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THE WATER RESOURCES OF THE UNITED ARAB EMIRATES : A COMPREHENSIVE EMPIRICAL APPRAISAL OF THEIR STATUS AND MANAGEMENT

By

KHALED ALI UQBA

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KHALED ALI UQBA, P. O. Box 707, SHARJAH, UNITED ARAB EMIRATES.
TELEPHONE : 009716 / 388 388 - FAX : 009716 / 388 388 OR 338 558



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CHAPTER SIX

HYDROCHEMISTRY

6. HYDROCHEMISTRY

6.1. Introduction

In this chapter, the quality of the water in the Emirates is described based mostly on groundwater chemistry data of water samples collected and analyzed for this study. In any assessment of the groundwater resource, the evaluation of groundwater quality is as important as that of its quantity (described in Chapter 8). As is the case in many parts of the Emirates, there are opulent groundwater supplies in vast areas of the desert foreland, but the main constraint of poor quality renders these waters of limited use. The chemical, physical and bacteriological properties of groundwater govern its usefulness for the different applications. The study of groundwater quality involves "the description of the chemical composition of groundwater and the relation of this to water use" (Walton, 1970).

The chemical composition of groundwater in the different aquifers in the Emirates is the result of a number of factors, which include :

(i) The chemical composition of the recharge waters.

(ii) The soluble minerals, contained in the rocks within which water resides, and their geographical occurrence.

(iii) The porosity, permeability and transmissivity of the aquifer material that govern the degree of mineralization of groundwater by the rate of its flow within the aquifer.

(iv) The contamination with more saline deeper waters contained in salty formations in inland areas, or with seawater, through intrusion induced by overpumping in coastal areas.

Given these factors, the study of the chemical composition of



groundwater further clarifies the state of the groundwater resources, their relationship with the geology, and also their suitability for the different uses.

6.2. Water chemical analysis and presentation of the results

The water samples collected for this study from the different regions of the Emirates were analyzed in the laboratory to determine the major cation-anion composition. These water chemical analyses included:

(i) Determining the concentration of the inorganic constituents which comprise the **cations** (positively charged ions), which include calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}) and potassium (K^{+}); and the **anions** (negatively charged ions), which include sulphate (SO_4^{-}), chloride (Cl^{-}), fluoride (F^{-}) and nitrate (NO_3^{-}); and also those ions contributing to alkalinity in terms of the amount of carbonate (CO_3^{-}) and bicarbonate (HCO_3^{-}) in the water. The main ions and their mineral sources in the various rock types are given in Table 6.1.

(ii) Determining the level of alkalinity or acidity of the water (pH of the water), which relates to the hydrogen ion concentration, expressed in moles per litre. Natural water would have a pH value of 7.0 (which indicates an equal number of hydrogen (H^{+}) and hydroxide (HO^{-}) ions). Alkaline water would have a pH value of less than 7.0 (indicating a dominance of the hydrogen ions). Pure water normally has a pH value of 7.0; most groundwaters have values between 5.0-8.0. Very high pH values of above 8.5 are associated with sodium-carbonate-bicarbonate water; moderate pH values of 7.0-8.0 are associated with waters with a high bicarbonate content.

(iii) Determining the **Total Dissolved Solids (TDS)**, which is the concentration of the ions in groundwater, expressed in parts per million (ppm) or milligrams per litre (mg/l). The equivalent parts per million (epm) are the milligram equivalent per kilogram and, if derived from milligram per

Ion	Mineral source of the ion in rocks	Range in amount of natural occurrence (meq/l)	Tolerable concentrations (meq/l)
Cations			
Calcium (Ca^{++})	Sedimentary rocks: calcite, dolorite, anhydrite, gypsum. Basic and ultrabasic rocks: pyroxene and amphibolite.	0.5-5.0 (potable) 2495 (brines)	Up to 50.0
Magnesium (Mg^{++})	Sedimentary rocks: dolomites Igneous rocks: olivine, biotite hornblende and augite. Metamorphic rocks: serpentinite.	0.1-3.3 (potable)	Up to 12.5
Sodium (Na^{++})	Solution of feldspar and halite	0.1-4.0 (potable) 4350 (brines)	Up to 13.0
Anions			
Bicarbonate (HCO_3^-)	Mostly by evaporation in desert basins	0.16-13.0 0.8 - 6.4 (Normal)	Up to 13.0
Chloride (Cl^-)	Ancient seawater trapped in sedimentary rocks/ Solution of halite/ Evaporation of seawater as dry fallout from the atmosphere.	0.003-4230.0	Up to 16.0
Nitrate (NO_3^-)	Decomposition of organic matter + organic and chemical fertilizers	0.0-10.0 0.0- 0.16 (Normal)	Up to 0.8
Sulphate (SO_4^{--})	Hydrogen sulphide gas in the atmosphere derived from the decomposition of organic matter.	0.004-2082.0	UP to 10.0

Source: Adapted from information contained in: Hydrogeology, Davis and De Wiest, 1966; Groundwater Resource Evaluation, W.C. Walton, 1970.

Table: 6.1.

The main ions in water and their mineral sources in the different rock types.

Ions like calcium (Ca^{++}) and bicarbonate (HCO_3^-) have their source in sedimentary rocks. Sodium (Na^{++}) results from the solution of feldspars and halite, but mostly in the latter; hence its high content in waters in central Abu Dhabi where evaporites predominate in the water-bearing strata. Chloride (Cl^-) can mostly be the result of evaporation and concentration of salts that are then leached down the soil profile in inland locations; from old marine water bodies trapped in the strata; or from seawater intrusion in coastal areas. Nitrate (NO_3) is an ion that is mostly produced by the decomposition of organic matter and both organic and chemical fertilizers.

litre, the unit is called milligram equivalent per litre (meq/l). The epm are calculated by dividing the ppm by the equivalent weight of the ion under consideration. In a well-analyzed water sample, the epm sum of the cations should equal that of the anions (with a maximum tolerable difference of 5-10% between the two ionic groups).

Also determined in the water samples, is the Specific Electrical Conductance or Electrical Conductivity (EC), by both direct measurement using an EC-TDS digital meter (described in Section 6.4.) with temperature compensation facility at 25°C, or in the laboratory during the process of full chemical and physical analyses, and the results are expressed in micromhos per cm. (mmhos/cm.). The electrical conductance (conductivity) of the water is the ability of that water to conduct an electric current. The conductance of an electric current in the water is a function of temperature, type of ions and their concentration in the water. It is measured as a specific conductance of 1 cm^3 of water to conduct an electrical current at, or adjusted to, 25°C and is expressed as mmhos/cm. (micromhos/cm.). This is because the unit resistance, the mho., is too large a unit for fresh water; thus, micromhos or millionth part of mhos. are used for groundwater.

According to Davis and De Wiest (1966), calcium bicarbonate and calcium sulphate waters generally have the lowest ECs, while sodium chloride waters, have the highest ECs. Pure water would have an EC of 0.055 mmhos/cm. at 25°C, distilled water 0.5-5.0 mmhos/cm., rainwater 5.0-30.0 mmhos/cm. and ocean water 45,000-55,000 mmhos/cm. Normal groundwater of tolerable potable quality would have an EC range of 30-2000 mmhos/cm. All ECs are for the standard groundwater temperature of 25°C.

The general relationship between TDS and EC in all the water samples analyzed for the different areas of the Emirates is as follows :

(a) The TDS is 65% of the EC in waters with ECs of below 5000 mmhos/cm.

(b) The TDS is 70-75% of the EC in waters with ECs of above 5000 mmhos/cm.

The Sodium Adsorption Ratio (SAR) : The suitability of irrigation water was classified according to the US Department of Agriculture classification of irrigation water (Handbook 60, 1954), which is based on the salinity hazard (the EC at 25°C) and the sodium hazard (the SAR) of the water. Soils with high exchangeable sodium are undesirable for agriculture as this reduces the permeability of the soil and develops a hard crust that impedes drainage. Both conditions are caused by the replacement of the calcium and magnesium ions by the sodium ions. The extent of such replacement is calculated by the following SAR formula:

$$SAR = \frac{Na}{\frac{Ca + Mg}{2}}$$

In which: Na, Ca and Mg are ion concentrations in milli equivalents per litre (meq/l).

Broadly speaking, both the EC and SAR of the groundwaters in the Emirates increase away from the mountains westwards and southwards. This increase is due to both distance from the recharge areas (spatially) and also the occurrence of groundwater in deeper salty formations (vertically).

6.3. Water quality

The chemical and bacteriological properties of groundwater govern its usefulness for the various types of applications. Attention is focused in this chapter on the occurrence of the different constituents in

groundwater and the limitations these have on the various uses of water. If groundwater is classified on the basis of the TDS it contains, then natural waters range in their total mineral content (TDS) from 10 ppm (as in rainwater) to more than 300,000 ppm (as in the brines of the deep carbonate aquifers of central Abu Dhabi). The whole range of TDS of 300-300,000 ppm occur in the Emirates; fresh groundwater of prime quality of less than 200 ppm (TDS) has not been encountered in any region in the country. According to this arbitrary classification of water on the basis of its TDS content, the different groundwaters of the Emirates may be graded as given in Table 6.2.

Type of groundwater	Range of TDS in ppm	Regions of occurrence in the Emirates
Fresh water	250 - 1500	Mountain wadis/piedmont plains/sand dunes
Brackish water	1000 - 10000	Piedmont plains/desert foreland. * (most of the waters of the Emirates)
Saline water	10000 - 100000	Desert foreland/sabkhas
Brines	More than 100000	Deep carbonate aquifers of Simsima, UER and Dammam

Table: 6.2.

Arbitrary classification of groundwater in the Emirates on the basis of the Total Dissolved Solids (TDS) content.

By this rigid classification of water according to its total mineral (TDS) content, the whole range of TDS (10-300,000 ppm) is found in the waters of the Emirates. However, fresh groundwater of less than 200ppm. has not been encountered in any region in the Emirates.

The classification of groundwater on the basis of its use, on the other hand, is more flexible than the arbitrary rigid classification based on TDS that has just been described and shown in Table 6.2. According to this classification, irrigation water quality requirements differ for different crops. Of the crops grown in the Emirates, wheat, tomatoes, alfalfa, lettuces, cabbages and cauliflowers, tolerate medium concentrations of TDS; the date palm, beets and barley can tolerate high concentrations of TDS, while lemon and other citrus crops can tolerate low TDS concentrations in the irrigation water. Such a classification of

irrigation water based on crop types and their tolerance to salinity in the water does not always coincide in reality with the available type of water. This is further complicated by the fact that nearly all farms, regardless of the type of irrigation water available, tend to grow table crops or even salt-sensitive crops such as lemon, mangoes and oranges.

Specifications for drinking water are even stricter. They are based on taste, odour and colour on the one hand, and the presence of harmful inorganic (excess in ionic concentrations) or organic (bacteriological) substances, on the other. Therefore, maximum limits of ions like lead, fluoride, arsenic, sulphate, sodium, chloride and nitrate, are important. There are groundwaters in some areas in the Emirates with a very high fluoride, sulphate, chloride, sodium and nitrate content in excess of the extreme allowable limits for even poor irrigation water. Whereas exceptions could be made with regard to general purpose domestic water, that for drinking should be of prime quality and as health trouble-free as possible.

Water meant for industrial use should either be of a better standard than that for drinking, if the application is for food processing and boilers, or of an inferior quality, if it is to be used for cooling or fire fighting. However, water needed for boilers requires less dissolved solids for some ions than are required for drinking water.

Table 6.3. gives the quality limits for water for different uses.

6.4. Water quality data in the Emirates

The first water chemistry analyses appeared in the Parsons Report (Dubai Groundwater Investigation, Final Report, 1963) for 9 wells in Al Aweer Wellfield and 22 tawis (hand-dug wells) in different locations in the piedmont plains and the desert foreland, such as Tawis Buhayes, Al Dhaid, Hamdah, Murrah, Al Badea', Mileih, Buhuth and Saja'ah. Dubai Water Department had continued monitoring the quality of its three wellfields of Al Aweer, Al Hibab and Al Wuhoosh until 1980 when such monitoring ceased as desalinated water started to contribute most of Dubai's daily domestic water demand.

Ion	Drinking water	Irrigation water Good	Irrigation water Poor	Industrial Food processing	Boilers
	meq/l				
Bicarbonate	8.2	3.3	8.2	5.0	0.1 -0.8
Calcium	3.8 -10.0	-	-	4.0	0.05-2.0
Chloride	6.0 -17.0	2.8	8.5	8.5	-
Flouride	0.08	-	-	0.08	-
Magnesium	10.4	-	-	3.3	0.08-1.7
Nitrate	0.03- 0.8	-	-	0.3	- - -
Sodium	8.9	2.2	13.0	13.0	0.0 -2.2
Sulphate	5.2 - 8.3	4.2	10.4	-	-
TDS (ppm)	1500	500	3000	1000	100-2000

Adapted from WHO: Groundwater Studies, An international guide for research and practice (1972); and Davis and De Wiest: Hydrogeology (1966).

Table: 6.3.

International water quality standards for the various uses.

The classification of groundwater quality on the basis of its use is more useful than the arbitrary rigid classification based on the TDS of the waters (Table 6.2.). According to this classification on the basis of water use, irrigation water quality requirements differ for different crops according to crop tolerance to the salinity level in the water.

Quality specifications for drinking water are even stricter. They are based on taste, odour and colour, and also on the presence of harmful inorganic (excess in ionic concentrations) or organic (bacteriological) substances. Therefore, maximum limits for fluoride, lead, arsenic, sulphate, sodium, chloride and nitrate are important. There are groundwaters in the Emirates with very high concentrations of these ions, in excess of the maximum allowable limits for even poor irrigation water. Water meant for food processing or for use in boilers should be of a better quality than drinking water (i.e. requiring less TDS content); water used for cooling or fire fighting can be of an inferior quality (i.e. with high TDS content).

In Abu Dhabi, the section in charge of groundwater in the remote areas (in central Abu Dhabi), as part of the WED Abu Dhabi, occasionally carries out water quality analysis in the laboratory of the Agriculture Section of Abu Dhabi Municipality. Available water chemistry data for most of the wellfields of central Abu Dhabi belong to the initial stages of wellfield operation and are already outdated. The water quality data are partial, being limited only to the EC, TDS and total hardness ($CaCo_3$) of the water.

The water chemical analyses of the MEW had been presented as pH, TDS, total hardness (as $CaCO_3$), Ca, SO_4 and EC until 1987 when the full chemical analysis of the anions (HCO_3, CO_3, SO_4, Cl, NO_3 and F), and the cations (Ca, Mg, Na and K) form of expressing results was adopted. The results are means of water chemical results of several wells, or means of several individual results of chemical analyses of a single well. They are, therefore, not truly representative of the actual chemistry of the wells in a particular place. These results are not published and are not readily made available to the public.

Since its inception in 1981, the central laboratory of the MAF at Al Awha in Al Ain, has been presenting water chemistry data in the required full form, though its duties are limited to serving the agricultural sector by analyzing soil and irrigation water samples on request.

WED Al Ain keeps the most well-documented chemistry data for drinking water of its public supply wellfields. Results of the water chemical analyses for all the wells in the Al Ain wellfields are maintained without break. Lately, the laboratory has started a well-history presentation of the results of individual wells from the start of operation of the well to the present, at quarterly or biannual intervals. Some of the water chemistry data of WED Al Ain have been used in this study to analyze the short-term fluctuation in groundwater quality in the wellfields of the Al Ain region.

Water quality data of the shallow and deep wells of ADCO have also been used for the present study to detect salinity stratification in aquifers, some of which contain highly saline groundwater.

Partial water chemistry data were obtained for some of the forestry

wells in Abu Dhabi belonging to the Agriculture Section of Abu Dhabi Municipality and these have been used for comparison with new data from water chemical analyses performed for the present study. Many of these forestry wells were visited and their locations were used as convenient water sampling points for the present study.

6.4.1. Water chemistry and quality data for the present study

Apart from the limited available water quality data consulted, as outlined in the preceding section, a total of 750 water samples were collected for the present study and analyzed for the main cation and anion content; most of these water analyses are presented in the tables in this chapter. In addition, 800 direct EC measurements were taken with a Hach EC-TDS digital meter (model 44600), which compensated automatically for any deviation from the set standard temperature of 25°C. The maximum limit of the EC range of the instrument was 20,000 mmhos/cm; water conductivities higher than that range were determined in the laboratory. The results of the direct EC measurement are presented in Appendix 9.

The complete chemical analyses of the water samples collected for this study were undertaken in various laboratories having different facilities for water sample analysis, and uniformity was attained in the results of the major ions although some of the water samples were analyzed in laboratories that had not carried out such full water chemical analysis before. Thus, some elements of the results, such as those for CO_3 and K, appear in some results and not in others depending on the laboratory that carried out the analysis. The results of the water chemistry analyses in this study are all expressed in milliequivalent per litre (meq/l), the TDS in parts per million (ppm) and the electrical conductivity in micromhos per cm^3. (mmhos/cm.) at 25°C temperature of the water.

6.5. Groundwater chemistry and quality of the Emirates by region

The groundwater chemistry and quality of the whole Emirates are described by region and subregion within the two main relief provinces of the mountains and lowlands. The chemical composition is explained in

relation to the geology of the rock material over which water flows (in the hardrock catchment areas) or in which water resides in the different water-bearing strata in the mountain wadis, piedmont plains and desert foreland. The suitability of groundwater for human consumption and/or irrigation is described for every area in which there is groundwater abstraction. The regions and subregions (zones) for which the hydrochemistry is described are shown in Figs. 6.1. and 6.28., and are as follows :

A. <u>The mountain zone</u> (Fig. 6.1.)

(1) The ophiolite gabbro zone (6.5.1.1. in the text) (Fig. 6.2)

(2) The ophiolite peridotite zone (6.5.1.2 in the text) (Fig. 6.4)

(3) The ophiolite peridotite and Hawasina metamorphics zone of the Masfut-Hatta-Muzeirea' intermontane basin (6.5.1.3. in the text) (Fig. 6.6).

(4) The Hawasina metamorphics and volcanics Dibba Corridor zone (6.5.1.4. in the text)(Fig.6.8).

(5) The Hajar limestone massif of Ru'us Al Jibal zone (6.5.1.5. in the text) (Fig. 6.10).

B. <u>The lowland zone</u> (Figs. 6.1. and 6.28.)

B.1. <u>The piedmont plains</u>: (6.5.2. in the text)

(6a) The northern part of the western alluvial piedmont plains (6.5.2.2. in the text) (Fig. 6.12)

(6b) The central part of the western alluvial piedmont plains (6.5.2.3. in the text). (Fig. 6.14)

(6c) The southern part of the western alluvial piedmont plains (6.5.2.4. in the text). (Fig. 6.16)

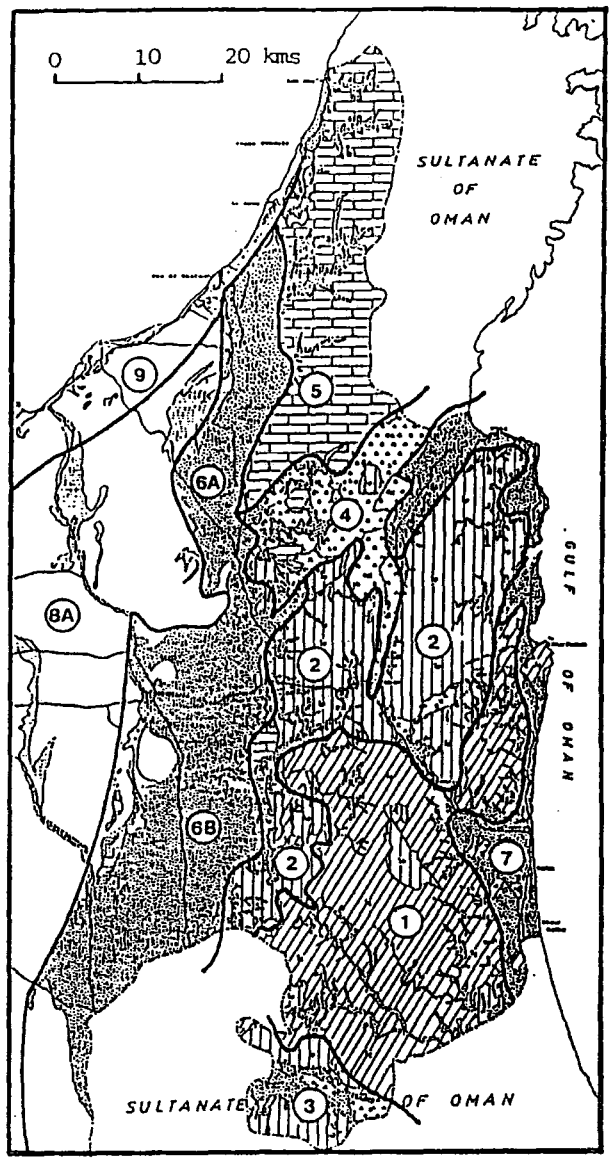


Figure: 6.1.

Subdivisions of the mountain area and the northern and central parts of the piedmont plains and the east coast (eastern piedmont plains) of the Emirates for which detailed water sampling was carried out and water quality is described in the text.

1) The ophiolite gabbro zone.
2) The ophiolite peridotite zone.
3) The ophiolite perodotite and Hawasina metamorphics zone of the 'Masfut-Hatta-Muzeirea' intermontane basin.
4) The Hawasina metamorphics and volcanics Dibba Corridor zone.
5) The Hajar carbonate massif of Ru'us Al Jibal zone.

6A) The northern part of the western alluvial piedmont plains.
6B) The central part of the western alluvial piedmont plains.
6C) The southern part of the piedmont plains (Al Ain) is shown in Fig. 6.28.

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7) The eastern piedmont plains of the east (Batinah) coast.

8A) The desert foreland of the Northern Emirates.

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9) The western (Gulf) coastal zone.

(7) The eastern piedmont plains of the east (Batinah) coast (6.5.2.5. in the text). (Fig. 6.19)

B.2 The desert foreland: (Fig. 6.28.) (6.5.3. in the text)

(8a) The desert foreland in the Northern Emirates (6.5.3.1. in the text).

(8b) The desert foreland between Tawi Nazwa and Al Ain (6.5.3.2. in the text).

(8c) The desert foreland between Al Ain and Bu Heeran in the west and Um Ez Zemool in the south (6.5.3.3. in the text).

(8d) The desert foreland of central Abu Dhabi (6.5.3.4. in the text).

(8e) The southern desert foreland of Eastern and Western Liwa (6.5.3.6. in the text).

(9) The western coastal zone (6.5.4 in the text).

6.5.1. The mountain zone (marked 1 to 5 in Fig. 6.1.)

6.5.1.1. The ophiolite gabbros zone (Area 1 in Fig. 6.1.)
(Table 6.4. and Figs. 6.2 and 6.3)

Delineation of the zone: This is the gabbro hardrock zone of the ophiolite central mountain block. It consists of a main part bounded by the following villages (from the north in a clockwise direction): Balaidah, Ghurah, Kidnah, Fara'ah, Sha'arah, Wadi Yifan, Hafrah, Wahlah, Nuslah, Huwailat, Wadi Al Qawr, Wadi Mansab, Al Ginniyah, Raseesah, Khabakheb, Muthaqqab, Rimhah, Wadi Ashwani and back to Maraheen; and a small triangular part overlooking the east coast and lying between Fujairah-Wadi Saham, the upper reaches of Wadi Safad, Nuhay, Rufaisah-Wadi Shi (or Shayy) and southwards along the east coast front down to Fujairah (Fig. 6.2).

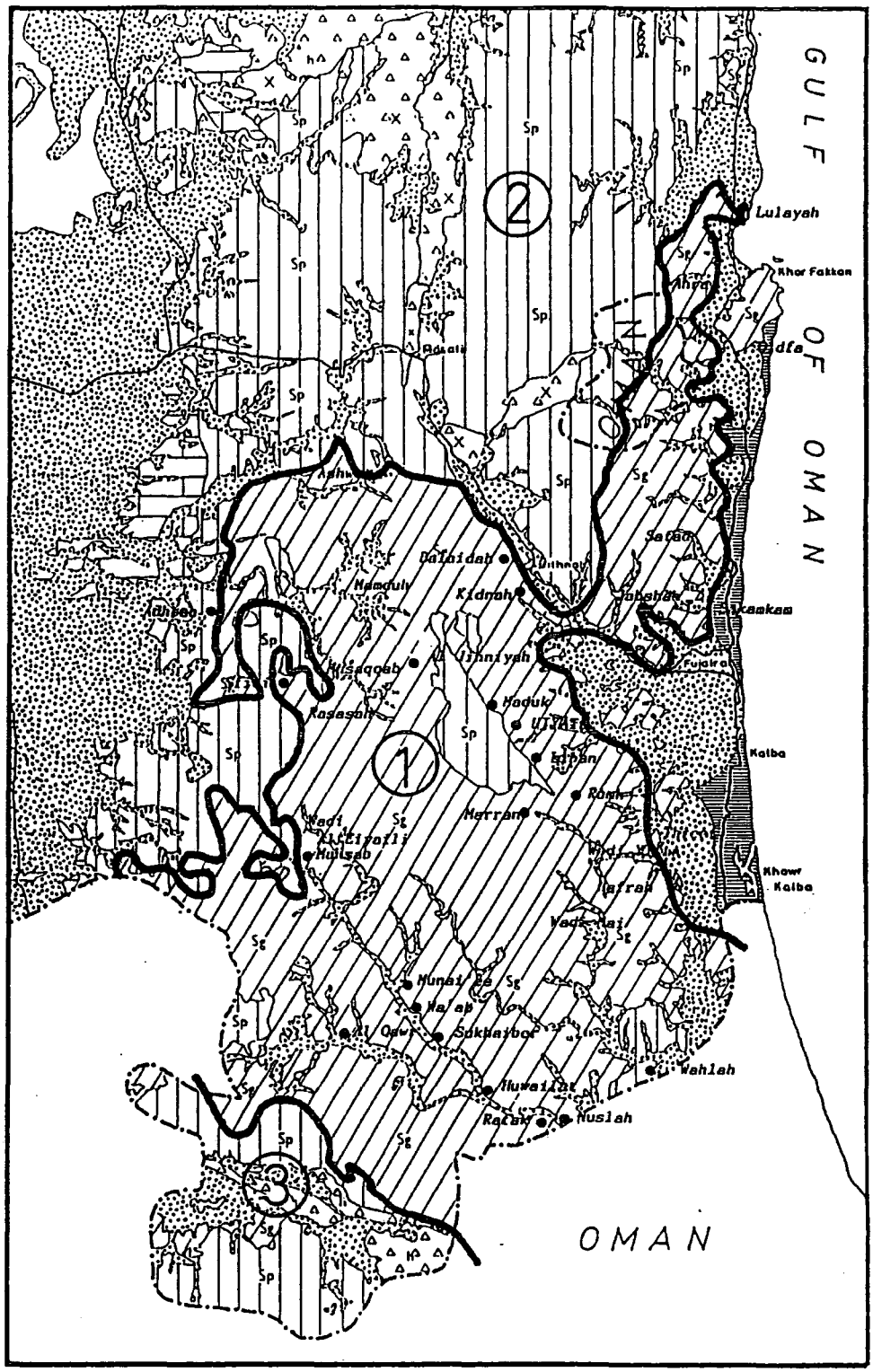


Figure: 6.2.

Area 1 of the mountain zone: the ophiolite gabbro zone.

Delineation of the zone and locations of the water samples as given in Table 6.4.

Chemical analyses of groundwater in the Mountain Area 1 (the ophiolite gabbro zone)

In meq/l

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Al Qawr (Village)	1648	1071	7.3	-	3.46	8.50	3.00	2.88	3.09	8.96	-	5.2	C_3 S_1
2. Huwailat (W. Al Qawr)	3317	2156	7.3	-	1.34	25.24	4.51	12.67	1.55	16.81	-	6.3	C_4 S_1
3. Rafak (W. Al Qawr)	5892	4124	7.2	-	0.82	45.69	8.58	26.78	2.06	26.21	-	6.9	C_4 S_1
4. Munai'ee (W.Munai'ee)	1020	663	7.5	-	4.69	3.08	3.00	3.15	2.64	5.18	-	3.1	C_3 S_1
5. Wa'ab "	1458	947	7.6	-	5.10	5.37	1.93	1.03	1.03	10.30	-	10.1	C_3 S_1
6. Sukhaiber "	1638	1064	7.4	-	6.18	5.37	3.43	1.31	1.03	12.80	-	11.6	C_3 S_1
7. Hafrah (W. Hamad)	1442	937	8.6	-	6.25	4.21	3.48	2.42	4.38	7.30	-	4.0	C_3 S_2
8. Al Hiyail(W. Hiyail)	1020	663	7.9	-	4.94	3.19	1.61	2.06	6.18	1.43	-	0.7	C_2 S_1
9. Maduk (W. Maduk)	613	399	7.8	-	3.63	2.15	1.07	1.15	2.50	3.09	-	2.3	C_2 S_1
10. Mai (W.Rumh)	1313	853	7.3	-	7.21	4.49	1.00	1.55	2.58	8.69	-	6.1	C_3 S_1
11. Farfar (W.Farfar)	1320	858	7.7	-	3.71	6.27	2.15	2.47	4.20	5.22	-	2.9	C_3 S_1
12. Wadi Jabsha	1828	1188	7.6	-	4.12	11.89	1.07	2.58	5.15	9.40	-	4.8	C_3 S_1
13. Blaidah (W.Ham)	1803	1172	7.9	-	3.09	13.49	1.93	1.65	9.06	7.57	-	3.3	C_3 S_1
14. Bithnah (W.Ham)	1004	653	8.0	-	2.81	4.76	1.82	1.03	4.33	3.90	-	2.4	C_3 S_1
15. Wadi Liban	680	442	7.8	-	3.29	1.86	3.70	0.21	1.80	6.78	-	6.8	C_2 S_1

EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Year of analysis 1988.

Table: 6.4.

Water chemical analyses of <u>AREA 1</u> of the Ophiolite gabbro zone.
(Figures 6.1. and 6.3.)

The average EC ranges from 500-1800mmhos/cm.. There are higher ECs at points like Huwailat (5720mmhos/cm.) and Rafak (3220mmhos/cm.), but these high salinities are due more to leached salts from recirculating irrigation water and the concentration of the Na ion than to the solution of plagioclase, feldspars and chlorides present in the water-bearing deposits.

The quality of the recharge waters is evident in the high Mg content in relation to that of Ca. Mg is derived from the magnesium-rich basalts as at Wadi Jabsha (analysis 12). Because of the mineralization of the waters by salinization from irrigation returns in the large wadis of Al Qawr and Munai'ee, the water quality changes from that of a CO_3-Na-Cl to that of Na-Cl-SO_4 type. In general the waters here are of the HCO_3-Cl-Mg-Na type.

Apart from the high salinity waters of places like Huwailat and Rafak, the waters elsewhere are of good to acceptable potable quality. The best irrigation water occurs at Al Hiyail (it is of the C_2 S_1, of medium salinity and low sodium hazard, class).

Water chemistry and quality of the zone

The average EC ranges from 500-1800 mmhos/cm., though there are points where the EC exceeds 3000 mmhos/cm. as at Huwailat and Rafak (3220 and 5720 mmhos/cm. respectively),but these high ECs are due more to washed salts from irrigation water return and the concentration of the sodium ion than to the solution of plagioclase, feldspars and chlorides. Rafak is situated in downstream Wadi Al Qawr and both surface and base-flows reach it after a long journey along the wadi course during which soluble chlorides and sodium are collected.

There is a noticeable change in the EC and TDS values between upstream and downstream points in mountain wadis. 6 water samples were collected: three for Wadi Al Qawr and three for Wadi Al Munai'ee, from upstream, midstream and downstream points in each wadi. The increase in EC values is clear in the analyses for Al Qawr village (upstream, 1648 mmhos/cm.), Huwailat (midstream, 3317 mmhos/cm.) and Rafak (downstream, 5892 mmhos/cm.) in Wadi Al Qawr (analyses 1-3, Table 6.4); and for Al Munai'ee (upstream: 1020 mmhos/cm.), Wa'ab (midstream: 1458 mmhos/cm.) and Sukhaiber (downstream: 1638 mmhos/cm.) in Wadi Al Munai'ee (analyses 1-6, Table 6.4).

The dominant cation is sodium (Na), which increases downstream in Wadi Al Qawr by more than three times between Al Qawr village (8.96 meq/l, analysis 1, Table 6.4.) and Rafak (26.28 meq/l, analysis 3, Table 6.4.); followed by calcium (C_a), which increases from 2.9 meq/l to 26.00 meq/l for the same two places.

The dominant anion is chloride (Cl), which increases sharply between Al Qawr village and Rafak from 8.5 meq/l to 45.69 meq/l. Sulphate (SO_4) increases from 3.00 meq/l to 8.58 meq/l for the same two points, while bicarbonate (HCO_3) decreases from 3.46 meq/l to 0.82 meq/l. Thus, the water in Wadi Al Qawr changes from a carbonate-sodium-chloride type upstream to a sodium-chloride-sulphate type downstream. The pH value averages 7.3.

The TDS generally changes from 1071 ppm. in Al Qawr village to 4124 ppm. for Rafak, indicating the increased dissolved solids in the water

downstream. Whereas the Mg-Ca ratio upstream is 1:1.5, characteristic of the recharge nature of waters, it is 1:13 downstream, with an increase in the chloride, sodium and sulphate ions.

Wadi Al Munai'ee, which is a tributary of Wadi Al Qawr joining it at Bida' Majed about 1 km from the village of Al Fashqah, exhibits the same increase in EC, though to a lesser degree, between Al Munai'ee village (upstream) and Sukhaiber (downstream) (analyses 4 and 6 in Table 6.4.), with the change in EC being almost two-fold. All the cations show a decrease downstream except for sodium, which increases by nearly two times from 5.18 meq/l to 12.80 meq/l between the two points. The anions show a relatively moderate increase except for bicarbonate, which increases from 4.69 meq/l to 6.18 meq/l. The Mg-Ca ratio is about 1:1 for both the upstream and downstream points of Munai'ee and Sukhaiber. Na and Cl are the two dominant anions though the increase downstream in Wadi Al Munai'ee is less than has been described for Wadi Al Qawr, because Wadi Al Qawr has a longer course and the cultivated area on either side of the wadi is more than is the case in Wadi Al Munai'ee. In addition, Wadi Al Munai'ee has a steeper gradient, and therefore quicker subsurface flow, than Wadi Al Qawr whose gradient in some places is so gentle as to cause ponding of both surface and subsurface water, as at Huwailat, which increases the possibility of the mineralization of groundwater.

Points like Al Hiyail (analysis 8, Table 6.4.), Maduk (analysis 9, Table 6.4.) and Bithnah (analysis 14, Table 6.4.) are situated in the centre of the gabbro zone in the upper courses of Wadis Al Hiyail, Maduk and Ham respectively. The first two wadis rise in an area of ultrabasic peridotite, serpentinite and magnesite in highly fractured silicified alternations. It is the only outcrop (about 3km. x 12km.) amidst the gabbro block and, like the bulk of the area to the north of Wadi Ham (i.e. Zone 2, discussed next), ultrabasic rocks produce good water. Therefore, it is not surprising that the ECs in these wadis are low, especially at Maduk (613 mmhos/cm.) whose wadi course lies almost totally in this isolated outcrop of ultrabasic peridotite rocks. Bithnah (analysis 14, Table 6.4), on the other hand, gets water from both sides of the ultrabasic peridotite and the basic gabbro outcrops to the north and south, with tributaries flowing into Wadi Ham, on whose left bank Bithnah is situated. Hence also the water is of relatively good

quality (EC 1004 mmhos/cm.). Bicarbonate is the dominant anion in Al Hiyail and Maduk, while Mg is the dominant cation, indicating to the recharge quality of the waters in these two wadis. Na is lower by comparison to that for Wadis Al Qawr and Al Munai'ee because agricultural activity in Wadis Al Hiyail and Maduk is negligible.

The Mg-Ca ratio for Maduk and Al Hiyail is 1:3, while for Bithnah the ratio is 1:4. Waters in the upper reaches of Wadis Al Hiyail, Maduk and Ham can be said to be of the bicarbonate type, whereas the waters in the lower reaches of Wadis Al Munai'ee and Al Qawr, as at Huwailat and Sukhaiber, are of the sodium-chloride-Bicarbonate-sulphate type.

The high chloride and sodium values for Balaidah and Wadi Jabsha (analyses 13 and 12, Table 6.4.) are largely attributed to the effect of irrigation water. The high magnesium values for Jabsha and Balaidah, which are the highest encountered so far in this zone (Table 6.4.), reflect the enrichment of waters with magnesium, especially those of Wadi Jabsha, from the magnesium-rich rocks (olivine, basalt and serpentinite) in the hardrock areas through which Wadi Jabsha flows.

Suitability of water for domestic consumption

Apart from the waters in Huwailat and Rafak (analyses 2 and 3, Table 6.4.), the waters in this zone are of good to acceptable potable quality. Even the water at Huwailat is used for drinking, despite its high total dissolved solids of more than 2000 ppm. The best potable waters in this zone are at Maduk, Al Hiyail and Bithnah, but such waters are pumped by the MEW from its boreholes and distributed unchlorinated directly to the villages.

Suitability of the water for agriculture (Fig. 6.3)

As can be seen from the SAR values and irrigation water class in Table 6.4., the best water for agriculture is found at Al Hiyail, followed by Al Munai'ee, Maduk and Liban. Apart from the water of Al Hiyail, which has a medium salinity and a low sodium hazard of C_2 S_1, the waters in the other three places, shown in Table 6.4., are of the C_2 S_2 irrigation class, which is of medium sodium and salinity hazard. Irrigation water in all the remaining places in this area is of the medium to high

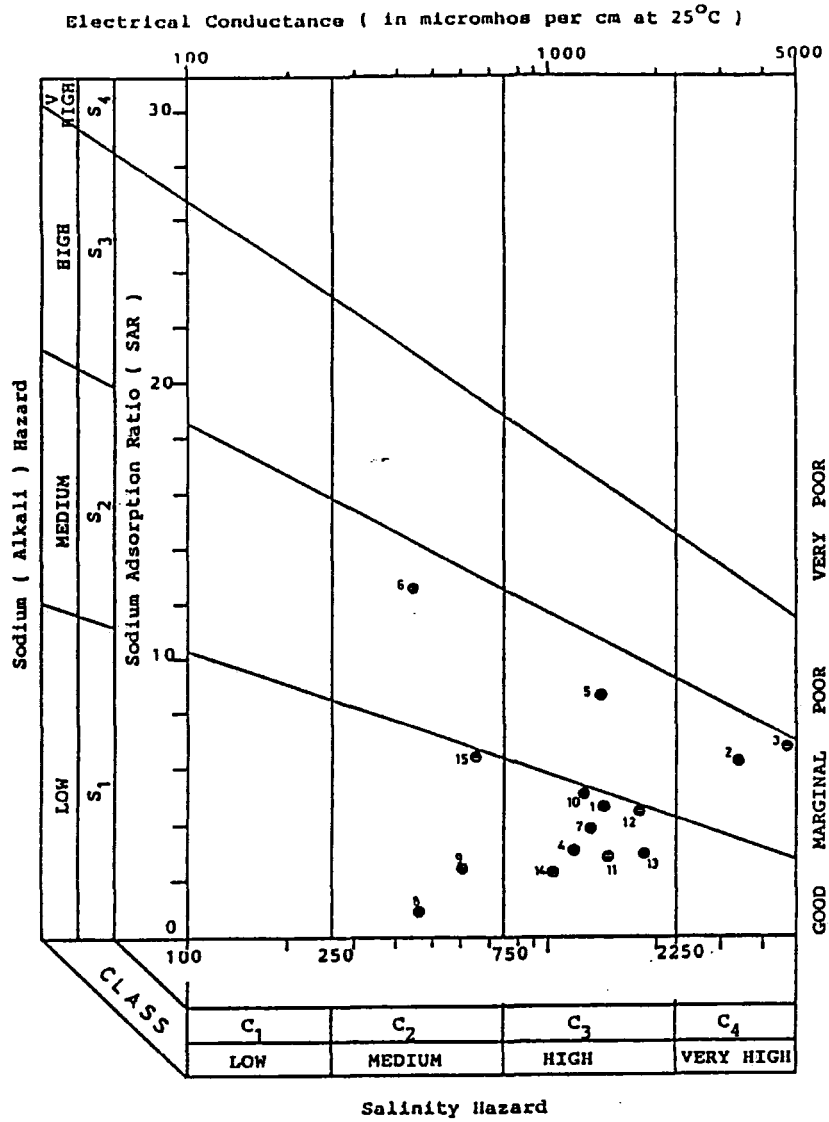


Figure: 6.3.

Irrigation water class of the waters of the mountain AREA 1 (the ophiolite gabbro zone).

The irrigation water class of most places in this zone is of the medium to high salinity hazard (C_3-C_4) and low sodium hazard (S_1). The SAR value for Wa'ab (analysis 5, Table 6.4) and Sukhaiber (analysis 6, Table 6.4) are 10.1 and 11.6 (of the the C_3 S_1 and C_2 S_2 classes, respectively)

(The numbers in the figure refer to the water analyses in Table 6.4)

salinity hazard class of C_3 - C_4, although the sodium hazard remains of the low class of S_1. The SAR values for Wa'ab and Sukhaiber are 10.1 and 11.6 (class C_3 S_1 and C_2 S_2) respectively, which are the highest values in this zone. The salinity (EC) and sodium (SAR) hazards for all the analyses in Table 6.4. for Area 1 are shown in Fig. 6.3.

