^3/year representing only 4.5 percent of the Sultanate's total water resources 917 Mm^3/year.

Desalination of sea water in coastal areas as well as of brackish ground water in the inland areas offers unlimited but expensive water source. This limits its use to potable supplies. The reverse osmosis method is appropriate for small and medium sized desalination plants. In Muscat area where demand for both water and electric power is large, combined power generation and desalination using flash distillation process is applied.

2.5 Treated Sewage Effluent (TSE0)

Treated sewage effluent (TSE) represents, according to recent studies (Al-Shuriani, 1991), a renewable source of water when properly managed. At present TSE amounts to about 70,000 m^3/day or 25.6 Mm^3/year, out of which about 30,000 m^3/day (11 Mm^3/year) are used by the municipality of the capital area for irrigating ornamental plants.

The potential for increasing both the generated and the consumed amounts of TSE is expected as programmes are to expand both water supply systems and piped sewerage schemes (MMDI, 1991_b). The standards established in 1986 within the Omani regulations for use of TSE (Royal Decree No. 10/82) restrict, however, the use or disposal of TSE. Omani standards aiming at zero health risk are considerably more stringent than guide standards suggested by WHO, and even those published recently in 1989.

Recent research findings of Al-Shuriani (1991) revealed that tertiary TSE of Dar Seet sewage treatment plant (near Muscat) was as safe as well water when used for irrigation of sun- flower oil crop, suggesting reviewing of the present standards and defining several standards to suit the different applications of TSE, i.e. irrigation of ornamental plants, trees for afforestation programmes, controlled cropping, industrial uses and aquifer recharge.

3. WATER USE:

3.1 Municipal and Industrial Water use (M&I)

The water supply in Oman has rapidly increased to cope with the socio-economic development since 1970. The supply for M&I increased from 46.3 MCM in 1986 to about 54 MCM in 1988, not including the supply from aflag and private wells. The average growth rate during this period was 7.9 percent. Out of this quantity, 40 MCM was supplied to the capital area in 1988, (74 percent) compared to 1.95 MCM in 1976.

Initially all the water supply relied on groundwater supplies. However, since 1977, with the construction of the first desalination plant at Ghurba, the relative dependence on groundwater sources decreased as shown in table (6) for the capital water supply:

Table .6: Domestic Water Supply for Muscat area

Year	Groundwater Supply MCM/Yr.	Desalinated Sea water MCM/Yr.	Total Supply MCM/Yr.
1977	1.4	3.1	4.5
1981	6.7	6.7	13.4
1984	3.5	16.0	19.5

In Salalah area the domestic water supply increased from 2 Mm^3 in 1977 to 5.2 MCM in 1982, to 8MCM in 1988. The supply sources are mainly groundwater wells with the exception of a small desalination plant for brakish groundwater at Dhalqut.

In addition, about 10 MCM of treated sewage water was used in 1990 for gardening and land scaping. The total water use in Oman is given in table (7).

Table 7: Water Use in the Sultanate of Oman (1990)

Region	Agricultural	Domestic	Total
Batinah & Capital Area	679	56	735
Dhahria & Dakliya	245	5	250
Sharqiya	165	4	169
Salalah	32	8	40
Nejd	7	1	8
Musandam	23	1	24
Central		5	5
Total	1151	80	1231

- Source MMDI (1990)
- Does not include agricultural demand in the Central Region.
- Does not include 11 MCM of treated sewage water which were used for street gardening in the capital area.

A greater reliance on desalinated sea water for domestic supply, and on treated sewage water for irrigation, is invitable to meet the future water demands in view of the scarce and over-exploited conventioned (traditional) water resources.

The overdraft conditions in some areas, such as Batinah and Salalah plains, which are mostly caused by pumping for irrigation by the private sector, have affected some domestic water supply wells by increasing their water salinity. Therefore, protection of the water supply wells and well fields from human activities and from over pumping is of atmost importance.

3.2 Agricultural water use:

Agriculture is the main water consumer in Oman, using about 94 percent of the total water use in 1990, which was estimated at 1151 MCM/Yr. by MMDI, 1991, and at 1295 by JICA, 1990 for the year 1988.

Out of this quantity about 57.3 percent (JICA,1990) to 59.0 percent (MMDI, 1991$_b$) was consumed in the Batinah plain. Meanwhile, the whole of irrigation water is based on groundwater resources through wells, aflaj, springs and rain, destributed as follows:

Water Sources	Irrigated (ha) area	Area (%)
Aflag	12410	26%
Wells	32000	67%
Springs	120	0.25%
Rain	478	1%
More than one source	2782	2.75%
Total	47,795	100%

Ref.: First agricultural sensus, 1978-1979

The geographic distribution of irrigation water-use may be represented by the irrigated areas in the different regions as given in table (8).

Table 8: Distribution of Irrigation Area in Oman by Region (1978-1979)

Region	ha	percent%
Batinah & Capital	12,113	44.17
Musandam	1,325	2.77
Hajar Al-Gharbi	1,900	3.97
Hajar Al-Sharqiya	10,010	20.9
Burami	795	1.66
Dhahira	2,603	5.44
Dakhilya	4,377	9.07
Sharqiya	3,883	8.12
Dhufar	1,826	3.81
Total	38,792	100%

The Falaj system of Oman has been providing water for domestic and irrigation purposes for 1500-2000 years. The present number of aflaj is not exactly known. However, they are estimated above 4000; only 2000 of them are listed in MAF files; and only 300 are located on maps.

Recently, the aflaj system has been suffering from a number of problems as follows:

1. Shortage of maintenance funds.
2. Lack of local labour.
3. Decline of groundwater table and consequently decline in their yield, because of pumping wells.
4. Excessive water losses in the falaj conveyance and distribution system
5. Water pollution by domestic and irrigation wastes.

The other water supply sources are the wells. About 30,000 to 40,000 wells are estimated to exist in Oman. Most of the water wells are privately owned by farmers. Presently it is forbidden to drill wells in Oman without a permit from the MWR, which is usually not easy to get.

The abstraction of water from wells was limited in the past as human or animal power was used to lift water. Large abstractions for irrigation were only possible where the water was at shallow depths. The governmental subsidized introduction of motorised pumps has enabled much larger water abstractions from deeper layers.

The water well system is presently suffering from the following problems:

1. Reduced capacity of the old hand-dug wells.
2. Lowering of the water table due to over pumping.
3. Sea water intrusion along the coasts.
4. Salinization of the groudwater in the inland areas.

Methods of irrigation applied are flood, sprinkle and drip. The areas under each method of irrigation are not known. It is, however, assumed that practically all the irrigated lands apply flood method. The water use efficiency of the traditional irrigation method is very low and range between 30 to 45 percent (Hydro Consult, 1985; Little, 1985; and Atkins, 1989). Improvement of the water conveyance efficiency, through lining of irrigation canals or using piped supply, could increase the water use efficiency to reach 65-70 percent, Table 9.

Table (9): Water use efficiency of different irrigation methods in Oman

Irrigation Method	Water Use Efficiency by Source (%)	
	Hydro Consult (1985)	Atkins (1989)
Flood irrigation, traditional	45	30
Flood irrigation, lined canals	65	-
Flood irrigation, piped supply	70	-
Sprinkle irrigation	75	60
Drip/trickle irrigation	80	85

Irrigation pumping is the major cause for the overdraft conditions. In addition, the salinity problem of the irrigation water, and the desire to have higher production, make the farmers over irrigate. Table (10) gives a comparison of the water requirements and the actual water application rate in Oman, as well as the overuse ratio for the major crops.

Table 10: Water Requirements and Actual Water Use of the Main Crops in the Sultanate of Oman

Crop	crop Area as percent of total Cultivated area	crop-water requirement m^3/ha/Yr.	Actual Water-use m^3/ha/yr.	Over Use ratio %
Dates*	44%	20,660	43,325	210%
Alfalfa*	16%	1,390	41,387	193%
Banana*	-	-	52,690	-
Tomato** & vegetables**	23%	8,430	11,900	141%
Fruits*	15%	18,390	37,950	206%

* Perennial crops.
** Seasonal crops.

4. WATER BALANCE

Planning for future development, especially in the agricultural sector, is largely based on availability of additional water resources. These resources could be:

(i) Surplus water in some regions to be transported to areas of shortages;
(ii) Enhanced exploitation of groundwater;
(iii) Savings due to rationalization of present uses;
(iv) New groundwater sources explored; and
(v) Extensive use of TSE or recharge to groundwater.

Calculations indicate that there are few groundwater resources available for development (Table 11). General trends of regional balance of groundwater are, as follows:

(a) Batinah Region indicate serious overdrafting of groundwater amounting to 342 Mm^3/year over the available groundwater recharge (438). Mm^3/year) or about 55 percent overdrafting. The overdrafting is mainly seen in salinization areas;

(b) Dakhliya and Dhahira regions show 31 Mm^3/year overdrafting about 14.1 Mm^3/year of the rechargeable groundwater;

(c) Sharqiya region also shows a negative balance amounting to 12 Mm^3/year or about 7.6 percent of the rechargeable groundwater; and

(d) Salalah region (Al-Janubiya) is reasonably balanced but need a better management. While Nejd shows a preliminary surplus of MMm^3/year which needs confirmation studies.

(e) The other areas of the Central region and Musandam seem in balance. However, additional nonrenewable brakish groundwater can be extracted from the Central region.

Potential new resources i.e. recharge facilities and use of TSE would significantly reduce the overdraft conditions in the future.

Table 11: Water Resources in the Sultanate of Oman; Demands, potential new resources and balance by region, status 1990, ($Mm^3.year^{-1}$)

	Regions							
	Batinah and Capital	Northern Dhahira and Dakhliya	Northern Sharqiya	Salalah Plain	Nejd	Musandam	Central Region al-Wusta	Total
A. Water Resources	481	219	157	41	25	Not Known Probably Equal to Demand 24	Poor Quality Water 5	952
B. Demands								
Agriculture	679	245	165	32.5	7	23	Not Known But Low	1,151.5
Domestic	56	5	4	7.5	1	<1	5	74.5
Total	735	250	169	40.5	8	24	5	1,231
C. Present Deficit	254	31	12	1	17	–	–	279

* Brackish water areas

Sources : Based on data collected from MMDI (1991 a)

Water quality for irrigation

There is no adequate information about the quality or irrigation water abstracted from the aquifers in different regions of the Sultanate of Oman. Information evaluated by MMDI(1991$_b$), however not mentioned, revealed that the availability data are either not comparable or of doubtful accuracy. Shallow wells showed increased salinities over the periods 1975 (Gibb, 1976) and 1983-1989 (MMDI) as indication of overexploitation of the aquifer. Similar findings were reported by Weidleplan and Muamir (1989) for the Batinah Region (Figure 10). Due to the extensive agricultural development in the Batinah plain since the early seventies and the extensive pumping from a large number of wells due to small farm units, the saline groundwater from seaside intruded into the fresh water aquifer. Soils irrigated with this water have become increasingly saline. Salinization of soils is continuing and the affected area is moving inland. Recent figures of affected areas indicate a 5 to 10 km wide strip of saline soils along the coast of Batinah Region (Figure 10).

The salt content of Falaj water was the lowest and hence presents the best quality for irrigation. Well water and TSE are of similar quality for irrigation.

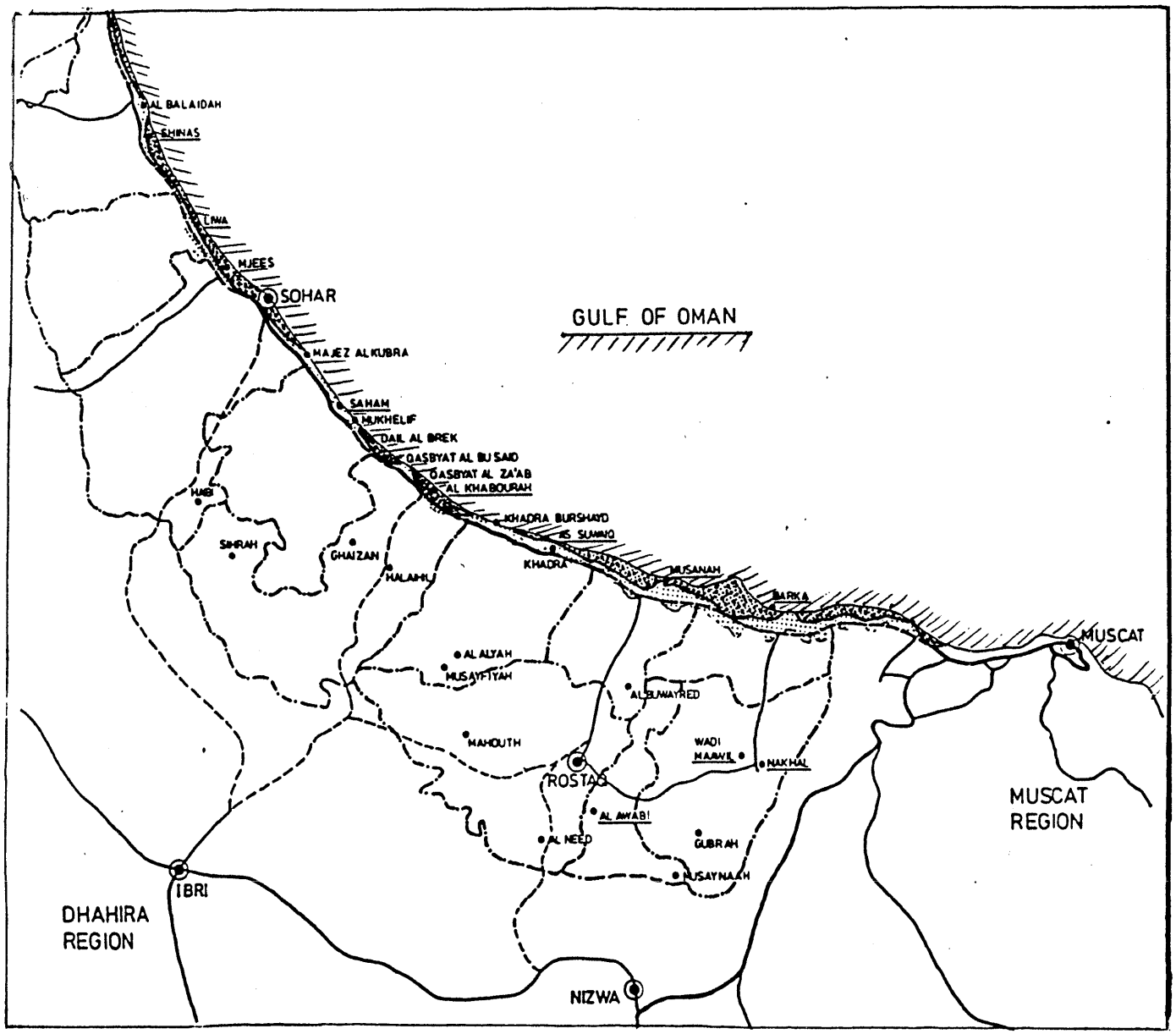


Fig. 10

SALINATION ZONES
BATINAH COASTAL AREA

LEGEND

- SETTLEMENT
- INTERNATIONAL BOUNDARY
- WILAYAT BOUNDARY
- HIGHWAY
- REGIONAL ROAD (TARMAC)
- TRACKS

SALINITY CLASSES

- GREATER THAN 6000 MICROMHOS
- BETWEEN 2000 AND 6000 MICROMHOS

Source: Weidleplan and Muam (1989)

5. ASSESSMENT OF THE PRESENT AND FUTURE WATER RESOURCES

5.1 Existing Resources

Estimates of groundwater resources available in Oman were made by several groups. JICA reported in 1990 of 1,239.8 Mm^3/year available groundwater (Table 12). This figure was by far higher than the estimates made by the MMDI group in 1991. Estimates of available groundwater carried out within the National Water Resources Master Plan were, according to MMDI (1991$_a$), only about 850 Mm^3/year. More than 50% of the available groundwater resources is in the Batinah and Muscat area. The different estimates of the present groundwater available was atributed by MMDI (1991$_a$) to one or more of the following factors:

(i) The short period of hydrological records; particularly surface runoff data;
(ii) The sparseness of hydrological data; and
(iii) The lack of accurate data on the extent of cropped areas and agricultural water use.

The above groundwater estimates were made by applying certain percentages to calculate the infiltration from flood flows which recharge the groundwater aquifers. More detailed work is actually needed to arrive at more realistic estimates of the groundwater resources. It is also important to say that the great uncertainties in estimating the surface runoff using estimated runoff coefficients would be a major cause for the poor accuracy of the groundwater recharge estimates from surface runoff water.

It is believed that the higher estimates of JICA, 1990, are exagerated, because of their original overestimation of the surface runoff from which the groundwater recharge was derived. The overestimation of the groundwater resources may be upto 20 percent. The estimates adopted here are given in table 12.

Table 12: Estimates of the Groundwater Resources

Region	MMDI (1991a))	JICA 1990	Ref.1*	Adopted Estimates
N. Batinah	438	240	119	438
S. Batinah		317	106	
Dhahira	217	137	59	217
Dakhliya		157	75	
Sharqiya	155	232	108	155
Musandam	?	30	18	24
Salalah	40	127	53	40
Nejd	??			25
Central				5
Total	850	1240	538	904

* Country paper, Symposium on Water Resources and their utilization in the Arab World, Kuwait, 1986.

5.2 Future New Water Resources

Opportunities to increase groundwater resources, the so-called potential new resources for groundwater, seems to be very limited as compared to the available resources at present. According to the Water Master Plan of Oman (MMDI, 1991a) only about 82 Mm^3/year could be added to the groundwater resources available at present, representing less than 10 percent increase. This quantity was proposed as follows as to the year 1990:

(a) Additional recharge dams for flood water:
- in Batinah 20 MCM
- in Dhahra & Dukhliya 5 MCM
- in Sharqiya 2 MCM

(b) Recharge of TSE in Batinah and Capital area 20 MCM

(c) Wadi Catchments flood flows:
- in Batinah 15 MCM
- in Dhahra & Dakhiliya 20 MCM

The total will be 82 MCM/Year.