6.5.1.2. The ophiolite peridotite zone (Area 2 in Fig. 6.1.) (Table 6.5 and Figs. 6.4 and 6.5.)

Delineation of the zone: This is the peridotite hardrock area that forms the northern and western parts of the ophiolite central mountain block. Its northern section is bounded by the following settlements in a clockwise direction from the north moving southwards: Dibba, Ras Dhadhnah, Dhadhnah, Aqqah, Al Badiyah, Amqah, Wadi Al Wurai'ah, Bega, Bithnah, Balaidah, Daftah, Al Gadf, Al Gamrah, Masafi, Dhawahi, Al Khulaibiyyah, Al Ghonah, Al 'Abadillah, Al Halah, Sinnah, Wadi Dalam, and back to Dibba (Fig. 6.4).

The western section of this peridotite zone can be subdivided into a larger northern part and a smaller and narrower southern part, both of which overlook the western piedmont plains. The northern part is bounded by the following settlements (from the north in a clockwise direction): Khabakheb, 'Asimah, Al Beerah, Dhawahi, Al Gadf, Daftah, Siji, Tuwaihah, Wadi Ashwani, Thoban, Ghail Al Hāmam, Hiniyat Al Ramlah, Mawred, Tawi Yal, and back to Khabakheb.

The southern section is bounded by the following settlements (in a clockwise direction from the north, moving eastwards): Wadi Ashwani, Rimhah, Muthaqqab, Mamduh, Al Kosh, Hakkakah, Wadi Sfini, Raseesah, Al Ginniyyah, Wadi Mansab, Shabakh, Tawi Nassas, Al Khari, Shawkah, Tawi 'Adbah, Khudhairah, Sfini, Khadhrah, and back to Wadi Ashwani.

The rocks of both sections of this peridotite zone are made up of ultrabasic peridotites, serpentinized peridotites and serpentinite (locally layered). Magnesite and crysotile veins are widespread. The serpentinite is highly fractured and silicified. There are both coarse and fine granite in numerous intrusions especially in the northern part

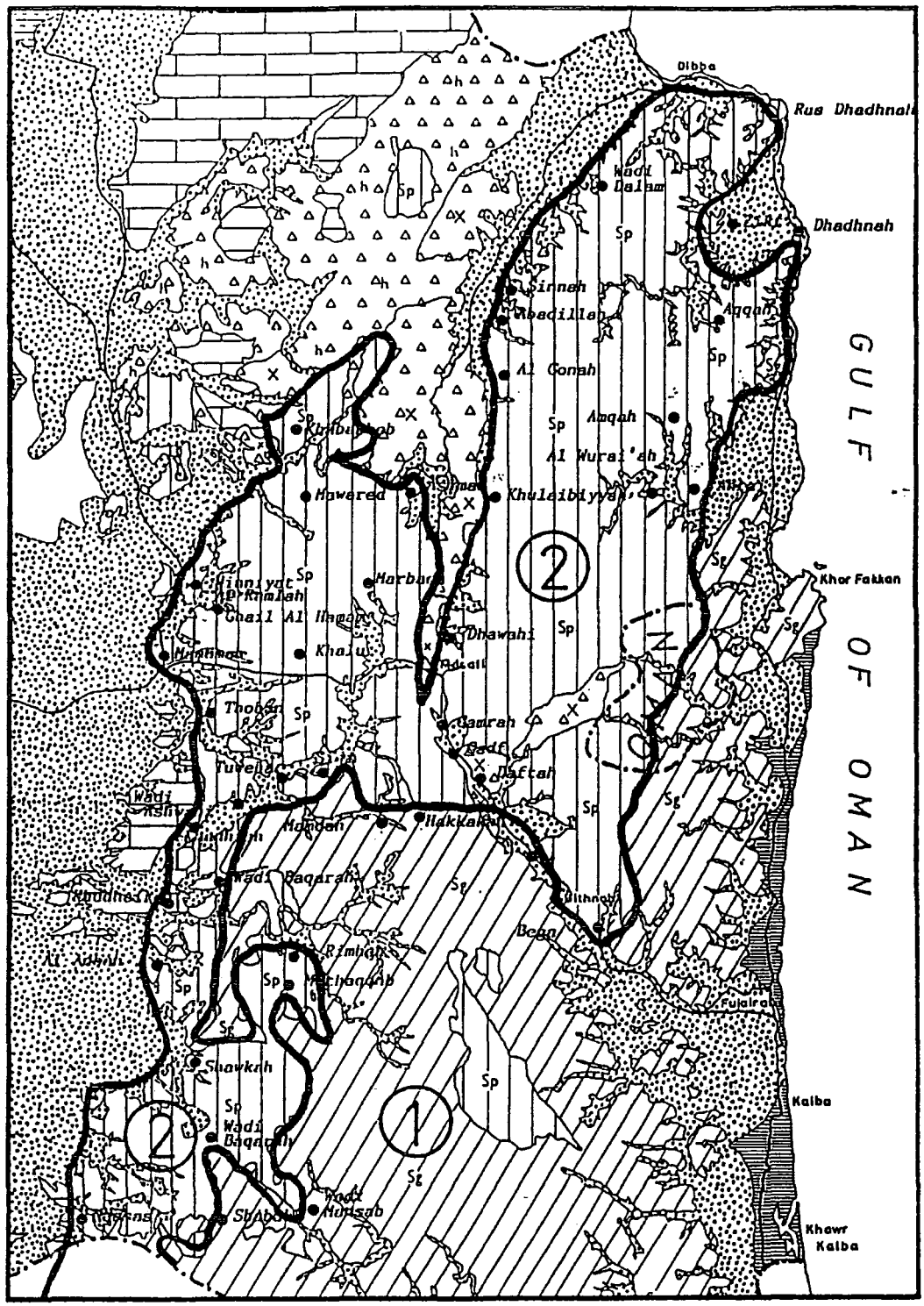


Figure: 6.4.

AREA 2 of the mountain zone: the ophiolite peridotite zone.

Delineation of the zone and locations of the water samples as given in Table 6.5.

of the zone between the Batinah coast and Wadi Al Baseerah. In its western section, this peridotite zone is narrowest between Al Khari and Wadi Ashwani to the south and north of Al 'Adbah village.

This zone has generally the best quality waters as reflected by the low EC values which range from 438 mmhos/cm. (Masafi) to 1787 mmhos/cm. (Al Ghail) (analyses 2 and 11, Table 6.5); and the only two exceptions are Wadi Sfini and Rimhah, which have comparatively high EC values (6623 mmhos/cm. and 4923 mmhos/cm., respectively) (analyses 13 and 16, Table 6.5). In the northern section of this zone, bicarbonate is the dominant anion and magnesium is the dominant cation and the waters are of the bicarbonate-magnesium type reflecting their recharge quality. In the western section of the zone, which forms the western flank of the mountains between Khabakheb and Tawi Nassas, Mg is the dominant cation, with high concentrations, largely derived from the magnesium-rich olivine, basalt and serpentinite; but bicarbonate still maintains its relatively high concentrations, together with chloride and sodium. Waters in this western section of the peridotite zone rise in both types of rocks (gabbro and peridotite), which reduces water quality slightly. There is also substantial agricultural activity within the wadis, which contribute to the high sodium chloride values obtained from mineralized irrigation water that eventually reaches the piedmont plains as recharge water (analyses for Siji, Al Ghail and Al 'Adbah in Table 6.5.). The waters in these western foothills of the central mountains are of the bicarbonate-magnesium-chloride-sodium type.

The exceptionally high TDS in Wadi Sfini and Rimhah are due to agricultural activity in both localities but also to ponding of base-flow in the wadi gravels in Sfini. The water in Sfini is the most striking example of increased mineralization of groundwater from upstream to downstream points, as was observed in the upper and middle courses of Wadi Sfini and also in its tributary, Wadi Mamduh, which rises in the area of ultrabasic peridotite rocks situated in the midst of the gabbro block referred to earlier (Section 6.5.1.1.).

The EC was measured in the upper course of Wadi Mamduh and the middle course of Wadi Sfini, a distance of 5.5km, and was found to change from 989 mmhos/cm. in Muthaqqab (analysis 15, Table 6.5.) to 2050 mmhos/cm. in Mamduh about 1.5 km. downstream; to 3800 mmhos/cm. in Majhalah,

Chemical analysés of the groundwater in the Mountain Area 2 (the ophiolite peridotite zone)

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Daftah	1035	673	7.9	-	4.00	4.90	1.50	0.42	5.53	4.13	-	2.4	$C_3 S_1$
2. Masafi	438	285	7.9	-	1.85	2.18	0.63	0.21	2.80	1.66	-	1.4	$C_2 S_1$
3. Zikt	670	436	7.5	-	3.31	1.48	1.1	2.6	3.0	0.13	-	0.1	$C_2 S_1$
4. Al Wurai'ah spring	474	308	7.7	-	2.39	1.72	1.72	0.58	3.2	2.23	-	1.6	$C_2 S_1$
5. Khalu (East)	706	459	7.2	-	3.71	5.59	3.00	1.0	4.12	6.89	-	4.3	$C_2 S_1$
6. Khalu (West)	788	317	7.4	-	3.50	3.63	1.18	0.8	5.36	2.15	-	1.2	$C_2 S_1$
7. 'Amqah	495	322	7.0	-	2.31	2.18	0.58	0.57	2.83	1.61	-	1.2	$C_2 S_1$
8. Siji	1380	897	7.3	-	3.91	6.82	2.36	1.65	8.43	3.00	-	1.3	$C_3 S_1$
9. Marbadh	948	616	7.7	-	2.27	4.51	1.82	0.92	6.40	0.70	-	0.4	$C_3 S_1$
10. A'simah	690	458	7.1	-	3.63	1.52	1.20	1.50	3.46	1.13	-	0.7	$C_2 S_1$
11. Al Ghail	1787	1162	7.4	-	3.50	11.61	3.50	2.1	6.80	9.78	-	4.6	$C_3 S_1$
12. Hiniyat Al Ramlah	1524	991	7.9	-	3.5	9.57	1.82	0.82	4.33	9.58	-	6.0	$C_3 S_1$
13. Wadi Sfini	6623	4636	7.7	-	1.24	34.84	19.31	16.69	6.80	31.93	-	9.3	$C_4 S_1$
14. Al 'Adbah	1153	750	8.0	-	6.39	4.35	1.93	1.55	8.34	2.64	-	1.2	$C_3 S_1$
15. Muthaqqab	989	643	7.7	-	5.52	3.31	1.39	1.48	4.37	4.16	-	2.5	$C_3 S_1$
16. Rimhah	4923	3200	7.5	-	4.53	9.20	6.40	3.91	8.45	7.70	-	3.1	$C_4 S_1$

EC in mmhos/cm. at 25°C; TDS in ppm.; ions in meq/l. Year of analysis 1988.

Table: 6.5.

Water chemical analyses of AREA 2 of the Ophiolite peridotite zone.
(Figs. 6.1, 6.4. and 6.5)

The geology of this area is made up of ultrabasic peridotites, serpentinized peridotites and serpentinites with widespread magmatic and crysotile veins.

This zone has the best quality water as demonstrated by the range of its ECs (438-1787mmhos/cm.). The waters are generally of the HCO_3-Mg type suggesting their recharge quality. Mg is derived from the magnesium-rich olivine, basalt and serpentinite. However, Cl and Na are also of important presence. The exceptionally high TDS for Sfini (analysis 3) and Rimhah (analysis 16) is due mainly to mineralization caused by recirculating irrigation water and also to the ponding of base-flows as occurs at Sfini.

Waters rising and flowing mostly in peridotite outcrops ('Amqah and Al Wurai'ah Spring (analyses 7 and 4)) have relatively better quality than waters rising and flowing mostly in gabbro or in both gabbro and peridotite outcrops (Muthaqqab and Al 'Adbah (analyses 15 and 14)). The waters are within the acceptable limits for drinking, as at Al 'Adbah and Muthaqqab; but are of the very poor quality, as at Rimhah and Wadi Sfini. The irrigation water quality is of the C_2-C_3, of the medium to high salinity, and of the S_1 low sodium, hazard.

another 1.5 km. downstream; to 4923 mmhos/cm. at Rimhah (analysis 16, Table 6.4.) a further 1.5 km. downstream at the confluence of Wadi Sfini and Wadi Baqarah. Finally, the EC reached 6623 mmhos/cm. below Sfini village proper, which also lies 1.5 km. downstream from Rimhah. The EC for Al 'Adbah, which lies 2 km. further downstream from the village of Sfini, was 1153 mmhos/cm. (analysis 14, Table 6.5.), which was found lower than would be expected according to the previous worsening trend in the EC just described. This is because the water sample had been collected from a well in a wadi terrace further up the wadi side from the main wadi channel away from any agricultural activity or irrigation water return. In addition, the water sample was collected immediately after the rains of February 17th. 1988, and the well the sample was collected from was situated near a fresh water stream in its upper reaches flowing through a desolate, narrow and barren ravine-like small wadi with no agricultural activity traced along its whole length.

Suitability of the water for human consumption

Waters in this zone are within the acceptable limits for drinking. The waters in wadis rising and flowing most of their courses within the ultrabasic peridotite country of the main block of this zone, to the north and northeast of Masafi, are of a better quality than the waters that rise and flow across both peridotite and gabbro outcrops, such as those along the western flank of the central mountains between Khabakheb and Nassas. This difference in quality in relation to the geology is evident in Muthaqqab, which is situated in the peridotite zone but its wadi rises and flows most of its course in the gabbro hardrock area, having a clear effect on the quality of its water (EC 986 mmhos/cm.), which is as good as that for Marbadh (948 mmhos/cm.) or even Asimah (690 mmhos/cm.).

The bicarbonate content of the water at Muthaqqab is lower than the maximum recommended limit (8.0 meq/l); sulphate content is low (1.39 meq/l). The chloride and sodium content is of the medium range (3.31 meq/l and 4.16 meq/l, respectively).

The suitability of water for drinking is, therefore, of the acceptable level for Muthaqqab and Al 'Adbah (analyses 14 and 15, Table 6.5), and to some extent for Mamduh, but is of very poor quality at Rimhah and

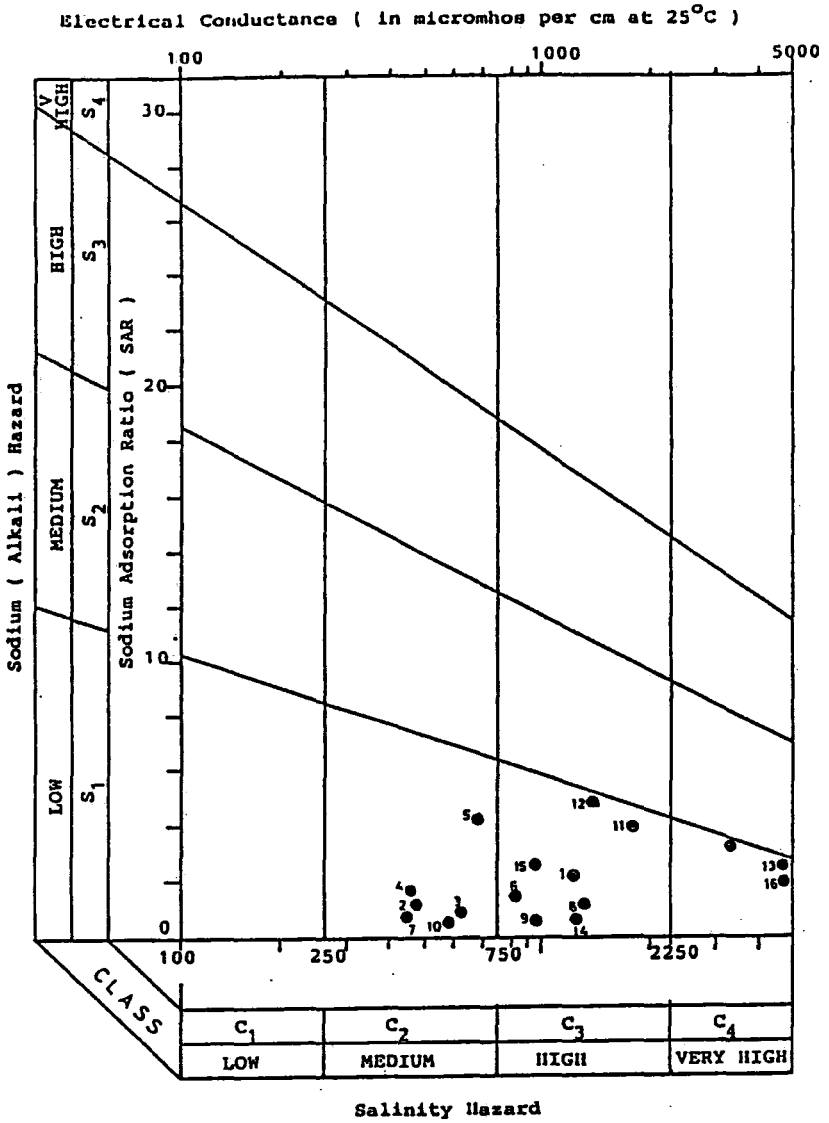


Figure: 6.5.

Irrigation water class of the waters of the mountain AREA 2 (the ophiolite peridotite zone).

The irrigation water of this zone is mostly of the C_2 C_3, medium to high salinity, and S_1, low sodium, hazard, class.

(The numbers in the figure refer to the water analyses in Table 6.5)

Sfini (analyses 13 and 16, Table 6.5). Besides Muthaqqab and Al 'Adbah, where the sulphate content is below 2.0 meq/l, the values for the same ion are high elsewhere, reaching the highest value in the whole zone at Sfini (19.3 meq/l).

Suitability of the water for agriculture (Fig. 6.5)

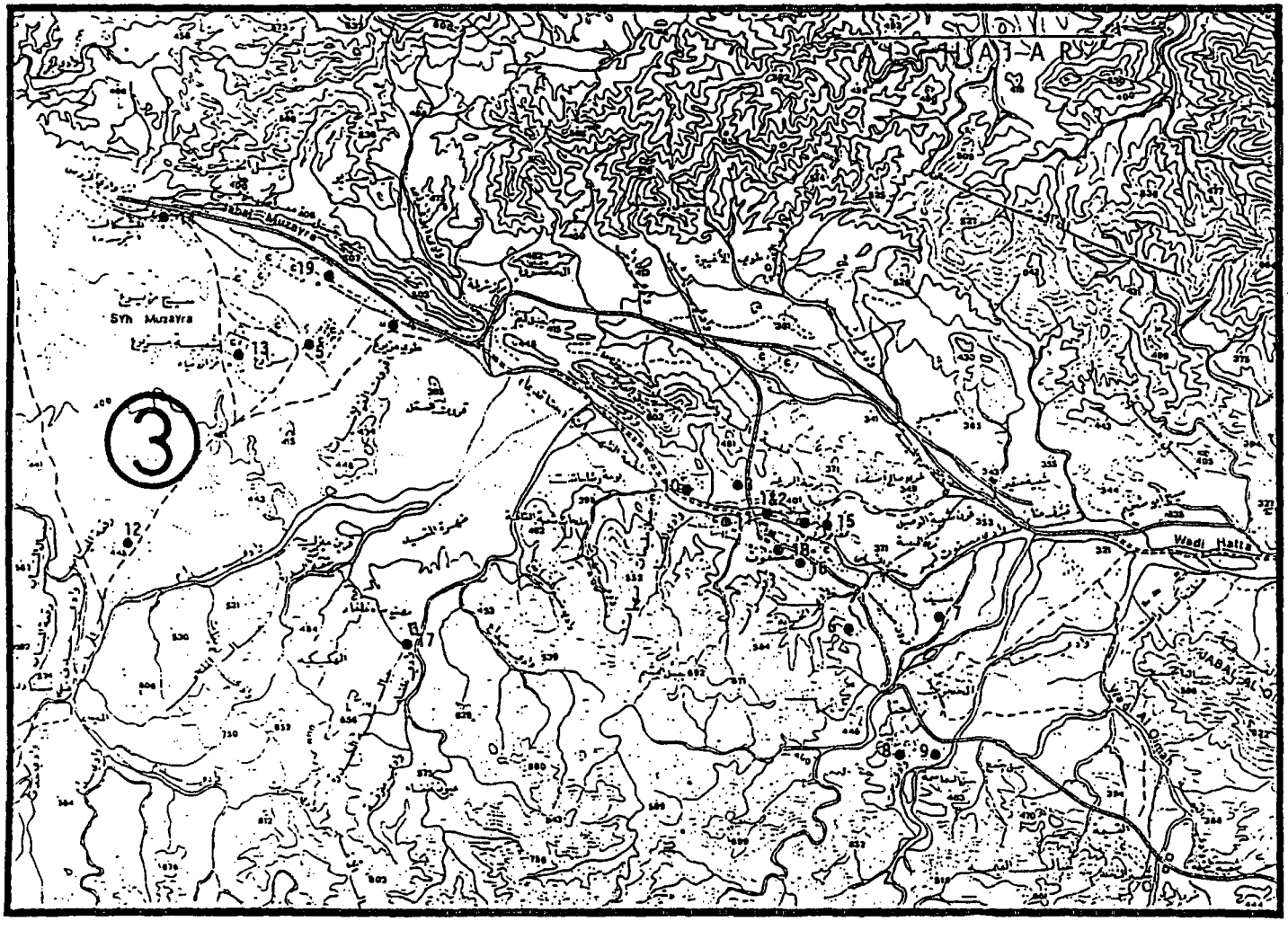
The SAR values for this peridotite area range from 0.4 (Marbadh) with a salinity hazard of between C_2 and C_3 and the sodium hazard S_1; to 4.6 (Al Ghail) with a salinity hazard C_3 and sodium hazard S_1, to 9.3 (Sfini) with the salinity-sodium hazard of C_4 S_1. The use of the C_4 S_1 irrigation water in the date plantations in Sfini results in the leaching of salts, which in turn increases water salinities progressively downstream. There is a slight amelioration of the groundwater salinities by the rains for a few days, but soon the groundwater quality returns to the previous poor state due to overpumping and the lessening of base-flow. The high Cl and Na values for Sfini are a result of this leaching of the salts by recirculating irrigation water.

6.5.1.3 The ophiolite peridotite and Hawasina metamorphics zone of the Masfut-Hatta-Muzeirea' intermontane basin

(Area 3 in Fig 6.1; Table 6.6. and Figs. 6.6 and 6.7)

This intermontane basin is situated in the extreme southern part of the central mountains in the Northern Emirates. It is bounded in the south by the peridotite mountains of Al Milhi, Al Aghbar, Al Yashm and Al Sidrah, which extend into Oman beyond Hatta and Sanadel (Fig. 6.5). In the north the zone is bounded also by the peridotite mountains of Al Khanfariyyah and Al Theeb. In the centre of the zone there are outcrops, of the Hawasina volcanics and metamorphics, that are made up of quartz, schist and amphibolite. The western half of the basin is dominated by the Muzeirea' alluvial outwash fan (Figs. 6.6).

As seen in Table 6.6., which presents the results of 19 samples collected at various points in the Muzeirea' alluvial outwash fan and the surrounding wadis (Fig. 6.6), water of the best quality is found near Masfut and in wells drilled along the buried wadi courses. ECs

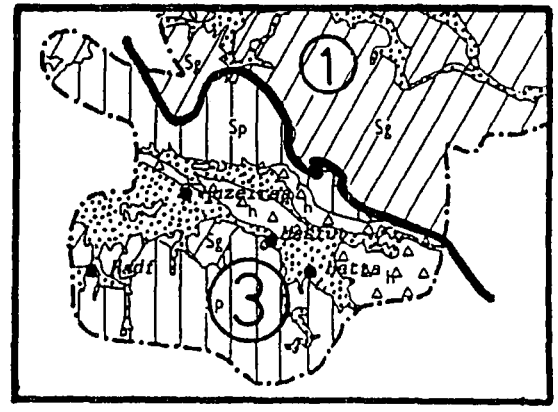


(The numbers on the map refer to the water analyses in Table 6.6.)

Figure: 6.6.

AREA 3 of the mountain zone: the ophiolite peridotite and Hawasina metamorphics zone of the Masfut-Hatta-Muzeirea' intermontane basin.

Delineation of the zone and locations of the water samples as given in Table 6.6.



are below 1000 mmhos/cm. for 60% of the analyses shown in Table 6.6, but they tend to increase with depth or with continued pumping in old-established gardens. Analyses 15, 16, 17 and 18 fall in this low conductivity water group, whereas analysis 3 for Masfut shows a slightly higher EC value due to the depth of the well and also to irrigation return by the leaching of salts from nearby gardens. The difference in the EC between samples 8 and 9, which are for two wells hardly 100m. apart, is because analysis 8 is for a sample from a well situated inside a plantation on the wadi terrace away from the wadi channel, where also a lot of irrigation water return is taking place, while analysis 9 is for a sample from a well outside the compound of the garden, but drilled into a highly permeable buried wadi channel; hence the better quality of the water.

The same is the case with analysis 11 for the private farm in Masfut. Both, analyses 11 and 8 represent waters pumped out of the compact Tertiary alluvium which has low permeabilities, in addition to irrigation returns from the date plantations in which the wells are situated (Table 6.6).

The high ECs for samples 5 and 14 (Table 6.6.) are largely due to overpumping, the subsequent lowering of the water-table and the concentration of dissolved solids and also the high evaporation taking place in an exposed, lightly cultivated surface where also wind-borne surficial salts are eventually leached to the water-bearing strata by rain and runoff. The high EC for Sinadel (1454 mmhos/cm., analysis 12, Table 6.6.), taken from a well in the wadi channel as it debouches on to the alluvial fan, is higher than the EC for Masfut (973 mmhos/cm., analysis 10, Table 6.6.), taken from a point near the centre of the outwash fan. This higher EC is due to the fact that the latter water sample is for a well drilled in the central wadi channel alluvium. Although Wadi Sanadel flows for most of its course within this zone in a barren wadi channel, it collects irrigation return from date plantations upstream. The two aflaj in the area (analyses 15 and 16, in Table 6.6.) have waters with ECs below 700 mmhos/cm., while the waters of Wadi Gulfa (analysis 17, Table 6.6), which are commercially bottled, have the best conductivities in this zone (280 mmhos/cm.).

Most of the pH values are close to 8.0, indicating alkaline waters.

Chemical analyses of groundwater in the Mountain Area 3 (the ophiolite peridotite and Hawasina metamorphics zone of the Masfut-Hatta-Muzeirea' intermontane basin. In meq/l

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Masfut (1)	676	439	8.2	-	2.26	2.14	1.60	2.15	1.58	2.17	-	1.6	$C_2 S_1$
2. Masfut (2)	719	467	8.4	-	3.25	2.14	2.22	0.90	4.33	2.43	-	1.5	$C_2 S_1$
3. Masfut (3)	1040	676	7.6	-	2.19	4.77	1.46	2.40	3.20	3.78	-	2.3	$C_2 S_1$
4. Muzeire'a (1)	1150	748	8.3	-	3.26	5.49	3.42	2.00	6.83	3.26	-	1.6	$C_3 S_1$
5. Muzeire'a (2)	5100	3570	7.5	-	1.20	38.80	8.33	22.00	8.60	17.17	-	4.4	$C_4 S_1$
6. Hatta	4840	3146	7.1	-	3.20	18.30	3.33	3.40	8.83	12.30	-	5.0	$C_4 S_1$
7. Hatta(pvt well)	590	384	7.9	-	4.11	1.49	1.0	1.30	2.58	2.52	-	1.8	$C_2 S_1$
8. Hatta (Sh.Mana' Al Maktoum's gdn., INSIDE WELL	3020	1763	7.8	-	4.38	21.89	3.46	6.00	5.79	17.74	-	7.3	$C_4 S_1$
9. Hatta (Sh. Mana' Al Maktoum's gdn., OUTSIDE WELL	1300	845	7.9	-	4.68	6.63	2.38	2.02	6.50	5.04	-	2.4	$C_3 S_1$
10. Masfut(MAF Nursery)	973	633	7.6	-	5.75	3.75	1.56	0.95	2.08	7.90	-	6.4	$C_3 S_1$
11. Masfut(pvt farm)	2690	1749	7.6	-	4.66	16.16	5.20	2.25	5.25	18.48	-	9.7	$C_3 S_1$
12. Well north of Sinadel	1545	1005	8.3	-	4.20	7.20	1.80	3.15	6.25	3.71	-	1.7	$C_3 S_1$
13. Well in the centre of alluvial fan	1662	1080	8.2	-	5.11	8.39	2.79	3.20	7.75	5.11	-	2.2	$C_3 S_1$
14. Pvt. well near the main road, 2 kms. north-west of Muzeire'a.	4017	2611	7.8	-	4.39	26.00	4.7	9.50	7.90	13.78	-	4.7	$C_4 S_1$
15. Falaj Wa'rah	550	326	7.9	-	3.28	1.55	0.89	1.2	2.58	1.96	-	1.4	$C_2 S_1$
16. Falaj Masfut (before destruction)	690	449	7.9	-	4.11	2.18	1.56	2.72	2.15	3.00	-	1.9	$C_2 S_1$
17. Wadi Gulfa	280	182	8.3	-	2.36	4.00	0.51	0.73	2.92	3.00	-	2.2	$C_2 S_1$
18. Masfut(gov't well)	540	351	7.9	-	1.97	2.10	1.27	0.90	2.93	1.52	-	1.1	$C_2 S_1$
19. Spring north-east of Muzeire'a.	960	624	8.1	-	1.61	7.41	0.52	1.70	4.58	3.25	-	1.8	$C_3 S_1$

Table 6.6. EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Year of analysis 1988.

Water chemical analyses of AREA 3 of the Ophiolite peridotites and Hawasina metamorphics zone of the Masfut-Hatta-Muzeirea' intermontane basin. (Figs. 6.1, 6.6 and 6.7)

The ECs of the water of this zone are below 1000mmhos/cm. for 60% of the water analyses shown in Table 6.6 above. However, ECs increase with depth or with continued pumping in old-established gardens. Analyses 15, 16, 17 and 18 fall in the low EC group of below 1000mmhos/cm.; whereas analysis 3 shows a slightly higher EC value because of the depth of the well the sample was taken from and also to recirculating irrigation water. The high ECs for analyses 5 and 8 are largely because of overpumping and the subsequent lowering of the water-table but also to the leaching of salts. Most pH values are above 8.0 indicating the alkalinity of the waters.

Na and Cl increase proportionately with the general increase in the TDS. The waters are generally of the HCO_3-Mg-Cl-Na type. The Masfut area has always been renowned for its good quality potable water. Irrigation water is mostly of the C_2 S_1 (medium salinity-low sodium hazard) although in some parts of the area where there is agricultural activity, it is of the C_4 S_1 (very high salinity-low sodium hazard). High salinity waters in Muzeirea', used for 15 years on non-saline soils, have caused these soils to develop a high sodium content that has led to their hardening and their subsequent reduced permeability.

Sodium is the dominant cation, followed by magnesium and calcium. Sodium and chloride increase proportionately with the overall increase in the TDS. The source of the sodium are the plagioclase feldspars available in the semail ophiolites, and the sources of magnesium are the dolomitic limestone and the volcanic igneous and metamorphic rocks. While the calcium values are well below the international recommended limit of 10.0 meq/l (except for analysis 5 for Muzeirea', Table 6.6, where the Ca value is 22.0 meq/l), sodium values are higher than the allowable limits for drinking water and are slightly higher than the recommended limit for poor irrigation water of 13.0 meq/l. Of the anions, chloride is the most dominant, reflecting the three causing factors: high evaporation and concentration of salts, recirculation of irrigation water and low permeabilities of the water-bearing materials and therefore slow movement of groundwater, especially in the old alluvial wadi terraces. In most of the analyses the chloride content exceeds the recommended limit for drinking water of 5.5 meq/l, though it is within the limit of poor irrigation water of 8.5 meq/l (except for analyses 5, 6, 8, 11 and 14, Table 6.6, where it is extremely high, averaging 16.6-38.80 meq/l). Both, the bicarbonate and sulphate values are well below the recommended limits (of 8.0 and 4.0 meq/l respectively) in most of the samples.

Suitability of water for human consumption

Apart from samples 5, 6 and 14 (Table 6.6.), water in this zone is of the good to acceptable potable quality. In the Masfut area, conductivities are below 1000 mmhos/cm. and TDS values are below 500 ppm. Masfut has been renowned for a long time for its good quality drinking water.

There is, however, stratification in the salinity of water in the basin, with water drawn from the upper part the aquifer in the alluvial deposits being relatively less saline than water drawn from the lower part of the aquifer, which, in most cases, lies within either the indurated Tertiary terrace alluvial deposits or the fractured bedrock with a high clay content. An example of this stratification was found in a well situated in the northeastern part of the Muzeirea' outwash fan, 2 km. south of Jabal Muzeirea' (analysis 13, Table 6.6 and point 13 in Fig 6.7). The EC in a sample taken from the lower part of the aquifer was

970 mmhos/cm., while that for a sample from the upper part of the aquifer was 690 mmhos/cm. This variation differed to a lesser or greater degree from one location to another and it attested to the mineralization, as evident by the high TDS values, of the waters at the bottom of the aquifer more than those higher up in the aquifer.

Where an EC value in a well is relatively higher than that in wells in the surrounding area (as occurs in Masfut (analysis 11, Table 6.6.), where the water is generally of good quality and the EC is lower), this is mostly attributed to either irrigation return or the location of the well in a terrace on the wadi side away from the main wadi flow channel. In the latter case, the well may be drawing water from compact Tertiary alluvium or that the surficial concentration of salts is leached down to the aquifer by infiltration.

There is also variation in the EC of base-flow in the wadis and the aflaj. The EC changes from about 415 mmhos/cm. in the headwaters of Falaj Masfut to more than 800 mmhos/cm. at the outfall of the falaj because of seepage of irrigation return through the sides of the falaj channel. Similarly, the EC of the base-flow in the upper reaches of Wadi Hadf (within Omani territory), is 770 mmhos/cm., but lower down the wadi, below Sinadel (within UAE territory), it rises to 1200 mmhos/cm., which is not only due to seepage from date gardens contributing to the higher TDS by the leaching of minerals, but also by the length of the journey of flow of the wadi waters.

Suitability of the water for agriculture (Table 6.6. and Fig. 6.7)

Irrigation water in the eastern part of the Muzeirea' fan (in the Masfut area proper) is of good quality with the salinity hazard being of the medium range (C_2) (analyses 1-4, Table 6.6). On the other hand, water abstracted in the central and western parts of the Muzeirea' fan tends to have ECs with a high salinity hazard (C_3) (analyses 13 and 14, Table 6.6.). The salinity exceeds 2500 mmhos/cm. The sodium content in most of the analyses in Table 6.6. is in the range of 2.0-8.0 meq/l with the exception of analyses 6 and 8 for Hatta (where Na values are 12.30 meq/l and 17.74 meq/l, respectively), and analyses 14 and 5 for Muzeirea' (13.78 meq/l and 17.17 meq/l), and also analysis 11 for Masfut (18.84 meq/l). These latter values exceed the permissible maximum limits of

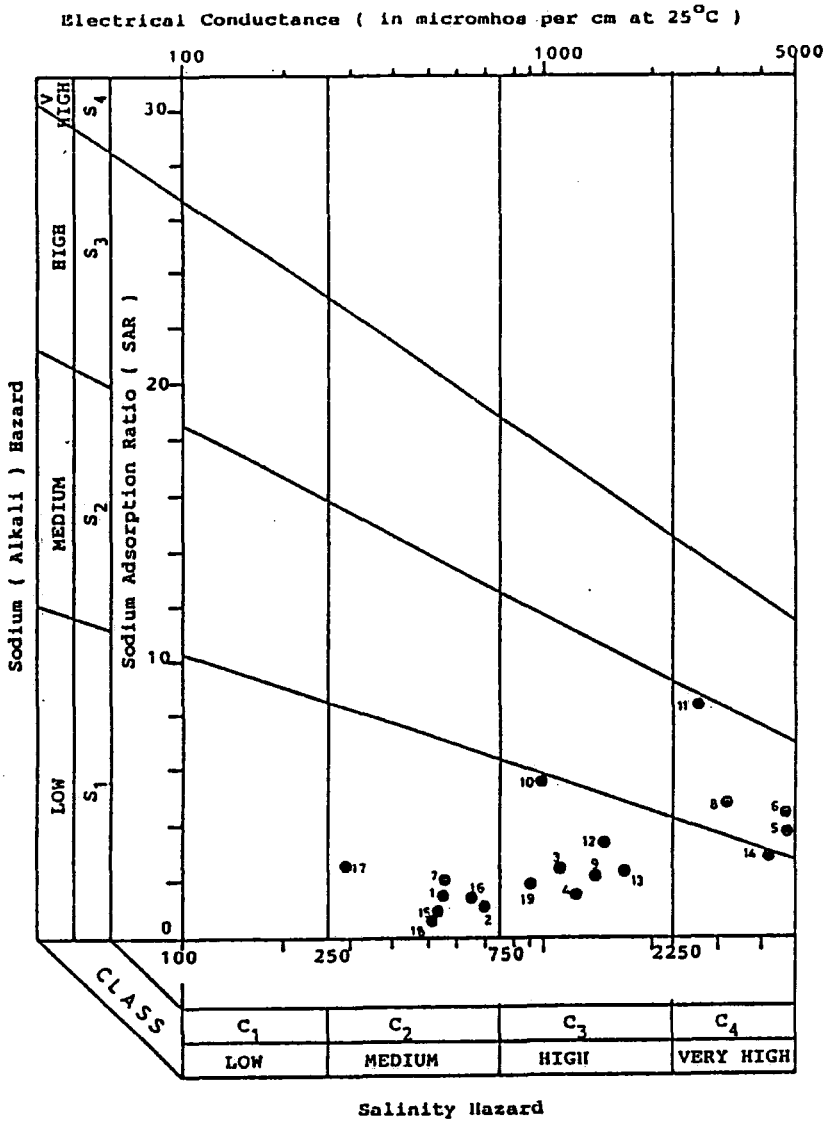


Figure: 6.7.

Irrigation water class of the waters of the mountain AREA 3 (the ophiolite peridotite and Hawasina metamorphics zone of the Masfut-Hatta-Huzeirea' intermontane basin).

Most of the waters of this zone fall in the C_2-C_3 (medium to high salinity), and S_1 (low sodium) hazard, class.

(The numbers in the figure refer to the water analyses in Table 6.6)

sodium for poor quality irrigation water. The magnesium content rarely exceeds 8.0 meq/l, and in the majority of the analyses, it is below 6.0 meq/l. Of the anions, chloride is high and appears to be linked with the high sodium values. More than half of the analyses show Cl values of over 7.0 meq/l, and half of these analyses are with values of over 14.0 meq/l. Bicarbonate is within the safe limit (of 8.0 meq/l) for drinking and no analyses appear to have values of more than 6.5 meq/l.

The SAR in this zone varies from 1.3 to 9.7, putting these waters within the range of low to medium sodium hazard. High salinity waters in places like Muzeirea', used for irrigation on non-saline soils for 15 years, have developed a high sodium content that has subsequently led to their hardening, which in turn reduced their permeability.

6.5.1.4. <u>The Hawasina metamorphics and volcanics Dibba Corridor zone</u> (Area 4 in Fig. 6.1, Table 6.7 and Figs. 6.8 and 6.9)

<u>Delineation of the zone</u>: This is the grabben that follows the Dibba-Idhn Fault Line. It is 11 km. across in its northeastern (Dibba) end and its southwestern (Idhn) end, but is 22 km. wide between Tuwaiyyain and Tayyebah. Its southern boundary is marked by the following line of villages, from northeast to southwest: Dibba, Wadi Dalam, Sinnah, Al Halah, Al 'Abadillah, Al Ghonah, Al Khulaibiyyah, Dhawahi, Masafi, then turns northwards through Al Beerah, 'Asimah, Khabakheb and Al Eiyaim (Fig. 6.8)

Its northern boundary is marked by the following line of villages, from northeast to southwest: Bajeel, Wadi Al Shaikh, Wa'abain, Tuwaiyyain; and in its western extremity lies the village of Idhn. (Fig. 6.8).

The zone is made up of Hawasina metamorphics, limestones and volcanics in a complicated juxtaposition. Limestones, marble and volcanics form the bulk of the subsurface geology in the western and northwestern half of the zone. These rocks are made up of quartzites, quartz schist, quartz mica schist, chloritic schist, crystalline marble and amphibolite. Limestones and metamorphics of the Hawasina series occur in the centre and in the triangular extension on both sides of Wadi Al

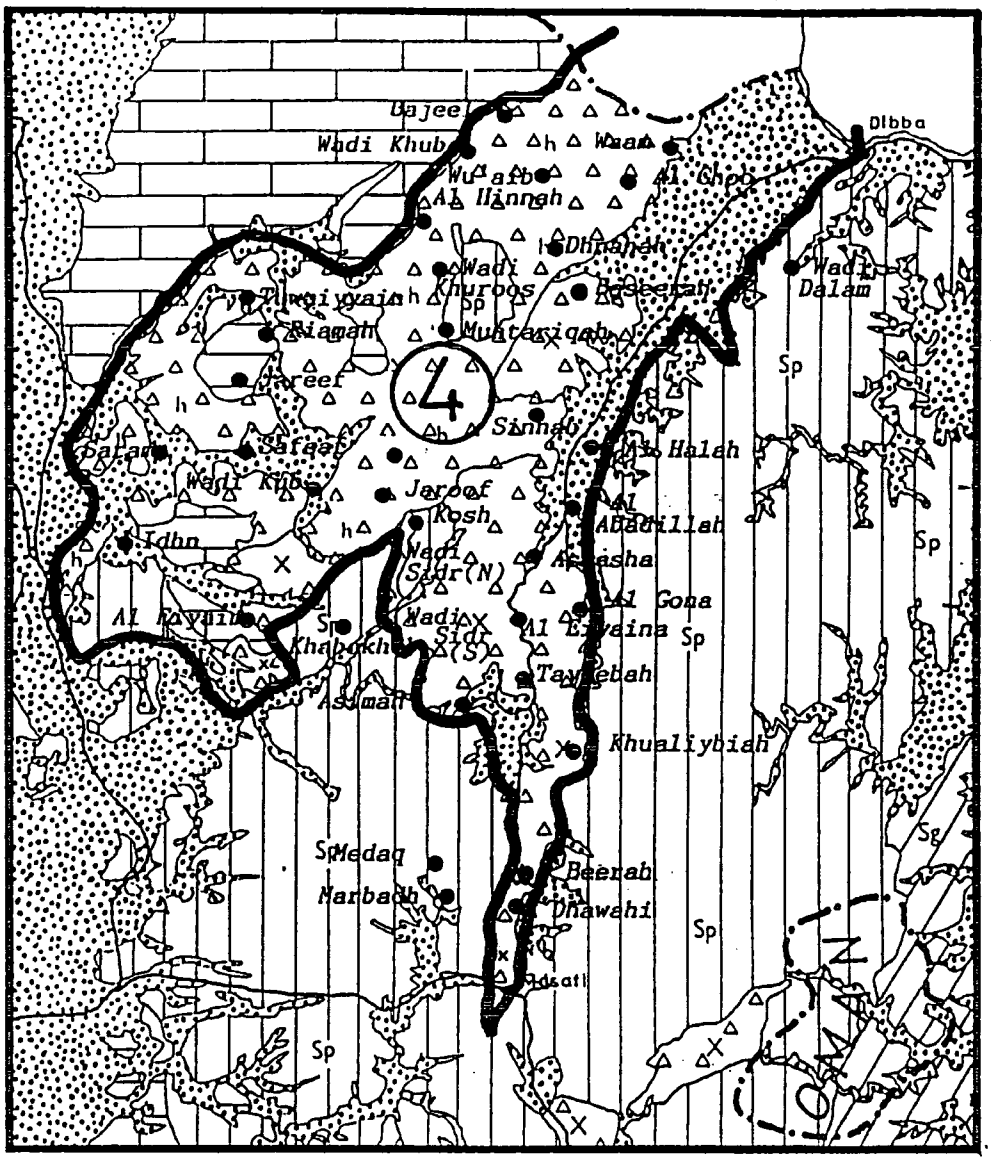


Figure: 6.8.

AREA 4 of the mountain zone: the Hawasina metamorphics and volcanics Dibba Corridor zone.

Delineation of the zone and locations of the water samples as given in Table 6.7.

'Abadillah between Al Ghonah and 'Asimah. The limestones are grey, brown and white with grey green shales and cherts. The volcanics consist of basic pillow lavas and agglomerates. There is a block of ultrabasic exposure to the east of Khuroos and Muhtariqah, and a block of Mussandam limestone and oolitic dolomite in the vicinity Jaroof and a third isolated block of Elphinstone-Ru'us Al Jibal limestones to the east of Idhn in the southwestern part of this zone. The Elphinstone and Ru'us Al Jibal limestones are a series of limestones, dolomites, shales, sandstones and cherts, marls and siltstones. Finally, there is an outcrop of silicified serpentinite ultrabasics to the north of Ramlat Sheesa in the southwestern extremity of the zone.

Waters rising in the ultrabasic peridotite block in the east, south and southeast of the zone are of good potable quality with ECs ranging from 736 mmhos/cm. (Dhawahi, analysis 5, Table 6.7.) to 1082 mmhos/cm. (Al Eiyyaim, analysis 2, Table 6.7.) and in a number of the analyses in Table 6.7. (analyses 1, 5, 6, 7, 9 10 and 11). A second grade quality water, ranging in EC from 1100 to 1700 mmhos/cm., is found in wadis that cross more than one rock type as in the northern part of the 'Corridor' in Wua'ib Al Hinnah (EC 1669 mmhos/cm.) and Wadi Al Ghob (EC 1710 mmhos/cm.), both of which flow eastwards into Wadi Al Shimal basin across Hawasina volcanics and limestones (analyses 18 and 20 in Table 6.7.). A third grade quality water (marginal) is found in wadis that rise and flow westwards in Hawasina volcanics, limestone and gravel, as in Wadi Saram (EC 4172 mmhos/cm.), Wadi Riyamah (EC 4975 mmhos/cm.) and Wadi Jareef (EC 4563 mmhos/cm.), which all rise north of Idhn and flow into Tuwaiyyain (analyses 3, 14 and 15, Table 6.7.).

The first grade waters tend to be of the bicarbonate type, whereas the second grade waters flowing across different geologies, are bicarbonate-sodium-chloride waters. The third grade waters, passing through limestone as well as alluvium, have high ECs, and are mostly sodium-chloride-sulphate waters.

The good quality water in Dhawahi (EC 736 mmhos/cm.), Al Ghonah (EC 644 mmhos/cm.), Al Khulaibiyyah (EC 1004 mmhos/cm.) and 'Asimah-Tayyebah (EC 690 mmhos/cm.) (analyses 5, 9, 6 and 8, Table 6.7) rise in, and cross, ultrabasic rocks of Zone 2 (described in section 6.5.1.2). 'Asimah (Tayyebah) derives its water from the wadi, that carries its name, which

has tributaries, such as Wadi Al Hiyail, which flows from the ultrabasic peridotite mountains in the south; and tributaries such as Wadi Faqi, which flows from the north across the Hawasina volcanics. The water of Al Gonah actually flows in barren rocks and is transported at one point by open canals hugging the steep slopes of the ravine-like wadi to irrigate date gardens tucked to the wadi side on a very narrow terrace. ECs of the water at Al Gonah would have been less had there not been some cultivation and free recirculation of irrigation water, returning to the ditch (actually a Ghaili falaj) from which the water sample was collected for analysis. Wadi Al Gonah flows into Wadi Al 'Abadillah, joining it under the road bridge on the Masafi-Dibba road.

The high ECs for Jareef (4569 mmhos/cm.) and Riyamah (4975 mmhos/cm.) (analyses 14 and 15, Table 6.7) can be explained by the fact that the waters of Wadi Riyamah rise in the limestones of the Mussandam Group which outcrop in an isolated block amidst Hawasina metamorphics; and the waters of Wadi Jareef rise and cross an area of Hawasina cherts and limestones. Tuwaiyyain (analysis 16, Table 6.7), which lies 2 km. to the north of Riyamah, has a better quality water because of fresh water input into Wadi Tuwaiyyain from several tributaries like Wadi Hayyar, Wadi al Khuroos and Wadi Al Muhtariqah. The last two wadis rise in a block of ultrabasic rocks surrounded by Hawasina metamorphics and volcanics; hence the good quality water at Tuwaiyyain (EC 920 mmhos/cm.).

It is usual in all low-salinity good quality recharge waters in catchment areas that the Mg content is higher than that for the Ca; the Ca-Mg ratio here is 1:3. The opposite is true with high-salinity marginal quality water, as at Riyamah (EC 4975 mmhos/cm.), where the Ca-Mg ratio is 1:1.

The interesting observation involving the Mg content in the three types of water in the Dibba Corridor was that waters that rise and cross the dolomitic limestones of the Mussandam Group and ultrabasic rocks tend to have higher Mg values (Wu'aib Al Hinnah, Mg:4.43 meq/l), than waters rising in ultrabasic rocks (Wadi al Sidr-South, Mg: 1.55 meq/l) (analyses 20 and 12, Table 6.7.). Waters of the ultrabasic peridotites and volcanic gabbros of the Semail ophiolites appear to have slightly less Mg content than those waters of the Hawasina volcanics and

Chemical analyses of the groundwater in the Mountain Area 4 (the Hawasina metamorphics and volcanics Dibba Corridor zone)

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Idhn	2142	1392	7.8	-	3.10	12.66	4.50	2.10	7.63	10.48	-	5.0	C_3 S_1
2. Al Eiyaim	1082	703	7.0	-	2.48	2.18	2.15	2.26	2.68	1.84	-	1.2	C_3 S_1
3. Wadi Sarram	4172	2287	7.3	-	5.36	23.20	7.11	4.74	4.74	26.16	-	12.0	C_3 S_1
4. Wadi Al Kub	2101	1366	7.4	-	3.50	10.35	5.38	2.10	4.74	12.37	-	6.7	C_3 S_1
5. Dhawahi	736	475	8.5	-	3.10	2.61	1.13	0.6	3.58	2.64	-	1.8	C_2 S_1
6. Al Khulaibiyah	1004	652	7.3	-	4.52	5.21	1.17	1.16	1.15	7.78	-	7.1	C_3 S_1
7. Al 'Abadillah	1035	672	7.6	-	4.32	3.72	1.17	1.17	1.15	6.87	-	6.2	C_3 S_1
8. Taiyyibah	999	649	7.4	-	3.81	4.93	1.39	1.13	3.71	5.28	-	3.4	C_3 S_1
9. Al Gona	644	419	7.7	-	1.75	3.48	0.86	0.52	3.71	1.90	-	1.3	C_2 S_1
10. Al Eiyainah	901	608	8.0	-	3.11	4.35	1.33	0.45	4.38	3.96	-	2.6	C_3 S_1
11. Wadi Sidr(North)	958	622	7.5	-	3.77	3.92	2.15	1.81	3.21	4.79	-	3.0	C_3 S_1
12. Wadi Sidr(South)	1669	1085	7.2	-	9.68	5.60	2.10	1.96	1.55	13.79	-	10.5	C_3 S_2
13. Jaroof	927	603	7.3	-	3.1	4.21	1.72	1.65	3.58	3.76	-	2.3	C_3 S_1
14. Jareef	4563	2966	7.7	-	2.27	24.11	10.73	4.94	3.71	28.44	-	13.5	C_4 S_2
15. Riamah	4975	3234	7.9	-	3.31	29.01	9.46	4.74	3.11	33.95	-	17.2	C_4 S_2
16. Tuwiyyain	920	598	7.9	-	3.00	2.60	1.70	1.20	5.11	1.00	-	0.6	C_3 S_1
17. Dhanhah	984	640	7.7	-	1.70	6.62	1.33	1.40	4.86	3.3	-	1.9	C_3 S_1
18. Al Ghob	1710	1112	7.7	-	6.18	8.56	2.36	1.49	4.58	10.93	-	6.3	C_3 S_1
19. Wum (Waam)	1009	656	7.7	-	1.81	5.11	1.59	1.48	4.03	3.00	-	1.8	C_3 S_1
20. Wu'aib Al Hinnah	1669	1085	7.9	-	4.90	6.10	2.40	1.03	4.43	7.89	-	4.8	C_3 S_1

EC in mmhos/cm. at 25°C; TDS in ppm.; ions in meq/l. Year of analysis 1988.

Table: 6.7.

Water chemical analyses of AREA 4 of the Hawasina metamorphics and volcanics zone of the Dibba Corridor. (Figs. 6.1, 6.8 and 6.9)

This zone is mostly made up of a melange (mixture) of Hawasina metamorphics and volcanics, which are rich in quartzite, schist, mica, marble and amphibolite.

Waters that flow from the ophiolite mountain block to the south (analyses 5 and 6 for Dhawahi and Al Khulaibiyyah) are of a better quality than waters that rise in the limestone mountains to the north (analysis 20 for Wu'aib Al Hinnah). ECs are lower (below 1000mmhos/cm) in the waters that flow into the Corridor from the ultrabasic mountain block to the east, south and southeast, than waters that flow across upland of mixed geological make-up in the northern part of the Corridor (Wu'aib Al Hinnah and Wadi Al Ghob (1000-2000mmhos/cm)).

The good quality waters are of the HCO_3 type, the medium quality waters are of the HCO_3-Na-Cl type and the third quality water, flowing in limestone and alluvial terrains, is of the Na-Cl-SO_4 type. The high Cl, SO_4 and Na content in the waters of the Dibba Corridor make them of a marginal-to-poor quality for potable use. Irrigation water is mostly of the C_3 (high salinity hazard) and S_1 (low sodium hazard) class.

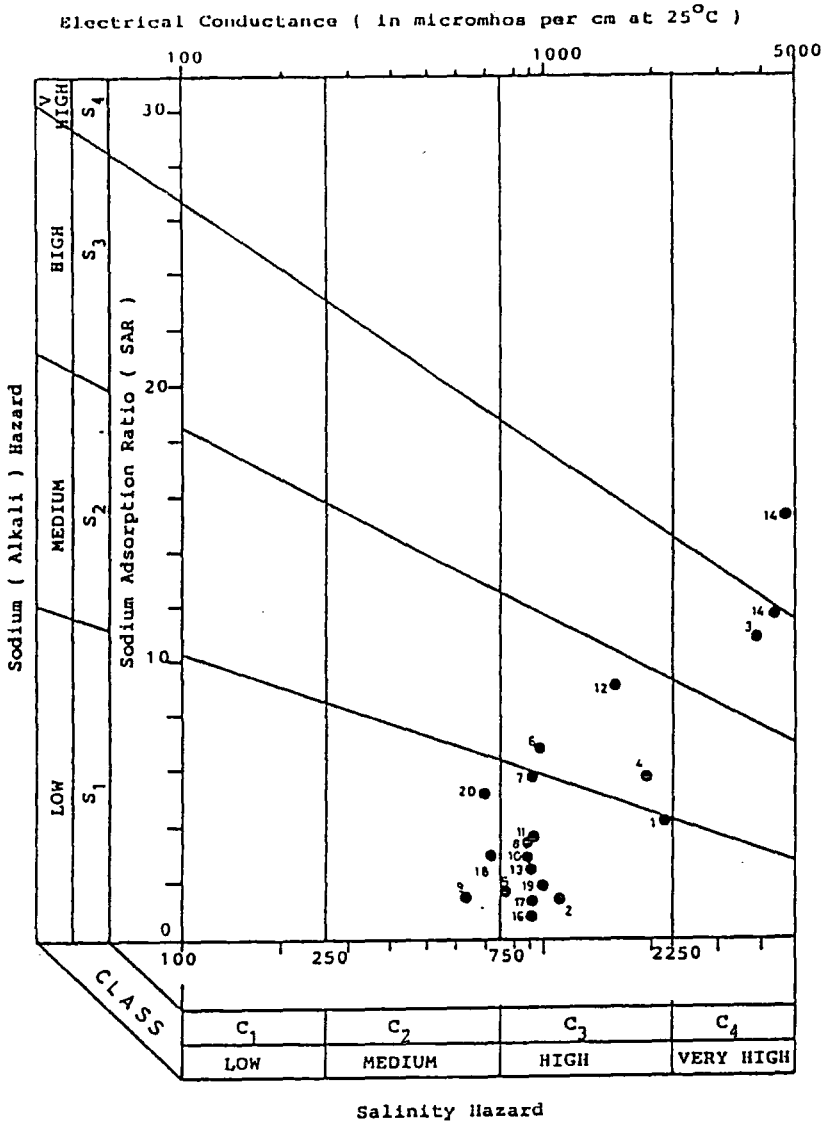


Figure: 6.9.

Irrigation water class of the waters of the Hawasina metamorphics and volcanics Dibba Corridor zone.

The irrigation water class in the Dibba Corridor is generally of the C_3 S_1, of the very high salinity and low sodium hazard, class.

(The numbers in the figure refer to the water analyses in Table 6.7)

metamorphics (Al Khulaibiyyah 1.15 meq/l, and Wadi Al Sidr North 3.21 meq/l, respectively; analyses 6 and 11, Table 6.7.). Ca is also higher in waters of the Hawasina volcanics than in waters of the ultrabasics, due to the preponderance of amphibolite, hornblende and schist (Al Khulaibiyyah 1.15 meq/l and Dhawahi 0.6 meq/l)(analyses 6 and 5, Table 6.7).

Suitability of the water for human consumption

As far as the suitability of water for human consumption is concerned, the high Cl, SO_4 and Na content makes the water in this zone marginal to poor in quality for drinking. As was observed in the field, water supplied by the MEW to the bedouin hamlets, is unchlorinated, making the water hygienically unsafe, besides being marginal in quality.

Suitability of the water for agriculture (Fig. 6.9)

Na is the dominant cation in the waters of the Dibba Corridor followed by Mg. Na values range from a low of 1.0 meq/l at Tuwaiyyain, in the heart of the Hawasina volcanics, to a high of 33.95 meq/l at Riamah, which is situated in the northwestern part of the Dibba Corridor, just to the south of Tuwaiyyain, in an area of complex geological make-up of Hawasina cherts and limestones, dolomites and volcanics of both the Hawasina and the semail ophiolites. It is this high Na content, especially in Wadi Saram, Jareef and Riamah (Table 6.9), that renders the waters in the Dibba Corridor hazardous for agriculture. Generally, in the whole zone, SAR values range from 0.6 (Tuwaiyyain) to 7.1 (Al Khulaibiyyah) and the irrigation water class is of the C_3 S_1, which is of the high salinity hazard (C_3) and low sodium hazard (S_1). The SAR values are above 13.0, as at Jareef and Riyamah (13.5 and 17.2,respectively), and the irrigation water class is C_4 S_2, which is of the high salinity hazard and medium sodium hazard.

6.5.1.5. The Hajar Limestone Massif of Ru'us Al Jibal zone

(Area 5 in Fig. 6.1; Table 6.8. and Figs. 6.10 and 6.11)

Delineation of the zone: This is the northern limestone zone to the north of the Dibba Corridor (Zone 4, section 6.5.1.4.). It is delineated in the south by a line from Wadi Bageel (north of Dibba) to a

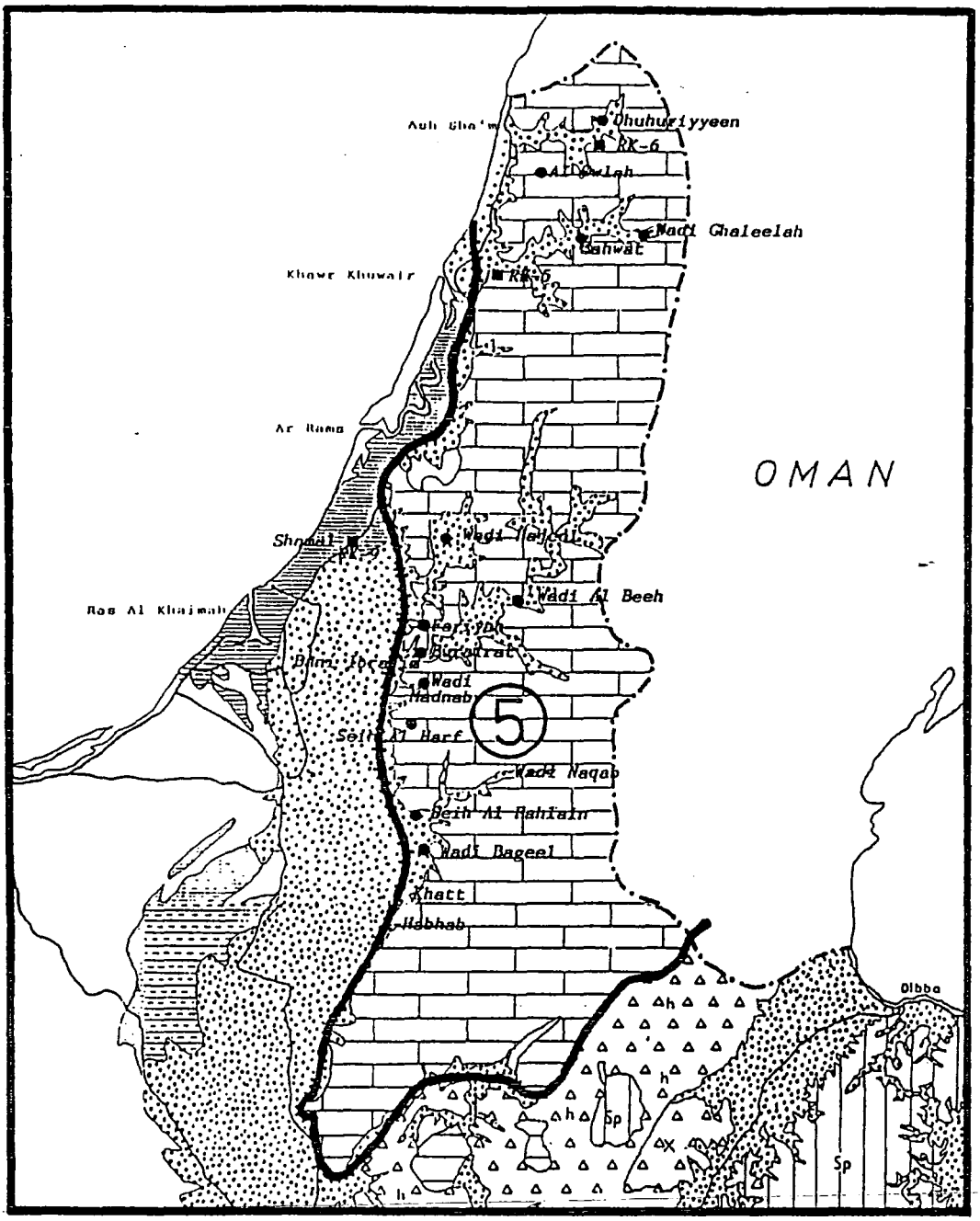


Figure: 6.10.

AREA 5 of the mountain zone: the Hajar carbonate massif of Ru'us Al Jibal.

Delineation of the zone and locations of the water samples as given in Table 6.8.

point north of Tuwaiyyain, and further west to a point north of Um Al 'Arj in the Jiri Plain. On the east, it is bounded by the international border with Oman in the Mussandam peninsula running 15 km. to the east of the Ras Al Khaimah coastline. On the west, the zone is limited by the Seer Plain along a line joining Habhab, Seih Al Beer, Seih Al Harf, Bani Ibrahim, Shamal, Al Khaisah and Sharm. The farthest point in the north of this zone is Dhuhuriyyeen in the extreme north. (Fig. 6.10).

ECs in this region are all above 2300 mmhos/cm. except for the water analyses 7, 12, 13 and 14 (Table 6.8.). The pH value is between 7.0 and 8.0 but exceeds 8.0 in Wadi Al Beeh and Wadi Bageel, and is below 7.0 in Dhuhuriyyeen (6.1). The most dominant cation is sodium, and the most dominant anion is chloride and both ions, in most of the analyses in Table 6.8., exceed the maximum acceptable limit for drinking. The Mg-Ca ratio has a minimum of 1:2, as in Al Beer, and Sahwat, but is mostly 1:5, as for most of the analyses, such as those for Al Owla and Al Burairat (samples 5, 7, 8 and 2 in Table 6.8.).

Bicarbonate values are all below 4.0 meq/l, except for Wadi Bageel (analysis 10, Table 6.8.) where it is 6.67 meq/l and in Dhuhuriyyeen, where the value is the lowest in this limestone zone (1.89 meq/l, analysis 11, Table 6.8.). Sulphate is noticeably low, ranging from a minimum value of 1.03 meq/l in Well RK-6 (analysis 14) to a maximum value of 5.36 meq/l in Fariyah (analyses 3 and 5, Table 6.8.).

6.5.1.5.1. **Groundwater quality in the Deep Wells Project Wells RK-5, RK-6 and RK-9 in the northern carbonate massif of Ru'us Al Jibal** (analyses 13, 14 and 15 in Table 6.8 (Fig. 6.10)

RK-5 was drilled to a depth of 315m. in Wadi Sha'am (1985). The aquifers penetrated were the alluvial aquifer (30m. thick), which showed ECs of approximately 800 mmhos/cm., and in which the SWL in the alluvium stood at 57m. below the surface. The other aquifer was in the Ghaleelah Limestone Formation below 57m. with ECs averaging 1600 mmhos/cm.

The difference in conductivities between the two layers is explained by the high permeabilities of the alluvial (8m/d), aquifer and the lower permeabilities of the limestone aquifer (0.8m/d, or 1/10th of that in

Chemical analyses of groundwater in the Mountain Area 5 (the limestone of the Hajar Mountains of Ru'us Al Jibal).

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Wadi Madnab	3265	2122	7.4	-	3.40	23.20	4.0	3.90	4.12	22.62	-	11.3	C_4 S_2
2. Al Burairat	5253	3677	7.1	-	3.03	42.10	4.30	5.05	6.71	37.66	-	15.5	C_4 S_2
3. Fariyah	3203	2082	7.3	-	2.90	20.02	5.36	5.56	3.60	19.10	-	8.9	C_4 S_2
4. Wadi Al Beeh	3142	2042	8.4	-	2.80	24.71	2.35	3.86	4.29	21.71	-	10.8	C_4 S_1
5. Al Beer	2657	1727	7.6	-	4.12	16.97	3.54	4.32	3.29	16.97	-	8.7	C_4 S_2
6. Wadi Ghaleelah (upstream)	690	449	7.6	-	2.47	0.73	1.18	1.44	1.44	1.48	-	1.2	C_2 S_1
7. Wadi Ghaleelah at Sahwat(downstream)	4002	2601	7.2	-	2.46	28.28	3.65	6.14	5.60	22.67	-	9.4	C_4 S_1
8. Al Owlah	2328	1513	7.2	-	2.10	17.30	1.93	5.25	4.84	11.29	-	5.0	C_4 S_1
9. Bani Ibrahim	3008	1955	7.3	-	2.54	22.29	2.36	4.33	3.48	19.35	-	9.8	C_4 S_1
10. Wadi Bajeel	3018	1962	8.2	-	6.67	11.61	4.18	1.65	4.76	16.06	-	9.3	C_4 S_1
11. Dhuhuriyyeen	2532	1646	6.2	-	1.89	18.89	3.82	3.78	3.68	17.14	-	8.9	C_4 S_1
12. Wadi Haqeel	1794	1166	7.1	-	3.31	10.35	3.80	2.41	1.92	13.3	-	9.1	C_3 S_1
Wells of the Deep Wells Project													
13. RK-5 Sha'am	1123	730	7.6	-	3.91	5.15	2.06	2.06	2.68	6.39	-	4.2	C_3 S_1
14. RK-6 Al Beeh	793	516	7.7	-	2.88	4.12	1.03	2.06	2.68	3.29	-	2.1	C_2 S_1
15. RK-9 in Sahwat	3780	2457	7.3	-	3.09	30.87	4.53	5.77	5.39	27.27	-	11.6	C_4 S_1

EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Year of analysis 1988.

Table: 6.8.

Water chemical analyses of AREA 5 of the part of the Limestone mountain block of Ru'us Al Jibal zone that lies within the Emirates, including analyses of the three deep Wells RK-5, RK-6 and RK-9 of the Deep Wells Project. (Figs. 6.1, 6.10 and 6.11)

ECs of the waters of this limestone massif of Ru'us Al Jibal are all above 2300mmhos/cm, except for analyses 7, 12, 13 and 14. The dominant cation is Na and the dominant anion is Cl, the concentration of both of which exceed the maximum allowable limits for drinking water. There is stratification of groundwater salinity in the limestone aquifer, as in Well RK-9 in Wadi Ghaleelah (analysis 15), drilled to a total depth of 216m., where groundwater salinity differs in three different overlapping depths: at about 100m., the EC is 3300mmhos/cm; at a depth of about 180m., the EC is 1700mmhos/cm and at a depth of over 200m. the EC is 3500mmhos/cm. The waters in this zone are mostly unpotable. The irrigation water is of the C_4 (very high salinity) and S_1 (low sodium) hazard, class.

the alluvium) (Geoconsult-Iwaco basic data on the wells for the Deep Wells Project, 1982-86).

Well RK-6 was drilled in the upper part of Wadi Al Beeh near the border with Oman to a depth of 402m.(1985). The alluvium was found to be 129m. thick but contained no water; only in the Hajeel limestone formation beneath the alluvium, at a depth of 142m. below the surface, was water encountered with good quantity and quality. The EC was found to be below 800 mmhos/cm.

The permeability at a depth of 170m from the surface was found to be very high, though no actual figure was offered by the Deep Wells Project. The discharge rate of the well was $40m^3/h.$, which, after 3 hours of continuous pumping, took only 4 minutes to recover. This fast recovery suggested the occurrence of groundwater in bedding planes. There was no change in groundwater quality after three hours of pumping (800 mmhos/cm.).

Well RK-9, was drilled in Wadi Ghaleelah to a total depth of 216m. (1985). It penetrated 69m. of alluvial mantle before it penetrated dolomitic limestone of the Milaha Formation (Late Triassic) down to the total depth of the well (the Ghaleelah Formation is exposed on the sides of Wadi Ghaleelah). The well was drilled in a fault trending NW-SE as was the case with both RK-5 and RK-6. The SWL stood at 79m. (1985).

There was stratification of salinity in the limestone aquifer in Well RK-9 at three intervals: from 79m. to 180m., the average EC was found to be 3300 mmhos/cm.; from 180m. to 172m. the EC was 1700 mmhos/cm.; and between 172m. to 213m. it was found to be 3500 mmhos/cm. The thickness of the saturated layer was estimated to be 133m. and the permeability was 1.9m/d. After two hours of pumping, the EC was 2200 mmhos/cm. from the combined sections of the saturated layer. A water sample taken to the laboratory for this study from RK-9 (at the same time the pumping tests were underway in January, 1985) gave an EC value of 3670 mmhos/cm. after several hours of pumping.

Suitability of the water for human consumption

With the maximum allowable TDS limit for potable water being 1500 ppm,

there are only few analyses in Table 6.8. that qualify for drinking. RK-5 and RK-6 are exploratory wells that are not meant for production despite the relatively good quality of their waters. This area is known for wells becoming highly saline as pumping proceeds; when deterioration in the water quality of a well reaches an unusable limit, wells are either deepened (with the likelihood of striking worse quality groundwater) or new wells are drilled further up a wadi. Although the TDS exceeds 2000 ppm (EC 2700 mmhos/cm.) in many wells, the water is used for drinking.

Suitability of the water for agriculture (Fig. 6.11)

The SAR values for 30% of the analyses in Table 6.8. are above 10. The value for Burairat (analysis 2, Table 6.8.), which is 15.5, is the highest in this zone. Most of the waters fall in the C_4 S_1 irrigation water class of very high salinity and low sodium hazard. Only one sample (analysis 6 for upstream Wadi Ghaleelah, Table 6.8) and also that for RK-6 (analysis 14 in Table 6.8.) are of the C_2 S_1 irrigation water class.

Water quality of Al Burairat and Al Beeh wellfields (analyses 2 and 4, Table 6.8)

Water abstraction in Al Burairat Wellfield started in 1965 with groundwater ECs of between 500-600 mmhos/cm. By 1977, when the Burairat RO plant started operating relying on intake water from the wellfield, 20 wells were in operation and the EC for the whole wellfield averaged 4700 mmhos/cm. By 1980, the EC had increased to 6900 mmhos/cm. and by 1987 the number of wells had shrunk to only 4 because of rising salinity.

As the boreholes are continuously being deepened, or substituted by new ones in Al Burairat, the EC fluctuates but remains within the general worsening trend. The average EC of the water of the 4 wells in 1987 ranged from 3700 to 6420 mmhos/cm. In 1988 two new wells were drilled to upgrade the quality of the intake water for the RO from the Burairat Wellfield the ECs of these two new wells averaged 1800-2000 mmhos/cm.

Wadi Al Beeh Wellfield, situated 5km. upstream of Al Burairat Wellfield,

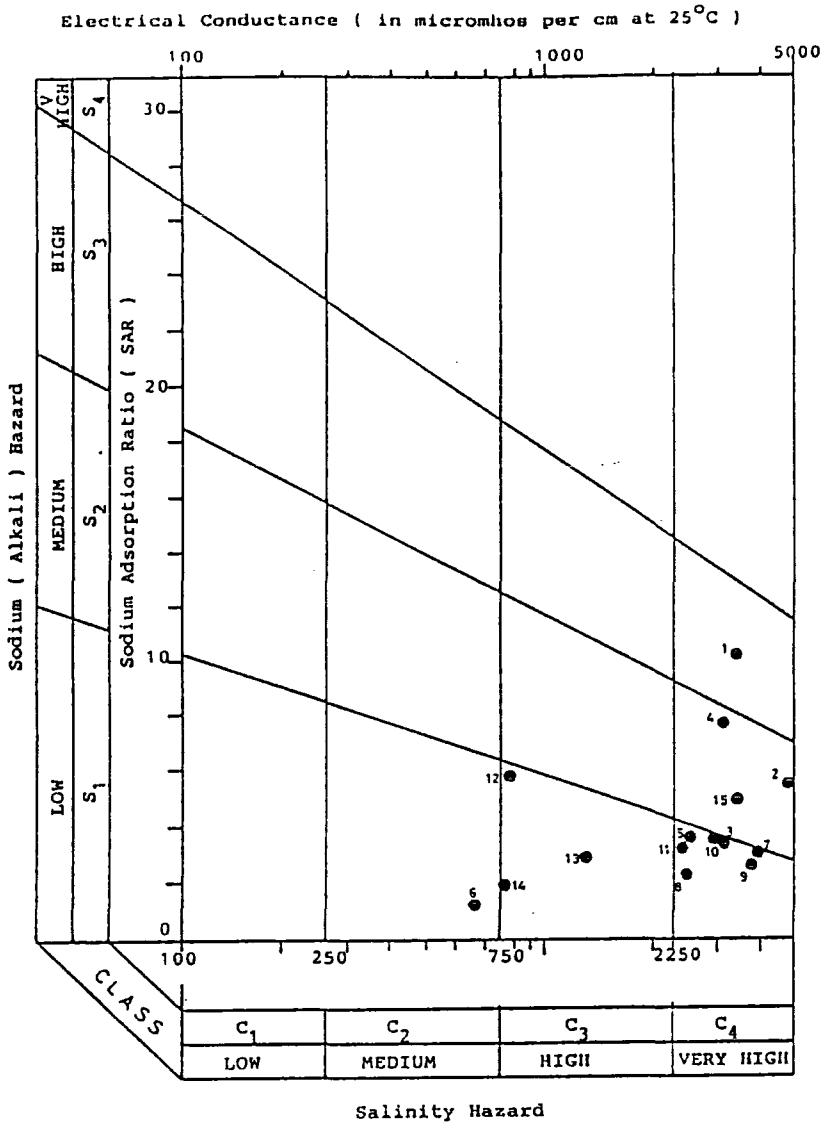


Figure 6.11.

Irrigation water class of the waters of the Hajar carbonate massif of Ru'us Al Jibal zone.

The waters are mostly of the C_3-C_4 (high to very high salinity hazard) and S_1-S_2 (low to medium sodium hazard) class.

(The numbers in the figure refer to the water analyses in Table 6.8)

had in 1988 23 operating wells with ECs ranging from 975 mmhos/cm. to 6240 mmhos/cm., with the average EC for all the wells being 3050 mmhos/cm. New wells in Wadi Al Beeh start with low ECs that then rapidly deteriorate as pumping continues. Downstream in the outwash fan in the Jiri Plain the EC values are four times greater.

6.5.2. The Lowland Zone

6.5.2.1. General

The water chemistry and quality of the lowlands of the Emirates are treated in two main sections: the western and eastern piedmont plains; and the desert foreland. The latter will be discussed in section 6.5.3. The western and eastern (Batinah) piedmont plains are subdivided into the following parts :

(i) The northern part of the western alluvial piedmont plains (from Falaj Al Mualla to Al Jiri Plain) (marked 6a in Fig. 6.1.).

(ii) The central part of the western alluvial piedmont plains (from Falaj Al Mualla to Al Madam) (marked 6b in Fig. 6.1.).

(iii) The southern part of the western alluvial piedmont plains of Al Ain (from Ghashabah to Um Ghafah) (marked 6c in Fig. 6.28).

(iv) The east coast alluvial piedmont plains (from Khawr Kalba in the south to Dibba in the north). (marked 7 in Fig. 6.1.).

The eastern piedmont plains are treated as a single unit from Kalba to Dibba with special attention on the Wadi Ham outwash fan and the Wadi Al Baseerah Basin.

Water chemistry and quality in the piedmont plains are affected by the following factors :

(i) Proximity to the recharge zone in the foothills on either side of the mountains: good quality water is found in wells that are located close to the recharge zones, or in buried wadi channels though these wells may be far from the foothills. In both instances groundwater of such good quality is found in the Quaternary alluvium.

(ii) Highly transmissive Quaternary alluvial and aeolian deposits, and less transmissive indurated Tertiary alluvium, shaly clastics (the Juweiza Formation) or salty evaporite (Oligo-Miocene Lower Fars) sequences : The Quaternary deposits in general are bearers of good quality water, except where they contain substantial amounts of clay and silt, which reduce water quality to marginality. The Tertiary deposits, whether in the form of old indurated alluvium, as occurs in the mountain wadis or parts of the plains; or carbonate clastics in a shale matrix of the Juweiza flysch, that underlie most of the northern part of the piedmont plains (in the Northern Emirates); or yet, the thick clay-marl-evaporite-gypsum-halite sequence that underlies the Quaternary sands and gravels in the whole of Abu Dhabi, are medium to poor transmitters of groundwater, which, together with their salty composition, give rise to poor quality brackish to supersaline waters.

(iii) Inland sabkhas and trapped ancient marine waters: Poor quality water is found in wells tapping groundwater in or near inland sabkhas, or those drawing water from old trapped marine lenses, or from ponded groundwater by impediments of subsurface geology, such as to the east of Jabal Fayah in the Ghareef Plain.

6.5.2.2. **The northern part of the western alluvial piedmont plains (from Falaj al Mualla to Al Jiri Plain)**

(marked 6a in Fig. 6.1.; Table 6.9 and Figs. 6.12 and 6.13)

In the northern parts of the piedmont plains, to the north of Seih Al Fahlain, ECs are higher (2000-4000 mmhos/cm., analyses 1-8, Table 6.9) than those for waters to the south of Seih Al Fahlain (1000-3000 mmhos/cm., analyses 9-12, Table 6.9). Points like Um Al 'Arj, Tawi Sohailah and Al Manama (analyses 13, 15 and 16, Table 6.9), where groundwater quality is relatively better, are points in the plains facing the outlets of wadis as they leave the hardrock catchment area in the mountains to the east, where enough fresh groundwater head is available. Wadi Idhn is responsible for the low EC in Um Al 'Arj; Wadis Al Sidr and Safsaf are responsible for the low ECs in Tawi Sohailah, while throughflow from various small wadis, together, is responsible for the low EC at Al Manama(Fig. 6.12).

ECs for Al Dhaid area range from 900 mmhos/cm. for recently drilled wells, to well over 3000 mmhos/cm. (in the old Dhaid wellfield ECs reached 2826 mmhos/cm. in November 1988). Generally, the ECs of groundwater, drawn from both the Quaternary alluvium and Juweiza clays range from 1800-2500 mmhos/cm.; ECs for waters drawn from the Hajar limestone aquifers, underlying these southern plains, range from 1000-4000 mmhos/cm.. ECs of waters drawn totally from the Juweiza formation range from 2000-11,500 mmhos/cm. (average 3000 mmhos/cm.).

The dominant cation is Na and the dominant anion is Cl, making the waters to the north of Seih Al Fahlain of the NaCl type. Na values exceed 20.00 meq/l in 70% of the water analyses (Table 6.9), while those for Cl are even higher (23.00 meq/l). In both cases the maximum allowable limits for drinking and irrigation water are exceeded. The highest Na and Cl values are found in Seih Al Ghob where they are 24.00 meq/l and 29.00 meq/l respectively (analysis 2, Table 6.9). The lowest values for Na and Cl for any location to the north of Al Dhaid are found at Al Jaheeli and Um Al 'Arj where they are 7.00 meq/l and 7.52 meq/l for Na, and 6.34 meq/l and 5.59 for Cl, respectively (analyses 10 and 13, Table 6.9).