On the longer term, the new water resources which may be developed are as follows:

1. Artificial recharge using surplus flood flows lost to the sea(MCM)

Region	Surplus flood flows	Additional Potential Recharge
Batinah	48	33 (13 to be developed by 1993)
Sharqiya	18	12
Salalah	10	7
Total	76	52

2. Artificial recharge using flood flow losses into the interior desert, which are estimated as follows in MCM:

Region	Flood losses	Additional Potential Recharge
Dhahira	68	34
Dakhliya	62	31
Total	130	65 (5 to be developed by 1995)

3. Direct or indirect use of treated sewage effluents based on 60 percent return flow (unconsumed water). This will be in the larger population centres and would require sewage collection and treatment systems.

	Muscat Area		
	1990	2010	2010
Domestic water demand	40	80 MCM	15
Sewage production rate	24	48 MCM	8

4. Water savings from improving the irrigation efficiencies based on the present irrigation requirement which are estimated on the average of 1200 MCM/yr.. The total water savings would be as follows:

Target efficiency%	Water savings (MCM/yr)
60%	240
55%	180
50%	120

5. Water savings from control of leakage from the domestic water supply system. The target declared by the Government of Oman is to reduce leakage rate from 30 to 20 percent by the year 2010. Based on domestic piped water demand of 100 MCM in the year 2010, the water savings would be 10 MCM/Yr. The assumed piped water demand is uncertain at the present time and is ////////////////subject to changes.

Consequently the total new additional water resources in the year 2010 would be about 325 MCM per year.

The National Water Master Plan prepared by MMDI (1991) for the Sultanate suggested several options for water savings; especially in the agricultural sector, amounting to 269 Mm^3/year. Most of the water saving suggested for the Batinah region is through improved irrigation efficiency by 5 percent (saves 30 Mm^3/year), replacement of date palms in 4,600 ha by winter vegetable crops (saves 30 Mm^3/year), replacement of date palms in farmland to alternative uses not dependent on groundwater abstraction (105 Mm^3/year).

The suggested savings in irrigation water seems realistic as the present water consumption in Oman for irrigating growing crops is more than twice as much as the water requirements estimated for Northern Oman (Table 10). The surplus water applied is much beyond the leaching requirements of salts, usually about 25 percent of the crop water requirements. Tomato was the only crop with reasonable excess of water, only 4 percent over the crop water requirements. Probably is because it is a winter crop.

However, the additional groundwater recharge potential can only compensate for part of the estimated depletion in the aquifer storage particularly in the Batinah plains. Therefore, it should not be considered as totally new additional resources. But their development would be an important mean for aquifer rehabilitation.

5.3 General Assessment of the Present and Future Situation of Water Resources in Different Regions.

5.3.1. Nejd area

One of the potential areas for groundwater development is the Nejd Region. An experimental farm near Marmoul, run by an oil company (petroleum Development of Oman), has an area 100 ha. Six wells, tapping two different horizons of the Um-Raduma aquifer, have been used to irrigate mostly fodder crops since 1985. The well depths range from 250-500m. Their yields range from 20-40 L/Sec. The water salinity is 860 ppm for the deep aquifer, and about 2000 ppm for the shallow aquifer. The depth to water levels ranges for 65-70 m below ground surface. The average annual pumping for irrigation since 1985

is about 3 MCM/yr. So far monitoring did not indicate any decline in groundwater levels, or reduction in well yields, or increase in water salinity. This is a practical and an excellent indication of the good potential development of th Umm-Raduma aquifer in the Nejd region. Similar projects can be established at appropriate spacing throughout the area.

5.3.2. Wahiba Sand area

There is a smaller potential for groundwater development in the Wahiba Sands area. The alluvial aquifer along Wadi Batha extends underneath the sand dunes area. Shallow groundwater also occur in the upper permeable sand deposits. The lack of open drainage network within this area indicates the abscence of surface runoff. This indicates the possibility of direct groundwater recharge to the sand and the underlying alluvial aquifer. Groundwater in the Wahiba Sands area may assist in the rehabilitation and improvement of the natural vegetation in this area; which in its turn would help stabilize the sand dunes and control their encroachment over the developed areas in Al-Wafi and Al-Kamil. Generally the groundwater resources in the Wahiba sand dunes area are still underdeveloped; however, further exploration and investigations are needed.

5.3.3. Batinah Plain

Augmentation of the depleted aquifer in the Batinah plain by artificial recharge processes is of atmost importance and should be continued. Although the role of the artificially recharged water would be to compensate for the depleted storage and consequently improve the water quality which has significantly deteriorated by sea water intrusion and by over exploitation and reuse of the groundwater; however, the performance of the already constructed dams has to be properly evaluated to ensure that the main purpose for their construction is being achieved. Based on this evaluation, planning of new additional recharge dams or other structures and facilities would be determined.

The groundwater situation in the Batinah coasted plain is very critical. The water salinity has increased to more than 8000 micromhos in some areas. There is generally a regional increase in salinity along the plains particularly near the coast. The water quality deterioration increases towards the sea.

The degree of deterioration varies also along the coast depending on the occurrence of active or abandoned alluvial channels which form the most preferable zones for groundwater flow and recharge from the flood water.

It is very important to remind at this time that the quantity of flood flows available for artificial recharge, and the pattern of geographic and hydrogeologic distribution of the existing recharge dams will not be sufficient to correct the hydrogeologic situation along the Batinah plain, particularly those areas or zones which suffer most from sea water intrusion.

Artificial recharge structures on the western and southwestern streams of the northern mountain areas should be selected and located with care to avoid possible adverse effects on existing water extraction facilities (Alfaj, wells, springs). Some of these extraction points may benefit at the expense of others. The selection of the appropriate type, size and location of the planned recharge structures are of utmost important to ugment the available water resources, while maintaining and protecting the existing systems.

5.3.4. Wadi Al-Batha

The groundwater salinity has increased to more than 7000 micromhos in most of the wells. The groundwater salinity build up in this area is attributed to the pattern of groundwater extraction as related to the irrigated land where the irrigation wells are located within the main irrigated areas and to tha lack of drainage systems. Due to the shallow water table conditions, high permeability of the overlying alluvial deposits, high top soil initial salinity being in arid area, the relatively slow movement of groundwater, and the over irrigation, a considerable part of the pumped groundwater returns as leachate to the water table withen a short time. Because of the slow groundwater movement (by nature), this return flow might be pumped again before escaping the radious of influence of the pumped wells, or may be intercepted again by a downstream well. Each time this cycle takes place some salts would be added to the groundwater.

The situation is very common in arid areas under similar hydrogeologic and extraction pattern and conditions. The best solution would be to re-locate the irrigation wells, to an upstream area from the irrigated land in order to avoid the recyclining process mentioned above. The other possible solution is to provide adequate drainage systems in the irrigated area, which would intercept, collect and carry away the return irrigation flow. However, the high vertical permeability of the alluvial soil in this area would require a closely spaced drainage network which would makes the cost too high compared to the first alternative.

It should be mentioned here, that the water quality deterioration in Wadi Al-Batha area does not necessarily indicate an overdraft condition rather than over irrigation, lack of adequate drainage system in the agricultural land, and mis-management of the groundwater extraction and irrigation.

5.3.5. Salalah Plain

In the Salalah plains the groundwater system in the coastal aquifer is slightly imbalanced by over pumping, leading to some encroachment of the sea water groundwater interface along the southern coast. The salinity map (Figure 9) also shows some signs of salt water intrusion from the east and west into the central fresh water zone of Salalah plain. The situation of this fresh water zone is considered very critical as it is surrounded by saline or brackish water environment from the south, east and west. Wise management of groundwater extraction is necessary to maintain adequate hydraulic conditions in this area.

Artificial recharge along the south-draining streams in Salalah plain could augment the available water resources and consequently prevent or control sea water intrusion.

5.3.6 Dakhliya Region

Groundwater, as in most of Oman, is the main water source in the Dakhliya Region. It occurs in fractured rocks and in the alluvial sediments, and is recharged from rain water and flood flows. The groundwater in this area is obtained from springs and Aflaj in the mountain regions, and from Aflaj and wells in the plains and the hilly areas.

The most important agricultural area in this region is Wadi Qrayat, 17 km south of the city of Bahla. This area was irrigated from the Aflaj water for centuries ago. However, the farmers started to dig wells and use pumps to lift the groundwater for irrigation purposes. Consequently large areas which used to be irrigated from the Aflaj water, have been abandoned with the Aflaj, and the remaining irrigated areas are centered in small areas around wells.

The deserted irrigation areas near the Aflaj are presently covered by thick natural vegetal cover. The irrigation water quality is good with the exception of relatively high sodium content in some areas which would be harmful to plants. The adoption of the drip system would assist alleviate this problem.

A study on the Aflaj system in this area indicated that the cost of repairing the abandoned Aflaj would be too high as compared to the alternative of drilling groundwater wells.

5.3.7. Dhahria Region

Agricultural activities are limited in the Omani part of this region and are limited around aosis Near Al-Bureimi. Aflaj forms the mainwater supply in this area.