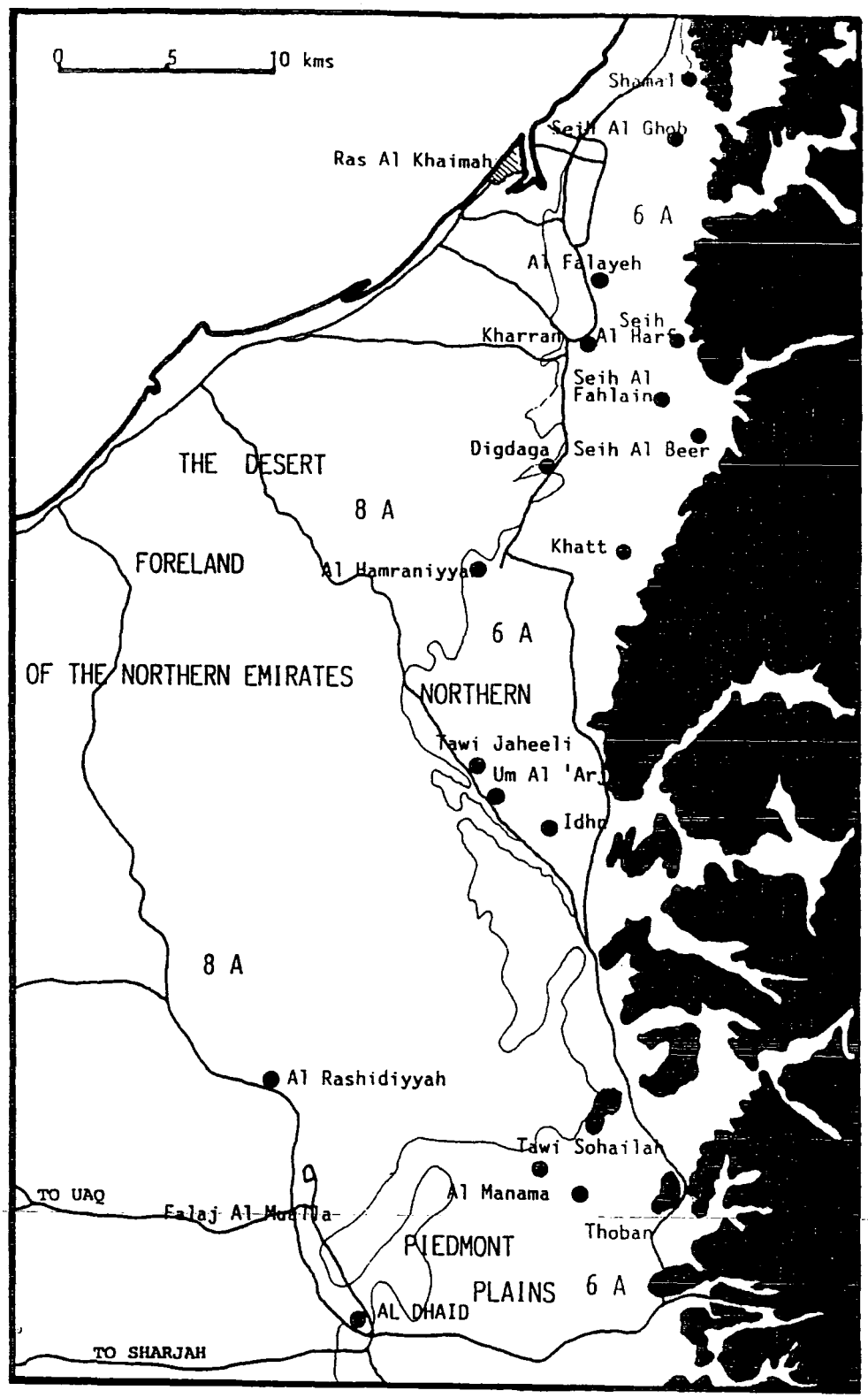


Figure: 6.12.

Delineation of the northern part of the piedmont plains from Falaj Al Mualla to Al Jiri Plain.

(The places marked with dots on the map coincide with the names in Table 6.9.)

HCO_3 concentration is between 3.00-4.50 meq/l in all the points north of Al Dhaid and this range is within the safe limits for both potable and irrigation water. SO_4 ranges in concentration from 2.00-4.60 meq/l, also within the safe allowable drinking and irrigation water limits. Ca is higher than Mg in these waters, with the Mg-Ca ratio varying from 1:1.5 to 1:2.0. The highest Ca and Mg values are at Shamal and Seih Al Ghob (analyses 1 and 2, Table 6.9), where they are above the maximum limits of water for both potable and agricultural use; but in all the other analyses they are within the acceptable limits.

Suitability of water for human consumption

The EC and TDS of groundwater of the Seih Al Fahlain Wellfield (MEW wellfield supplying Ras Al Khaimah town) range from 2800-7200 mmhos/cm. (EC) and 1800-4155 ppm. (TDS) for water meant for human consumption. Groundwater of acceptable quality for human consumption occurs near the foothills of the mountains as at Tawi Sohailah, Manama, Um Al 'Arj, Tawi Jaheeli and Al Dhaid (Table 6.9). Groundwater elsewhere, as shown in Table 6.9 is of unpotable quality, with the TDS increasing markedly during the summer making the waters more unacceptable for human consumption during that season. Even the waters of acceptable to marginal quality are of the sodium-chloride-sulphate type, like the rest of the poor quality water of the whole zone.

Suitability of water for agricultural use: (Fig. 6.13)

The quality of the water for irrigation in this zone is clearly illustrated in the SAR and irrigation water classification data in Table 6.9. SAR values range from 4.3 to 11.7, with the highest values being in Shamal, Seih Al ghob and Seih Al Harf (analyses 1, 2 and 5, Table 6.9). The irrigation water of this zone falls in the C_3 - C_4 high to very high salinity hazard, and S_1-S_2 low to medium sodium hazard. The poorest irrigation waters are found at Shamal, Seih al Ghob, Digdaga, Seih Al Harf, Al Falayeh and Al Rashidiyyah. Digdaga is an important traditional agricultural area (Fig. 6.13).

The Western Piedmont Plains, the section to the north of Al Dhaid in the Northern Emirates (AREA 6A) In meq/l

LOCATION	EC	TDS	pH	NO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Shamal	3842	2497	7.6	0.16	3.71	28.50	3.54	5.77	5.77	23.91	0.40	10.0	C_4 S_2
2. Seih Al Ghob	3677	2390	7.3	0.09	3.29	29.01	2.79	5.41	5.25	24.00	0.39	10.3	C_4 S_2
3. Kharran	3564	2317	7.6	0.06	3.71	21.66	4.39	6.59	3.91	18.54	0.41	8.1	C_4 S_1
4. Digdaga	3512	2283	7.4	0.06	3.91	24.23	4.51	5.36	4.22	22.84	0.24	10.4	C_4 S_2
5. Seih Al Harf	2709	1761	7.5	0.08	3.71	17.99	3.76	3.50	2.10	19.61	0.37	11.7	C_4 S_2
6. Al Falayeh	3523	2290	7.3	0.15	3.50	24.40	4.51	5.20	3.90	23.02	0.42	10.8	C_4 S_2
7. Al Beer	2657	1727	7.6	0.14	4.12	16.97	3.54	4.12	3.29	16.97	0.24	8.8	C_4 S_2
8. Seih Al Fahlain	2771	1801	7.6	0.11	4.12	18.57	3.00	3.91	3.71	17.78	0.41	9.1	C_4 S_1
9. Al Hamraniyah	1926	1252	7.4	0.11	3.09	12.04	3.97	2.06	4.94	12.09	0.29	6.5	C_3 S_1
10. Al Jaheeli	1365	887	7.4	0.07	2.68	6.34	3.21	1.24	4.00	7.00	-	4.3	C_3 S_1
11. Khatt Spring (N)	2960	1924	7.2	-	4.02	15.15	3.95	4.23	2.58	16.17	0.21	8.8	C_4 S_1
12. Khatt Spring (S)	2900	1885	7.2	-	3.99	15.11	3.93	4.20	2.58	16.11	0.21	8.8	C_4 S_1
13. Um Al 'Arj	1200	780	7.2	-	3.71	5.95	3.43	1.24	4.33	7.52	-	4.5	C_3 S_1
14. Al Rashidiyyah North of F. Mualla	3605	2343	7.7	0.14	4.50	24.95	5.52	2.27	7.00	24.32	0.41	11.3	C_4 S_2
15. Tawi Sohailah	1875	1219	7.8	-	3.90	13.10	2.79	1.34	3.10	15.10	0.24	10.1	C_3 S_2
16. Al Manama	1735	1128	7.5	0.07	3.40	11.10	2.81	1.0	4.00	12.10	0.24	7.7	C_3 S_2
17. Al Dhaid	2018	1312	7.4	0.09	4.11	10.39	4.19	0.97	3.51	13.71	0.40	9.1	C_3 S_1

EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Year of analysis 1988.

Table: 6.9.

Water chemical analyses of AREA 6 (A) of the northern part of the western piedmont plains from Falaj Al Mualla to Al Jiri Plain.

ECs of the waters of the part of the northern piedmont plains from from Seih Al Fahlain to Al Dhaid (analyses 9-13 and 15-17) are lower than those for waters of the part to the north of Seih Al Fahlain (analyses 1-8). ECs of the part of the plains to the north of Seih Al Fahlain average 2000-4000mmhos/cm, while ECs for the part to the south of Seih Al Fahlain average 1000-3000mmhos/cm. Points like Um Al 'Arj on the plains have better (lower) ECs because they face the mouths of wadis as they leave the mountains (in the case of Um Al 'Arj, the mouth of Wadi Idhn). ECs for waters in Al Dhaid range from 900mmhos/cm. for a recently drilled well, to over 3000mmhos/cm. for an old well (e.g., ECs in the old Al Dhaid wellfield average 2826mmhos/cm.). The higher ECs in Al Dhaid are usually for groundwater drawn from the shaly Tertiary Juweiza Formation.

The waters have high values of HCO_3, Cl, Ca and Na and are of the acceptable potable quality in the parts of the plains nearer to the foothills, such as at Tawi Jaheeli, Um Al 'Arj and Manama (analyses 10, 13 and 16). Waters of both potable and marginal quality are of the Na-Cl-SO_4 type. The irrigation water class of the parts of the plains north of Al Dhaid is generally of the C_3-C_4 (high to very high salinity hazard) and the S_1-S_2 (low to medium sodium hazard).

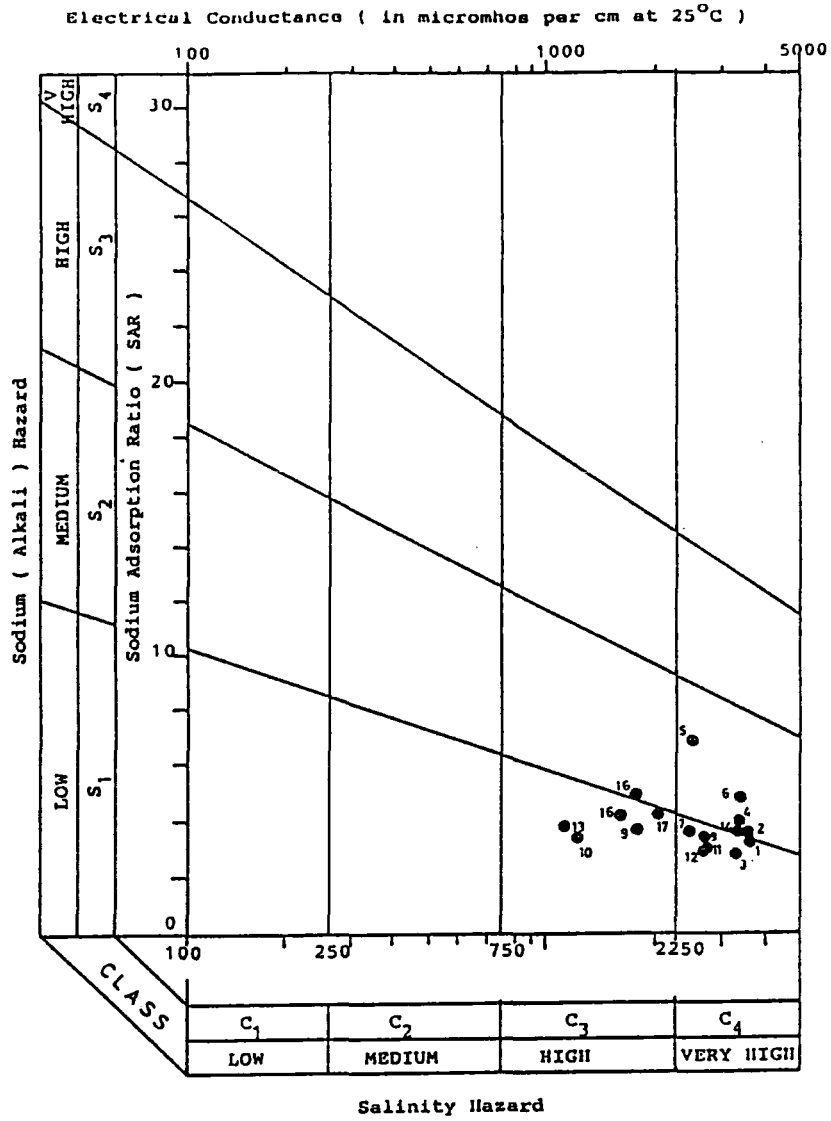


Figure: 6.13.

Irrigation water class of the waters of the northern part of the piedmont plains from Falaj Al Mualla to Al Jiri Plain.

The irrigation water class is generally of the C_3-C_4 (high to very high salinity hazard) and S_1 S_2 (low to medium sodium hazard) class.

(The numbers in the figure refer to the analyses in Table 6.9)

6.5.2.3. **The central part of the western alluvial piedmont plains (from Falaj Al Mualla to Al Madam)**
(marked 6b in Fig. 6.1.) (Table 6.10) (Figs. 6.14 and 6.15)

ECs of groundwater in the western piedmont plains between Seih Al Fahlain in the north and Tawi Mileiha in the south, are lower than those to the north of Seih Al Fahlain. They range from 1000 and 2000 mmhos/cm., though in some localities they exceed 2000 mmhos/cm., as in Fareej Al Kindi (2668 mmhos/cm.), Tawi Khalfan (5686 mmhos/cm.) and Mileiha (3049 mmhos/cm.) (Table 6.10).

Na and Cl still dominate the composition of groundwater, though in lesser amounts than those in the waters north of Al Dhaid. The Ca-Mg ratio varies from 1:1.5 for Hamdah (analysis 4, Table 6.10) some distance from the foothills, to 1:8 for Thoban (analysis 1, Table 6.10) at the point where Wadi Thoban leaves the mountains at Tawi Huwayrah (recharge waters). However, the high EC for Tawi Khalfan (5686 mmhos/cm., analysis 6, Table 6.10), which is on the northwestern side of Jabal Mileih, is most likely to be due to the fact that the Fayah-Mileiha anticline acts as a barrier to fresh groundwater movement from the main mountain block to the east, the slow movement of groundwater to the west of the anticline and also the presence of the clayey Juweiza formation that underlies the Quaternary alluvium.

This high EC in Tawi Khalfan does not seem to correlate with the ECs of the waters of the deep wells GP-17 and GP-6 (Deep Wells Project wells), both of which were drilled in the same area to more than 270m in depth in the Juweiza formation, but have ECs of between 2200 and 2500 mmhos/cm. (analyses 4 and 11, Table 6.12.). The explanation is that the stagnance or long residence of groundwater to the east of the Fayah-Mileiha anticline is responsible for the higher salinities as compared with the relatively freer groundwater movement in the Juweiza in the deep wells to the west of the anticline. Added to this is the very high NaCl content compared to the rest of the analyses in this zone, which indicates the possibility of contamination with trapped old marine waters or excessive leaching of salts from the extensive sabkhas. The sabkhas are widespread and extend from the northeastern tip of Jabal Fayah to Al Dhaid.

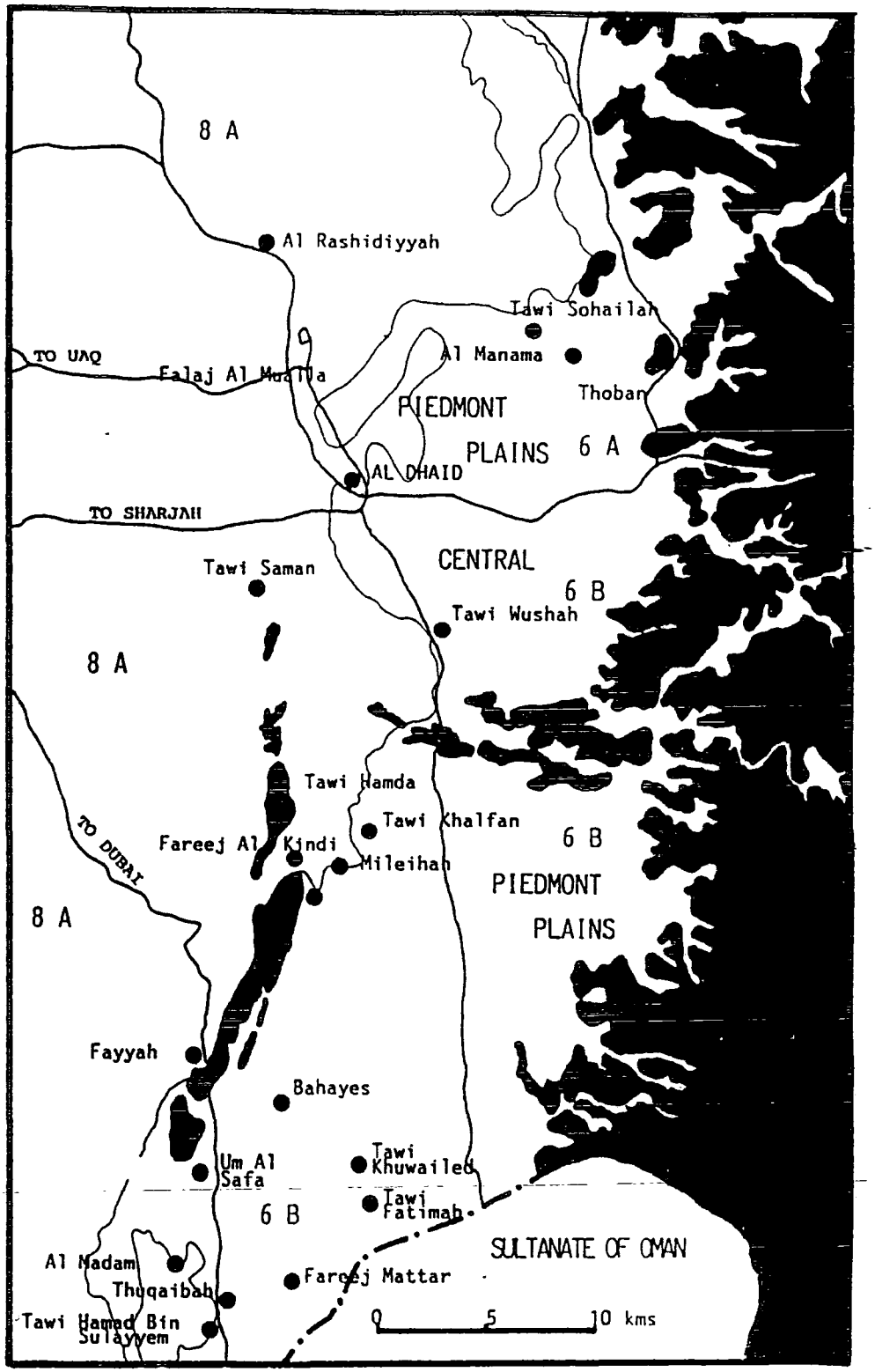


Figure: 6.14.

Delineation of the central part of the piedmont plains from Falaj Al Mualla to Al Madam.

(The places marked with dots on the map coincide with the names in Table 6.10.)

The high ECs of Buhayes (3996 mmhos/cm.) and Mileiha (3049 mmhos/cm.) (analyses 9 and 7, Table 6.10), are largely attributed to the recirculation of irrigation water as both localities occur within heavily cultivated areas. In the case of Buhayes, the Jabal Fayah anticline diverts the waters of Wadi Yudaiy'ah northwards away from it. As was discussed for the carbonate zone of Ru'us Al Jibal (Zone 5 in the mountains, section 6.5.1.5.) salinity can also be derived from the limestone of Jabal Fayah at whose foothill Tawi Buhayes is situated.

Despite the fact that the Mg-Ca ratio varies from 1:2 to 1:8, the waters still retain their NaCl character, with SO_4 and HCO_3 values increasing with the increase in EC. Table 6.10 gives results of water analyses of locations to the south of Al Dhaid (from north to south) and the EC values show a general improvement in salinities southwards. The lower ECs for Tawi Khuwailed, Tawi Fatima, Tawi Thuqaibah and Fareej Mattar (analyses 11-14, Table 6.10) are because all these locations are in Al Madam Plain facing the outflow of Wadi Al Qawr (West) and Wadi Muzeirea'.

<u>Suitability of the water for human consumption</u>:
(all reference to analyses are in Table 6.10)

The high Cl and Na content in Fareej Al Kindi (16.25 and 16.03 meq/l, (analysis 5)), Tawi Khalfan (35.43 and 29.90 meq/l, (analysis 6)), Mileiha (16.10 and 13.97 meq/l, (analysis 7)), Buhayes (24.50 and 30.58 meq/l, (analysis 9)) and Al Madam (11.80 and 15.14 meq/l, (analysis 15)), which are in some cases more than 4-5 times the maximum recommended limit for drinking water (the maximum limit for Cl is 7.0 meq/l, for Na it is 9.0 meq/l). SO_4 is also extremely high in Tawi Khalfan (analysis 5) where it is 2.5 times the maximum recommended limit for drinking. Tawi Khalfan and Buhayes have the poorest water for human consumption. The best drinking water is found in Tawis Khuwailed, Fatima, Thuqaibah and Fareej Mattar (analyses 11-14).

<u>Suitability of the water for agriculture</u>: (Table 6.10, Fig. 6.15)

Despite the high concentration of the ions and the generally high TDS content, the SAR values are moderate, varying from 2.7 (Thoban, analysis

The Western Piedmont Plains: the central part between Al Dhaid and Al Madam in the Northern Emirates (AREA 6 B)

LOCATION	EC	TDS	pH	NO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Thoban	1087	707	7.6	-	2.47	6.38	1.55	0.62	5.16	4.52	0.11	2.7	C_3S_1
2. Tawi Saman	1828	1188	7.7	0.1	4.33	9.72	2.89	1.65	3.91	11.1	0.4	6.7	C_3S_1
3. Tawi Wushah	1411	917	7.7	0.07	3.50	7.54	3.22	1.23	1.65	11.24	0.13	9.4	C_3S_1
4. Tawi Hamdah	1833	1192	7.5	0.03	4.50	8.90	2.79	2.27	3.91	9.85	0.13	5.6	C_3S_1
5. Fareej Al Kindi	2668	1734	7.8	0.06	3.50	16.25	3.51	1.85	5.15	16.03	0.21	8.6	C_4S_1
6. Tawi Khalfan	5686	3980	7.3	0.05	7.42	35.43	12.88	5.60	19.78	29.90	0.60	8.4	C_4S_1
7. Mileiha	3049	1982	7.4	0.14	5.50	16.10	5.47	3.76	9.12	13.97	0.34	5.5	C_4S_1
8. Fayah	1241	807	7.6	0.06	5.15	3.48	2.10	1.24	2.27	6.94	0.21	5.2	C_3S_1
9. Buhayes	3996	2597	7.6	0.18	6.60	24.50	7.11	2.47	4.98	30.58	0.32	15.8	C_4S_2
10. Um Assafa	1478	961	7.3	0.06	5.97	4.79	2.68	1.03	2.47	9.67	0.32	7.3	C_3S_1
11. Tawi Khuwailed	824	536	7.2	0.02	4.94	2.76	1.61	1.44	2.88	4.75	0.24	3.2	C_3S_1
12. Tawi Fatima	999	649	7.4	0.07	5.53	3.05	1.27	1.44	3.09	5.06	0.26	3.4	C_3S_1
13. Tawi Thuqaibah	865	562	7.5	0.07	5.36	2.90	1.61	1.24	2.68	5.69	0.29	4.1	C_3S_1
14. Fareej Mattar	876	569	7.3	0.06	4.94	2.47	1.39	1.24	2.68	4.66	0.26	3.3	C_3S_1
15. Al Madam	2678	1741	7.6	0.09	5.77	11.80	3.29	3.09	7.52	15.14	0.21	6.6	C_4S_1
16. Hamad Bin Sulaiyem	1030	670	7.3	0.07	5.15	2.90	1.61	1.24	2.47	5.73	0.26	4.2	C_3S_1

EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Year of analysis 1988.

Table: 6.10.

Water chemical analyses of AREA 6 (B) of the central part of the western piedmont plains from Falaj Al Mualla to Al Madam. (Figs. 6.1, 6.14 and 6.15).

ECs of the waters in this central part of the plains between Al Madam and Falaj Al Mualla range from 1000 to 2000mmhos/cm., although there are points where the ECs exceed 2000mmhos/cm., such as Fareej Al Kindi (2608mmhos/cm), Tawi Khalfan (5686mmhos/cm) and Mileiha (3049mmhos/cm.) (analyses 5-7).

Na and Cl are the dominant ions. The high Na Cl content in the waters in this part of the plains is due to both the recirculating irrigation water and the slow groundwater movement in the less transmissive clayey or evaporatic strata from which most wells draw their water (than the highly transmissive Quaternary alluvium). The waters here are generally of the HCO_3-Cl-Na type. Only in limited points on the wedge-like buried alluvial wadi channels do the waters qualify for potable use (e.g., at Tawis Khuwailed, Fatima and

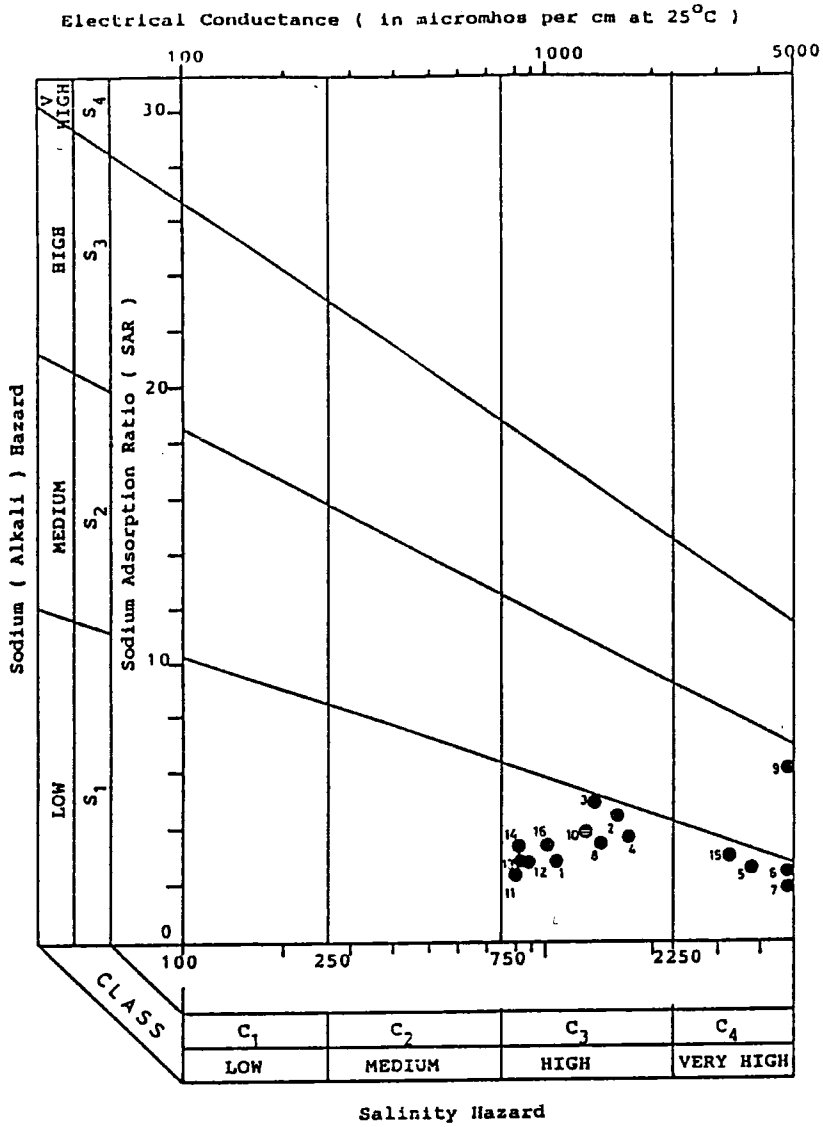


Figure: 6.15.

Irrigation water class of the waters of the central part of the piedmont plains from Falaj Al Mualla to Al Madam.

The irrigation water class is of the C_3-C_4 (high to very high salinity hazard) and S_1 (low sodium hazard) class.

(The numbers in the figure refer to the analyses in Table 6.10)

1) to 9.4 (Tawi Wushah, analysis 3). The irrigation water class is mostly of the C_3 S_1, which is of the high salinity and low sodium hazard. In nearly 30% of the analyses shown in Table 6.10, C_4 S_1 irrigation water class, which is the very high salinity and low sodium hazard type, is also widespread. Irrigation water in Al Dhaid area varies in the salinity hazard from medium to high but is low in the sodium hazard, putting the waters generally in the C_2/C_3 - S_1 class (Fig. 6.15).

Two samples were collected for each of two wells in a garden in Al Dhaid at two different dates, one in April and the other in June 1982, for the purpose of detecting any change in the concentration of the ions due to recharge from the heavy February rains of that year. The rains started in February and continued intermittently until May (1982), and the time the samples were taken from the wells was when subsurface flow had already been recharged from the rains of the past few weeks. A slight, though interesting variation in the values of the ions was detected and the results of the analyses are given in Table 6.11.

As seen in the Table 6.11, both Cl and Na ions were diluted by the freshly recharged groundwater from the winter rains. All the other ions increased in both analyses, with an inexplicable increase in SO_4 being most striking, especially in the analysis of Well 1. The increase in Mg signified fresher groundwater supplies from the magnesium-rich rocks of the catchment areas of the mountains to the east. There was an increase in Ca, but not as pronounced as that for Mg. The EC increased but the pH value bettered with a marked drop from 8.6 to 7.9 in Well 1. The SAR improved by about 40% as a result of the dilution of Na and the increase in Mg. It should be noted that it is quite normal also for locations in the piedmont plains, close to the line of recharge at the foothills, to exhibit fluctuation in both the ionic composition and EC of groundwater at the height of the summer owing to replenishment from convectional rainstorms that occur between May and October in the mountains and several parts of the piedmont plains, as is common in Al Ain during July and August.

Location	EC	TDS	pH	HCO_3	Cl	SO_4	Ca	Mg	Na	SAR	Class
WELL 1											
1-04-1982	928	-	8.6	3.26	4.22	0.75	0.61	1.46	6.09	6.0	C_3 S_1
20-6-1982	870		7.9	3.90	3.69	2.07	0.88	3.62	5.18	3.5	C_3 S_1
WELL 2											
1-04-1982	745	-	8.4	2.61	3.39	0.60	0.49	1.17	4.87	5.4	C_2 S_1
20-06-1982	710	-	8.1	3.16	2.99	1.68	0.71	2.93	4.20	3.1	C_2 S_1

Table: 6.11.

Seasonal variation in groundwater quality in Al Dhaid (April-June 1982).

Variation in the chemical composition of groundwater in two wells in Al Dhaid showing a slight improvement in water quality due to recharge from the winter rains by about 5-6% (1982). While chlorides became less, magnesium increased but there was also an increase in sulphate, which is difficult to explain. The increase in magnesium signified groundwater recharge.

The groundwaters in wells in the plains south of Um Assafa (analyses 10-16, Table 6.10) tend to be of the bicarbonate rather than the sodium chloride type, as the HCO_3 values here are higher than in the waters of wells north of Um Assafa. The Ca-Mg values are lower but the ratio between these two ions remains 1:1.5 or 1:2. In the case of Hamad Bin Sulaiyyem, Tawi Fatima and Tawi Khuwailed (analyses 11, 12 and 16, Table 6.10) the ratio is almost 1:1.5. Although there is a high concentration of Ca and Mg in Al Madam, the ratio remains also 1:1.5 (analysis 15, Table 6.10).

6.5.2.3.1. **Water chemistry and quality of wells of the Deep Wells Project in the piedmont plains (1982-86)**

(Table 6.12.: Fig. 5.29, Ch. 5, location map of the wells)

The drilling of the deep wells of the Deep Wells Project (1982-86) and their water chemical analyses were completed between 1983 and 1985. Only three deep wells were drilled in the Al Jaww Plain in Al Ain; the

rest were all concentrated in the northern and central parts of the piedmont plains in the Northern Emirates. Except for Well GP-14 at Manama (analysis 8, Table 6.12.), drilled to a total depth of 106m., all the other wells are deeper than 200m., with the majority of them having a total depth (each) averaging between 300-400m. The deepest well is Well GP-2 at Al Rashidiyyah, to the north of Falaj Al Mualla (463m. total depth).

The majority of the deep wells penetrated the Upper Cretaceous Aruma Juweiza Formation, consisting of a flysch of eroded carbonate clastics and silicified shales of various ages. This sequence is characterized by low permeability, though it is an important aquifer system of marginal quality water. In some parts of the plains this shaly sequence is as close as 60m. from the surface, as was shown by drill cuttings of the deep wells (refer to Chapter 5, Hydrogeology, Section 5.3.2.4.).

As seen in Table 6.12., ECs vary widely although they are for waters from wells drilled mostly in the same aquifer material (the clayey Juweiza), which, as is expected from its low permeability due to its shaly composition, produces marginal to brackish waters. To illustrate this variation, the EC in Well GP-1A is 720 mmhos/cm., while that for GP-15 is 2390 mmhos/cm.(analyses 1 and 7, Table 6.12). The latter EC is within the normal range of salinity for groundwater in the Juweiza aquifer (1000-4000 mmhos/cm.). GP-11, which is totally within the Juweiza water-bearing strata has an EC of 15,100 mmhos/cm. In GP-9 and GP-12, both of which draw water from both the Quaternary and the Juweiza formations (with extremely low permeabilities for GP-9), the ECs are 3520 and 3950 mmhos/cm. respectively (analyses 13 and 14, Table 6.12).

The excessively high EC of GP-11 can be explained by the fact that the well was drilled to the east of Jabal Mileiha (1983), which, as noted in Section 6.5.2.3, acts as a barrier to groundwater movement from the mountains to the east, causing longer groundwater residence and therefore concentrated mineralization. The pH values are high and the majority of wells have values above 8.0, with GP-9, to the east of Al Hamraniyyah, recording the highest pH of 11.1.

Na and Cl are the dominant ions and, excluding the unusually high ECs

for Wells GP-11 and BHR-3 (analyses 7 and 20, Table 6.12.) maximum values of up to 24.30 meq/l for Cl and 23.70 meq/l for Na (Well RK-15, analysis 17, Table 6.12.) and minimum values of 3.40 meq/l for Cl and 2.30 meq/l for Na (Well GP-16A, analysis 10, Table 6.12), also occur. Mg values are generally higher than those for Ca and can reach 9.60 meq/l (Well BHR-1, Table 6.12.). The Ca-Mg ratio varies from 1:1 to 1:13; the latter is in Well GP-17 (analysis 11, Table 6.12.). Sulphate does not occur in abnormal levels and does not seem to be connected with high salinities as for example in the EC of 11,400 mmhos/cm. for Well BHR-3 (analysis 20, Table 6.12), where the SO_4 is only 3.80 meq/l. For Well BHR-1, with an EC of 4260 mmhos/cm., SO_4 is 9.80 meq/l. Again, in Well GP-15, with an EC of 2390 mmhos/cm., SO_4 is 8.40 meq/l (analyses 19 and 9, Table 6.12).

HCO_3 can be as low as 0.30 meq/l as in Well GP-9 (analysis 13, Table 6.12), and as high as 7.00 meq/l as in Well GP-11 (analysis 7, Table 6.12) and, as the latter is being an abnormal case of high salinity (EC 15,100 mmhos/cm.), it may be excluded from this generalization of trends in the composition of the ions of waters of the deep wells. HCO_3 values do not exceed 4.50 meq/l (in Well GP-6 (analysis 4, Table 6.12)), and the majority of the values are between 3.00 and 4.00 meq/l.

Most of the waters represented by the analyses of the deep wells (in Table 6.12.) can be said to be unsuitable for potable use due to their high Na-Cl content but, as the majority are exploratory wells, they are unlikely to be made available for human consumption, though some are clandestinely being used for that end (GP-15 in Al Dhaid).

As far as the suitability of the groundwaters of the Deep Wells for agriculture is concerned, the waters contain a high salinity hazard as most of them are in the C_3 and C_4 classes of high to very high salinity hazard. Sodium hazard falls between the low and the medium groups (S_1-S_2) with the very high S_4 class occurring in the high EC waters. It should be reiterated that the deep wells are exploratory wells and their waters are not necessarily available for public use and they were only drilled to verify aquifer parameters. The analyses are presented and discussed in the present study to portray the chemistry of the waters in the Tertiary aquifers the deep wells penetrated, because the wells were intended to explore the existence of fresh water below the

Chemical analyses of the groundwater of the deep wells of the Deep Wells Project in the Piedmont Plains In meq/l

LOCATION	EC	DEPTH m	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. GP-1A Manama (Juz)	720	350	8.9	-	2.60	4.00	1.03	0.50	3.00	4.20	0.1	3.2	$C_2 S_1$
2. GP- 2 Rashidiyah near F.Mualla(Juz)	1900	463	8.0	-	2.20	12.40	2.60	1.90	5.80	9.60	0.2	5.0	$C_3 S_1$
3. GP- 3 Ramlah(Juz)	1225	202	8.1	-	2.90	6.90	2.50	1.40	3.90	7.00	0.2	4.3	$C_3 S_1$
4. GP-6A T.Khlfan(Juz)	2350	202	7.6	-	4.50	5.00	3.40	2.40	3.10	7.50	0.1	4.5	$C_4 S_1$
5. GP-10 Wushah(Juz)	2460	330	8.4	-	3.90	13.50	6.20	1.80	4.80	17.00	0.1	9.3	$C_4 S_1$
6. GP-10A Khadhrah(Juz)	1820	-	-	-	4.00	9.50	5.90	1.20	2.60	15.50	0.1	11.2	$C_3 S_2$
7. GP-11 Muleiha(Juz)	15100	-	8.1	-	7.00	116.00	34.40	5.90	15.80	135.00	1.0	41.0	$C_4 S_4$
8. GP-14 Manama(Juz)	1280	106	8.3	-	4.10	4.80	0.60	0.50	0.60	10.20	0.2	13.8	$C_3 S_2$
9. GP-15 Wushah(Juz)	2390	-	8.1	-	3.30	13.90	8.40	1.50	5.40	18.50	0.2	10.0	$C_4 S_1$
10. GP-16A Huwairah(Juz)	600	338	7.8	-	3.00	3.40	-	0.80	3.20	2.30	0.10	1.6	$C_3 S_1$
11. GP-17 T.Saman(Juz)	2230	250	8.0	-	3.50	15.20	1.90	0.30	4.00	14.80	0.30	10.1	$C_3 S_1$
12. GP- 8 T. Jaheeli(Juz)	3100	345	8.4	-	3.40	20.40	5.20	0.80	7.40	20.70	0.20	10.4	$C_4 S_1$
13. GP- 9 Khatt(Qt/Juz)	3520	354	11.1	-	0.30	19.60	7.10	7.50	0.50	21.10	0.90	10.6	$C_4 S_1$
14. GP-12 Hamraniyah (Qt/Juz)	3950	213	7.7	-	3.30	26.80	7.70	2.60	5.70	29.00	0.40	14.5	$C_4 S_2$
15. RK-11 Seih Al Fahlain (Hajar)	2490	207	7.3	-	4.00	18.00	3.40	5.60	5.00	14.50	0.20	6.3	$C_4 S_1$
16. RK-14 Khatt(Hajar)	1730	321	7.6	-	2.00	12.00	2.40	2.80	8.00	10.10	0.20	4.4	$C_3 S_1$
17. RK-15 Idhn (Hajar)	3370	387	7.5	-	3.80	24.30	2.90	3.60	4.30	23.70	0.20	11.9	$C_4 S_2$
18. RK-16 T. Sarram (Hajar)	1670	360	7.3	-	4.50	7.30	3.10	2.30	2.20	10.20	0.20	6.8	$C_3 S_1$
19. BHR-1 Khatt (Juz)	4260	153	8.0	-	2.40	35.0	9.80	5.0	9.60	32.1	0.40	11.9	$C_4 S_2$
20. BHR-3 Muthalatha -	11400	296	8.1	-	2.50	117.0	3.8	4.0	20.0	97.8	1.20	28.3	$C_4 S_4$
21. AA-1 Malaqet -	23300	366	7.6	-	5.10	220.6	43.40	35.10	42.80	189.10	2.10	30.5	$C_4 S_4$
22. AA-2 Mazyad(Evap)	3850	442	7.9	-	4.40	26.6	8.80	5.20	5.30	28.90	0.4	12.6	$C_4 S_2$
23. AA-3 Um Ghafa(Qt)	925	412	7.9	-	3.50	3.75	2.50	1.80	3.50	4.40	0.1	2.7	$C_3 S_1$

(Juz)=Juweiza, (Qt)=Quaternary,(Evap)=Oligo-Miocene Evaporites EC in mmhos/cm at 25°C; ions in meq/l (1988)

Table: 6.12.

Water chemical analyses of the wells of the Deep Wells Project in the western piedmont plains from Al Manama to Um Ghafah. (see Fig. 5.29 (Chapter 5) for the location of the Deep Wells in the Plains).

ECs of the waters of the wells of the Deep Wells Project (1982-86) vary widely, although they are for wells drilled mostly in the same aquifer material (the shaly clastics of the Tertiary Juweiza Formation). The EC in Well GP-1 is 760mmhos/cm., while the EC in Well GP-15 is 2390mmhos/cm. Na and Cl are the dominant ions.

The waters of the wells of the Deep Wells Project can be said to be unsuitable for potable use due to their high Na-Cl content. As these deep wells are observation wells, it is unlikely that their waters are to become available for human consumption, although some wells are clandestinely being used for irrigation and possibly human consumption. The irrigation water quality of the waters of these deep wells is mostly of the C_3-C_4 (high to very high salinity hazard) and of the S_1-S_2 (low to medium sodium hazard) class. Very high sodium hazard (S_4) is found in high EC waters (analyses 5, 20 and 21).

Quaternary alluvium.