On the other side of the border, in the United Arab Emirates, large irrigated agricultural activities exist based on groundwater wells which resulted in lowering the water table. As the source of recharge for this groundwater comes from the northern mountains of Oman, high yielding wells can be drilled in the Omani area, however, they will effect groundwater development across the border.

6. THE STATUS OF DESERTIFICATION IN OMAN

6.1 Background

Desertification is the man-made process of the degradation of land water and other natural resources so that they lose their capacity to provide economic returns under cultivation or grazing. In other words, desertification leads to the increase of the deserted area and the decrease of the fertile and productive land. Deserts are not always the sources from which desertification starts. Desertification may occur in areas which have been fertile and productive for decades.

The process has recently been recognised internationally as a world-wide problem with the United Nations Conference on Desertification held in Nairobi, Kenya in 1977. Accordingly, desertification commonly appears as the deterioration of land, water and other natural resources under ecological stress. Deterioration implies that activities in an area have been unsuitable or unbalanced either in degree or in kind with the capacities and potentialities of the natural resources. Such activities may have been pursued because of lack of environmental knowledge or experience, because alternatives were lacking or, in an attempt to maximize short-term gain at the expense of long-term productivity. Education, soil, technological and economic advancement and the adjustment of population growth to the developed resources are the key elements responsible for initiation of desertification or successfully combating it.

While water, soil biological and other resources are often the limiting physical factors, social political and other human systems for managing these resources, making decisions and implementing plans, and the adequate availability of financial resources, may constitute the major constraints to development, prevention of desertification, and rehabilitation of desertified lands.

6.2 Identification of Desertification in Oman

6.2.1. General

In undertaking the mission to Oman for the preparation of a national plan of action to combat desertification, one of the main objectives was to identify, assess and evaluate desertification in the various areas and regions through field visits and observations in addition to office discussions with concerned parties, and review of relevant literature. This process included identifying and assessing the extent and magnitude of desertification and its causes and effects, and identify which parts of the country are affected or vulnerable. The process also included the various physical component of the environment: land and water and their plant and animal products. Further analysis of the collected data has served evaluate possible trend of desertification in each area or region, as well as to set priority programmes and projects. Although, the gathered survey is believed satisfactory for preparation of the plan, a continuous, survey, monitoring and assessment system will be necessary.

6.2.2. Types of Water related desertification:

Based on the survey, the following types of desertification which are related to water have been observed, which are discussed in more details later on for the different areas:

1. Sand dunes reactivation, movement and advancement. Two forms of desertification are identified here:

(a) Over grazing and cutting of trees and the natural vegetations within the sand dunes area have led to partial loss of the vegetal cover giving rise to land surfaces which are more vulnerable to wind transport (wind erosion).

(b) The transported fine particles are lifted and carried long distances as dust. The coarser sand particles, are drifted over and above the surfaces and are either trapped by plants in small dunes, or transported and deposited to the adjacent areas, down wind, where they cover some agricultural land and oasis.

These forms of desertification are observed in the Wahiba sand dunes and the adjacent Wadi Al-Batha areas. They are not directly related to water factors, however, the availability of groundwater in these areas may be helpfull in rehabilitating the vegetal cover; which in its turn would assist in sand dune fixation and wind erosion.

2. Irrigated land: Water and soil salinization: The main forms of desertification on irrigated lands are water and soil salinization leading to partial or complete loss of soil fertility, productivity, and ultimately loss of crops.

Two causes of groundwater salinization could be identified: saline groundwater and sea water intrusion and return irrigation water. The first cause is the most dominant in the coastal plains of Al-Batinah and Shargiya. The second cause is more dominant in the inland areas such as in the irrigated areas along Wadi Al-Batha.

3. Range and forest lands in the southern mountains: Water and vegetal cover relationships in this area are of atmost importance to the continued benefit of both resources. Forests in the Dhufar mountains increase the soil moisture and groundwater recharge through capturing water from the fog. Increase of soil moisture subsequently supports a better grass cover. On the other hand, loss of the vegetal cover by overgrazing and trees cutting would reduce soil moisture and groundwater recharge. Meanwhile it would increase surface runoff and consequently soil erosion and soil productivity.

4. Rain-fed farming:

In areas of rain-fed farming such as Jebel Al-Akhdar in northern Oman, desertification may occur due to removal of the natural vegetal cover for cultivation, and inappropriate soil conservation measures, which would lead to loss of the fertile agricultural soil.

6.2.3. Identification of desertification in the different regions of Oman:

6.2.3.1. Batinah Coasted Plain:

Desertification was observed to various degrees along almost the whole strip of land between the main highway and the coast with some exceptions in limited areas and some locations in suwaiq, Al-Maragha town south of Musanah, Al-Suwadah Town, and some areas in the far northern part of Batinah coast.

Different levels of desertification were observed along the coast increasing towards the coast. Desertification in this area was manifested by water and soil salinization, soil degradation, and degradation of crops and trees. Based on various levels of deterioration of these aspects, three strips or longitudinal zones parallel to the coast line can be identified:

1. A severly affected zone near and along the coast: this area was easily identified by the type and health conditions of the crops and trees. Abandoned farms were seen in this zone with complete loss of crops and other trees including palm trees, (the most resistant fruit trees observed in the area).

2. A moderately affected zone next to the first, and towards the highway. This zone can be classified into two sub-zones: the first closer to the sea and is more affected by soil and water salinization. It can be identified in the field by the occurance of moderately affected mango trees and complete destruction of citrus and banana trees. The second sub-zone is characterized by healthy mango trees and partly affected citrus trees. The palm trees in these two sub-zones are still in acceptable conditions.

3. Slightly unaffected zone, mostly west of the main highway, with some patches or strips immediately east of the highway. Citrus and banana trees are in good healthy conditions in this zone, and almost all vegetable crops are being grown in this zone.

The main cause of desertification in the Batinah plain is the salinization of the groundwater leading to soil salinization, and consequently loss of soil productivity or suitability for economic crops. The salinization of the groundwater in this region is caused by sea water intrusion, which in its turn is caused by aquifer over-exploitation and reversing of the hydraulic gradient due to decline in water table. With continued overdraft the groundwater salinity will continue to increase, and the area affected will continue to expand leading to further soil salinization, and deterioration of agricultural products.

It is to be reminded that Al-Batinah coast is the most important agricultural area in Oman where it produces about 60% of the total country agricultural product. The irrigation water sources are mainly wells in the near coast area, and aflaj in the inland higher plains, where wells are of secondary importance.

6.2.3.2. Al-Sharqiya:

This area includes the coastal plain from Muscat to Ras-Al-Had, and the mountain and desert areas to the west.

Agriculture in this area forms the main economic activity. It is based on groundwater wells and aflaj. Groundwater wells are more abundant in Qraiyat and Sur plains, in middle and lower Wadi Batha, while aflaj are found in Wadi Batha, and in Mudhaibi area, Wadi Dhaiqa and Wadi Mijlass.

The groundwater situation in Wadi Al-Batha (Al-Wafi and Al-Kamil areas) has reached a critical stage based on information gathered during a field visit to the area from the field office of the ministry of Water Resources. Some irrigation wells have dried out. Wells with water salinity above 3000 micromhos have increased from 40% to 80% of the existing 5000 wells (approximately). The salinity increased in these wells to about 7000 micromhos. In addition, the water levels in most of these wells dropped, on the average, about 3m in Al-Wafi and Al-Kamil, and 3-5 m Bani Bu-Hasan and Bani Bu-Ali area.

As a result of the groundwater salinity build-up in this area, about 10% of the presently irrigated area (about 4000 ha) has been severely affected by salinization. Deserted farms and badly damaged palm trees due to high water and soil salinity were observed during the field visit. The groundwater salinity build up in this area is attributed to the pattern of groundwater extraction as related to the irrigated land where the irrigation wells are located within the main irrigated areas.

Increased groundwater salinity was also observed in the coastal plain of Sur and Qraiyat as a result of sea water intrusion due to over-pumping. Groundwater salinity in these areas is higher near the coast where it reaches up to 5000 and 10,000 micromhos in Qraiyat and Sur plains respectively.

Groundwater salinity increase up to 10,000 micromhos was also reported in the coastal area of Wadi Maih.

Soil Salinization in these areas of high water slinity have been observed and there is a potential desertification hazard in these areas, particularly in Sur area, where agricultural productivity of the soil has been seriously affected.

Another form of desertification was observed in the Wahiba sand dunes area and the adjacent Wadi Batha in the east and south east. This form of desertification is not related, however, to water resources. Overgrazing and deterioration of the natural vegetal cover has led to active sand movement by wind action. This reactivation of the Wahiba sand dunes have resulted in the advancement of sand dunes towards agricultural lands and oasis.

6.2.3.3. The Southern Region

In the Salalah plains the groundwater system in the coastal aquifer is slightly imbalanced by over pumping, leading to some encroachment of the sea water- groundwater interface along the southern coast towards the pumping centers. The salinity map (Figure 9) shows some signs of salt water intrusion from the east and west into the central fresh water zone of Salalah plain. The situation of this fresh water zone is considered very critical as it is surrounded by saline or brackish water environment from the south, east and west.

In the mountain and Nejd areas, groundwater is still underdeveloped and the natural conditions have not been significantly changed. However, the occurrence of fresh and brakish groundwater in alternating zones within the main aquifer (Umm Raduma) makes the fresh groudwater suceptable for salinization under heavy pumping conditions and inappropriate well designs.

6.2.3.4. Dhahira and Dakhila Regions

Agricultural activities in Dhahira Region are very limited. No signs of deterioration in soil, water, and vegetal cover have been reported. However, the extensive groundwater development accross the borders, in the UAE, will cause some decline in the water table, and will limit the opportunity for additional groundwater developmemt in Oman as the water source is the same.

In the Dakhliya Region, no serious deterioration in water and land have been reported, except for the abandonment of a large number of Aflaj, and the relocation of the irrigated lands to new areas arround groundwater wells. Large number of farms, which used to be irrigated by Aflaj have been deserted.

6.3 Causes of Desertification

The desertification process may be initiated where pressure on land, water and vegetation use by man continues above the natural capacities of these resources. It may also occur because of misuse and bad management of any of these resources in certain areas which are not yet fully developed.

While analyzing the causes of desertification, physical factors related to climate, types of soil, natural vegetation and the scarcity of water resources are not considered direct causes for desertification rather than constraints to th development of these resources which we have to accept and deal with knowledgeably. The existance of such constraints would only facilitate and accelerate the desertification process if not carefully considered in managing the development of these resources.

Within this context, the causes of desertification in Oman have been identified. These causes may be grouped in different ways:

(A) Physical factors and socio-economic factors.
(b) Resource -related factors suchas:

- Human factors;
- Water related factors;
- Soil related factors;
- Agricultural factors;
- Factors related to the natural vegetal cover;
- Animal resources.

In this report, only the factors related to water resources and their exploitation will be discussed. Other factors will be discussed in the main report of the National Plan for Combating Desertification in Oman which will be prepared later on.

Before discussing these factors, it seems relevant and important to discuss the physical constraints which have a significant role in facilitating and accelerating the process of desertification as related to water resources. These constraints are mainly hydrologic and hydrogeologic in nature.

6.3.1 Water Resources Constraints

1. Climatic constraints, mainly:

- Rainfall, being rather low, sporadic, and highly variable in space and time.

- High rate of evapotranspiration, which is several times the annual rainfall.

- The hot and some times speedy desert winds which facilitates soil erosion and sand blowing and migration.

- The occurrence of successive drought years which, under the prevailing fragile ecosystem, would help initiate desertification.

2. The characteristics of surface water resources which may be summerized as follows:

- Nearly absence of perennial streams except for Wadi Dayqah, 70 km south of Muscat.

- The characteristics of surface runoff which reflect the characteristics of the rainfall pattern which causes it, being highly variable in time and space and only generates after heavy rain storms. These characteristics, and the limited amount of this water source, make its development for direct use difficult and costly.

3. The characteristics of groundwater which may be summarized as follows:

- As the source of recharge for most of the groundwater aquifers is infiltration of surface runoff (flood flows), the constraints of surface runoff are also reflected here on the annual rate and frequency of occurrence of recharge.

  Away from alluvial channels, the groundwater systems are not so dynamic, giving rise to higher water salinity and lower rate of replenishment.

- The lateral extent of the alluvial aquifers, except in Salalah plains and parts of the Interior plains, have limited areal extent and thickness giving rise to limited storage capacity for the groundwater. This in turn, with the low and highly variable annual recharge, reduces the reliability of the resource during extended drought periods.

- The proximity of the fresh groundwater aquifers to saline water bodies, the sea for the coastal aquifers, and brakish to saline groundwater bodies in the inland region. This saline water environment of the fresh groundwater aquifers, together with the hydraulic connection between fresh and saline water bodies, facilitates salt water intrusion, encroachment, and upconing into the fresh water aquifers under inappropriate rate and/or pattern of groundwater development. This is happening along the Batinah coastal plain and to a lesser extent in Salalah plain.

- The occurrence of evaporites sediments within and near the limestone aquifers. This causes high dissolved salts in the groundwater in these aquifers, such as in north and north-eastern Nejd and in the central region.

6.3.2 Water-Related Causes of Desertification

The main and major traditional source of water in Oman for all purposes is the groundwater. The large reliance on groundwater for different purposes, the rapid increase of water demand for socio-economic development, the development of mechanized wells and pumping systems, together with the major and significant constraints on the groundwater resources in Oman, have led to serious aquifer depletion and water quality deterioration in many areas, both in the coastal areas and in the inland regions.

The result is an over-exploitation problem of the resource in the absence of adequate control and management based on full understanding of the resource capabilities and potentialities as well as the constraints associated with the resource. The causes of over development my be given as follows:

1. The urgent and rapid water development plans which were needed to cope with the rapidly increasing water demands.

2. The lack of adequate hydrologic and hydrogeologic data base particularly at the early stages of development.

3. The lack of appropriate assessment of the quantity and quality of the existing water resources, because of lack of data , and some hydrologic and hydrogeologic uncertainties.

4. Delay in initiation and implementation of water legislation for water resources development and management.

The presently adopted measures which are the prohibition of well drilling and the construction of recharge dams will not alone stop deterioration and sea water intrusion. The additional potential groundwater recharge, its quantities and geographic distribution, would not fit the amount and location of over- draft and the areas suffering most from sea water intrusion. This additional recharge potential would not even compensate for the present annual rate of overdraft.

On the other hand, the well ownership or a drilling permit gives absolute right for the farmers to pump all the water they like, even during critical drought periods, and for any use regardless of its economic return, and sometimes in a wasteful inefficient way.

The important point which should be realized here, that once an aquifer or a soil becomes highly salinized, it would require long time, great efforts, and high cost to recover it. Therefore, delay in taking prompt action may lead to ir-reversible effects and irricoverable situation.

5. Administration problems related to the scattering of responsibility for water resources between various Ministries prior to the recent establishment of the Ministry of Water Resources.

6. Insufficient cooperation between the Ministry of Water Resources and other Ministries or agencies responsible for managing water supply and water use.

7. The over use or sometimes misuse of irrigation water by the farmers for the following reasons:

- To control the building of salt concentration in the soil within the root zone.
- The increasing salinity of irrigation water.
- The inefficient irrigation methods used.

Farmers tend to over irrigate growing crops to control the build up of salt concentration in the soil within the root zone. The facilitated water abstraction through motorised pumping contributed to the problem. In the Batinah Region, especially in Eastern Batinah, severe over abstraction was reported (MMDI, 1991). Water levels have been falling steadily during the last seven years. Salinity of both irrigation water and cultivated soils has increased to an extent damaging to crops of coastal farms. Abandonment of agricultural activities in coastal farms of Batinah Region represents a real threat. Water balances in this area indicate, according to MMDI(1991), abstractions of as much as twice the recharge to the aquifer. The available water resource in the Batinah is estimated to be about 440 Mm^3/year (table 7) while the present use ranges between 720 (JICA, 1990) and 760 Mm^3/year (MMDI, 1991).

Financial subsidies are allocated and policies are adopted by the government to encourage farmers to introduce improved irrigation methods aiming at rationalization of water consumption in the agriculture sector. Modern irrigation methods i.e. sprinkle, pivot, drip and bubbler are introduced to some newly established farms and have achieved higher productivity. Shortage of capital, awareness and adequate technical knowledge delay the acquaintance of these irrigation methods by many of the Omani farmers and/or landlords.

Over irrigation under certain soil conditions may lead to water logging and subsequent soil salinization. On the other hand under irrigation on low permeable soils can also lead to soil salinization if the irrigation water is salty.

8. The scarcity of water resource other than groundwater in Oman, the limited potential of groundwater, and the rapidly increasing water demand have put a great pres -

-sure on the groundwater resources leading to over-exploitation of some aquifers, particularly in the Batinah coastal plain. Consequently, salinization of the groundwater has occurred as a direct consequence of sea water intrusion in the coastal aquifers. Groundwater salinization would also create a problem in inland aquifers by intrusion of saline groundwater from adjacent, overlying or underlying aquifers. This potential problem may occur in the Nejd region and in the northern Dhahira and Dakhliya regions. In adequate well design and overpumping in such cases may create such problems.

9. In Al-Wafi and Al-Kamel areas, overpumping does not seem significant. However, water and soil salinization have occurred. Recycling of the groundwater between the ground surface and the water table, reuse of groundwater by different wells, and the absence of drainage systems, are the main reasons for this soil salinization problem.

10. The zero-value of water when calculating production costs of agricultural commodities leads to ever increasing demand for water in the agricultural sector. This has led to overuse of groundwater without any control or accounting for it.

11. In some cases water is not the primary factor of desertification, but it plays a secondary role after initiation of desertification by other causes such as:

- Loss of vegetal cover in range and forest lands by overgrazing, fires, or by deforestation by man for comercial purposes. Under such condtions, the exposed fertile soil will be more vulnerable to erosion by sufrace runoff which will also increase under such conditions.