Whether groundwater at the medium depth reached by the wells of the Deep Wells Project, or the greater depth investigated by the petroleum companies and other authorities in central Abu Dhabi (to be discussed in section 6.5.3.7.), it is clear that the waters of the pre-Quaternary aquifer systems indicate only a slim possibility of finding fresh water in deeper water-bearing strata below the Quaternary.

6.5.2.4. The southern part of the alluvial piedmont plains: Al Ain region from Wadi Ma'aisheq to Um Ghafah

(Tables 6.13 to 6.29; Figs. 6.16 to 6.18)

6.5.2.4.1. General

The Al Ain region is by far the most important and fastest developing agricultural area in the Emirates where the irrigation water used ranges from the prime potable quality to the highly saline. It has been deemed necessary to study in detail the water quality of the Al Ain region in view of this widespread agricultural development to assess the actual status of the groundwater resources of the region. The synthesis of the water chemistry and quality in this section is based mostly on analyses of water samples collected for this study from wells in different parts of the Al Ain region, and also direct EC-TDS measurement with the Hach meter. Also, analyses of wells of the public supply wellfields were made available by WED Al Ain and these have been used to study the long- and short-term variation in the chemistry of the waters. In addition, groundwater chemistry and quality data of the agricultural areas (from the Agriculture Department of Al Ain) have been used to portray the up-to-date state of the irrigation water from published official sources. Furthermore, old water analyses of some wells, that still exist, or new ones close to the old sites collected by this study, were also used for comparison to detect long-term changes in water chemistry.

Factors affecting groundwater quality in the Al Ain region include:

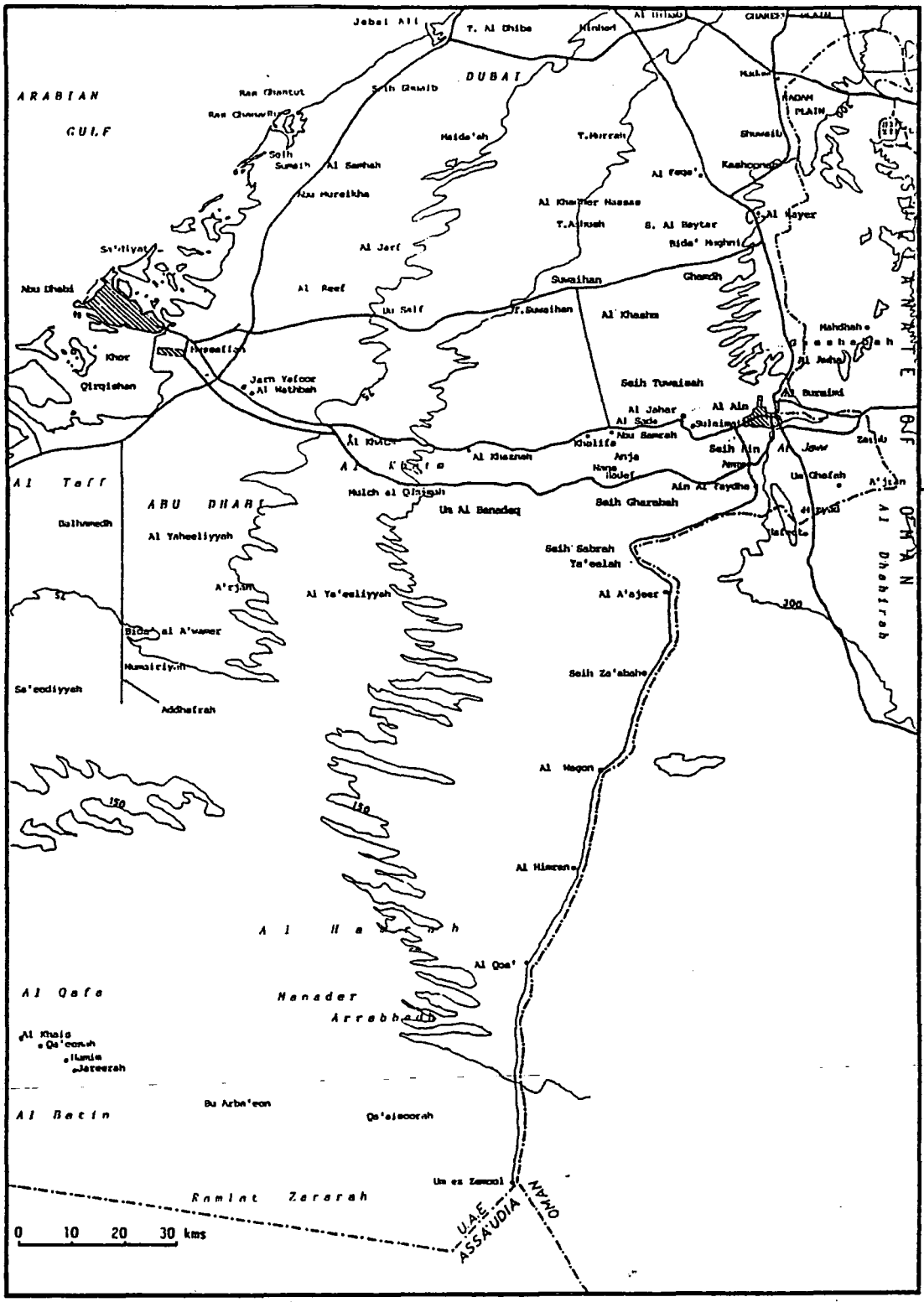


Figure: 6.16.

Location map of the Al Ain region showing the southern part of the piedmont plains (marked as 6 C in Figures 6.1 and 6.28), the northern dune area to the north of Al Ain and the western and southern desert)

(i) The widespread occurrence of the salty Oligo-Miocene Lower Fars Formation, consisting of carbonates, shales, marls and anhydrites, which underlies the Quaternary alluvial and aeolian water-bearing strata.

(ii) Distinct groundwater flow channels that follow buried wadi channels running generally from east to west (similar to those described for the Northern Emirates).

(iii) Porosity of the water-bearing material and groundwater flow.

(iv) Distance from the Oman Mountains recharge sources to the east.

(v) Depth of groundwater occurrence.

(vi) Rates of groundwater abstraction.

(vii) Local lithological anomalies such as the occurrence of a gypsum layer overlying a porous alluvial layer.

(viii) Salt deposition on the surface by evaporation.

ix) Recirculating irrigation water.

Water quality deteriorates both laterally towards the west and south, and also vertically with depth into the evaporites sequence.

6.5.2.4.2. <u>The quality of the recharge waters in the Al Ain region</u>

(Tables 6.13 and 6.14; Figs. 9.4 and 9.5, Chapter 9 for the locations of the BU-EH and ZG Omani wells)

The only available water chemistry data for through-flow recharge waters into the Al Ain region from the mountains of Oman to the east, are those presented in Tables 6.13 and 6.14, which contain analyses of locations

upstream and downstream of the mountain gaps from Mahdhah to Zarub close to the border with the Emirates (refer to Figs. 9.4 and 9.5, Chapter 9 for locations of the Omani wells in these two areas). The water chemistry data for the southern mountain gap of Zarub are for wells located within the gap or immediately upstream of it, a few hundred metres from the Emirates-Oman border. Analysis 2 in Table 6.13, for example, is for Well ZG-X, located in the constriction of the Zarub Gap (Fig. 9.4, Chapter 9). The data for the northern Mahdhah Gap (Table 6.14) are also for wells upstream of the gap, but also for wells across the Mahdhah outwash fan as far as the border with the Emirates at Al Awha along the Al Ain-Dubai highway (Fig. 9.6, Chapter 9). Water chemistry data in both Tables are from Omani water authorities and consultants working for them (Regional Development Council (RDC), Public Authority for Water Resources (PAWR) and Groundwater Development Consultants (GDC).

As seen in Tables 6.13. and 6.14., the EC values for the Zarub waters are lower than those for Mahdhah. The main reason for this is the longer distance throughflow has to travel in the Mahdhah sector than that in the Zarub sector, and also in the presence of Hawasina metasediments in the hardrock catchment area of Mahdhah and ophiolites in Zarub. The Hawasina have been described for the Dibba Corridor in the Northern Emirates and have been found to have water of inferior quality to that in the ophiolites (Section 6.5.1.4.). The only two analyses with relatively high ECs in the Zarub Gap are analyses 6 and 8 (Table 6.13.), and this is because these two chemical results are for samples from wells drilled in indurated alluvium off the main channel of flow. The extremely high ECs in analyses 9-12 (Table 6.14.) in Mahdhah, are due to the location of the wells within the U-shaped Seih Huwaiyyah enclave, which is enclosed by the horse-shoe like Jabal Huwaiyyah. The EC range in Zarub is 178 to 934 mmhos/cm., and the EC range in Mahdhah is 540-1630 mmhos/cm. (excluding the extremely high EC values occurring in both groups).

Mg is the dominant ion in the recharge waters of the Zarub Gap with values ranging from 7.75 meq/l and 24.30 meq/l, attesting to the recharge quality of the waters. The Ca-Mg ratio ranges from 1:3 to 1:17. The recharge waters in the Zarub Gap are mostly of the carbonate-magnesium type.

Chemical analyses of groundwater in the recharge Zarub (Musaileq) area of Oman to the east of Al Ain — In meq/l

LOCATION	EC	TDS	pH	$CaCO_3$	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. ZG- 1 Zarub Gap uppermost in gap	346	220	8.4	2.10	-	0.80	0.47	1.45	8.75	-	-	-	-
2. ZG- X Zarub Gap centre of gap	351	202	7.6	1.99	-	0.90	0.45	1.30	11.10	-	-	-	-
3. ZG- 2A Zarub Gap lowest in gap	388	312	8.0	1.84	-	0.81	0.48	1.75	9.58	-	-	-	-
4. ZG-12 Zarub Gap on southern side	378	250	7.6	2.16	-	1.04	0.75	2.10	9.25	-	-	-	-
5. ZG-13 5kms SE of gap on W. Shik	178	110	8.3	0.93	-	0.42	0.25	1.40	4.33	-	-	-	-
6. ZG-10 1.5kms NW of gap between Jabals Umbaq and Hamar off Wadi Al Ain	1764	1080	7.5	4.84	-	10.73	4.83	3.65	24.30	-	-	-	-
7. ZG- 8 Between Jabals Zarub and Sababah on W. Shik right channel	628	398	7.5	2.59	-	3.24	1.21	2.45	13.58	-	-	-	-
8. ZG-11 0.5km to the south of ZG-8 off wadi channel	1302	814	7.6	3.48	-	3.80	3.29	6.45	15.58	-	-	-	-
9. ZG- 6 1.5kms NE of Jabal Umbaq	294	184	8.2	5.70	-	0.73	0.48	0.50	8.33	-	-	-	-
10. ZG- 4 8kms SW of Zarub Gap on trib. of Wadi Shik	430	336	8.3	1.80	-	0.96	0.65	1.90	7.75	-	-	-	-
11. ZG-14 11kms SW of Zarub Gap off wadi course	798	494	7.7	2.48	-	4.11	1.58	2.75	14.42	-	-	-	-
12. ZG- 7 3kms NNW of Zarub Gap	934	578	8.1	2.76	-	5.10	1.67	3.00	16.25	-	-	-	-
13. ZG- 9 1.5kms NNW of Zarub Gap U/S in a trib. of W. Al Ain	315	182	7.8	7.0	-	0.76	0.58	2.20	8.80	-	-	-	-

Source: Drilling Appraisal in Zarub Gap, Buraimi region, Oman-N.Saines & S.Ansari, Regional Development Council, 1985.

EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Year of analysis 1985.

Table: 6.13.

Water chemical analyses of the recharge waters of the Zarub (Musaileq) catchment in Oman to the east of the southern part of the western piedmont plains: the Al Ain region from Ghashabah to Um Ghafah (Fig. 6.16; marked 6 C in Fig. 6.28).

Because these are recharge waters, they are of good quality as is evident in the low ECs (178-934mmhos/cm.), except for analyses 6 and 8, which are for water samples from wells tapping water from less transmissive indurated Tertiary alluvium away from the central flow channel in the Zarub Gap than the highly transmissive Quaternary alluvium of the main flow channel. Mg is the dominant ion attesting to the recharge quality of the waters in these foothill locations. The waters are generally of the $CaCO_3$-Mg type. The pH values are high (of more than 8.0) indicating to the alkalinity of the waters. Because no Na values are available for the Zarub Gap (main channel) water analyses (analyses 1-3), no SAR values could be calculated. However, the low salinities of the waters in the Zarub Gap suggest an absence of the salinity hazard in the irrigation water.

In meq/l

Chemical analyses of groundwater in the recharge area of the Mahdhah outwash fan in Oman (east of Al Ain)

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. BU-EH 6 Mahdhah fan across border from Al Awha wheat farm	825	-	8.6	-	3.7	2.70	1.90	1.0	2.1	4.7	0.18	3.8	$C_3 S_1$
2. BU-EH 5 1.5 kms to the south	830	-	8.6	-	3.8	3.60	1.40	1.2	2.7	4.4	0.11	3.1	$C_3 S_1$
3. BU-EH10 at the head of Mahdhah fan on active wadi channel	460	324	8.4	-	3.0	0.91	0.48	0.8	1.8	2.9	0.10	2.5	$C_2 S_1$
4. BU-EH12 close to BU-EH10	640	374	8.31	-	3.8	1.41	1.02	1.0	1.2	3.9	0.31	3.6	$C_2 S_1$
5. BU-EH11 along main channel of W.Mahdhah	540	472	8.52	-	3.9	0.63	0.94	1.0	0.8	3.8	0.09	4.0	$C_2 S_1$
6. BU-EH 8 SE of BU-EH11	630	584	8.37	-	4.4	2.80	0.83	1.0	3.2	2.4	0.10	1.7	$C_2 S_1$
7. BU-EH13 Mahdhah Gap	680	460	8.6	-	4.0	2.25	1.04	1.4	2.9	2.6	0.09	1.8	$C_2 S_1$
8. BU-EH 7 Mahdhah Gap	620	616	8.5	-	3.6	2.10	0.83	1.2	3.0	2.4	0.10	1.7	$C_2 S_1$
9* BU-EH 1 S. Huwiyyah	9000	7174	8.7	-	0.5	37.70	64.60	29.0	1.0	67.8	1.84	17.5	$C_4 S_2$
10* BU-EH 2 "	37000	29624	8.2	-	1.8	383.00	99.20	42.0	98.0	325.0	3.6	38.8	$C_4 S_4$
11* BU-EH 3 "	10200	8720	8.6	-	0.2	110.00	19.60	21.0	27.0	100.0	0.03	20.4	$C_4 S_4$
12* BU-EH 4 "	6900	4906	8.6	-	1.2	49.0	15.4	16.0	2.0	45.2	0.75	15.1	$C_4 S_2$

* All these boreholes are situated within the 'U' shaped enclave of S. Huwiyyah bounded by Jabal Huwiyyah where groundwater is ponded in low-transmissivity clays, silts and evaporites. Jabal Awha to the west provides an additional subsurface barrier with its 9.5 km long NNW-SSE trending anticline.

Source: Soil and Groundwater Survey for Buraimi, Final Report, Vol. III, Groundwater Resources & Development, Groundwater Development Consultants(Intl.) Ltd., October, 1982. (Ministry of Agriculture & Fisheries, Oman)

EC in mmhos/cm. at 25° C; TDS in ppm.; all ions in meq/l. Year of analysis 1982.

Table: 6.14.

Water chemical analyses of the recharge waters of the Mahdhah catchment and outwash fan in Oman to the east of Al Ain (from Ma'aisheq to Ghashabah) (Fig. 6.16; marked 6 C in Fig. 6.28).

The ECs of the recharge waters of the Mahdhah outwash fan are slightly higher than those for the recharge waters of the Zarub Gap mainly because of the greater distance from the mountains the inflow has to travel and the analyses are for water samples from wells in the Mahdhah outwash fan. The very high ECs for analyses 9-12 are for wells located in the U-shaped Seih Huwaiyyah where there is groundwater ponding. ECs of the waters of the Mahdhah outwash fan generally range from 540-1630mmhos/cm. Na and Cl are the dominant ions, but HCO_3 and Mg are also relatively high indicating the recharge characteristics of the groundwater in Mahdhah. The irrigation water class in the outwash fan is of the C_2-C_3 and S_1 (medium to high salinity and low sodium hazard) class.

In the Mahdhah waters, on the other hand, Na and Cl are the dominant ions, although HCO_3 and Mg are relatively high reflecting the recharge character of the water. The Na and Cl values are attributed to acquired salts from irrigation water return and the longer journeys groundwater travels, but also to the dissolution of minerals in the igneous and metamorphic rocks of the Semail ophiolite and Hawasina metasediments that make up the geology of the Mahdhah area.

In both the Mahdhah and Zarub areas, SO_4 is low and the pH is 8.0 or even more, indicating to the alkalinity of the waters. No Na values were available for the Zarub Gap analyses (Table 6.13) and therefore no calculations of SAR values were possible; but calculation was possible for the Mahdhah Gap analyses (Table 6.14). The irrigation class of the waters in Mahdhah ranges from the $C_2/C_3 - S_1$ class, which is of the medium to high salinity but of the low sodium hazard for the low EC water (analyses 1-8, Table 6.14); to the C_4 S_4 class for the high EC water (analyses 9-12, Table 6.13.), which is both of the very high salinity and sodium hazard.

6.5.2.4.3. <u>The chemistry of the waters of the Al Ain region</u>
(Table: 6.15; Fig. 6.16)

In <u>*northern Al Jaww Plain*</u> (analyses 1-3, Table 6.15), Mg and HCO_3 are of marked concentration, as at Um Shatarain to the east of Al Qattarah (analysis 1, Table 6.15), and at the Defence Camp west of Um Ghafah (analysis 2, Table 6.15). Cl and Na are the dominant ions, with values three times those for Mg and HCO_3 in the latter place. SO_4 is as high as Mg, and Ca is higher in the Defence Camp water than that in Um Shatarain.

At Tawi Hamad Bin Jawwal, half-way between the Zarub Gap in the east and Al Qattarah in Al Ain vicinity in the west (analysis 3, Table 6.15), HCO_3 and Mg are again dominant, followed by SO_4. Ca is reduced to only 1.73 meq/l and Cl is low as these are recharge waters, and Hamad Bin Jawwal is located on the active northern wadi channel (Wadi Al Ain). Mg and HCO_3 are dominant because the samples were taken from wells situated in the recharge northern channel noted earlier, whereas the Cl and Na values for the well in the Defence Camp (analysis 2, Table 6.15) are due

to the fact that this well is situated off the wadi channel and also because of overabstraction of groundwater in the area. The EC is the highest among the three analyses for northern Al Jaww. The waters are generally of the sodium-chloride-magnesium-bicarbonate type.

In *central Al Jaww Plain* (analyses 4-6, Table 6.15), from where most of the water samples were collected from wells located between the northern and southern channels of surface flow of Wadis Shik and Hamad, ECs are higher (ranging from 496-1426 mmhos/cm.) than those for northern Al Jaww. Mg and HCO_3 values are dominant, while the Na and Cl values increase markedly southwards (analysis 6, Table 6.15). SO_4 is high as at Khawr Al Wadiyyain where it is 6.50 meq/l (analysis 4, Table 6.15).

Waters of central Al Jaww Plain still retain the characteristics of recharge waters, being close to the mountains, but Na, Cl and SO_4 are also of a noticeable presence in them. The waters here are generally of the bicarbonate-magnesium-sodium type.

In *eastern Al Jaww Plain* (analyses 7-11, Table 6.15), along the foothills of the Oman Mountains in or near the mountain gaps, from where recharge waters emanate, EC values are low (395-830 mmhos/cm.) but Mg and HCO_3 values are high signifying the recharge characteristic of the waters (analyses 7 for Sa'ah and 8 for Malaqet, Table 6.15). Samples collected from wells in the Zarub Gap proper contain moderate amounts of Mg though they are recharge waters with low ECs (e.g. analysis 11, Table 6.15).

The high Mg values for Sa'ah and Malaqet (9.80 meq/l and 10.00 meq/l respectively), are attributed to the magnesium-rich rocks of basalts, serpentinites and dolomites across which the waters flow. Hence, the availability of Mg 3-4 times the amount of Ca. It should also be noted that both Malaqet and Sa'ah are situated in the lee of a series of hills that act as a barrier to groundwater flow, which only flows through the Zarub Gap. Movement of water is slow and concentration of the ions by mineralization is therefore effective. In the analysis for the Zarub Gap proper (number 11, Table 6.15), Mg is less in amount and the Ca-Mg ratio is 1:4. Groundwater movement is fast in the constriction of the Zarub Gap and therefore its residence time is short and the source of the Mg appears to be totally from the ophiolites of the mountains to the

east. As these waters move westwards, they pick up more Mg from the alluvial material in Al Jaww Plain in addition to what is already derived from the same Mg-rich rocks in the catchments. The waters of eastern Al Jaww are generally of the magnesium-bicarbonate type.

The farther groundwater travels westwards from the mountain front, the higher becomes the SO_4 content, as shown in analysis 10 (Table 6.15) for a sample taken from a well 2 km. from the Zarub Gap. The SO_4 value in this well is 7.40 meq/l as compared to only 0.50 meq/l in analysis 11 in the Zarub Gap proper. Although the Cl concentration is low in analysis 10 (2.60 meq/l), the high SO_4 content, noted earlier for the same sample, seems to coincide with an even higher Na content (8.40 meq/l) and the higher EC (1254 mmhos/cm.).

In *southern Al Jaww Plain* (analyses 12-18, Table 6.15), Cl and Na increase with distance from the mountain gaps and also by contamination of groundwater from the Lower Fars evaporites sequence. In 'Iraqiyyah (analysis 13, Table 6.15) Cl is 8.00 meq/l and Na is 12.78 meq/l. 'Iraqiyyah is situated 7 km. from the Zarub Gap. 2km. west of Tawi Mowafa (analysis 16, Table 6.15) Cl is 11.00 meq/l and Na is 15.00 meq/l. In Seih Al Raq (analysis 17, Table 6.15.), midway between the two main channels of Wadi Shik and Wadi Hamad, Cl is 13.80 meq/l and Na is 19.31 meq/l. However, in all these places in southern Al Jaww, Mg, with 7.80 meq/l at 'Iraqiyyah, maintains its presence, though in a reduced amount, waning with distance westwards. SO_4 values are high in the central and southern parts of Al Jaww, particularly off the wadi channels as at 'Iraqiyyah (9.50 meq/l), 2 km. west of Tawi Mowafa (11.00 meq/l) at Seih Al Raq in Niadat (13.80 meq/l) (analyses 13, 16 and 17, Table 6.15). Ca values are low (ranging from 0.60 to 4.60 meq/l).

The interesting result of the analysis of the water at Mazyad (analysis 18, Table 6.15), which has a very high Mg value of 21.40 meq/l as well as an HCO_3 value of 7.40 meq/l, indicates a recharge quality, though the location of Mazyad is about 20 km. from the Ajran Gap. It should be pointed out that this Mg value is too high for a purely recharge water reaching Mazyad from the Ajran Gap, and most of this Mg must be derived *in situ* from the dissolution of the Simsima limestones of Jabal Hafeet.

It is therefore clear that in Al Jaww Plain there are fresh waters in

the northern and eastern parts of Al Jaww and also in points situated within the active wadi channels where there is occasional recharge from surface runoff. Such fresh waters are of the bicarbonate-Magnesium type. The high HCO_3 and Mg content indicate their recharge character. On the other hand, waters in the central off-wadi channel areas, and also in areas in southern Al Jaww, have a high Cl, Na and SO_4 content making them of the chloride-sodium-sulphate type.

The *Al Ain town vicinity* (analyses 19-24, Table 6.15), was reported by the Gibb Report (Water Resources Survey of Abu Dhabi, 1970) as a number of villages (oases) separated by open land. Present day Al Ain is a sprawling town with hardly any open space between the old villages that have become urban sectors. Some of the wells mentioned by the 1970 report, or existing ones close to old wells that have since disappeared, have been revisited and most of them are located at present in private date gardens, in the compounds of private villas or in government institutions, as shown in Table 6.15) (analyses 19-24). Samples were collected for this study in the Al Ain vicinity from Al Hilli, Al Mu'taredh, Al Mas'udi, a private well near the Hilton Hotel, a private well behind the Clock Tower and a well at Al Jimi.

Na, Cl and HCO_3 are the dominant ions, with Na being the most dominant of the three (ranging from 3.80 to 20.00 meq/l). Both the Na and SO_4 values are largely derived from the decomposition of organic material, as the wells the samples were collected from were all located in intensively cultivated date gardens within the vicinity of Al Ain town. The values for Cl range from 3.40 to 16.00 meq/l, while those for SO_4 range from 2.50 to 9.80 meq/l. HCO_3 is second in importance, with the highest values occurring in Al Mas'udi (8.10 meq/l, analysis 21, Table 6.15) and near the clock tower in the town centre (14.00 meq/l, analysis 23, Table 6.15). In the good quality water at Al Hilli, HCO_3 is the most dominant ion with a value of 8.20 meq/l. SO_4 is highest near the Clock Tower (Al Ain town-centre) and at Al Mas'udi (analyses 23 and 21, Table 6.15); with the former location having the highest EC of the waters of Al Ain vicinity. The Ca:Mg ratio ranges from 1:1 to 1:3, which indicates long residence of the groundwater, but with slightly recharge characteristics. The waters of the Al Ain vicinity are therefore of the sodium-chloride-bicarbonate-magnesium type.

Chemical analyses of groundwater in the Al Ain vicinity and surrounding alluvial and aeolian areas

In meq/l

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
Northern Al Jaww													
1. Um Shatarain, east of Al Ain, pvt well	585	451	7.8	-	4.02	2.1	2.0	1.73	4.18	2.20	0.14	1.3	$C_2 S_1$
2. Defence complex, on the road to Um Ghafah	1904	1178	8.4	-	6.13	9.48	4.25	2.40	4.20	13.04	0.29	7.2	$C_3 S_1$
3. Tawi Hamad bin Jawal	388	389	8.0	-	3.10	1.31	2.40	1.73	2.66	2.30	0.06	1.6	$C_2 S_1$
Central Al Jaww													
4. Khawr Al Wadiyyain	1426	1128	8.0	-	8.56	3.59	6.50	3.90	5.69	8.87	0.30	4.1	$C_3 S_1$
5. Niadat, centre of Wadi Shik	496	322	8.0	-	2.90	4.80	2.30	2.10	5.67	2.30	0.06	1.2	$C_2 S_1$
6. 5kms south-east of Tawi Malaqet	922	778	7.8	-	5.60	3.83	3.25	1.80	2.40	8.35	0.23	5.8	$C_3 S_1$
Eastern Al Jaww													
7. Sa'ah, in the gap	658	428	8.1	-	8.20	3.00	2.50	2.00	9.80	1.90	0.01	0.8	$C_2 S_1$
8. Malaqet	830	540	7.7	-	6.30	2.90	2.80	6.10	10.00	3.30	0.01	1.2	$C_3 S_1$
9. Thuqbat Sa'ah, NW of 'Ajran Gap	1094	750	7.8	-	4.90	2.40	5.00	3.70	4.30	4.20	0.20	2.0	$C_3 S_1$
10. 2kms below the Zarub Gap to the west	1254	852	7.6	-	3.00	2.60	7.40	2.40	2.10	8.40	0.22	5.6	$C_3 S_1$
11. In Zarub Gap proper	395	366	8.0	-	3.40	3.16	0.50	1.15	4.80	1.25	0.06	0.7	$C_2 S_1$
Southern Al Jaww													
12. Um Ghafah Wellfield	436	293	8.0	-	3.10	1.20	1.00	0.60	3.00	1.60	0.06	1.2	$C_2 S_1$
13. 'Iraqiyyah, 7kms SW of T. Malaqet	1620	1410	8.0	-	5.40	8.00	9.50	2.40	7.80	12.78	0.16	5.9	$C_3 S_1$
14. Wadi Muraikhat, near 'Ajran Gap	627	351	8.0	-	3.60	1.90	3.00	1.10	5.00	2.50	0.23	1.5	$C_2 S_1$
15. Wadi Muraikhat, 6km west of Sa'ah	730	516	8.0	-	3.84	2.60	2.10	1.44	3.40	3.71	0.30	2.4	$C_2 S_1$
16. 2kms west of Tawi Mowafa	1824	1252	8.0	-	5.40	11.00	4.50	2.10	3.30	15.00	0.24	9.0	$C_3 S_1$
17. Seih Al Raq; at Niadat off wadi channel	2280	1565	8.0	-	6.77	13.80	5.60	2.60	4.13	19.31	0.30	9.3	$C_4 S_1$
18. Mazyad	1093	711	7.9	-	7.40	4.10	3.20	4.60	21.40	2.50	0.21	0.7	$C_3 S_1$

EC in mmhos/cm. at 25°C; TDS in ppm: ions in meq/l. Year of analysis 1988.

/continued from previous page

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
Al Ain vicinity													
19. Al Hilli	1082	739	8.0	-	8.20	3.40	2.50	2.30	6.80	4.00	0.18	1.9	$C_3 S_1$
20. Al Mu'taredh	1596	1204	7.9	-	7.30	8.30	4.50	2.90	6.80	10.0	0.42	2.2	$C_3 S_1$
21. Al Masu'di	3045	1995	7.8	-	8.10	16.00	7.70	4.70	15.00	18.30	0.60	6.1	$C_4 S_1$
22. Pvt well, 700m NW of Hilton(date gdn)	1060	690	8.6	-	5.70	3.70	2.00	3.40	3.60	4.60	0.24	2.4	$C_3 S_1$
23. Pvt well, 1km SW of Clock Tower(date gdn)	3000	2000	8.0	-	14.00	11.40	9.80	6.90	15.40	20.00	0.40	6,1	$C_4 S_1$
24. Al Jimi, near Men's Colleges,UAE Univ.	1565	1435	8.4	-	7.60	5.40	4.30	4.00	7.00	3.80	0.09	1.6	$C_3 S_1$
Northern alluvial and sand dune area													
25. Al Awha	1070	696	8.0	-	5.10	5.30	2.70	1.90	9.00	2.90	0.19	1.3	$C_3 S_1$
26. Ghashabah	848	551	7.8	-	5.20	4.70	2.40	1.30	9.00	2.00	0.15	0.9	$C_3 S_1$
27. Al Hamam	850	553	7.8	-	6.90	2.60	2.00	2.50	6.50	2.40	0.15	1.1	$C_3 S_1$
28. Bida' bint Sa'ud	845	553	7.9	-	5.40	3.10	2.20	2.00	6.00	2.80	0.15	1.4	$C_3 S_1$
29. Al Kara'	698	454	8.1	-	4.42	3.70	1.50	1.80	5.00	2.50	0.11	1.4	$C_2 S_1$
30. Al Hayer North	971	631	8.0	-	7.00	10.70	3.50	3.50	6.00	11.60	0.26	5.3	$C_3 S_1$
31. Al Mohayyer	750	488	7.9	-	5.02	2.70	2.10	2.00	6.70	2.50	0.08	1.3	$C_2 S_1$
32. Al Shuwaib	1197	775	7.6	-	9.00	5.60	3.10	3.20	10.00	4.50	0.15	1.8	$C_3 S_1$
33. Kashoonah	1200	750	7.8	-	7.70	6.90	3.00	3.20	10.20	4.30	0.14	1.7	$C_3 S_1$
34. Suwaihan	1489	967	8.1	-	10.03	9.67	4.42	6.12	13.09	4.93	0.15	1.6	$C_3 S_1$
35. Al Khadher	2660	1695	8.2	-	5.70	20.00	4.90	6.30	9.00	15.00	0.17	5.4	$C_4 S_1$
36. Al Faqa'	1300	845	7.9	-	5.90	7.20	2.80	3.70	5.00	7.00	0.19	3.3	$C_3 S_1$

EC in mmhos/cm at 25° C; TDS in ppm.; all ions in meq/l. Year of analysis 1988.

Table: 6.15.

Chemical analyses of the waters of the Al Ain region: Northern, central, eastern, and southern Al Jaww Plain; Al Ain vicinity and the northern alluvial (gravel) and dune area. (Fig. 6.16)

Mg and HCO_3 are the dominant ions in the waters of northern Al Jaww Plain, although Na, Cl and SO_4 are also equally present, while Ca is low, because these are recharge waters. ECs increase westwards and the EC at the Defence Camp (analysis 2) is the highest among those for the three water analyses for northern Al Jaww. In central Al Jaww the waters still retain their recharge characteristics but Na, Cl and SO_4 are high in occurrence. The waters in this part are of the HCO_3-Mg-Na type. In eastern Al Jaww, Mg and HCO_3 are high in the recharge waters of the Oman foothills. As groundwater flows westwards it becomes mineralized as seen in the analyses for the Al Ain vicinity. In southern Al Jaww, Cl and Na increase with distance from the mountain gaps. Mg, as an indicator of recharge water, still maintains its presence, although the high Mg value for Hazyad in this westernmost part of Al Jaww Plain is derived from the limestone of Jabal Hafeet besides the contribution from the ophiolites of the catchment area. The waters in southern Al Jaww are generally of the Cl-Na-SO_4 type. In the Al Ain vicinity, Na, Cl and HCO_3 are also dominant and the Ca-Mg ratio is 1:1 testifying to the long residence of groundwater in the area. Waters of the northern dune area, are of the Mg-HCO_3 type indicative of their recharge quality. In the northern dune area also the waters change into Na-Cl-SO_4 dominated (analyses 33 and 34 for Suwaihan and Al Khadher).

Waters in the part of the Al Ain region to the *north of Al Ain as far as Al Faqa'* (analyses 25-35), a 55 km. front of public supply wellfields, are mainly of the magnesium-bicarbonate type. Mg values in all the analyses are above 10.00 meq/l while similarly HCO_3, in all the analyses also, is above 3.00 meq/l (analyses 25-35, Table 6.15), except for Al Khadher wellfield where the Cl value is 16.00 meq/l and the Na value is 15.00 meq/l, which are attributed to the mineralization caused by the longer residence of the groundwater in an upper stratum of very compact, low transmissivity limestone that recurs in wellfields in these northern areas in Al Ain. SO_4 values are all moderate in comparison with Al Ain vicinity and they never exceed 5.00 meq/l in any of the analyses (analyses 25-35) in Table 6.15).

To the west of Jabal Hafeet, *in the western plains*, the chemistry of the water changes drastically into sodium chloride-dominated, with Mg still prominent, and Ca next in importance; indicating to a possible recharge nature of the waters, although most of the Mg may be derived *in situ* from the sedimentary rocks of the area. HCO_3 and SO_4 are of moderate values and are only of a high concentration where the EC of the water is high as in Seih Al Miyah, southwest of Al Ain, where ECs reach 19000 mmhos/cm.. SO_4 values can be as high as 122.00 to 130 meq/l (analyses 2 and 5, Table 6.17) where they seem to correlate with the high Na and Cl values (to be described later for the water chemistry in the desert foreland).

Generally speaking, the recharge waters of the through-flow of the area to the north of Al Ain are of a magnesium-bicarbonate type, while those further west are markedly of the sodium-chloride-magnesium type.

6.5.2.4.4. Increase of salinity with depth and distance from the foothills (Table 6.16)

The Water Resource Survey of Abu Dhabi (Gibb's Report, 1970), after the drilling of a few deep wells, some of which reached a maximum depth of 600m. in the Al Ain region, concluded that:

" No potable groundwater, of EC less than 2000 mmhos/cm, was found below 100m. Upper Cretaceous, Eocene and Oligocene rocks are tight at depth, have very low permeability, and may be partly gypsiferous; and aquifers are thin and contain highly mineralized waters. Deep aquifers are usually subartesian, with very low artesian heads."

The report showed the change of EC with depth in well BH-25, along the Abu Dhabi highway, at depths of 60, 100 and 600m., where the change in EC was 2660 mmhos/cm., 6000 mmhos/cm. and 10000 mmhos/cm. in each level respectively. Again, in Well BH-10 at Al 'Iraqiyyah in Um Ghafah, at depths of 26, 69 and 90m., the ECs were 877 mmhos/cm., 1600 mmhos/cm. and 2200 mmhos/cm. respectively.

The location of both these old wells were revisited for this study in June 1987 and the ECs were measured from levels in wells as close as those quoted in 1970 by the Gibb Report, although the wells were not the same but were wells near to those that existed in 1970. The first (BH-25) is now within Al Maqam Palace (analysis 1, Table 6.16.), the second well (BH-10) is in the vicinity of Um Ghafah wellfield of WED Al Ain (analysis 11, Table 6.16.). As can be seen in analysis 11, Table 6.16. for Um Ghafah, the increase of salinity with depth at 30m. and 100m. is nearly three times from 992 mmhos/cm. to 2622 mmhos/cm., which confirms the observation made by the Gibb Report.

The Oligo-Miocene Lower Fars evaporite formation is found in places in the Al Ain region close to the surface, where it occurs as thin layers intercalated with sand and gravel as was observed in drill cuttings of wells even near the foothills to the east. In Mazyad and further south, the evaporites sequence is encountered below 200m. but in greater thickness and extent at 'Iraqiyyah northeast of Mazyad.

Waters in the upper layers of the Fars Formation, in contact with fresh waters in the Quaternary alluvial or aeolian deposits, are less saline than those waters totally resident in the Lower Fars, which tend to have a high Na, Cl and SO_4 content. The difference in EC between the two waters can sometimes be five times (Niadat, in Um Ghafah: EC 922 mmhos/cm. (analysis 11, Table 6.16); Seih Al Miyah, southwest of Al Ain EC 4960 mmhos/cm.) (analysis 3, Table 6.17).

In meq/l

Chemical analyses of groundwater in the Al Jaww Plain (the southern part of the Piedmont Plains (AREA 6C))

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
AL JAWW PLAIN													
1. 'Iraqiyyah(1) 45m	1620	1410	8.0	-	5.40	8.0	9.5	2.40	7.8	12.78	0.16	5.7	C_3 S_1
2. " (2)235m	9636	7032	7.7	-	5.10	84.8	26.0	13.00	8.7	93.90	0.65	28.5	C_4 S_4
3. Seih Malaqet 95m	868	708	7.5	-	5.88	2.7	2.9	1.50	2.7	7.30	0.17	5.0	C_3 S_1
4. Wadi Muraikhat, near 'Ajran Gap 100m	627	351	8.0	-	3.60	1.9	3.0	1.10	5.0	2.50	0.23	1.4	C_2 S_1
5. Wadi Muraikhat, 6kms west of Sa'ah 60m	730	516	8.0	-	3.84	2.6	2.1	1.44	3.4	3.71	0.30	2.4	C_2 S_1
6. " 105m	833	625	8.0	-	3.95	4.9	1.5	0.90	3.0	6.53	0.25	4.7	C_2 S_1
7. Thuqbat Sa'ah(1) 35m	1094	750	7.8	-	4.90	2.4	5.0	3.70	4.3	4.20	0.20	2.1	C_3 S_1
8. " (2)100m	7416	5520	7.5	-	2.10	10.2	68.5	29.34	18.6	31.80	0.30	6.5	C_4 S_1
9. Military Camp near Um Ghafah 42m	1904	1178	8.4	-	6.13	9.5	4.25	2.40	4.2	13.04	0.29	7.2	C_3 S_1
10. " (2) 60m	1938	1380	8.6	-	6.40	10.0	6.50	2.10	5.1	15.65	0.17	8.2	C_3 S_1
11. Wadi Shik, east of Um Ghafah 30m	992	778	7.8	-	5.60	3.4	3.25	1.80	2.4	8.35	0.23	5.8	C_3 S_1
12. " 100m	2622	1872	8.0	-	5.90	13.9	8.18	0.48	6.6	21.38	0.17	11.4	C_4 S_2
13. Um Ghafah	436	293	8.0	-	3.10	1.2	1.00	0.60	3.0	1.60	0.06	1.2	C_2 S_1
14. Seih Ar Raq at Niadat of wadi ch.	2280	1565	8.0	-	6.77	13.8	5.60	2.60	4.13	19.31	0.30	10.6	C_4 S_2
15. Mazyad (1) 40m	1196	773	7.8	-	4.90	3.0	5.50	1.15	7.85	4.40	0.18	2.1	C_3 S_1
16. " (2) 55m	1595	1238	8.1	-	5.20	9.5	6.10	2.00	6.90	11.70	0.28	5.6	C_3 S_1
17. " (3) 95m	1500	1110	8.1	-	6.20	9.2	5.23	2.60	5.95	11.74	0.37	5.6	C_3 S_1
18. Zarub Gap proper40m	395	366	8.0	-	3.40	3.2	0.50	1.15	4.80	1.25	0.06	0.7	C_2 S_1
19. Zarub Gap, 2kms below gap	1254	852	7.6	-	3.00	2.6	7.40	2.40	2.10	8.40	0.22	5.6	C_3 S_1

EC in mmhos/cm. at 25°C; TDS in ppm.; ions in meq/l. Year of analysis 1988.

Table: 6.16.

Chemical analyses of waters in the Al Jaww Plain in the Al Ain region showing the increase in groundwater salinity with depth and distance from the foothills (Fig. 6.16).

Salinity stratification in the aquifers of Al Ain is a common feature. At 'Iraqiyyah (analysis 1), the increase in groundwater salinity between 45m. and 235m. depth is more than 5 times. There is also lateral increase in groundwater salinity towards the west and south: in Zarub Gap in the easternmost part of Al Jaww (analysis 18) the EC is 395mmhos/cm, while at Mazyad in the extreme southwestern tip of Al Jaww the EC is 1196mmhos/cm.

Chemical analyses of groundwater in the desert and sabkha of the western, southwestern and southern areas of the Al Ain region.