- In areas of rainfed framing, desertification often originated on land cleared for cultivation or left fallow. The main factor here is soil erosion by surface runoff.

The above conditions and factors have significant potential in Oman mountains and in Dhufar mountains. The southern foothills of Dhufar mountains have lost significant forest cover. In the northern mountains, uncontrolled rain-fed agriculture and other human activities, such as road opening will lead to further erosion of soil by surface runoff.

7. REVIEW OF PAST AND CURRENT EFFORTS TO COMBAT DESERTIFICATION IN OMAN

7.1 General:

The people of Oman have adopted through long experience, conservationally sound ways of exploiting their local resources in general, and their water resources in particular. The aflaj of Oman have provided communities with water for domestic and irrigation purposes for 1500-2000 years. The Aflaj systems adopt themselves very well to the amount of water flow, especially in the dry season. In addition, farmers in Oman, knew how to adopt their production to the aflaj water levels within the so called subsistance economy. However, these old-age water systems need periodical maintenance. They also can not meet the increasing water demands in the country. The mechanized well drilling and pumping systems have led to overpumping and water quality deterioration, and consequently to loss of soil fertility and productivity.

7.2 National Efforts to Combat Desertification:

Realizing the consequences of the causes of desertification given in chapter (6), and the imputs of the continuing desertification process on the socio-economic development in general, and on the water and agricultural resources in particular, the government of Oman has started several activities to help improve and conserve the water resources and consequently other related sustainable developments.

Considering the fact that the Sultanate of Oman is in its early years of organization and administration renaissance, the government's current efforts to combat desertification indicate awareness of the problem and high degree of determination to take necessary measures to combat desertification in the country. Allocating budgets in the second, third and fourth five year plans for related activities, initiation of institutions to deal with major aspects and promulgation of legislation necessary to prevent or minmize causes of desertification are good examples of such determination.

In this report, the Government efforts in the field of water resources development and conservation of water resources will be given. Efforts in other fields will be given in the main report of the Plan of Action to Combat Desertification in Oman.

7.2.1. Development and Conservation of Water Resources

The utmost importance of water to the inhabitants of arid regions, Oman is not an exception in this respect, has caused the Omani Government to pay great attention to water resources development and conservation in the country. This was reflected in many governmental efforts implemented all over the country to explore, develop and manage the water resources availabe and to optimize water use. In the following the current efforts are summarized:

* The establishment of a Ministry for Water Resources (MWR) acting as central authority for water resources development, conservation and management. The structure of MWR.

* Preparation, for the first time in Oman, of a National Water Resources Master Plan, completed by the end of 1991. The studies were carried out by Mott MacDonald International Ltd. in association with Watson Hawkesley (MMDI, 1991a and b). The Master Plan envisaged:

  (a) The strengthening of the institutional and legal framework to provide effective management of water resources in the interests of the Sultanate's long term development.

  (b) Giving priority to domestic and industrial water supplies, but using desalinated seawater, despite the high cost, to minimize the impact of new potable water supply schemes on existing agriculture.

  (c) Policies to curb demands for potable water and improve the efficiency of agriculture without increasing water use.

  (d) Restricting agricultural development strictly in accordance with the available resource and reducing agriculture where resources are presently overdrawn.

  (e) Controlled development of non renewable water resources.

  (f) Augmenting the resource wherever possible.

* Adoption of a research plan in 1989 to be carried out by the Ministry of Agriculture and Fisheries (MAF) with special emphasis on water use by crops, improvement of yield/Water relation and salinization problems. Improvement of irrigation methods is given high priority.

* Establishment of several meteorological stations covering the different regions of the Sultanate. The development of a network for agrometeorological data collection and processing is also considered (MAF, 1989).

* Strengthening of the programme for construction of recharge dams through the construction of 27 recharge dams until 1985 (MMDI, 1991$_b$) and additional 8 dams until 1992 (MWR, 1991).

* The Sultan Qaboos University contributed recently to the research on Siltation and Storage Efficiency of Recharge Dams (Saleh, 1992).

* Allocation of 42 MRO in the Fourth Five Year Development Plan (1991 - 1995) for priority projects at MWR and 45.7 MRO in the same plan for the irrigation sector at MAF. The total budget allocated for water resources development and conservation will amount to 87.7 MRO to be spent in the coming 5 years to help combat desertification through water resources management (Development Council, 1991).

* Preparation of "A Master Plan for Agricultural Development" by Japan International cooperation Agency (JICA). This comprehensive study (5 Volumes) is giving both 5 and 10 year plans for development in the agricultural sector. Improvement of irrigation methods is highly emphasized.

* Water resources of Wahiba Sands were also studied. Hand dug wells contained water of 35 to 1,000 years of age. Deeper water reached by boreholes entered the ground 4,000 to 8,000 years ago (Gibb, Sir Alexander and partners, 1985). This study is very important for agricultural projects as it indicates the depletable nature of the groundwater in the Wahiba Sands.

* The MAF is presently experimenting a new irrigation method called the double-ring method for trees. The method uses the bubbler system with double-ring ditch system instead of a flat irrigation basin. This method provided a much better uniform distribution of the irrigation water. Adding few kilograms of silt, evenly distributed throughout the circular irrigation ditch significantly improved the system.

* Reduction of leakage losses of potable water from the distribution network has been decided as a continuous programme, with a target to bring it down to 20% by the year 2000.

* The use of desalinated sea water for municipal purposes has been adopted as a first choice wherever possible. This decision is taken to relieve the pressure imposed on the natural groundwater resources.

* The use of treated sewage water for street gardening has been applied. Plans for expansion of Sewerage and treatment facilities have been considered for the major cities and population centers for environmental purposes as well as to provide a new source of irrigation water.

* The sea-water intrusion problem into the coastal plain of batinah region is being monitored and investigated by the MWR for the purpose of finding possible solutions.

* As a first step to alleviate the problem of sea-water intrusion problem in the Batinah region, and to prepare for adequate planning development and management of the other groundwater resources in the rest of the country, the water resources in the Sultanate of Oman were declared as a public commodity owned by the government. Drilling of new groundwater wells for agricultural purposes has been banned, and would require a special permit from the MWR.

* Groundwater exploration in the Nejd region is ongoing by the MWR for the purpose of assessing its potential.

* A continuous programme for maintaining and rehabilitating the Falaj water systems in the country is being implemented by the MAF.

Further work is, however, still needed to compile data on rechargeability of groundwater in the different regions. Changes of pezometric levels and salinity of groundwater need to be monitored. This information as well as crop water requirements are inevitably important for successful action to combat desertification.

8. NATIONAL PLAN OF ACTION TO COMBAT DESERTIFICATION: THE ROLE OF WATER RESOURCES MANAGEMENT

8.1 Justification and Objectives

Most of the Sultanate of Oman is desert land. Areas where soil is suitable for agriculture is less than 0.7 percent of the total area of the country; while the area presently under cultivation is about 5400 ha (0.15 percent of the total area).

On the other hand, the water resources in Oman are very limited. Under such arid conditions, the available quantity and quality, of water are the limiting and d minant factors for agricultural development as well as for other socio-economic developments.

Over-exploitation of the main water resources (the groundwater) to meet the rapidly increasing water demands has led to resource depletion and water qaulity deterioration in some areas of Oman, particularly in the Batinah coastal plain which provides 60 percent of the total country's agricultural production. The consequent soil salinization problem in these areas is threatenging the sustainability of agricultural development in these areas. This comes out at a time when increased water resources and food production are badly needed to support the growing population request of development. Continued deterioration of the available, scarce and valuable, water resources is an obvious threat to the future progress in Oman. This is particularly true for the fragile water resources system in Oman, where continued water resources deterioration may become irriversible; which means a permanent loss of the resource. In addition deterioration progresses, the cost, effort and time required to rehabilitate and restore the healthy hydrogeologic conditions of the affected aquifer become higher.

Under the existing rate and pattern of groundwater extraction, there is no hope for controlling water salinization in the affected areas. The surplus flood water available for artificial recharge is by far less than the over-draft. Moreover, the geographic distribution of the new recharge areas may not affect some badly affected groundwater areas.

The immediate goal of the Plan of Action to Combat Desertification is to prevent and arrest the advance of desertification and, where possible, to reclaim desertified land for productive use.

The practices of misuse, over use, over-exploitation and mismanagement of the water resources are important factors for the desertification process in Oman. Therefore, changing such practices within the framework of a country-wide rational and integrated water resources management is a key factor for combating desertification. However, similar efforts are needed at all levels and in other resources/sectors.

The management aspects and objectives of the Water Resources Plan to Combat Desertification do not differ from those of a general water resources management plan. However, special emphasis is given here to the relationship of water to the productivity of the ecosystems in general and to the land productivity in terms of agricultural crops and natural vegetation in particular.

Within this context, the main objectives of the Water Resources Management Plan to combat desertification would be:

- To protect the existing available water resources which have not been seriously affected by development.
- To control water salinization resulting from different causes, with particular emphasis on the sea water intrusion problem in the coastal aquifers.
- To augment the depleted groundwater resources by aritficial recharge and other non-conventional resources.
- To explore, assess, and develope new, groundwater resources where possible.