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Al Maqam	2403	1925	8.1	-	3.8	15.00	10.50	1.32	7.20	22.20	0.40	10.6	C_4S_2
2. Seih An Nashash	19451	17732	8.0	-	7.0	148.00	122.00	18.00	35.00	224.00	3.00	33.9	$C_4S_4^2$
3. Seih Al Miyah	4960	3224	8.0	-	6.2	51.70	6.20	16.00	4.80	40.00	3.30	12.5	$C_4S_4^2$
4. Seih Sabrah	5952	3869	7.3	-	7.0	62.00	7.10	19.20	5.76	48.00	3.00	13.6	$C_4S_2^2$
5. Seih Az Za'alah	10130	7091	6.5	-	6.0	30.10	130.20	30.00	20.00	116.00	0.60	23.2	$C_4S_3^2$
6. Seih bin Ammar	5380	3482	7.3	-	6.3	45.00	6.39	17.20	5.18	32.20	2.70	9.6	$C_4S_1^2$
7. Seih Shabak	4063	2641	8.1	-	6.88	26.30	7.78	3.13	4.79	32.51	0.53	16.3	$C_4S_2^2$
8. Seih Al Baitar	5901	4131	8.1	-	5.54	31.85	20.59	5.21	8.91	43.33	0.55	16.3	$C_4S_2^2$
9. Seih As Sulaimat	4950	3218	8.1	-	4.66	26.78	17.32	4.38	7.49	36.94	0.47	15.9	$C_4S_2^2$
10. Haza' Al Boasch	4000	2240	8.1	-	3.74	17.10	21.80	3.36	4.14	34.64	0.51	17.9	$C_4S_2^2$
11. Seih Gharabah	5650	3955	8.0	-	5.29	30.40	19.66	4.98	8.51	41.37	0.53	15.9	$C_4S_2^2$
12. Al 'Ushoosh	4470	2503	8.0	-	4.20	24.13	15.60	3.95	6.75	32.83	0.42	14.2	$C_4S_2^2$
13. Al Khashm	4163	2706	8.2	-	5.63	28.40	7.84	3.10	8.63	29.63	0.45	12.2	$C_4S_2^2$
14. Bu Samrah	4968	3229	8.1	-	2.36	36.80	6.62	5.75	6.45	33.12	0.46	13.4	C_4S_2
15. Al Sad	4117	2676	8.0	-	1.73	26.52	11.88	3.52	7.9	28.26	0.43	11.8	$C_4S_2^2$
16. Al Yahar	3850	2503	8.1	-	4.69	24.41	7.40	2.94	3.85	29.35	0.30	16.0	$C_4S_2^2$
17. Al Tuwaisah	5267	3687	8.1	-	2.30	38.27	10.32	6.01	9.69	34.75	0.45	12.4	$C_4S_2^2$
18. Al Khaznah	5819	4073	7.5	-	1.99	46.86	50.60	9.20	11.50	78.12	0.71	24.3	$C_4S_3^2$
19. Ain Bu Sakhinah	10780	7546	7.6	-	1.66	114.65	7.33	12.65	39.60	67.00	4.90	13.6	$C_4S_2^2$
20. Al Wagn	6430	4501	8.0	-	2.45	49.78	10.59	8.97	12.35	40.99	0.51	12.5	$C_4S_2^2$
21. Al Qoa'	10000	6560	7.5	-	3.60	86.40	15.10	13.20	18.60	72.00	1.18	18.1	$C_4S_2^2$
22. Um ez Zemool	22426	14577	7.3	-	8.10	172.00	6.90	35.00	30.00	121.00	0.40	21.2	$C_4S_3^3$

EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Date of sample collection June-July, 1988

Table: 6.17.

Chemical analyses of irrigation water in the gravel and sabkha (seihs) areas of western, southwestern and southern Al Ain region (Fig. 6.16).

Still in the theme of the increase in salinity with depth and distance from the foothills, nearly all the water analyses are for samples from wells in the Oligo-Miocene Lower Fars (Gachsaran) evaporites and clastics. Waters in the upper layers of this evaporite water-bearing sequence, in hydraulic contact with fresh waters in the Quaternary alluvial or aeolian deposits (analyses 1, 15 and 16), are less saline than waters residing totally in the salty Lower Fars (analyses 4, 5, 11, 17, and 19-22), which tend to contain high concentrations of Na, Cl and SO_4.

Table 6.17 gives the water chemistry results of points in the western, southwestern and southern areas of the Al Ain region. Analysis 1 for Al Maqam is within the Al Ain vicinity and the analysis for Al Yahar (analysis 16) is for a western point (in relation to the foothills) in the western fringe of the Al Ain environs. All the other analyses are for points to the west of Al Ain.

(*Refer to location map of the Gibb (1970) wells in Appendix 8*)

6.5.2.4.5. **Long-term fluctuation in water quality in the Al Ain region** (Table 6.18.)

Long-term fluctuation in groundwater quality in the Al Ain region is due to two main reasons: the first, the tapping of aquifers in the gypsiferous Fars Formation; the second, the heavy exploitation of the Quaternary aquifer to exhaustion leading to suction of saline water from the underlying Fars Formation. Long-term fluctuation in water chemistry and quality has been detected from water analyses of WED Al Ain for wells that have records going back for several years. The data are presented without notes concerning the time the sample was collected in relation to the operation of the well and whether the sample was taken after a well had been allowed to rest, sometimes for up to 1-3 months. The majority of wells, for which there are water chemistry data, undergo deepening, cancellation, transfer to another site but still retain the same old well number.

Thus water chemistry data for the wells of WED Al Ain, though they are the best prepared by any water department in the Emirates, should be used with care in view of the anomalies they may contain. The most common anomaly is the sudden change in EC for the better after a long and consistent deterioration over the years. The water chemistry data in the form they are presented by WED Al Ain do not reveal the main factors responsible for the change in quality, although in most cases it has been observed to be due to stopping production from a well for some weeks to allow the water in the well to recover its level and quality. In most cases, the water sample is taken from a well immediately after being restarted after a long stoppage. This sampling cannot be taken as representative as, shortly after the resumption of pumping, the quality deteriorates.

Water analyses from old consultancy reports have also been used to compare water chemistry and quality data with recent data to detect the general long-term change. Apart from the Gibb Report (1970), pumping tests under the supervision of the same consultant, were carried out in Al Hayer in 1974 when ECs of the wells in that area ranged from 560-1500 mmhos/cm. Since that date (1974), the whole northern sand dune area of Al Ain has been developed with a continuous series of public supply wellfields. The ECs for Al Hayer in 1988 ranged from 710 to 3600 mmhos/cm. (Table 6.18.).

The government wheat project of Al Awha, north of Al Ain town, was started in 1977 and 200 wells have been in operation at any one time since that date for the irrigation scheme of the project. In 1977 ECs were all below 1000 mmhos/cm.; by 1988 the ECs averaged 4000 mmhos/cm. and a large number of the wells had run dry (Table 6.18.).

Location	Electrical Conductivity mmhos/cm 1975	1988	
Al Hayer.....	560 - 1500	710-3600	
Ghashabah..... (Wheat farm)	1000	4000	
Um Ghafah.....	580	1200	(1982)
Seih Al Baitar.....	3454	6490	
Haza' Al Boash.....	2500	10000	(1980)
Al Za'alah.....	5262	13000	
Al Khadher.....	2900	4500	

Sources: GWE/ Lahmayer (1979) Al Ain Department of Agriculture/ Gibb-Hunting (1974)
Table : 6.18.

Long-term change in water quality in some areas in Al Ain 1975-1988.

Deterioration in water quality has been between two and five fold between 1975 and 1988. The worst deterioration has been in Al Hayer and Ghashabah were the waters have turned from potable quality to brackish.

In Um Ghafah, the wells draw water from the shallow Quaternary alluvial aquifer, which is replenished occasionally through the mountain gaps in the Oman Mountains to the east, ECs increased two-fold from 580 mmhos/cm. in 1982 to 1200 mmhos/cm. in 1988 with wells running dry in Um

Ghafah village, the citizens' gardens and the forestry nursery. A very intricate management system is adopted in Um Ghafah wellfield by alternating operation of the 30 wells so as to maintain a minimum daily flow of water from the wellfield and yet maintain acceptable quality.

In Haza' Al Boash wellfield, salinities increased from 2500 mmhos/cm. in 1980 to 10,000 mmhos/cm. in 1988, and were accompanied by a drastic drop of output of the wellfield.

The wellfield of Za'alah (old) came into existence, was overpumped, deteriorated rapidly both in quantity and quality and was subsequently abandoned; all this happened within the short time span of 4-5 years. The 10 wells of the old Za'alah wellfield started with high ECs exceeding 5000 mmhos/cm. (1979) but later deteriorated to 10000-15000 mmhos/cm. (1984).

6.5.2.4.6. Short-term fluctuation in water quality in the Al Ain region (Tables 6.19. to 6.25.)

Monthly, quarterly or yearly water chemistry data of the public supply wellfields of WED Al Ain have been used in the ensuing sections of the short-term or seasonal fluctuation of water quality in the Al Ain region. The water analyses presented in Tables 6.19. to 6.25. are all for potable water quality in which the values of the ions are expressed in milligrams per litre (mg/l) as prepared by WED Al Ain.

Factors affecting short-term fluctuation in water quality include: (i) surface runoff, whether emanating from the mountain gaps of the Oman Mountains or originating within the wadis in the Al Ain region; (ii) direct rainfall over the sands and gravels of the region. The rainfall responsible for these effects is derived from the winter rains, the conditions of which prevail over the whole of the Emirates; from monsoon rainstorms occurring in the mountains to the east and also from localized convectional storms within the Al Ain region (Climate, Chapter 3). It is thus not surprising to see a slight relative improvement in water quality in the summer after the rainstorms, although the worsening in quality due to overabstraction remains the dominating trend. The general seasonal variation in water quality is within 10-20% between winter and summer.

Short-term fluctuation in water quality, as far as the public supply wellfields of WED Al Ain are concerned, takes place in two forms:

(i) A seasonal variation between winter and summer.
(ii) A more localized, even shorter-term variation, as detected from analyses for the same wells taken twice a month.

There is stratification in the mineralization of groundwater in the aquifers in the Al Ain region and, with continued pumping, groundwater becomes more saline.

Four water samples from Um Ghafah and four for Al Hayer North wellfields were studied (Tables 6.19 and 6.20). The water quality data for the four Um Ghafah wellfields are for February, July and November (Table 6.19); while the data for the four Al Hayer North wells are for February, July and October (Table 6.20).

In three of the four Um Ghafah wells shown in Table 6.19 (Wells 103, 105 and 412), the highest EC was reached in November. The deterioration in quality in Um Ghafah Well-103, between July 1987 and November 1987 was 8%, while the improvement in quality between November 1987 and February 1988 was 12%. The same was the case for Um Ghafah Well-105. For Um Ghafah Well 412, the deterioration between July 1987 and November 1987 was only 3%, while the improvement between November 1987 and February 1988 was 9%. Um Ghafah Well 508 showed an improvement between July 1987 and February 1987 of 30% (Table 6.19).

The fluctuation in water quality in Al Hayer North wellfield was greater in Well 604 where the deterioration between July and October 1987 was about 100%, and the improvement between October 1987 and February 1988 was about the same (Table 6.20). In the other three Al Hayer North Wells Nos. 1005, 1012 and 913 (Table 6.20), the deterioration in Well 1005 between July and October (1987) was 30% and the improvement between October 1987 and February 1988 was 6%. For Well 1012, the improvement between July 1987 and February 1988 was 14%; while for Well 913 the improvement between October 1987 and February 1988 was 25%. The average fluctuation in the EC of Al Hayer North wellfield was 38% (Table 6.20).

	UM GHAFAH-WELL 103			UM GHAFAH-WELL 105			UM GHAFAH-WELL 412			UM GHAFAH-WELL 508			In mg/l	
	JULY 87	NOV. 87	FEB. 88	JULY 87	NOV. 87	FEB. 88	JULY 87	NOV. 87	FEB. 88	JULY 87	NOV. 87	FEB. 88		
Physical Test:														
Appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear		
Colour "Hazen"	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5		
EC mmhos/cm at 25°C	625	680	600	646	680	590	923	950	860	1090	1050	770		
Odour	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less		
pH	8.1	8.1	8.4	7.9	8.3	8.0	8.0	8.0	8.1	8.2	8.2	8.1		
Taste	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-les	T-less		
Turbidity TE/Formazine	0.23	0.47	0.60	0.34	0.32	0.26	0.31	0.55	1.50	0.30	0.20	1.20		
Chemical Test:														
Alkalinity as MO	146	146	152	150	160	162	166	168	168	148	152	156		
Ammonia	0.03	0.06	0.07	0.04	0.03	0.06	0.07	nil	0.03	0.04	0.02	0.08		
Carbon Dioxide	65	68	70	67	73	73	75	77	77	67	70	71		
Chlorides (Cl)	89	91	87	85	108	85	127	133	135	195	205	125		
Calcium Hardness $CaCO_3$	52	44	48	45	52	50	92	90	94	64	62	52		
Iron	0.07	0.01	nil	nil	nil	nil	nil	0.04	0.01	nil	0.01	0.04		
Magnesium Hardness Mg	148	168	178	165	140	166	218	224	226	146	148	116		
Manganese	0.04	0.02	0.01	0.04	0.01	0.02	0.02	0.03	0.02	0.03	0.02	0.01		
Sulphate SO_4	0.7	0.6	0.5	0.8	0.3	0.1	0.7	0.8	0.2	0.4	0.6	0.8		
Total Hardness	200	212	226	210	192	216	310	314	320	210	210	168		
TDS	413	442	390	420	442	384	600	618	559	709	683	501		
Total Silicate as SiO_2	2.08	1.18	1.50	0.85	0.8	0.65	0.78	1.38	3.75	0.75	0.5	3.0		
	Better by 12%			Better by 15%			Better by 11%			Better by 27%				

Data source: Water and Electricity Department, Al Khubaisi, Al Ain. Ions in mg/l.

Table: 6.19.

Short-term variation in groundwater quality in some of the wells of the Um Ghafah public supply wellfield in the Al Ain region (1987-88).

The maximum deterioration (increase) in the EC varied from 3-10% in the Um Ghafah Wells 103, 105 and 412 between July and November 1987; while the improvement in the EC varied from 12-30% between November 1987 and February 1988. The general deterioration was due to overpumping; the improvement was due to recharge from the winter (February) rains or the laying-off of the wells for up to two months to recover their water levels and quality.

	AL HAYER NORTH-WELL 604			AL HAYER NORTH-WELL 1005			AL HAYER NORTH-WELL 1012			AL HAYER NORTH-WELL 913			In mg/l	
	JULY 87	OCT 87	FEB 88	JULY 87	OCT 87	FEB 88	JULY 87	OCT 87	FEB 88	JULY 87	OCT 87	FEB 88		
Physical Test:														
Appearance	Turbid	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Turbid	Clear	Clear		
Colour "Hazen"	<10	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5		
EC mmhos/cm at 25°C	710	1380	630	2875	3600	3400	1970	1920	1700	1610	1410	1200		
Odour	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less		
pH	7.6	8.0	7.9	7.3	7.8	7.7	7.6	7.9	7.8	7.9	7.8	7.9		
Taste	T-less	T-less	T-less	Salty	Salty	Salty	T-less	T-less	T-less	T-less	T-less	T-less		
Turbidity	5.3	1.20	0.44	0.27	0.28	0.24	0.39	0.25	1.40	3.40	0.33	1.30		
Chemical Test:														
Alkalinity as MO	192	176	174	240	262	256	206	202	198	118	116	120		
Ammonia	0.08	0.09	0.02	0.18	nil	0.02	0.02	0.06	0.02	0.04	0.01	0.03		
Carbon Dioxide	88.0	79.0	78.0	106	118	114	92.0	94.0	90.0	54.0	53.0	55.0		
Chlorides (Cl)	162.8	300.0	89.0	660.0	882.0	864.0	421.0	417.0	382.0	328.0	307.0	278.0		
Calcium Hardness $CaCO_3$	58.0	74.0	60.0	120.0	90.0	128.0	92.0	94.0	96.0	114.0	100.0	92.0		
Iron	0.09	0.06	0.01	nil	nil	nil	0.01	0.02	0.02	0.03	0.005	0.08		
Magnesium Hardness Mg	146	180	132	328	408	372	214	214	204	188	178	152		
Manganese	0.05	nil	nil	0.02	nil	0.02	0.02	nil	0.03	nil	0.01	0.02		
Sulphate SO_4	0.2	0.4	0.7	0.8	nil	0.8	0.4	0.8	0.1	0.5	0.8	0.6		
Total Hardness	128	164	78	219	250	234	172	172	175	179	163	156		
TDS	666	897	410	1869	2340	2210	1281	1248	1105	1047	917	780		
Total Silicate as SiO_2	13.25	3.0	1.10	0.68	0.70	0.60	0.98	0.63	3.50	8.5	0.83	3.25		
	Better by 120%			Better by 6%			Better by 13%			Better by 15%				
Data source: Water and Electricity Department, Al Khubaisi, Al Ain. Ions in mg/l.														

Table: 6.20.

Short-term variation in groundwater quality in some of the wells of the Al Hayer North public supply wellfield in the Al Ain region (1987-88).

Seasonal variation in groundwater quality in the Al Hayer North wellfield was greater than that for the Um Ghafah wellfield (Table 6.19). In the Al Hayer North Well-604 the deterioration in the EC of the groundwater was 100% between July and October 1987. The general fluctuation in the EC for the whole of the Al Hayer North wellfield averaged 38% for the same period.

In Ghashabah (Table 6.21), a wellfield situated close to the Al Awha wheat farm, the general deterioration between April and November 1987 of 38% was in Wells 1 and 15, which exhibited a localized deterioration in quality (i.e., rise in EC) between April and November of 79% and 100% respectively. These two wells are closest to the wheat farm where the effect of the heavy groundwater abstraction was evident in the deterioration in quality in the Ghashabah wellfield. The deterioration in water quality is high for a wellfield close to the recharge zone of the Mahdhah outwash fan, which is at the outflow of one of the three mountain gaps through which emanate recharge waters to the groundwater system of Al Ain.

The EC in Ghashabah Well-15 changed from 650 mmhos/cm. in April to 1300 mmhos/cm. in November 1987 (Table 6.21). The marked increase was in Cl, Ca and Mg to almost two-fold, while sulphate increased by about 50% of the value for April. The lowest deterioration in quality was found in Well-5, which was situated at the easternmost fringe of the Ghashabah wellfield, close to the foothills where the deterioration in quality between April and November 1987 was only 4% (Table 6.21). It is clear that wells that are situated on the western parts of the Ghashabah wellfield, close to the heavy abstraction area of the Al Awha wheat farm, show deterioration in quality more than the wells situated on the eastern part of the wellfield near the recharge zone.

The situation in the Kara' wellfield (Table 6.22) does not differ much from those wellfields previously described, with the general variation in quality between summer and winter in the three sections of the wellfield: Kara' North, Jubaita and Bida' Bint Ahmad was between 12-28%. (June 1987-January 1988). Locally, the highest change (improvement in quality) was in Well-310 in Kara' North, just a few metres off the Al Ain-Dubai highway before reaching the village of Al Hayer. In the three sections of the wellfield, the Bida' Bint Ahmad section, seemed to exhibit relatively better quality water than the rest of the wells of the other two sections (see Table 6.22).

Sulphate values in the whole Kara' wellfield seem to increase proportionately to those of Ca, Mg and Cl. This is in contrast with the wellfields further south discussed earlier where SO_4 does not show important increases.

	GHASHABAH-WELL 1		GHASHABAH-WELL 5		GHASHABAH-WELL 10		GHASHABAH-WELL 12		GHASHABAH-WELL 15		GHASHABAH-WELL 17		In mg/l	
	APR 87	NOV 87	APR 87	NOV 87	APR 87	NOV 87	APR 87	NOV 87	APR 87	NOV 87	APR 87	NOV 87		
Physical Test:														
Appearance	Clear	Turbid	Clear	Clear	Clear	Turbid	Turbid	Clear	Turbid	Clear	Clear	Clear		
Colour "Hazen"	< 5	<10	< 5	< 5	< 5	<10	<10	< 5	<10	< 5	< 5	< 5		
EC mmhos/cm at 25°C	700	1250	750	780	1200	980	570	660	650	1300	710	790		
Odour	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less		
pH	8.2	8.6	8.2	8.0	8.1	8.6	8.4	8.2	8.3	8.0	8.2	8.3		
Taste	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less		
Turbidity	0.22	3.88	0.25	0.24	0.27	2.70	3.70	1.50	3.00	0.32	0.21	1.70		
Chemical Test:														
Alkalinity as HO	206	224	202	194	198	226	224	204	198	190	196	200		
Ammonia	0.04	0.12	0.08	0.08	0.20	0.09	0.01	0.03	0.11	0.04	0.08	0.08		
Carbon Dioxide	92.0	102.0	90.0	87.0	88.0	106.0	104.0	93.0	90.0	85.0	86.0	92.0		
Chlorides (Cl)	101	220	97	107	226	159	92	107	92	288	89	111		
Calcium Hardness $CaCO_3$	50	76	48	56	92	70	36	54	54	112	54	50		
Iron	0.02	0.15	nil	0.02	0.03	0.06	0.04	0.03	0.005	0.02	0.005	nil		
Magnesium Hardness Mg	168	216	170	168	298	208	144	156	160	362	160	188		
Manganese	0.03	0.05	0.04	0.02	0.07	0.05	0.08	0.04	0.07	0.02	0.06	0.02		
Sulphate SO_4	0.5	0.4	0.6	0.7	0.9	0.6	0.2	0.6	0.6	0.8	0.5	0.8		
Total Hardness	218	292	218	224	390	278	180	210	214	474	214	238		
TDS	455	813	488	507	780	637	371	429	423	845	462	479		
Total Silicate as SiO_2	0.55	9.5	0.63	0.6	0.68	6.75	0.04	0.03	7.5	0.8	0.53	4.3		
	Worse by 79%		Worse by 4%		Better by 20%		Worse by 16%		Worse by 100%		Worse by 11%			

Data source: Water and Electricity Department, Al Khubaisi, Al Ain. Ions in mg/l.

Table: 6.21.

Short-term variation in groundwater quality in some of the wells of the Ghashabah public supply wellfield in the Al Ain region (1987-88).

The Ghashabah public supply wellfield is close to the Al Awha government wheat farm and the heavy abstraction in the wheat project has affected groundwater quality in the Ghashabah wells. This is evident in Wells 1 and 15, the closest of the wells to the wheat farm, in which the deterioration in the EC was between 79-100% between April and November 1987. Only Well-10 showed an improvement in the EC of 20% during the same period. All the other wells did not record any improvement during the same period (April-November 1987).

	AL KARA'				JUBAITA				BIDA' BINT AHMAD				In mg/l	
	WELL 101		WELL 310		WELL 414		WELL 423		WELL 201		WELL 207			
	JUNE 87	JAN 88	JUNE 87	JAN 88	MARCH 87	SEPT 87	MARCH 87	SEPT 87	JUNE 87	JAN 88	JUNE 87	JAN 88		
Physical Test:														
Appearance	Clear	Turbid	Clear	Clear	Clear	Clear	Clear	Turbid	Clear	Clear	Clear	Clear		
Colour "Hazen"	< 5	<15	< 5	< 5	< 5	< 5	< 5	<20	< 5	< 5	< 5	< 5		
EC mmhos/cm at 25°C	700	560	800	530	1200	1440	1100	1410	660	590	810	700		
Odour	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less		
pH	7.9	8.2	8.2	8.3	8.0	8.1	7.9	8.2	7.9	8.1	8.0	8.1		
Taste	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less		
Turbidity	0.53	4.70	0.70	0.30	0.40	0.27	0.36	7.90	0.45	0.41	0.26	0.34		
Chemical Test:														
Alkalinity as HO	144	140	148	124	222	220	238	242	138	136	146	148		
Ammonia	0.11	0.01	0.09	0.07	0.04	0.05	0.05	0.07	0.05	0.07	0.05	0.06		
Carbon Dioxide	65	63	67	58	98	100	104	111	63	61	65	67		
Chlorides (Cl)	89	87	111	75	193	191	149	207	97	93	133	131		
Calcium Hardness $CaCO_3$	40	38	42	36	50	48	44	52	44	52	50	46		
Iron	0.03	0.12	0.08	0.01	0.005	0.03	0.005	0.01	0.02	0.02	0.04	0.03		
Magnesium Hardness Mg	138	132	114	110	156	168	122	162	131	128	140	134		
Manganese	0.02	0.01	0.06	0.01	0.04	nil	0.06	0.04	0.03	nil	0.02	0.02		
Sulphate SO_4	98	80	111	87	154	171	126	178	105	90	115	102		
Total Hardness	178	170	156	146	206	216	166	214	175	180	190	194		
TDS	423	364	520	348	780	936	715	917	429	384	527	397		
Total Silicate as SiO_2	1.33	11.8	1.75	0.75	1.00	0.68	0.90	19.8	1.23	4.50	0.65	0.85		
	Better by 22%		Better by 34%		Worse by 22%		Worse by 28%		Better by 11%		Better by 14.5%			
Data source: Water and Electricity Department, Al Khubaisi, Al Ain.. Ions in mg/l.														

Table: 6.22.

Short-term variation in groundwater quality in some wells of the public supply wellfields of Al Kara', Jubaita and Bida' Bint Ahmad in the Al Ain region (1987-88).

The deterioration in the three sections of Al Kara' Wellfield: Al Kara' North, Jubaita and Bida' Bint Ahmad was 12-28% during the period June 1987 to January 1988. The highest improvement in the EC was in Kara' North Well-310. The Bida' Bint Ahmad section of the wellfield has the best-quality groundwater in the whole wellfield. SO_4 shows an increase proportional to the increase in Ca, Mg and Cl.

Table 6.23 presents the water chemistry data for selected wells in Al Khader wellfield, which lies to the north of Suwaihan and supplies large consumers in Abu Dhabi. The deterioration in quality occurs in some wells in winter, contrary to the norm (i.e. deterioration in the summer, long after recharge from the winter rains), but others in the same wellfield show the usual expected improvement in the winter after the rains. The wellfield taps the shallow Quaternary sands and the deterioration in quality in the winter, as shown by the ECs of Wells 41, 47 and 52, ranges from 8 to 29% (Table 6.23). This is not necessarily the result of excessive pumping or drop in groundwater levels, but is due to a rise in the water-table effected by the winter rains infiltrating the dune sands causing a localized rise in the groundwater level that submerges an overlying evaporite layer, leading to contamination by its salts with this temporary hydraulic connection in the two layers. This can clearly be seen from the increase in Cl values of 5-25%, with the lowest being in a well where the highest deterioration in quality occurs as indicated by the increase in the EC (Well 52, Table 6.23); the highest change in the Cl values are in a well exhibiting the lowest variation in EC (Well 41, Table 6.23).

Although there is an 8% deterioration in quality as indicated by the EC in Well 41 from 4650 mmhos/cm. (in August 1987) to 5000 mmhos/cm. (in December 1987), the increase in Cl was 25%. In Well 52, the deterioration in EC was from 4725 mmhos/cm. (August 1987) to 6100 mmhos/cm. (December 1987), which was an increase (i.e. deterioration) of 29%. The increase in Cl was only 5%.

The Mg content remains high and increases only slightly in December to signify recharge, an increase that could have been more had it not been for the increase in Cl and SO_4 due to contamination effected by the rise in the static water level and the inundation of the overlying evaporites stratum noted earlier.

On the other hand, Wells 40, 49 and 35 (Table 6.23) show a normal range improvement in quality in the winter following the rains, which may be possible because of the lack of an overlying evaporite layer suggesting the possibility of lens-type limited aquifers. The improvement in quality was 2-27%, with the best being in Well-49, where it was 27%.

AL KHADHER	DETERIORATING						IMPROVING							
	WELL 41		WELL 47		WELL 52		WELL 40		WELL 49		WELL 35		In mg/l	
	AUG 87	DEC 87	AUG 87	DEC 87	AUG 87	DEC 87	AUG 87	DEC 87	AUG 87	DEC 87	AUG 87	DEC 87		
Physical Test:														
Appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear		
Colour "Hazen"	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5		
EC mmhos/cm at 25°C	4650	5000	5260	5650	4725	6100	3110	2950	3150	2300	3160	3100		
Odour	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less		
pH	8.2	8.1	8.1	8.2	8.0	8.1	8.1	8.1	8.3	8.3	8.2	8.2		
Taste	Salty	Salty	Salty	Salty	Salty	Salty	Salty	T-less	Salty	T-less	Salty	T-less		
Turbidity	0.31	0.24	0.31	0.25	0.25	0.32	0.30	1.40	0.28	0.26	0.22	0.23		
Chemical Test:														
Alkalinity as MO	192	192	168	170	152	156	206	204	206	218	190	200		
Ammonia	0.03	0.05	0.07	0.01	0.01	0.005	0.005	0.02	0.03	0.03	0.02	0.03		
Carbon Dioxide	86	87	76	80	69	71	92	90	93	99	85	81		
Chlorides (Cl)	923	1156	1276	1380	1350	1424	546	536	581	399	561	561		
Calcium Hardness $CaCO_3$	128	144	180	182	176	182	160	232	72	94	204	138		
Iron	nil	0.03	nil	nil	nil	nil	nil	0.03	nil	0.02	nil	0.02		
Magnesium Hardness Mg	200	274	228	246	270	288	120	170	128	98	124	114		
Manganese	0.05	0.02	0.01	0.01	0.01	0.01	0.03	0.03	0.01	0.05	0.02	0.03		
Sulphate SO_4	290	305	270	300	285	305	275	280	240	235	265	270		
Total Hardness	328	418	408	428	436	470	280	402	200	192	328	252		
TDS	3023	3250	3419	3673	3071	3965	2022	1918	2948	1495	2054	2015		
Total Silicate as SiO_2	0.78	0.60	0.78	0.63	0.63	0.80	0.75	3.50	0.70	0.65	0.55	0.58		
	Worse by 8%		Worse by 7.5%		Worse by 29%		Better by 7%		Better by 27%		Better by 2%			

Data source: Water and Electricity Department, Al Khubaisi, Al Ain. Ions in mg/l.

Table: 6.23.

Short-term variation in groundwater quality in some of the wells of the public supply wellfield of Al Khadher Nassas in the Al Ain region (1987).

The deterioration in the groundwater quality of the Al Khadher Nassas wellfield occurs in winter contrary to the norm (i.e., of recharge after the winter rains and relative improvement in the EC as a result). This is particularly evident in Wells 41, 47 and 52. All the other wells show deterioration in summer and improvement in winter. The deterioration in Well-41, of 8% between August and December 1987, may be due to a rise in the water-table which inundates the gypsum layer on top of the alluvial layer causing an increase in salinity by contamination with the salts of the gypsum.

The EC upgraded from 3150 mmhos/cm. in August to 2300 mmhos/cm. in December (1987). Cl values improved by 40% and, unlike the other wells, which exhibited deterioration in quality, SO_4 remained stable and showed little or no change in the wells of improved quality in winter.

In Wells 504, 511 and 512 in Suwaihan Road wellfield (Table 6.24), improvement in quality between September (1987) and February (1988) varied from 15 to 20%. There was a reduction in the values of Cl, Mg and SO_4 in all the wells that showed improvement in quality, but the Ca content was only slightly altered by the composition of the Oligo-Miocene limestones. Well 505 showed a three-fold deterioration in quality between September (1987) and February (1988) with the EC increasing from 715 mmhos/cm. to 2050 mmhos/cm. in February. Cl increased six-fold, while Ca and Mg values increased by four times. The increase in SO_4 was negligible.

The very high increase in Cl in Well 505 (Table 6.24) despite recharge after the winter rains, is again explained by the sudden mixing with Cl concentrates in the overlying evaporites, whereas the high Mg and Ca content is indicative of the recharge constituent of the recent water and also the composition of the aquifer material (limestone). Well-507 (Table 6.24) is an example where quality remained stable between September 1987 and February 1988 and where, though the EC remained the same at 1000 mmhos/cm., Cl hardly changed but Mg altered slightly. The most pronounced increase was in SO_4, which amounted to 16%.

Table 6.25 shows the variation in groundwater quality in some of the villages in the Al Jaww Plain between September 1987 and February 1988. There is a clear improvement, though slight, in the waters of all the villages due to the dilution of the Cl content. Villages like Sa'ah and Malaqet exhibited little variation as these places are situated near the Zarub Gap where through-flow takes place all the year round, but with a reduced volume in summer. On the contrary, Al Awha showed a deterioration in quality for February due mainly to: its location some distance away from the recharge zone (inflow takes a long time to reach it); and to overabstraction in the Ghashabah public supply wellfield and the Al Awha government wheat farm.

SUWAIHAN ROAD

	WELL 504		WELL 511		WELL 512		WELL 505		WELL 506		WELL 507		In mg/l	
	SEPT 87	FEB 88	SEPT 87	FEB 88	SEPT 87	FEB 88	SEPT 87	FEB 88	SEPT 87	FEB 88	SEPT 87	FEB 88		
Physical Test:														
Appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear		
Colour "Hazen"	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5		
EC mmhos/cm at 25°C	715	620	600	490	810	670	715	2050	836	780	1000	1000		
Odour	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less		
pH	8.2	8.1	8.2	8.1	8.1	8.0	8.2	8.0	8.1	8.0	8.1	8.0		
Taste	T-less	T-less	T-less	T-less	T-less	T-less	T-less	Salty	T-less	T-less	T-less	T-less		
Turbidity	0.23	0.20	0.25	0.17	0.68	0.40	0.29	0.88	0.76	0.18	0.24	0.20		
Chemical Test:														
Alkalinity as MO	150	150	142	144	148	140	150	154	150	146	168	166		
Ammonia	0.09	0.02	0.04	0.09	0.01	0.01	0.09	0.01	0.02	0.04	0.03	0.02		
Carbon Dioxide	70	68	69	67	68	64	70	51	68	67	76	76		
Chlorides (Cl)	107	103	74	75	151	135	107	645	137	139	189	187		
Calcium Hardness $CaCO_3$	50	42	54	53	74	72	50	198	54	54	70	70		
Iron	0.03	0.01	nil	0.01	nil	0.02	0.03	0.03	0.02	0.01	nil	0.01		
Magnesium Hardness Mg	130	140	110	114	190	171	130	568	140	152	172	164		
Manganese	0.01	0.01	0.01	0.03	nil	0.04	0.01	0.04	nil	0.02	nil	0.02		
Sulphate SO_4	134	98	122	78	130	94	134	144	134	103	163	138		
Total Hardness	180	182	164	167	264	243	180	766	194	206	242	234		
TDS	465	403	390	319	527	436	465	1333	543	507	650	650		
Total Silicate as SiO_2	0.71	0.50	0.63	0.43	1.44	0.95	0.71	2.20	1.40	0.45	0.60	0.50		
	Better by 15%		Better by 20%		Better by 19%		Worse by 287%		Better by 7%		Stable			

Source: Water and Electricity Department (WED) Al Ain. EC in mmhos/cm. at 25° C Ions in mg/l.

Table: 6.24.

Short-term variation in groundwater quality in some of the wells of the Suwaihan Road public supply wellfield of the Al Ain region (1987-88).

The improvement in the EC in the Suwaihan Road wellfield was 15-20% between September 1987 and February 1988. However, the deterioration in the EC in Well-505 was three-fold during the same period (from 715mmhos/cm in in September 1987 to 2050 in February 1988). The high increase in Cl in Well-505 was due to contamination with the salt in the overlying evaporites layer by a rise in the water-table. It should be noted that evaporite and alluvial material intercalate in the water-bearing strata in most areas of the Al Ain region.

	SEPTEMBER 1987							FEBRUARY 1988						
In mg/l	Mazyad	Um Ghafah	Sa'ah	Malaqit	Al Awha	Al Mussala	Sababa	Mazyad	Um Ghafah	Sa'ah	Malaqit	Al Awha	Al Mussala	Sababa
Physical Test:														
Appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	NA	Clear
Colour "Hazen"	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	NA	< 5
EC mmhos/cm at 25°C	1093	726	627	790	1133	1000	485	995	712	563	780	1223	NA	486
Odour	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	O-less	NA	O-less
pH	7.9	8.3	8.1	7.6	8.2	8.5	8.0	8.2	8.3	8.4	7.8	8.0	NA	8.0
Taste	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	T-less	NA	T-less
Turbidity	0.23	0.24	0.16	0.19	0.24	0.21	0.17	1.10	0.30	0.23	0.24	0.55	NA	0.51
Chemical Test:														
Alkalinity as MO	278	173	147	230	233	182	136	256	177	140	222	237	NA	132
Ammonia	0.04	0.05	0.07	0.04	0.05	0.09	0.05	0.07	0.04	0.03	0.02	0.04	NA	0.02
Carbon Dioxide	125	79	68	103	106	84	63	114	80	63	113	106	NA	60
Chlorides (Cl)	145	94	86	99	182	155	66	127	128	77	97	195	NA	62
Calcium Hardness $CaCO_3$	91	56	57	116	106	60	50	74	74	47	105	105	NA	46
Iron	0.02	0.02	nil	0.03	0.05	nil	nil	0.002	0.002	nil	0.02	0.08	NA	0.02
Magnesium Hardness Mg	257	134	146	182	235	156	98	211	207	142	185	222	NA	104
Manganese	nil	nil	nil	nil	0.03	0.05	nil	0.01	nil	0.01	0.02	0.04	NA	0.03
Sulphate SO_4	154	119	114	130	141	139	103	127	128	77	102	109	NA	67
Total Hardness	348	187	203	298	339	216	148	281	281	189	290	341	NA	150
TDS	711	472	408	514	737	650	315	647	647	366	507	796	NA	316
Total Silicate as SiO_2	0.60	0.60	0.41	0.48	0.70	0.53	0.43	2.70	0.30	0.60	0.60	1.40	NA	0.02

Note: (1) The general slight improvement in the EC except for Al Awha where it has worsened by 8% in February despite the location of this point on the Mahdhah outwash fan supposedly a recharge area. This also true of an increase in the chloride content by about the same order, otherwise Cl becomes less in all points.

Data source: Water and Electricity Department, Al Khubaisi, Al Ain. Ions in mg/l.

Table: 6.25.

Short-term variation in groundwater quality in some of the wells of the outlying villages of Al Ain (1987-1988).

There was a slight improvement in groundwater quality in the wells of all the villages between September 1987 and February 1988. The negligible improvement in Sa'ah was due to the fact that this village is located close to the Zarub Gap where fresh groundwater flow takes place all the year round. On the other hand, the deterioration shown in Al Awha in February 1988 was due to both distance from the Mahdhah Gap and also to groundwater overabstraction in both the Ghashabah public supply wellfield and the Al Awha wheat farm.

6.5.2.4.7. **The relationship between the drop in groundwater levels and the deterioration in groundwater quality** (Fig. 6.17)

As noted in Section 6.5.2.4.6., water quality in the Al Ain region not only deteriorates with the drop in groundwater levels but also with their rise, caused by localized recharge. The latter effect is common west of Al Ain where Upper Eocene gypsum is close to the surface overlying the fresh water-bearing limestones, clastics or even conglomerates. Thus, any rise in the water level following the winter rains leads to the saturation of the gypsiferous strata and the contamination of the fresh or marginal waters in the underlying strata by the salts of the overlying gypsum.

ECs can improve in wells being recharged in the winter by the ensuing dilution of the salts. In summer, when levels drop after months of abstraction since the last recharge event in winter, salinization takes place unless alleviated by a summer downpour. In the long term, the drop in groundwater levels and quality is systematic.

In the Al Jaww Plain, during the time of the Gibb Water Resources Survey (1970), aquifer water had the same EC as that of the recharge water. This is no longer happening and the relationship of groundwater level drop and deterioration in water quality is close and is characterized by the following features:

(i) The continuous, consistent decline in groundwater levels at a rate ranging from 1-4m. per year in the Al Ain region. (Chapter 5, Section 5.5.1 and 5.5.2)

(ii) The increase in salinities as a result of this drop in groundwater levels, the subsequent compaction of the water-bearing material and the resulting slow groundwater flow.

As a result, production from the Al Ain wellfields is intentionally reduced so as to maintain a minimum daily flow of water of potable quality. There is localized partial recovery of groundwater levels and

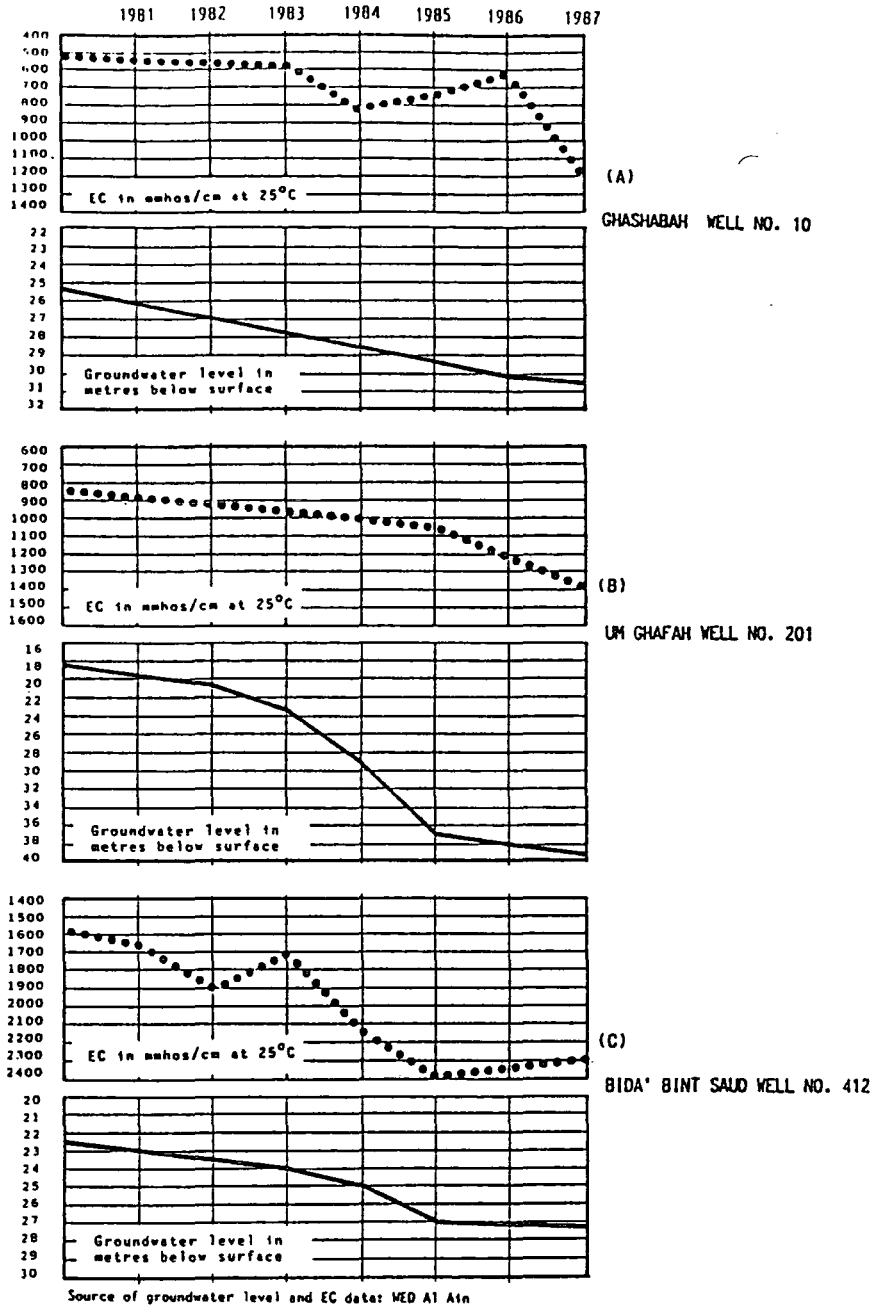


Figure: 6.17. (A to C).

The relationship between the drop in groundwater levels and the deterioration in groundwater quality in the Al Ain region (1981-87)

There is a close relationship between the drop in groundwater level and the deterioration in groundwater quality as seen in these combined groundwater level-electrical conductivity (EC) graphs for the three representative wells of Ghashabah Well No. 10 (A), Um Ghafah Well No. 201 (B) and Bida' Bint Saud Well No. 412 (C). The three main features that can be deduced from the graphs are: the consistent recession in water levels at an annual rate of 1m.; the equally systematic deterioration in the EC of groundwater as water is pumped from the deeper Tertiary Lower Fars evaporite sequence; and, the apparent lessening of abstraction by laying off wells to partially recover their groundwater levels and quality as seen from the relative flattening of the groundwater-level hydrographs and the upward trends in the limbs of the EC graphs.

improvement in groundwater quality by resorting to the practice of allowing production wells to rest for up to three months. Figure 6.17 presents groundwater level and EC graphs of selected representative wells from the public supply wellfields of the Al Ain region (Ghashabah Well 10; Um Ghafah Well 201 and Bida' Bint Saud Well 412) to illustrate the relationship between the two for the period 1981-1987.

6.5.2.4.8 Suitability of groundwater for domestic use in the Al Ain region

The World Health Organization's (WHO) maximum safe limits of salinity (TDS) for potable water is between 1000-1500 ppm (equivalent to EC 1500-2000 mmhos/cm.). Such water is found in the Al Jaww Plain but also in some of the public supply wellfields of the northern dune area of Al Ain. In the latter place, there are wellfields with ECs of below 1000 mmhos/cm., with waters derived from the shallow Quaternary aquifer receiving recharge water directly from the Oman Mountains to the east. Some of the ECs of the waters in the northern dune area are comparable to those in the mountains in the Northern Emirates (Section 6.5.1.).

Groundwaters to the west and south of Jabal Hafeet are derived from aquifers in the Fars evaporites formation and are therefore highly saline with excessive individual mineral content in which the values for Na, Cl and SO_4 are so high as to render these waters unpotable. Yet, residents in these parts of the Emirates drink such waters with ECs of more than 4000 mmhos/cm.

Nitrate (NO_3) concentration of more than 0.8 meq/l is dangerous to health, especially if present in waters given to infants. It is directly caused by contamination from animal and vegetal matter near open wells, or from chemical and organic fertilizers percolating into the groundwater system with recirculating irrigation water. There is a strong likelihood of dangerous concentrations of NO_3 in waters in heavily cultivated and irrigated areas with generous application of fertilizers and high soil infiltration rates (Chapter 11, Section 11.6.2).

Besides parts of the Al Jaww Plain and the wellfields of the northern dune area, where waters of potable quality occur, waters elsewhere are marginal to brackish and saline and are therefore unusable for humans.

6.5.2.4.9. Suitability of groundwater for agriculture in the Al Ain region (Tables 6.26 to 6.28; Fig. 6.18)

The 1987-88 Statistical Year Book of the Al Ain Department of Agriculture listed the samples of irrigation water analyzed, for most of the area under the supervision of the department, according to salinity class. The data have been modified here to percentages under each salinity group of irrigation water and are presented in Table 6.26.

As shown in Table 6.26, 82.5% of the irrigation water in the Al Ain region is of the C_4-C_6 classes which are of the very to the extremely high salinity hazard (i.e. with ECs ranging from 4000 to over 6000 mmhos/cm.). Those waters within the C_5-C_6 classes (i.e. of ECs of 4000-6000 mmhos/cm.) make up 60% of the total samples (analyzed by the Al Ain Department of Agriculture). Less than 18% of the waters fall within the C_2-C_3 classes (250-2250 mmhos/cm). In most areas, the class of irrigation water is C_4 or of even poorer class, and the sodium hazard is of the S_2-S_4 classes; while that of the S_4 (very high sodium hazard) is in the irrigation waters in all areas to the west of Al Ain. As the TDS limits of good and poor irrigation water are 500 ppm. and 3000 ppm. (EC 650 mmhos/cm. and 4000 mmhos/cm.) respectively, the waters in most areas in the Al Ain region are of very poor quality to sustain successful cultivation for many years.

The irrigation water used in the Al Awha government wheat farm started with ECs ranging from 700-800 mmhos/cm. (1980), in the C_2 salinity and S_1 sodium hazard class (Soil and Water Quality Survey, Desert Development Institute of Japan (DDIJ), 1980). By 1986, the irrigation water had already become of the C_3 S_2 class (high salinity and medium sodium hazard), and a number of wells in the wheat farm had waters of the C_4-C_6 salinity classes of over 4000 mmhos/cm. (Statistical Year Book, Al Ain Dept. of Agriculture, 1986-87). This may be largely attributed to the depletion of the shallow Quaternary alluvial aquifer in Ghashabah (the lower Mahdhah outwash fan), where the wheat farm is

AREA	C_1 0-250	C_2 250-750	C_3 750-2250	C_4 2250-4000	C_5 4000-6000	C_6 >6000 mmhos/cm	
1. Al Hayer	-	12.5	35.2	34.8	13.0	4.5	
2. Ghamdh	-	-	7.6	15.2	31.0	46.2	
3. Al Faqa'	-	-	40.0	60.0	-	-	
4. Al Ain	-	26.4	36.8	15.8	10.5	10.5	
5. Al Qattarah	-	2.2	39.1	43.5	10.5	4.3	
6. S. bin Ammar	-	6.3	6.3	25.0	37.4	25.0	
7. Al Yahar	-	-	8.0	4.2	42.0	45.8	
8. Al Sad- East	-	-	-	33.3	33.3	33.3	
9. Al Sad- West	-	-	-	33.4	17.6	50.0	
10. Al Tuwaisah	-	-	-	-	-	100.0	
11. Suwaihan	-	-	-	15.4	7.6	77.0	
12. Bu Samrah	-	-	7.5	55.5	18.5	18.5	
13. Al Khaznah	-	-	-	-	-	100.0	
14. Al 'Arrad	-	-	-	-	70.0	30.0	
15. Al Wagn	-	-	-	3.8	5.7	90.5	
16. Seih Gharabah	-	-	-	-	9.0	91.0	
17. Az Za'alah	-	-	-	-	-	100.0	
18. Al Khashm	-	-	-	-	100.0	-	
19. Al 'Ushoosh	-	-	-	-	-	100.0	
20. Al 'Ajeer	-	-	-	-	-	100.0	
21. 'Aanjah	-	-	-	21.4	71.4	7.5	
22. Al Maqam	-	-	-	-	25.0	75.0	
Others	-	-	19.0	22.0	27.0	32.0	
Total	-	3.5	14.0	19.5	23.5	39.5	
					82.5 %		

Adapted from the 1987-88 Statistical Year Book of the Al Ain Department of Agriculture pp 36-37.

Table: 6.26.

Irrigation water quality in the Al Ain region by the percentage of groundwater samples analyzed according to the various water salinity groups (by the Al Ain Department of Agriculture (1987-88).

More than 82.5% of the samples of the irrigation water of the Al Ain region (1987-88) were of the C_4-C_6 classes (very high to extremely high salinity hazard) of ECs of between 4000 and 6000mmhos/cm. More than 60% of the water samples analyzed were for waters in the C_5-C_6 classes (i.e., of ECs of between 4000 and 6000mmhos/cm). Only 18% of the samples were of the C_2-C_3 (ECs of 250 to 2250mmhos/cm.). In most areas the irrigation water class is of the C_4 or even poorer quality (i.e., of more than 4000mmhos/cm.).

situated, but also to other soil related factors as will be discussed in this section later.

Waters mostly of the very high salinity (C_4) and poorer classes, are unsuitable for agriculture on their own, let alone when used on highly saline soils. When the characteristics of soils and irrigation practices are considered, the suitability of such water for irrigation becomes more unfavourable. The salinity, calcium carbonate ($CaCO_3$) content and alkalinity of the soils in the Al Ain region are given in Table 6.27 for 1987-88.

Although the soils in the areas to the north and west of Al Ain are mostly sandy non-sodic, after years of application of brackish to saline irrigation water, these soils have become saline sodic (i.e. with a high calcium-sodium content) to wholly saline, rendered so by the substantial carbonate content as shown in Table 6.27. Soils in the Al Awha wheat farm were non-saline non-sodic in their upper horizons in 1979, though they were saline lower down the profile. The heavy application of compost on these soils, which was found by DDIJ (1980) to have increased their carbon content and subsequently, their ECs, by 2-5 times owing to an increase in sodium, has changed them during the past decade to saline-sodic soils.

The carbonate content of the soils at Suwaihan can be as high as 40% of the total weight of the soil. The SAR values of the soil are higher than those for irrigation water in many wells, but the very high sodium accumulation throughout the soil profile, and the salt content as well as the SAR values of both the irrigation water and the soil, generally match.

In Al Wagn, in the southern desert of Al Ain, the soil texture is of the sandy type, but with a good percentage of fine sand, silt and clay. The carbonate content is lower in the coarser than in the finer sands. The SAR values of the soil are higher than those for irrigation water, but there is a high Na accumulation throughout the profile and the soils are also generally saline-sodic to wholly saline.

AREA	$CaCO_3$	ECe	pHs	Soil samples
				from 0-40cm. depth
Al Khaznah	33.5	9000	7.6	
Bu Samrah	41.0	5500	7.8	
Al Sad (South)	41.2	11800	7.7	
(West)	42.0	14900	8.3	
(East)	41.0	7500	8.0	
Al Tuwaisah	39.0	23120	7.6	
Suwaihan	38.7	4700	7.9	
Al Yahar	34.0	10200	7.8	
Seih Bin Ammar	38.8	8400	7.9	
Al Qattarah	37.0	10200	7.7	
Al Ain	37.5	6400	7.8	
Um Ghafah	32.5	7900	8.1	
Al Arrad	32.5	8800	8.3	
Al Wagn	37.0	3230	8.1	
Al Hayer	36.0	2700	0.5	
Al Faqa'	41.0	5000	8.2	
Ghamdh	39.0	8100	8.4	
Al Shuwaib	31.7	1100	8.4	
Al 'Uwaiyah	37.7	9300	8.1	
	meq/l	mmhos/cm		

Source: Al Ain Department of Agriculture (1988)

Table: 6.27.

Salinity (ECe), calcium-carbonate ($CaCO_3$) content and alkalinity (pHs) of the saturated soil extract of the soils of the Al Ain region (1988).

Irrigation water of the C_4 (EC 4000 mmhos/cm and over) used on soils in Al Ain with such high salinity levels cannot sustain successful cultivation for a long time.

In Al Khaznah, where irrigation waters are the poorest in quality in the whole area to the west of Al Ain, the high salt and sodium content renders them of the S_2, S_3, S_4, or even poorer, sodium hazard classes. The top soil is generally a loamy sand, becoming purely sandy down the profile. This is paralleled with a high carbonate content higher up the profile. Salt content in the soil is twice as much as that of calcium. Soil alkalinity (pHs) values are high ranging from 7.6 to 8.5. In Al Shuwaib, in the recharge zone of the foothills in the east, pHs is 8.4, while in Al Wagn and Al Sad, further west and south, the pHs is 8.1 and 8.3 respectively (Table 6.27).

Table 6.28 presents the EC, TDS, pH, Ca. Mg, Na and the SAR and irrigation water class data for different areas in the Al Ain region. According to Table 6.28, irrigation waters are mostly of the very high salinity and the low to high sodium classes (C_4 and S_1-S_2-S_3). Na concentrations are high especially in or near sabkhas as in Seih Bin Ammar, Al Tuwaisah, Ghamdh and Al Khaznah. Ca and Mg concentrations are about equal in most places but there is a dominance of the former in places where groundwater occurs in sandstone strata of alternating dolomites, anhydrites and gypsum, as at Suwaihan, Ghamdh, Al Khaznah, Al 'Arrad and Al Wagn. The poorest irrigation water is found in Tuwaisah, Ghamdh, Suwaihan and Al Khaznah, where it is of the C_4 very high salinity hazard and either of the S_2 or S_3 medium to high sodium hazard class (Fig. 6.18).

There is a close correlation between the increase in the EC and the SAR values westwards in the Al Ain region. This is more noticeable along the Al Ain-Abu Dhabi highway as shown in Table 6.29. The irrigation water class increases from the C_3 S_2 class in Al Sad, Al Yahar and Bu Samrah to the C_4 S_4 in Bida' Al Ajam, Al Khaznah and Bu Remramah.

Thus, applying such saline irrigation waters to already saline soils, that are rendered more saline every day by the generous doses of fertilizers of all kinds, but more so, by that of compost, would eventually lead to intolerable salinization of the soil as is already happening in many places, even in the most coarse-grained highly permeable sandy soils, not only in the Al Ain region, but elsewhere in the desert foreland of the Emirates.

In meq/l

AREA	EC mmhos/cm	TDS ppm	pH	Ca	Mg	Na	SAR	CLASS
1. Al Ain	4313	2803	7.0	46.69	7.82	9.32	1.8	C_4S_1
2. "	1921	1248	7.6	4.14	11.96	4.26	1.5	C_3S_1
3. Al Qattarah	8200	6149	7.3	8.51	18.63	55.55	15.1	C_4S_2
4. "	3761	2444	7.4	12.77	20.59	12.19	3.0	C_4S_1
5. Um Ghafah	1147*	745	7.8	2.10	8.10	3.22	2.3	C_3S_1
6. Abu Samrah	7740	5805	7.8	20.13	20.24	48.65	10.8	C_4S_2
7. "	4865	3162	7.7	12.77	13.46	27.72	7.7	C_4S_1
8. Al Sad	7372	5529	7.8	21.16	16.22	46.92	10.9	C_4S_1
9 "	7004	5253	8.0	13.80	22.54	38.10	8.9	C_4S_1
10. "	5497	3573	8.3	5.29	10.81	39.22	13.8	C_4S_2
11. "	15100	11385	7.9	15.87	25.53	124.20	27.3	C_4S_4
12 "	2289	1488	8.1	2.10	5.98	11.96	6.0	C_4S_1
13. Al Tuwaisah	10879	8159	8.0	10.58	17.79	85.22	22.7	C_4S_3
14. "	7510	5632	8.1	7.48	10.70	60.26	20.0	C_4S_3
15. "	3784	2459	8.4	3.22	6.90	26.45	11.8	C_4S_2
16. Seih bin Ammar	9729	1297	7.5	11.62	38.87	66.13	13.2	C_4S_2
17. "	6371	4778	7.7	14.84	41.63	26.22	4.9	C_4S_1
18. Al Yahar	4071	2646	7.9	3.22	14.95	23.69	7.9	C_4S_1
19. "	7452	5589	7.8	11.62	20.70	49.80	12.4	C_4S_2
20. "	1599**	1039	7.9	1.04	7.02	9.55	4.8	C_3S_1
21. Al Hayer	2657	1726	8.0	6.33	16.91	9.55	2.8	C_4S_1
22. Al Shuwaib	1162	754	8.3	0.81	7.25	6.33	3.2	C_3S_1
23. Ghamdh	12880	9660	7.9	36.00	14.49	103.50	20.6	C_4S_3
24. "	4554	2960	8.2	4.26	16.91	24.96	7.7	C_4S_1
25. Al Faqa'	5486	3565	7.8	8.51	15.76	32.43	9.3	C_4S_1
26. "	3140	2040	8.1	3.22	7.82	19.78	8.4	C_4S_1
27. Suwaihan	16100	12075	8.0	39.22	34.39	140.30	23.0	C_4S_3
28. "	8970	6728	7.9	21.16	12.08	52.44	12.8	C_4S_2
29. "	13225	9919	7.5	39.22	19.32	90.97	16.8	C_4S_2
30. Al Khaznah	11615	8711	7.7	24.38	26.11	92.00	18.4	C_4S_3
31. "	12420	9315	7.6	20.13	18.17	104.31	23.8	C_4S_3
32. "	7199	5399	7.8	13.8	11.39	55.55	15.7	C_4S_2
33. Al Waqn	10570	7926	7.6	28.64	15.76	72.11	15.3	C_4S_2
34. "	4163	2706	8.0	3.22	10.93	27.83	10.5	C_4S_2
35. Al 'Arrad	8694	6521	7.9	20.13	17.25	58.54	13.6	C_4S_2
36. 'Oayah	10740	8056	7.8	30.71	22.77	73.37	14.2	C_4S_2

* Possibly of a mixed source from the public supply system
** Newly drilled borehole in the thick sands

Note: Sample collection was in May-June, 1989.

Table: 6.28.

Water chemical analyses and classes of the irrigation water in the various agricultural locations in the Al Ain region -1989. (also refer to Table 6.27)

The poorest irrigation water in the Al Ain region is found at Al Tuwaisah, Ghamdh, Suwaihan and Al Khaznah (analyses 13, 23, 27 and 30) where the irrigation water class is of the C_4 (very high salinity hazard) and S_2 or S_3 (medium to high sodium hazard) classes.

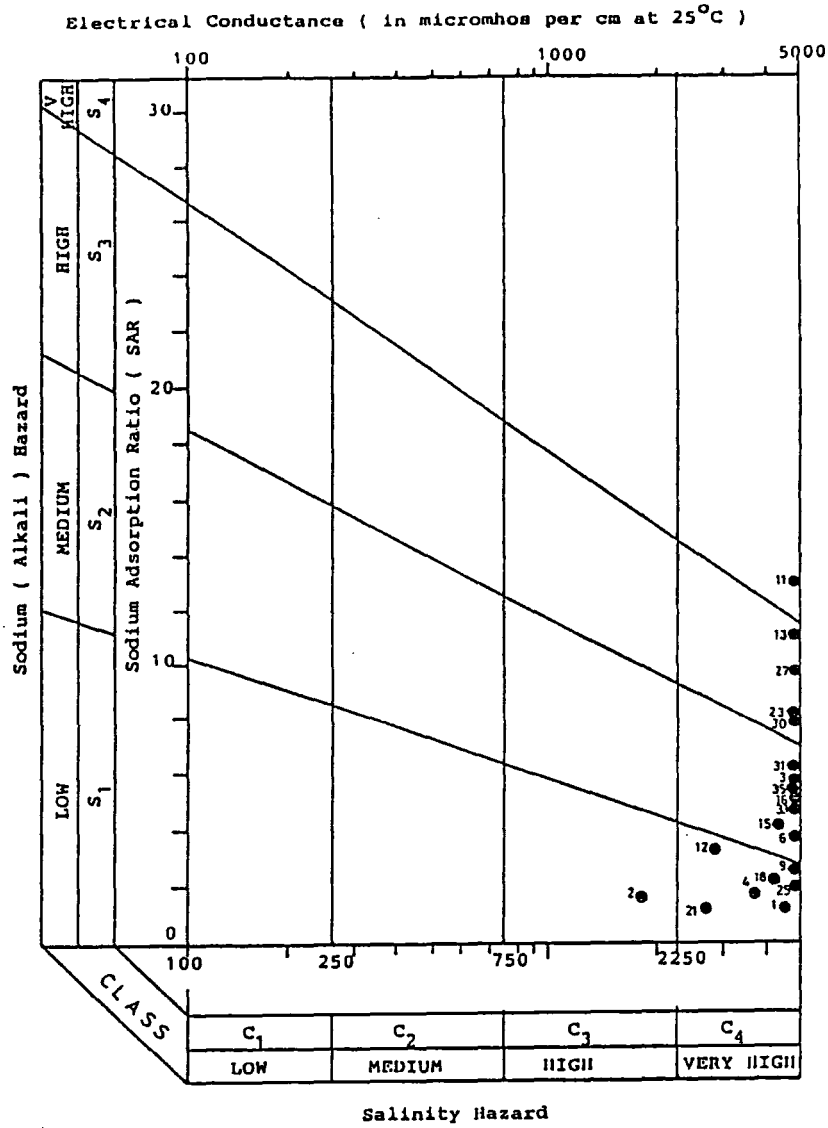


Figure: 6.18.

The irrigation water class of the waters of the Al Ain region.

Based on water quality data from the Al Ain Department of Agriculture (Tables 6.27 and 6.28), most of the irrigation water of the Al Ain region falls in the C_4 (very high salinity Hazard) and S_1 S_2 (low to medium sodium hazard) class.

Location	pH	EC mmhos/cm	SAR	CLASS
Al Sulaimat	7.5	2121	8.0	C_3 S_2
Al Yahar	7.9	1669	5.5	C_3 S_2
Al Sad	7.7	1899	6.3	C_3 S_2
Bu Samrah	7.8	1702	6.0	C_3 S_2
Remah	7.8	2070	8.8	C_3 S_2
Shaikh Khalifa Rest-House	7.9	3265	10.2	C_4 S_2
Bida' Al 'Ajam	8.7	7340	24.7	C_4 S_4
Tawi Abu Mardam	7.8	9336	28.3	C_4 S_4
Al Khaznah	7.8	10390	29.7	C_4 S_4
Madsoos	7.4	4333	5.9	C_4 S_2
Dahan	8.1	19433	32.9	C_4 S_4
Al Shubaisi	7.8	17808	33.4	C_4 S_4
Abu Remramah	7.6	22170	32.7	C_4 S_4

Table: 6.29.

The increase in the EC and SAR and the deterioration in the irrigation water class westwards along the Al Ain-Abu Dhabi highway.

There is a close correlation between the increase in EC and the SAR values westwards in the Al Ain region, with the worst irrigation water occurring to the west of Shaikh Khalifa Rest-house on the Al Ain-Abu Dhabi highway.

6.5.2.5. Water chemistry and quality of the east coast (the eastern piedmont plains)

6.5.2.5.1. General

The east coast of the Emirates stretches for 78 km. from Khawr Kalba in the south to Dibba in the north. Physically, it is broadly divided into two sections: a northern coastal section from Khawr Fakkan to Dibba; and a southern coastal section from Khawr Fakkan to Khawr Kalba.

Unlike the more extensive western piedmont plains that grade into the desert foreland, the eastern piedmont plains of the Batinah coast of the Emirates are contained in a series of alluvial embayments that are between 1-5 km. wide and end up directly on the shoreline of the Gulf of Oman. The only two extensive areas are the Wadi Al Baseerah broad flood plain in the north, and the Wadi Ham outwash fan in Fujairah and Kalba in the south (Fig. 6.19).

The water chemistry and quality of the east coast are treated in this section, first, generally, for the northern part (north of Khor Fakkan) and the southern part (south of it) owing to a marked difference in water quality in these two sections of the eastern coastal plains; and, second, a detailed treatment of each of the Wadi Al Baseerah-Dibba, and the Wadi Ham-Fujairah, wadi basins and outwash fans.

6.5.2.5.2. Groundwater chemistry and quality in the two sections of the east coast to the north and south of Khor Fakkan

(Table 6.30; Figs. 6.19, 6.20 and 6.21)

ECs in the northern section of the east coast are generally below 1000 mmhos/cm. in the upper parts of the outwash fans or alluvial embayments. On the seaward parts of the outwash fans ECs are high because of seawater intrusion caused by overpumping of the coastal aquifer. To the south of Khor Fakkan, ECs are higher: in Fujairah and Ghurfah they average 3500 mmhos/cm., though generally they are in the range of 1500-4000 mmhos/cm. This broad difference in the ECs of the waters of the coastal strip to the north of Khor Fakkan and the ECs of the waters to the south of it, is attributed to the fact the wadis flowing towards the coast between Ras Dibba and Al Badyah (8 km. to the north of Khor

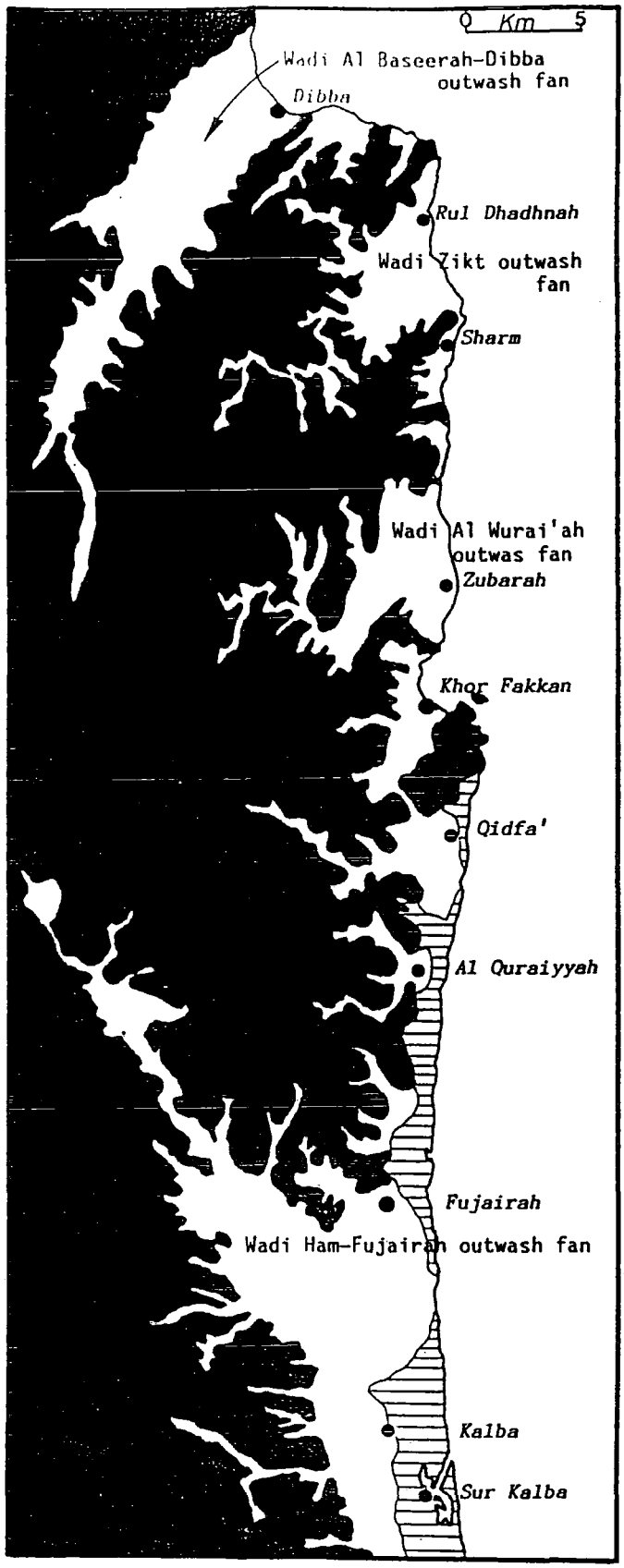


Figure: 6.19. The eastern alluvial embayments of the east (Batinah) coast from Sur Kalba in the south to Dibba in the north.

(showing the two sections of the alluvial coastal plains to the north and south of Khor Fakkan (Section 6.5.2.5.2), the Wadi Al Baseerah Basin (Section 6.5.2.5.3) and the Wadi Ham-Fujairah outwash Fan (Section 6.5.2.5.4)

Fakkan), cross the mountain block of ultrabasic peridotites and serpentinites (Zone 2 in the mountains described in section 6.5.1.2.) which, as shown earlier, gives good quality water with low salinities, high Mg values with a Ca-Mg ratio varying from 1:2 to 1:5. The majority of the water analyses in this part of the coastal plain have a Ca-Mg ratio of 1:4. pH and bicarbonate values are high, and bicarbonate is the most dominant ion followed by Mg and SO_4. Ca has the least value among the ions (analyses 1-9, Table 6.30).

The high salinity indicated by the Lulaiyyah analysis (number 8, Table 6.30) is largely due to seawater intrusion as the sample was collected from a well in a date garden less than 500m. from shoreline. Cl and Na values are high (24.20 meq/l and 22.41 meq/l, respectively), so is the Mg value (9.60 meq/l), which is mostly of marine origin. HCO_3 and SO_4 ions are about equal in amounts, while Ca is least in importance. The waters in this northern part of the east coast have the highest SAR values on the east coast, and these are of the C_4 S_1 irrigation water class of very high salinity but low sodium hazard.

In the section of the east coast south of Khor Fakkan, ECs range from 700 to 1000 mmhos/cm. at Khor Fakkan, to more than 4000 mmhos/cm. at Ghurfah near Fujairah (analyses 9 and 15 in Table 6.30). There are higher individual EC values in Fujairah. The average EC for this stretch of the east coast to the south of Khor Fakkan is 2100 mmhos/cm. and the pH is 8.0 and in some places even more (pH values range from 7.1 to 8.0, analyses 10-18, Table 6.30). Cl and Na are the dominant ions, followed by Mg, HCO_3 and SO_4. The presence of high Mg content points to the recharge nature of the waters, but in wells near the coast the high Mg values appear to be derived from seawater (analysis 15, Table 6.30). Ca is insignificant compared to Mg and the Ca-Mg ratio varies from 1:1 to 1:6. Waters flowing into this southern section of the east coast rise in the mountains to the west in both ultrabasic peridotite and basic gabbro hardrock areas which explains the slightly increased ECs.

The SAR and EC values are closely related and waters to the north of Khor Fakkan are generally of the C_2 S_1 (Fig. 6.20), while those to the south of Khor Fakkan are of the C_3 S_1 and the C_4 S_1 (Fig. 6.21) irrigation water classes, as at Fujairah and Ghurfah (analyses 15 and 16, Table 6.30; and the same numbers in Fig. 6.21). The general

Analyses of groundwater in the East (Batinah) Coast north and south of Khorfakkan — In meq/l

LOCATION	EC	TDS	pH	NO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
NORTH OF KHORFAKKAN													
1. Dibba	700	455	8.3	-	3.00	3.20	0.60	0.60	4.00	2.20	0.11	1.5	C_2 S_1
2. Rol Dhadhnah	644	419	7.9	0.14	2.49	2.93	0.88	0.52	3.85	1.87	0.13	1.3	C_2 S_1
3. Dhadhnah	442	287	7.8	0.06	2.08	1.61	0.88	0.42	3.02	1.04	0.11	0.8	C_2 S_1
4. 'Amqah	645	419	7.9	0.13	4.00	2.00	1.48	0.83	4.41	2.22	0.16	1.4	C_2 S_1
5. Sharm	660	429	7.8	0.12	2.43	3.38	1.48	0.84	3.37	3.03	0.21	2.1	C_2 S_1
6. Badyah	723	470	7.9	0.11	1.92	4.39	2.17	0.42	2.71	5.24	0.22	4.2	C_2 S_1
7. Zubarah	830	539	7.9	0.13	2.16	5.20	2.46	0.47	3.20	5.91	0.24	4.4	C_3 S_1
8. Lulaiyyah	3326	2162	7.6	0.20	3.39	24.20	3.29	1.80	9.67	22.41	0.54	9.4	C_4 S_1
9. Khor Fakkan	718	466	7.7	0.09	3.67	2.19	1.11	0.43	2.47	5.00	0.07	4.2	C_2 S_1
SOUTH OF KHORFAKKAN													
10. Sakamkam	1091	709	7.4	0.08	2.70	6.45	1.71	1.73	0.58	7.83	0.06	7.3	C_3 S_1
11. Qidfa'	1508	980	7.1	-	3.23	9.38	1.52	1.90	6.25	6.00	0.12	3.0	C_3 S_1
12. Murbah	2683	1744	7.8	0.20	3.75	20.23	2.38	2.90	13.33	10.04	0.29	3.5	C_4 S_1
13. Quraiyyah	1862	1210	7.9	0.14	2.82	10.23	1.68	2.10	10.0	2.74	0.05	1.1	C_3 S_1
14. Muraished	1773	1153	8.0	0.44	2.49	12.73	1.42	1.80	9.75	5.17	0.38	2.2	C_3 S_1
15. Al Ghurfah	4222	2744	7.5	0.06	2.29	46.42	2.38	10.20	28.30	12.39	0.33	2.8	C_4 S_1
16. Al Fujairah	3859	2508	7.8	0.09	2.17	32.96	1.71	6.80	8.17	21.52	0.36	7.9	C_4 S_1
17. Kalba	1629	1059	8.0	-	2.21	10.73	2.42	3.30	2.60	9.17	0.18	5.3	C_3 S_1
18. Al Hafrah	1633	1062	7.8	-	6.00	5.13	1.96	1.45	1.10	10.65	0.11	9.4	C_3 S_1

EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Year of analysis 1988.

Table: 6.30.

Water chemistry and quality of the two sections of the east (Batinah) coast to the north and south of Khor Fakkan, 1988. (Fig. 6.19)

ECs in the part of the east coast to the north of Khor Fakkan are generally below 1000mmhos/cm. in the upper parts of the alluvial embayments, but ECs are higher in the lower parts of the embayments because of seawater intrusion. In the part of the east coast to the south of Khor Fakkan ECs are between 1500 and 4000mmhos/cm.; in the coastal strip of Fujairah groundwater ECs average 3500mmhos/cm. The lower ECs in the northern section of the coast are attributed to the fact that the waters that flow into that part of the coast rise in the ultrabasic peridotite hardrock areas that were shown in Section 6.5.1.2. to give good quality water. The higher ECs in the southern section of the east coast are because the waters flowing into this part cross both ultrabasic peridotite and basic gabbro hardrock areas. Waters of the coastal section north of Khor Fakkan are generally of the C_2 S_1, while those of the southern coastal section are of the C_4 S_1, irrigation water class. The general difference in the irrigation water class between the two coastal sections of the east coast is only in the salinity hazard.

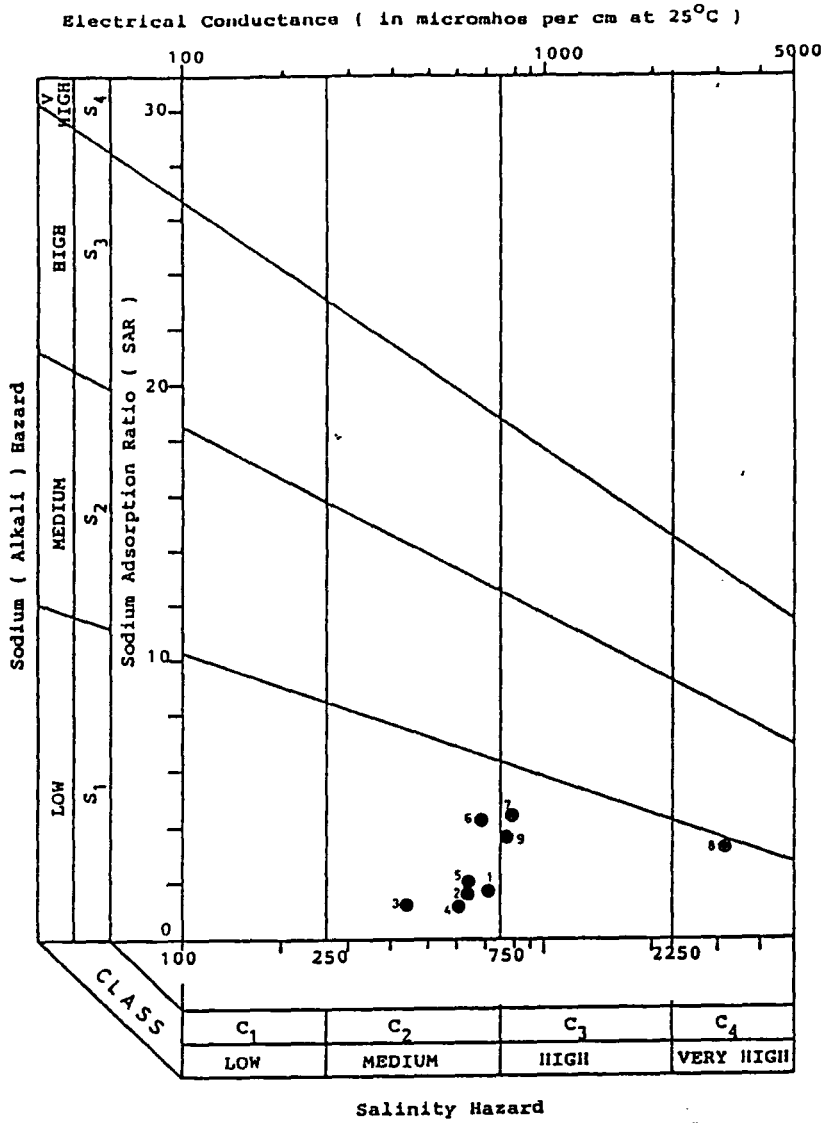


Figure 6.20.

Irrigation water class of the waters of the alluvial embayments of the section of the east coast to the north of Khor Fakkan.

Most irrigation waters are of the C_2 S_1 (medium salinity and low sodium hazard) class.

(The numbers in the figure refer to the water analyses Numbers 1 to 9 in Table 6.30)

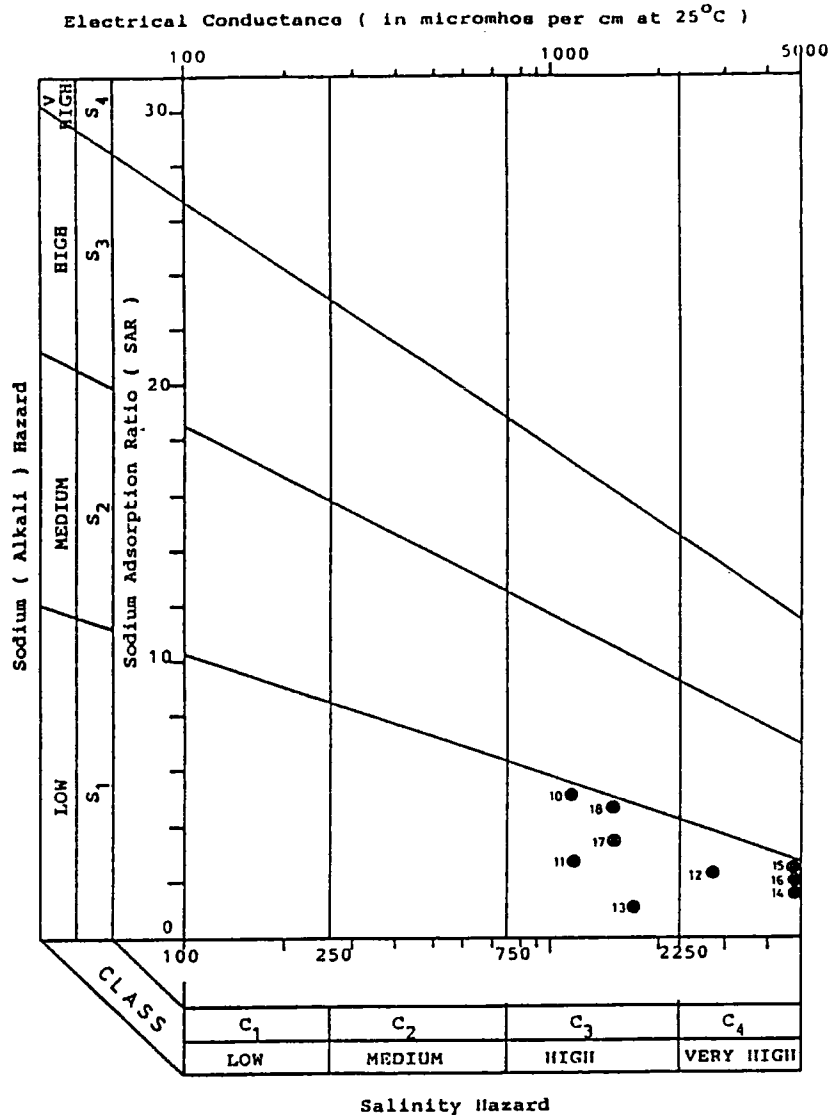


Figure: 6.21.