These objectives can be achieved through Implementation of appropriate set of activities and programmes as will be discussed later on.

8.2 Policy and Approach

Action to combat desertification is urgently required before the costs of rehabilitation rise beyond practical possibility, or before the opportunity to act is lost forever.

Integrated management of the water resources with other natural resources, such as land, vegetal cover, agriculture, and environment, with due consideration to the socio-economic aspects are of vital importance to combat desertification, and should form a major component of the proposed plan of action. The integrated water resources management should include groundwater, surface water, desalinated sea water, and treated sewage effluents. The most practical and effective method of managing water resources is to plan and control development and use within the resource capability.

The achievement of such management requires the following:

* A full knowledge of the physical total water resource system including; its potential and constraints, and the relationships between the various components of the water resources system as well as their relationship to other natural and environmental systems. The adoption of the integrated system approach is therefore necessary.

* Technically competent technical and management staff.

* Adequate organizational/institutional framework.

* Regulatory controls to manage water development and water use.

As the agricultural sector in Oman is the major water user, and the agricultural land is the most seriously affected by the salinization of the water resources, greater emphasis should be given in the plan on conserving water and decreasing soil salinization by applying more efficient irrigation technologies and agricultural planning.

In setting out the programmes and projects of the national plan, due consideration has been given to the ongoing national efforts in the various sectors which are believed to serve the proposed plan for combating desertification. Meanwhile the programmes and projects included in the fourth five-year development plan 1991-1995 have been taken into consideration. This approach would facilitate the planning, budgeting and implementation of the proposed programmes and projects in reasonable time.

Fortunately, there is a good number of water resources projects in the fourth five-year plan which fit very well to the requirements of the desertification combating plan. Little modifications, adjustments, and reordering of priorities may be required on some original projects or activities. In fact this match between the two plans strengthen the positions of the proposed common projects which in this case would serve multiple purposes. Consequently a higher priority will be given to such project. In addition, the implementation schedule, supervision and final assessment of the project have to be done in proper and effective coordination to achieve these multiple purposes.

8.3 The Role of Water Management for Combating Desertification:

8.3.1 General

In arid and semi-arid zones, developing countries are now, and will face in the future, more serious water related problems than ever before. The world's deserts are enlarging, and frequent intensive droughts are contributing to economic devastation of entire nations. The drought-striken countries portray the difficult problems being faced by arid countries. In addition, factors of higher temperatures, less precipitation, limited water resources, and soil moisture, in such countries, could probably worsen the current critical problems of water supply. These adverse conditions and constraints, when combined with the heavy pressure on available water resources resulting from rapidly increasing water demand for different purposes, have resulted in serious water resources probolems, manifested by depletion of groundwater revisions, deterioration of water quality, soil salinization in areas irrigated with salinized groundwater, and consequently degradation of soil productivity. These problems have been magnified in the lack of appropriate rational, effective, and integrated water resources management.

Since 1970, the begining of socio-economic era in Oman, emphasis has been put on planning and development of water resources and water supply projects. Insufficient attention was given to management and environmental aspects. Sometimes, the results were impressive; however, in many cases serious social and environmental costs have been incurred.

These inadquacies and undesirable consequences of water development projects, and their implications on other natural resources such as land and environment, necessitate a halt for reconsideration of the water resources management, policies, programmes, and projects. So far, the emphasis has been mostly on some technical aspects. There is a distinct need for more broadly based approaches to water resources management in Oman that consider all relevant aspects of a given problem situation, and that will consider water as an integral component of the overall natural/environment system.

An integrated water resources management means a set of actions that takes appropriate account of the important physical, economic, social and cultural linkages within the system being managed, such as: linkages between surface and groundwater, groundwater and sea water in the coastal areas, groundwater and irrigation, water availability and the natural vegetal cover, the role of the non-conventional water resources (desalinated sea water and treated sewage water), the economic and social linkages between water uses, development, and the people who are benefitted or adversely affected.

Water resources management as outlined above should be the core of the National Plan for Combating Desertification in Oman. The main aim of the plan should be to preserve the most important natural resource required for agriculture and for the natural vegetal cover, namely water. With almost all the renewable fresh water resources in Oman being developed, the continuation of the present situation will lead to serious damage to the agricultural sector in particular where large areas of the agricultural land would be deserted.

The proposed water resources management plan is part of an overall plan of action for compating desertification; and forms one input. It will be combined with other inputs on other natural resources such as range and forest lands and pastoralism. Activities within the proposed plan may be grouped under three categories:

- Programmes: Long term (2010).
- Priority projects: Medium and short term (1997).
- Corrective measures: Short term (1995).

Although the various activities are fairly independent, the given recommendations for the various sectors need to be implemented if desertification is to be put to and end.

8.3.2 Long Term Programmes and Projects (2010)

The water resources management plan would include the following major programmes. Under each programme, a number of projects are listed for consideration on the long term. The choice of priorities of these projects are left to the government to decide upon based on the need, urgency, and budget as related to the projects given in the fourth five-year development plan.

1. Data collection and processing, field surveys and monitoring of programmes:

   1.1 Rehabilitating and intensifying the hydormiteorological, hydrological and hydrogeological monitoring network.

   1.2 Field inventory and survey of groundwater wells in the different basins.

   1.3 Field inventory and survey of aflaj.

   1.4 Periodical monitoring of groundwater levels, quality, and extraction in the affected areas.

   1.5 Establishment of a water data bank.

2. Investigation and Studies

   2.1 Assessment of rainfall quantity, distribution and frequency.

   2.2 Assessment of surface runoff which is the source of groundwater recharge.

   2.3 Groundwater exploration in Nejd, Wahiba sands, and in the Central regions.

   2.4 Assessment of the long term practical and sustainable groundwater yield in Batinah, Salalah, Nejd and Wadi Al-Batha regions.

   2.5 Assessment of the performance of the existing recharge dams and select new potential recharge sites.

   2.6 Assessment of sea water intrusion problems, (magnitudes, extent) in the coastal plains.

   2.7 Assessment of the present water use and actual demand for irrigation in Batinah, Salalah, Dakhliya and Wadi Al-Batha areas.

3. Development and Management

3.1 Groundwater Management models for Batinah, Salalah, Nejd and Wadi Al-Batha areas.

3.2 Development of the groundwater resources in the Nejd region for irrigation.

3.3 Construction of artificial recharge projects including dams and other facilities in the Batinah, Wadi Al-Batha, Salalah, Dakh liya and Dhahira Regions.

3.4 Maintenance and improvement of the aflaj water system.

3.5 Collection of fog water in Dhufar mountains by appropriate techniques for forestation.

3.6 Encouragement of applying more efficient techniques for irrigation.

3.7 Reduction of leakage losses from the water supply systems in the major cities.

4. Research

4.1 Rainfall - runoff relationships (experimental catchments).

4.2 Appropriate methodologies for increasing groundwater recharge from surface runoff.

4.3 Aquifer recharge using treated sewage water, (assessment of appropriate methodologies and environmental impacts).

4.4 Effect of irrigation practicies on groundwater quality and quantity.

4.5 Hydraulic boundaries as a possible means for control of sea water intrusion.

5. Monitoring and assessment of Desertification as related to water

5.1 Mapping of areas which are presently affected by water and soil salinization using remote sensing data and the GIS system.

5.2 Based on historical information, study the rate and possible future trend of water and soil salinization, by using appropriate models.

8.3.3. Priority Projects

The following special priority projects have been selected for implementation in the short-term, 1993-1997. These priority projects are targeted towards the main strategic aim: Combating desertification, they have been selected with due consideration to the following important related issues:

1. Priority projects should address the most critically affected areas by desertification, which are also the most demanding areas for remidial measures.

2. Priority projects should be related to the long term programmes set for the target data 2010. This would allow and facilitate future additions, followup and evaluation.

3. The selected priority projects have been selected to match as much as possible the water sector programmes proposed in the fourth five-year development plan of Oman (1991-1995). This would facilitate implementation and budgeting, and would give them additional significance, support and enforcement as they would now achieve multiple purposes.

The priority projects are presented here in a brief form. Each project needs to be formulated in more details prior to its implementation

Project No. 1:

Project: Monitoring and assessment of desertification, particularly in critical areas, using remote sensing technology and the geographic information system (GIS).

Objectives:

1. To identify and assess desertification in the local situation, its magnitude, type, extent, causes and effects.
2. To indicate the relative seriousness of the situation in all regions.
3. To standarize monitoring and evaluation facilities and criteria.
4. To provide base-line information for future comparison in order to assess the change and the rate of change in the status of desertification as a result of human activities and the implementation of the proposed corrective measures, projects and programmes.

Priority areas: Batinah plains, Wadi Batha, Wahiba sand dunes, Dhufar mountains and Salalah plain. The project should continue to cover the rest of the country gradually.

Projects No. 2 & 3

Project: Aquifer recharge using treated sewage water and urban drainage water.

Objective: Control sea water intrusion into coastal aquifers.

Priority areas: Southern Batinah and the Salalah plains, using the treated waste water and drainage flood water of the capital city of Muscat, as well as of Salalah city.

Projects No. 4 & 5

Project: Artificial recharge of flood water using low-cost, simple retention dykes and spreading areas along selected stream channels and alluvial fans.

Objectives:

1. To augment the presently exploited groundwater resources by using surplus, unused flood water.
2. To help control sea water intrusion and improve the groundwater quality.

Priority areas: Selected streams on Batinah and Salalah plains.

Project No. 6

Project: Groundwater exploration, assessment and development in the Nejd area.

Objectives:

1. Provide irrigation water for fodder and other agricultural crops.
2. Assess the long term potential sustainable yield of the main aquifer (Umm Raduma) in this area.

Location : Nejd Area

Project No. 7

Project: Groundwater Exploration and Asssessment in the Wahiba sand-dunes area.

Objectives:

1. Explore and assess the groundwater potential in the alluvial deposits, and determine its hydraulic continuity with the developed groundwater in Wadi Al-Batha.
2. Determine its explotability for rehabilitation of the natural vegetal cover as a means for sand dune stabilization.

Location: Wahiba Sand-dune area

Project No. 8

Project: Well Inventory and Survey.

Objectives:

1. Collect physical and hydrogeological data on groundwater levels, quality, extraction and water use for all groundwater wells in the different regions.

2. Provide this information as an input to the proposed water data bank.

Priority areas: The project should be started in the Batinah plain, Wadi Al-Batha, Salalah plain, and the coastal areas of the Sharqiya region. The project should then be extended to other areas which are less affected by aquifer over-exploitation and desertification.

Project No. 9

Project: Assessment and strengthening the existing hydrological, hydrogeological and hydromite orological monitoring networks and programmes.

Objectives:

1. To strengthen the existing water data base particularly for the time-dependent information, and to keep it up-to-date.

2. To provide the required information for the proposed technical studies, and for the planning and management process.

Priority areas: Start with the most important groundwater basins and surface water catchments in the Batinah, Sharqiya and the Southern regions, then proceed to the other regions.

Project No. 10

Project: Establishment of a computerized water data bank, and data management system.

Objectives:
1. Integration of water data being collected by various ministries and agencies.
2. Provide a base for a knowlegeable, and understanding water resources management and planning.

Project No. 11

Project: Inventory and survey of the Aflaj systems in Oman including site hydrogeology, discharge measurements, water quality sampling, water use, the present conditions, and the need for maintenance and operation.

Project No. 12

Project: Rehabilitation of the Aflaj system in Oman, based on the outcome of project No. 10, and the priorities as decided by the government.

8.3.4. Corrective Measures:

The following corrective measures should be undertaken through appropriate means and programmes:

1. Increase public awareness for the value of water, water conservation, and its effect on desertification.
2. Put a value for the irrigation water.
3. Control groundwater pumping by appropriate penalty or incentive system. The idea of absolute water rights for the well owners should be changed, particularly during drought periods and in critical groundwater basins.

4. Encourage the use of efficient irrigation systems.

5. Encourage the use of low water demanding crops, and the abandonement of high water demanding crops, particularly in critical groundwater areas.

6. Encourage the use of brakish groundwater resources and treated waste water for appropriate irrigated crops and prevent the use of fresh groundwater for such crops in critical areas such as Batinah and Salalah plains.

7. Initiate plans to reduce leakage losses from the water supply systems particularly from large cities.

8. Reduce dependency on groundwater for domestic supplies and increase sea and brakish water desalination use for this purpose.

9. Adopt the clean technology policy (No waste production) for the industrial sector to conserve water and prevent environmental pollution. This can be done by encouraging recycling of water within the factories.

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10. Water Resources and Utilization in the Sultanate of Oman. Symposium on Water Resources and Utilization in the Arab World; Kuwait 17-20 March, 1986.

List of Persons met by the Mission to the Sultanate of Oman
5 - 26 September 1992

- First meeting, Ministry of Regional Municipalities and Environment MRM & E, 7.9.1992.
  - Mr. Najeeb Bin Ali Al-Rawwas/Director, Environmental Planning and Permits.
  - Mr. Ali Bin Sa'eed Al-Bloushi, Sultan Qaboos University, Geography Department.
  - Mr. Salem Bin Abdullah Al-Jfaili/Acting Head, Marine Pollution Division.
  - Mr. Abdul-Mahdi Bin Ali Al-Ajami/Head, Division of Regional Agencies for protection of Marine Environment.
  - Mr. Azeez Bin Ali Al-Rashidi/Head, Air Pollution and Noise, Division.
  - Mr. Ibrahim Bin Saleh Al-Mugaini, Chemist,MRM & E Laboratories.
  - Dr. Tahir Abdul-Rahman Ba-Omar/Biology Department, Sultan Qaboos University.
  - Dr. Lutfi A.Q. Dasooqi/Expert of Natural Reserves, MRM & E.
  - Mr. Sa'eed Bin Ahmad Al-Mugadam/Head, Division of Implementation and Follow-up of the National Plan of Environmental Protection, MRM & E.
  - Mr. Hamdan Bin Nasir Al-Hassani/Acting Head, Division of Environmental Impacts and Risk Assessment.
  - Mr. Hilal Bin Mohammad Al-Nabahani, Acting Head, Division of Coastal Management.
  - Mr. Ali-Bin Amer Al-Kaiyoumi/Director, Directorate of the National Strategy for Environmental Protection.
  - Musa Bin Jaafar Al-Mousawi/Acting Director of International Organization Affairs.
  - Dr. Ali El-Tom & Consultant on the National Conversation Strategy, MRM & E.
  - Mr. Aram Bin Hamad Al-Shanfari/Technical Coordinator, Planning Commission for Development and Environment/Salala.

- U.N.D.P., Muscat, Oman.
  - Mr. Saleem Kassum, UNDP Resident Coordinator.
  - Mr. Aeneas C. Chuma, Assistant Resident Representative.

- Ministry of Housing.
  - Mr. Ali Mohammad Al-Mazrooi/Deputy Director-General of Town Planning and Survey, and Director of Technical Affairs.

- Ministry of Water Resources
  - Mr. Basghash Bin Ghalib Al Said/Director General, Water Resources Assessment.
  - Mr. Steve S. Luxton, Water Management.
  - Mr. Wayne C, Curry, Surface Water Department.
  - Mr. Harly Young, Water Resources Assessment.
  - Mr. Bryan L.Eccleston/Director, Groundwater Assessment.
  - Mr. Geoff Wright/Asst. Deputy Director General, Directorate, General of Regional Affairs.
  - Mr. Mohammad Al-Kalbani, Water Resources Management.
  - Mr. Philip Johnson/Deputy, Director General, Water Resources Assessment.

- Ministry of Agriculture and Fisheries (MAF).
  - Mr. Ahnuf Bin Omar Al-Zuheiri/Adviser to the Minister on Agricultural Affairs.
  - Mr. Asadulla Ahmed Taki/Director, Soil and Water Research Department.
  - Mr. Yaslam Taher Al-Yafie.

- MAF, General Directorate of Irrigation.
  - Mr. Masood Al-Harthi/Director General.
  - Mr. Imad Abdel Majeed Abdel Baqi/Director of Irrigation Dept.
  - Mr. Ali M. Al-Raimi/Director of Aflaj and Wells.
  - Dr. Hassan Wahbi/Irrigation Expert.
  - Dr. Naim Abdel Rahman/Dam Adviser.
  - Mr. Issa Abdula S. Al-Amij/Ch.s. of I.DPT.
  - Dr. Ali Afifi/Dam Construction Adviser.
  - Mr. Hilal Malik Mohamed Al-Batashi/Dams Dept.

- Development Council - General Secretariat
  - Mr. A.Mahdi A.Baqi/Director-General, Production Planning.
  - Mr. Abdel-Rahman Ibrahim Al-Abry.
  - Mr. Salim Bin Hamad Al-Taugi.
  - Mr. Issa Ibrahim.
  - Mr. Mehdi Al-Abduwani.

- MWR, Wilayat Al-Wafi
  - Mr. Awad Al-Burami/Director.
  - Mr. Mohammad Isam Eddin Saleh/Hydrogeologist.
  - Mr. Saeed Al-Saadi.
  - Mr. Ibrahim Abdalla Ba-Biker/Civil Engr.

- Quitbit
  - Sheikh Mussulem Bin Sa'eed Gaddad/Governor of Muqshim Wilayat.
  - Mr. Ahmed Mushin Ghalib/Director in the Office of the Governor of Dhofar.

- Desert Agricultural Project-Petroleum Development of Oman.
  - Mr. M. Martin-Farm Superintendent.
  - Mr. M.Stanton, Soil and Water Specialist.
  - Farm Agronomist.

- MWR, Water Resources Administration/Salalah
  - Mr. Salem Omar Al-Shanfari/Director.
  - Mr. Salem Ahmed Alsh/Geologist.
  - Mr. Saleh Salem/Engr.

- MAF, General Directorate of Agriculture/Salalah.
  - Mr. Saleh Al-Shanfari/Director-General.
  - Mr. Sale, Aleiwali/Head of follow-up and Dams.
  - Dr. Engr. Mohammad S. Fareed/Expert.