Irrigation water class of the waters of the alluvial embayments of the section of the east coast to the south of Khor Fakkan.

Most irrigation waters are of the C_3 S_1 (high salinity and low sodium hazard) class.

(The numbers in the figure refer to the water analyses Numbers 10 to 18 in Table 6.30)

difference in the irrigation water class between the two sections of the coastal plain is only in the salinity hazard (compare Figs. 6.20 and 6.21).

6.5.2.5.3. **Groundwater chemistry and quality in Wadi Al Baseerah Basin** (Tables 6.31 to 6.33; Figs. 6.22 to 6.25)

Wadi Al Baseerah (also called Wadi Al Shimal) flows from the southwest to the northeast in a wadi basin that averages 1 km. in width, east of Al Halah, but widens to 4 km. in its lower course between Jabal Waam and Jabal Dalam. The wadi ends up in a coastal front about 6 km. wide. Wadi Al Fayy is the most important tributary running parallel to Wadi Al Baseerah and joining the latter in its wide flood plain to the west of Dhanhah. Numerous small tributaries, most of which bear no names, flow into Wadi Al Baseerah from the northwest and southeast. As these tributaries rise and flow in hardrock catchment areas of various rock types, already discussed under the mountain zone and found to give waters of different quality (Zones 1, 2, 3, 4 and 5 in the mountains, Section 6.5.1.), and as the variation in quality is so marked within the Wadi Al Baseerah flood plain as far as the coast, it was deemed necessary to investigate in detail the quality of the water in the whole wadi basin. Water samples were collected for this study in the following zones in the Wadi Al Baseerah basin: (Fig. 6.22)

(i) 16 water samples were collected from the coastal aquifer in the seaward end of the wadi basin for wells within the date plantations (analyses 1-16 in Table 6.31).

(ii) 11 samples were collected from points along the whole length of the main Wadi Al Baseerah central channel (1-11, Table 6.32).

(iii) 4 samples were collected from the eastern flank of Wadi Al Baseerah (analyses 1-4, Table 6.33), and 5 samples from the western flank of Wadi Al Baseerah (analyses 5-9, Table 6.33).

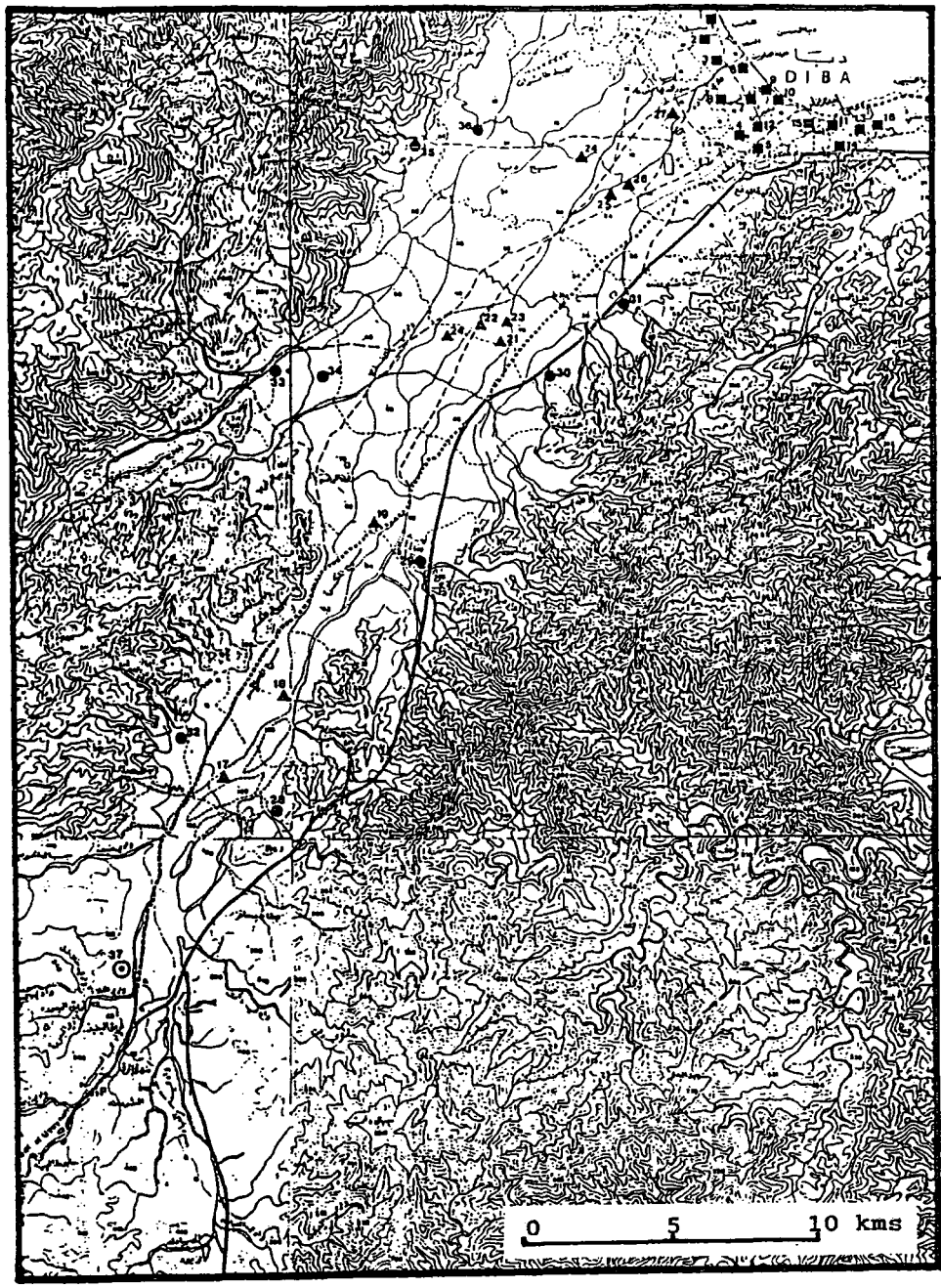


Figure: 6.22.

Locations of water samples analyzed for the Wadi Al Baseerah basin on the east coast: the coastal aquifer (Table 6.31), the central wadi channel (Table 6.32) and the eastern and western flanks of the wadi basin (Table 6.33).

Numbered as 37 = is for a water sample from a well in the old compact wadi-terrace ('stagnant' groundwater), the detailed chemical analysis for which is given separately in Table 6.34.

(iv) 1 water sample was collected from a well in the old compact Tertiary wadi terrace deposits in upstream Wadi Al Baseerah near Al Halah (Table 6.34).

There are the following water quality types in the Wadi Al Baseerah basin:

(i) Good quality groundwater along the main wadi channel in the centre of Wadi Al Baseerah flood plain, where the ECs range from 300 to 1200 mmhos/cm.(Table 6.32).

(ii) Good quality groundwater, though slightly inferior to that of the central channel (i), on the eastern and western sides of Wadi Al Baseerah with ECs ranging from 400 to 1500 mmhos/cm.(Table 6.33).

(iii) Groundwater of slightly higher ECs is found in wells tapping water from aquifers in indurated Tertiary wadi terrace deposits where such ECs range from 1400 to 2000 mmhos/cm.(Table 6.34).

(iv) Groundwater of marginal to brackish quality in the coastal zone with ECs ranging from 1400 to 8000 mmhos/cm. ECs in wells on the main wadi outflow channels in this coastal zone can be as low as 480 mmhos/cm, only 500m. from the shoreline (analysis 8, Table 6.31).

6.5.2.5.3.1. **Groundwater quality in the coastal aquifer of Wadi Al Baseerah at Dibba** (Table 6.31; analyses 1-16; Fig. 6.23)

The high ECs of the Dibba coastal zone (1400-8000 mmhos/cm.) are attributed to two causes: the first is irrigation water return from intensively cultivated date plantations; the second, is seawater intrusion as a result of the overabstraction in this heavily cultivated zone so close to the shoreline. A seawater intrusion tongue stretches for about 1 km. inland beneath another thin brackish water tongue

(Chapter 5, section 5.3.2.6.4.). Water in many coastal wells is pumped from a mixed brackish ground and sea water zone. The water samples collected in the Dibba coastal zone were from wells located 1 km. inland from the shoreline.

As seen from the ECs in analyses 1-16 in Table 6.31, there are three types of groundwater quality in the Dibba coastal zone:

(i) Waters with ECs ranging from 300 to 1000 mmhos/cm (analyses 4, 7 and 8, Table 6.31), which are from wells located on the main wadi flow channels near to their seaward outflow sections.

(ii) Waters with ECs ranging from 1000 to 3000 mmhos/cm. (analyses 2, 3, 5, 6 and 14, Table 6.31), which are from wells near the main wadi channels but at points where overabstraction is attracting mixed brackish and sea water.

(iii) Waters with ECs above 3000 mmhos/cm. from wells away from the main wadi outflow channels where, besides mineralized recirculating irrigation water from the date gardens, there is a definite pump intake from the mixed fresh-seawater transition zone (analyses 1, 10, 11, 12, 13 and 15, Table 6.31).

Although the water of the whole of the Wadi Al Baseerah basin can generally be said to be of the sodium-chloride-magnesium type, the high Mg values in the low EC waters in the main outflow channels in the coastal zone attest to the recharge characteristic of the water as far as these outward points close to the sea (analyses 4, 7 and 8, Table 6.31).

With regard to the irrigation water class, it is more of the very high salinity hazard (C_4) than the sodium hazard (S_1 and S_2) (Fig. 6.23). The date palms grown in a continuous 7.5 x 2 km. stretch of date gardens, tolerate high salinity waters. As far as the suitability of these coastal waters for domestic consumption is concerned, the high Cl and Na content renders them unpotable save for isolated wells drilled in the main outflow channels (analyses 4, 7 and 8, Table 6.31).

Chemical analyses of groundwater in Wadi Al Baseerah (Al Shimal) - coastal locations

In meq/l

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Shaibat Al Ashkharat 200m from shoreline	3047	1950	8.6	1.12	3.89	19.29	5.99	2.13	8.26	19.70	0.22	8.6	$C_4 S_1$
2. Wadi Bimarah, on wadi channel on coast	1446	926	8.5	0.56	4.44	6.82	2.99	1.65	3.93	9.10	0.12	5.5	$C_3 S_1$
3. Wadi Bimarah, on wadi channel on coast	1136	739	8.7	0.35	3.20	4.02	4.13	1.12	3.97	6.51	0.12	4.10	$C_3 S_1$
4. Sumbarairah, on main channel, 1km from coast	723	463	8.3	0.67	2.89	3.31	0.62	0.62	4.90	2.27	0.11	1.4	$C_2 S_1$
5. In Dibba town, 1.2km from coast on W.Safa ch.	1859	1209	7.9	-	2.79	12.9	2.38	1.34	5.47	11.00	0.31	5.9	$C_3 S_1$
6. Ghaleelat Dalwain 500m from coast	1653	1058	8.3	1.12	4.44	8.02	3.41	1.74	4.65	10.30	0.11	5.8	$C_3 S_1$
7. On channel of Wadi Khasarah, 500m from coast	950	608	8.5	0.67	2.99	4.34	1.55	1.14	4.18	4.18	0.09	2.6	$C_3 S_1$
8. On channel of Wadi Khasarah, 1km from coast	481	359	8.7	0.67	2.23	2.43	0.84	0.62	2.80	2.60	0.16	2.0	$C_2 S_1$
9. Ghaleelat Faisalah, on channel, on coast	2892	1880	8.1	1.12	3.90	21.00	3.20	2.69	10.12	16.11	0.14	6.4	$C_4 S_1$
10. Harat Az Zutut, on coast/seawater intrusion on main wadi channel	7748	4958	4.4	-	6.70	64.00	7.30	4.86	18.90	53.72	1.00	15.6	$C_4 S_2$
11. Ghaleelat Raziqi, sea water intrusion, off channel of W.Khasarah	3822	2446	8.0	-	3.34	29.33	5.40	1.10	10.39	25.63	1.00	15.6	$C_4 S_2$
12. On main wadi channel 700m from coast/sea-water intrusion in Sumbarairah	4649	2975	8.2	1.00	4.82	36.36	4.29	3.60	11.93	30.58	0.40	11.0	$C_4 S_2$
13. Al 'Akamiyyah, 300m from coast	4339	2777	8.2	-	6.68	30.57	5.99	3.31	11.98	27.37	0.47	9.9	$C_4 S_1$
14. Al 'Akamiyyah near fort 800m from coast on flow channels from Jibal Arridah	1859	1190	8.1	0.56	2.51	12.90	2.48	1.10	6.66	10.33	0.24	5.2	$C_3 S_1$
15. Al 'Akamiyyah, off channel, 800m from coast	4029	2578	8.4	-	3.34	31.61	4.55	2.17	10.22	26.66	0.51	10.7	$C_4 S_2$
16. Al 'Akamiyyah at Ghurfah, 700m from the coast	2273	1454	8.0	0.52	2.79	15.19	4.41	1.96	7.74	12.91	0.29	5.9	$C_4 S_1$

EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Year of analysis 1988.

Table: 6.31.

Chemical analyses of groundwater in the coastal aquifer of Wadi Al Baseerah (Al Shimal). (1988)

The alternating high and relatively lower ECs in the Dibba coastal strip are due to well location away from the wadi discharge channels or within these channels where there is a fresh groundwater head, with low ECs, that is maintained along these narrow flow channels as far as the shoreline. Analyses 1, 10, 11, 12, 13 and 15 depict a mixed fresh and seawater groundwater; analyses 2, 3, 5, 6 and 14 represent water a short distance from the main wadi flow channels; while analyses 4, 7 and 8 are from boreholes within the fresh main wadi flow channel.

6.5.2.5.3.2. **Groundwater quality in the central channel of Wadi Al Baseerah** (Table 6.32, analyses 1-11; Fig. 6.24)

The ECs of the groundwater in wells along the whole length of the main central Wadi Al Baseerah channel are below 1000 mmhos/cm., and in 60% of the analyses (Nos.1-11) in Table 6.32, the ECs are even below 600 mmhos/cm. and only in 1 out of 11 analyses is the EC above 1000 mmhos/cm. (1136 mmhos/cm., analysis 3, Table 6.32). pH values are high and are above 8.0 for all the samples, attesting to the alkalinity of the waters. Na and Cl are the dominant ions, followed by Mg and HCO_3, the latter two ions indicating the recharge nature of the water. SO_4 content is low.

The waters of the central wadi channel are of potable quality. As far as the suitability of these waters for agriculture is concerned, they are of the medium salinity (C_2) and low sodium (S_1) hazard (Fig. 6.24). Water used in the MAF fruit farm (about 6 km. from the coast) is of ECs of 300 to 500 mmhos/cm. and the irrigation water class is of the C_2 S_1 (Fig. 6.24)

6.5.2.5.3.3. **Groundwater quality in the eastern and western flanks of Wadi Al Baseerah**
(Table 6.33, analyses 1-9; Fig. 6.25)

The results of the analyses of water samples in Wadi Al Baseerah brought out a distinction in the quality between waters in wells at locations on tributaries flowing into Wadi Al Baseerah from the eastern ultrabasic ophiolite block, and those flowing into it from the western Hawasina metamorphics and volcanics. Although ECs in either case are below 1500 mmhos/cm., ECs in the wells in the eastern foothills are much lower, ranging from 400 and 640 mmhos/cm. (analyses 1-4, Table 6.33), than those from wells on the western foothills which range from 700-1450 mmhos/cm. (analyses 5-9, Table 6.33).

The ECs of 3 out of 5 water samples for the western foothills are above 1000 mmhos/cm. pH values on both the eastern and western sides are above 8.0, with those for the eastern foothills being slightly higher

Chemical analyses of groundwater in Wadi Al Baseerah (Al Shimal) - Central main wadi channel

In meq/l

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Flow stream,confluence of Wadis Dhanha/Uyainah	888	568	8.3	0.44	4.00	2.58	1.86	0.87	2.27	5.47	0.19	4.4	C_3 S_1
2. On main channel at confluence with Wadi Al Huwais	764	490	8.6	0.44	2.89	3.20	1.00	1.08	2.48	3.92	0.09	3.0	C_3 S_1
3. On the main channel at confluence with Wadi Al Aqbabah	1136	727	8.0	0.67	3.23	5.17	2.10	1.34	2.69	6.92	0.14	4.9	C_3 S_1
4. On main channel at confluence with the Big and Small Wadi Al Qareen	475	304	8.5	0.33	1.65	1.90	0.90	0.62	2.00	2.10	0.08	2.2	C_2 S_1
5. On main channel to the west of Khabbat Shairoot near the tile factory	548	350	8.5	0.44	1.33	2.62	1.01	0.55	2.83	1.96	0.07	1.8	C_2 S_1
6. On main channel at confluence with 2 from Jibal Faisan to the east	537	344	8.7	0.44	1.45	2.17	1.00	0.92	2.42	1.96	0.07	0.8	C_2 S_1
7. On main channel in Khubbat Shairoot at confluence with Wadi Maqarah	558	357	8.1	0.23	1.24	2.79	1.00	0.40	2.38	2.48	0.08	2.3	C_2 S_1
8. On main channel in western outskirts of Dibba town	599	389	8.5	0.33	1.65	2.48	1.18	0.67	2.38	2.58	0.08	2.1	C_2 S_1
9. On main channel in Waset, southern outskirts of Dibba	310	198	8.7	0.46	1.33	1.00	0.36	0.52	1.81	0.70	0.05	0.7	C_2 S_1
10. On main channel D/S in Waset	403	383	8.2	0.33	1.55	3.16	0.91	0.87	2.58	2.38	0.08	1.8	C_2 S_1
11. On main channel further D/S in Waset	754	482	8.3	0.37	3.34	2.90	1.69	0.75	4.20	2.38	0.21	1.5	C_2 S_1
							EC in mmhos/cm at 25° C, TDS in ppm, ions in meq/l						

Table: 6.32.

Chemical analyses of groundwater in the central channel of Wadi Al Baseerah (1988).

Water samples collected from points along the whole length of the main Wadi Al Baseerah channel gave groundwater ECs that ranged from 300–1200mmhos/cm., a quality maintained downstream as far as the Dibba shoreline. Waters are of potable quality although Na and Cl are the dominant ions. The high occurrence of Mg in the waters of the main wadi channel attests to the recharge nature of the inflow.

Chemical analyses of groundwater in the EASTERN and WESTERN flanks of Wadi Al Baseerah(Al Shimal) — In meq/l

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
EASTERN FLANKS													
1. On Wadi Al Huwais 16kms. from Dibba	410	266	8.4	0.20	1.43	1.93	0.66	0.17	3.04	1.00	0.06	0.8	C_2 S_1
2. On Wadi Al Aqbabah 11.5kms from Dibba	431	280	8.2	0.21	1.09	2.24	0.71	0.39	2.45	1.31	0.07	1.1	C_2 S_1
3. In Bitah Salwan between Wadis Al Qareen & Aqbabah	638	412	8.3	0.31	1.57	2.90	1.01	0.60	3.11	2.02	0.10	1.5	C_2 S_1
4. On tributaries from Jibal Al Faisan	444	284	8.6	0.22	1.12	2.10	0.72	0.40	2.28	1.44	0.07	1.2	C_2 S_1
WESTERN FLANKS													
5. Between Wadis 'Uwashah and Sinnah on wadi side	1425	912	8.0	0.89	5.95	6.77	0.46	1.54	3.25	9.14	0.24	5.9	C_3 S_1
6. On right tributary of Wadi Dhanhah/Al Fay	1239	739	8.0	0.77	5.17	5.89	0.40	1.34	2.83	7.95	0.21	5.5	C_3 S_1
7. D/S on Wadi Dhanhah on its main channel	878	562	8.1	0.44	2.79	3.62	1.91	0.87	2.69	5.10	0.12	3.8	C_3 S_1
8. Left bank of tributary of W. Waam	1023	655	8.2	0.47	3.67	3.93	1.76	0.92	1.76	7.00	0.12	6.0	C_3 S_1
9. On confluence of Waam with Al Baseerah	723	463	8.1	0.44	2.23	3.20	1.55	0.98	2.38	3.93	0.09	3.0	C_2 S_1

EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Year of analysis 1988

Table: 6.33.

Chemical analyses of groundwater in the eastern and western flanks of Wadi Al Baseerah (1988).

There is a distinction in groundwater quality between waters on the eastern and western flanks of Wadi Al Baseerah. Inflow into the Baseerah wadi alluvium from the eastern ultrabasic ophiolite mountain block is of a better quality than the inflow from the western Hawasina metamorphics and volcanics of the Dibba Corridor. ECs of the waters from wells on the eastern wadi tributaries range from 400 to 650mmhos/cm; ECs of waters from the western wadi tributaries range from 700 and 1500mmhos/cm. Despite the good quality water on both the eastern and western sides of Wadi Al Baseerah, the waters retain the Na-Cl character.

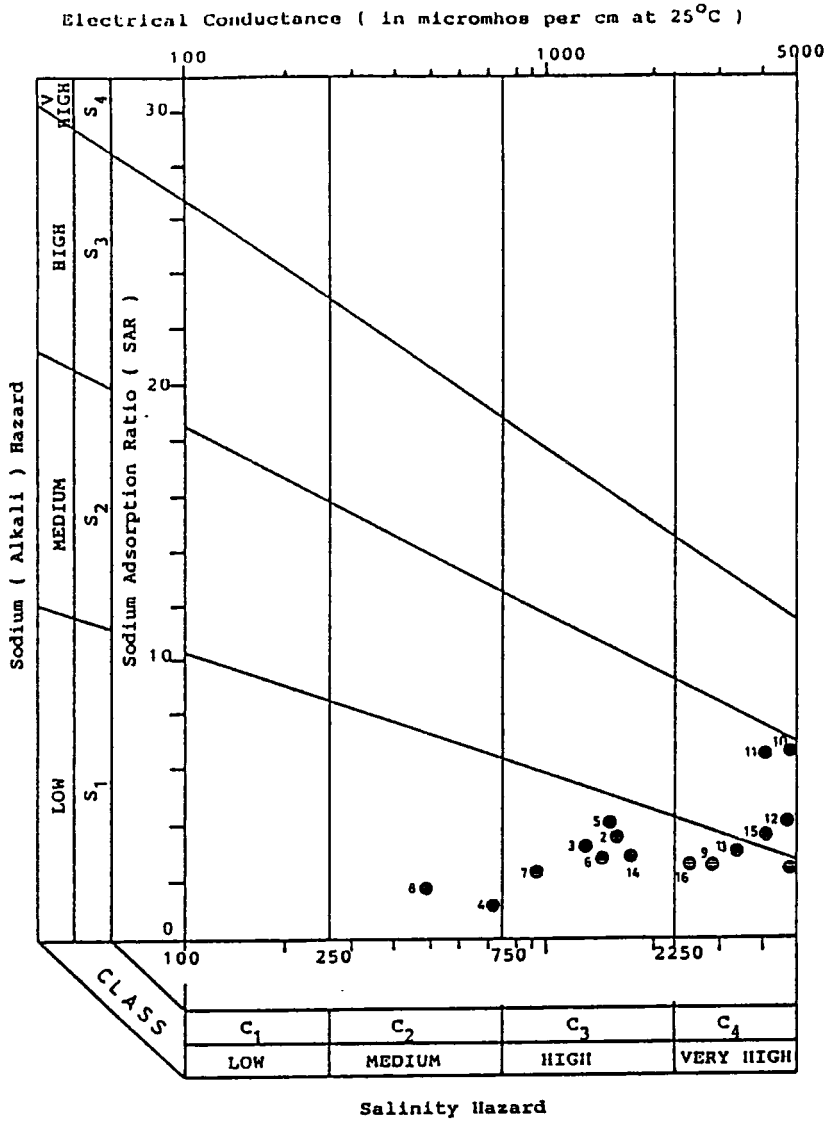


Figure: 6.23.

Irrigation water class of waters of the coastal aquifer of Wadi Al Baseerah on the east coast (analyses 1-16, Table 6.31).

Overpuming of groundwater in the date plantations of the Dibba coastal strip has led to seawater intrusion. There is a mixed fresh and seawater groundwater zone except in the courses of the wadi distributaries that flow to the sea. Most irrigation waters in the Dibba coastal strip are of the C_3-C_4/S_1-S_2 classes of high to very high salinity, and low to medium sodium, hazard, class.

(The numbers in the figure refer to the water analyses in Table 6.31)

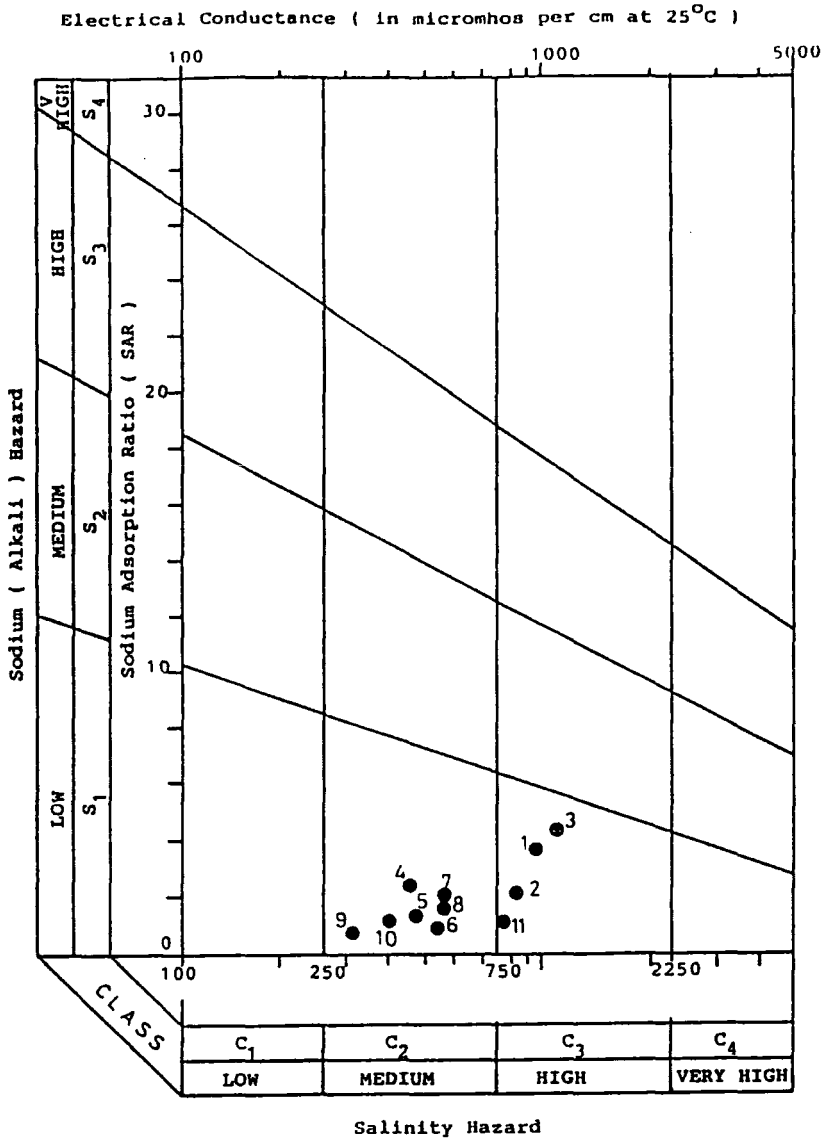


Figure: 6.24.

Irrigation water class of the waters of the central Wadi Al Baseerah flow channel (analyses 1-11, Table 6.32).

Irrigation water quality in the central Wadi Al Baseerah flow channel is mostly of the C_2 C_3 and S_1 class (of medium to high salinity and low sodium hazard). Analysis 11 is for a well only 700m from the shoreline at Dibba.

(The numbers in the figure refer to the water analyses in Table 6.32)

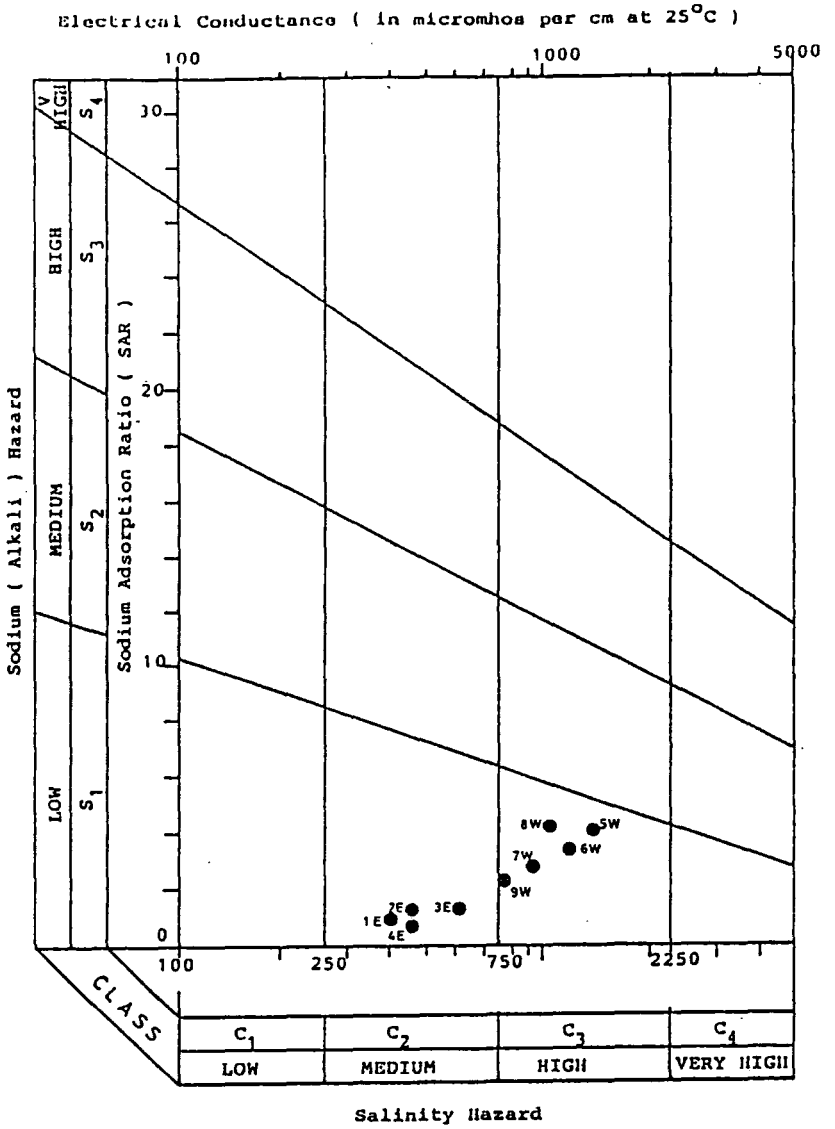


Figure: 6.25.

Irrigation water class of the waters of the eastern (marked with the prefix E) and western (marked with the prefix W) flanks of Wadi Al Baseerah on the east coast.

The irrigation water of points on the eastern flank of Wadi Al Baseerah is of the C_2 S_1 (medium salinity and low sodium) class; the irrigation water for points on the western flank of Wadi Al Baseerah is of the C_3 S_1 (high salinity and low sodium hazard) class.

(The numbers in the figure refer to the water analyses in Table 6.33)

(the pH of 8.6, analysis 4, Table 6.33). HCO_3 concentration is less in waters on the eastern than on the western foothills where, in some samples (analyses 5 and 6, Table 6.33), HCO_3 is five times greater (than, for example, analyses 2 and 4, Table 6.33). This reflects the existence of carbonates, whether in the sandstone strata (limestone) or the metamorphosed (marble) rocks on the western side, but a lack of carbonates on the eastern side, where the rocks are ultrabasic ophiolites. Mg, on the other hand, seems to be of greater concentration in eastern than in western wells because of its preponderance in the magnesium-rich basalts and serpentinites of the ultrabasic ophiolites. Although Ca in all the analyses on both sides of the wadi basin is low, it is lower on the eastern than on the western side (where limestone rocks exist).

Despite their good quality, the waters on both sides of Wadi Al Baseerah retain their underlying sodium-chloride characteristic. This is is less so in waters on the eastern than the western side of the wadi basin. The difference in the values of the Na and Cl can be three fold. With regard to the suitability of these waters for agriculture, the SAR values on the eastern side range from 0.8 to 1.5, and those on the western side from 3.0 to 6.1. The irrigation water class is of the C_2 S_1, of the medium salinity and low sodium hazard on the eastern flank, and of the C_3 S_1 high salinity and low sodium hazard on the western flank (Fig. 6.25).

6.5.2.5.3.4. **The quality of the old 'stagnant' wadi-terrace groundwater** (Table 6.34; marked 37 in Fig. 6.22)

Only one water sample was collected from a well in an old Tertiary wadi terrace where, according to JICA (1980), groundwater is thought to be in a semi-stagnant state and is more than 100 years in residence. Although the water sample was the most upstream one to be collected for this study in the Baseerah basin, being at the confluence of Wadi Al Halah and Wadi Al 'Uyainah, the EC was found to be 1601 mmhos/cm. (Table 6.34), almost two times the EC value of sample 1 of 888 mmhos/cm (Table 6.32), situated 3km. downstream on the main central flow channel of Wadi Al Baseerah (analyses 5-9, Table 6.33).

This stagnant old terrace water is of the sodium-chloride-bicarbonate type. Mg content is low, which is a reflection of the long residence in the indurated Tertiary terrace alluvium, and the slight or total lack of recent recharge. On the other hand, Ca is high in occurrence. The concentration of Ca in this old groundwater is the highest among all the water samples collected in the whole Wadi Al Baseerah basin. The SAR value is high (9.0) and the irrigation water class is of the C_3 S_1, which is similar to that of the waters emanating from the Hawasina metamorphics and volcanics on the western side of Wadi Al Baseerah (Table 6.34).

Location	EC	TDS	pH	HCO_3	SO_4	Cl	Ca	Mg	Na	SAR	Class
Well in an old wadi terrace at the confluence of Wadi Al Halah and Wadi Al 'Uyainah (Marked 37 in Fig. 6.22)	1601	1025	8.2	5.3	3.22	6.7	2.1	1.6	12.20	9.0	C_3 S_1

Table: 6.34

Water chemical analysis of a water sample from a well in an old indurated wadi terrace alluvium at the confluence of Wadi Al Halah and Wadi 'Uyainah in upper Wadi Al Baseerah.

The stagnant old terrace water is of the Na-Cl-HCO_3 type, which is a reflection of its long residence in indurated Tertiary alluvium. As a result, the salinity is high (C_3) and sodium remains low (S_1) as in the waters of the rest of the zones in Wadi Al Baseerah.

6.5.2.5.4. **Groundwater chemistry and quality of the Wadi Ham-Fujairah alluvial outwash fan** (Table 6.35; Figs. 6.26 and 6.27)

At its base, the Wadi Ham-Fujairah alluvial outwash fan extends for 6 km. along the coast from Fujairah to Kalba; and for about 9 km. from the coast to its apex below the retention dam. The outwash fan is flat in its southern part, to the south of Fujairah, but this flat topography is interrupted in the centre by the series of Jabal Haqab, Jabal Aswad, Qurun Dehiyyat, Jabal Al Nu'aimat, Qurun Al Haleeqa and Qurun Al Rams. Wadi Ham is the main wadi draining southeastwards, opening to the sea at Al Rughailat and Sur Kalba. Wadi Al Farfar is the second wadi flowing across the outwash fan at Misyal Tawi Al Shaikh and enters the sea at Kalba proper. Wadi Al Hiyail is the third wadi that crosses the outwash fan in a west-east flow course, entering the sea also at Kalba, just to the north of Jabal Hafrah. The three wadis produce a strong fresh groundwater head towards the southeast, which directly affects groundwater quality in the southern part of the Ham outwash fan as far as the shoreline of the Gulf of Oman at Kalba.

Unlike at Dibba further north, the date plantations on the coastal strip at Fujairah and Kalba are some distance inland from the shoreline. The date plantations extend from Al Heesha (to the west of Khawr Za'ab) to Al Rughailat and Al Ghurfah (just to the south of Fujairah town). The alluvial deposits (both the old compact Tertiary, and the less compact Quaternary deposits) average 40-50m. in thickness, though nearer the location of analysis 14, to the north of Jabal Haqab (Table 6.35) the deposits measure 75m. in thickness, as deduced from borehole cuttings (Deep Wells Project, Final Report, Vol. on Fujairah, Geoconsult, 1985)

Three factors affect the quality of groundwater in the Wadi Ham-Fujairah outwash fan. These are :

(i) The two different types of alluvial fill of the outwash fan: the upper highly permeable Quaternary alluvium; and the underlying less permeable indurated Tertiary alluvium.

(ii) Seawater intrusion in the coastal part of the outwash fan

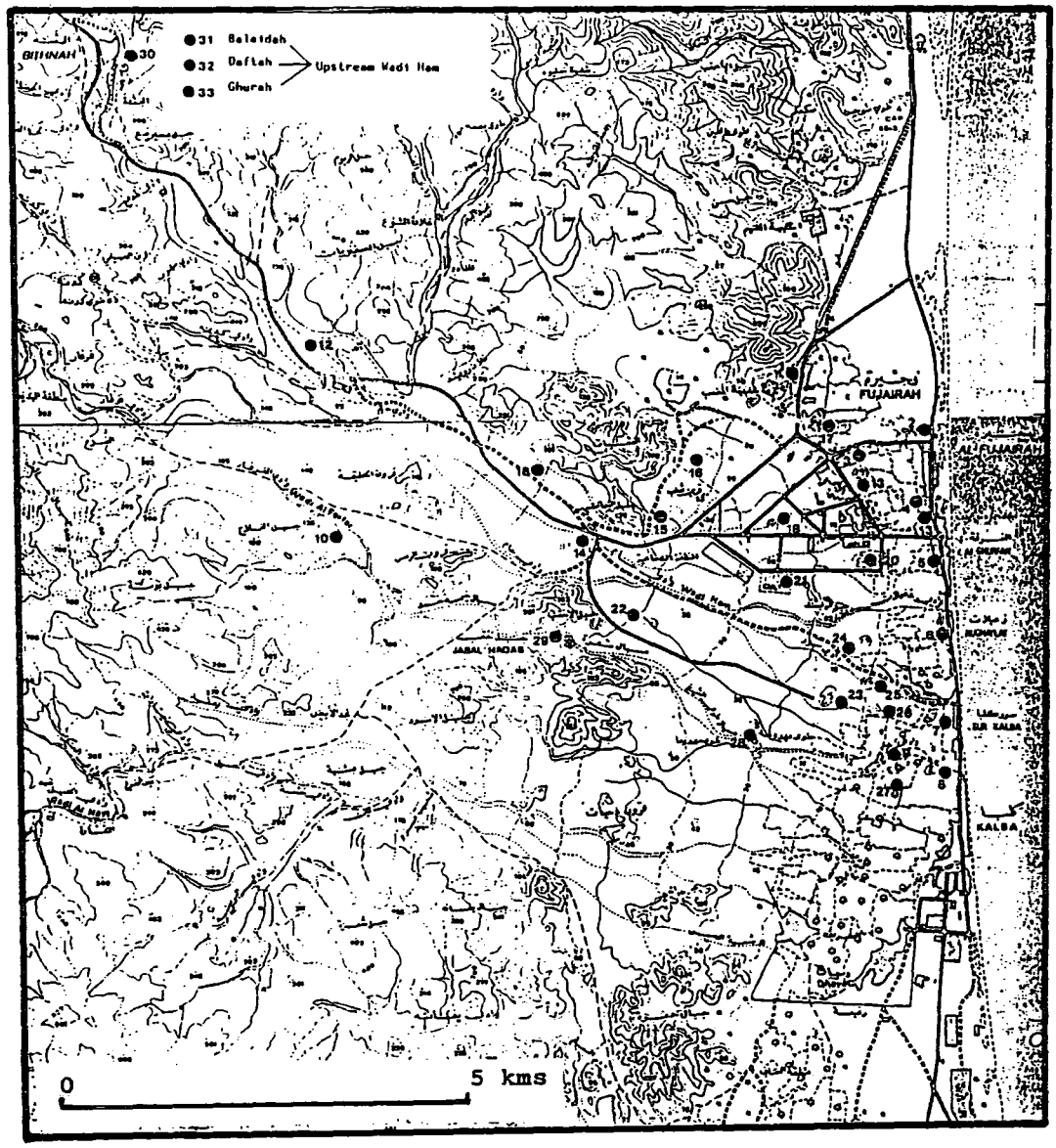


Figure: 6.26.

Locations of water samples analyzed for the Wadi Ham-Fujairah alluvial outwash fan and some points upstream (Balaidah, Diftah and Ghurah) (see Table 6.35).

where, though this intrusion may extend inland as subterranean tongues through all types of coastal lithologies, but mostly in the highly transmissive Quaternary deposits. Its advance inland is slowed down through the Tertiary deposits by their consolidated texture. Hence, the marginal groundwater held in the Tertiary deposits is found in some places beneath tongues of intruding seawater.

(iii) The concentration of flow of recharge waters within the main flow channels of Wadis Ham, Al Farfar and Al Hiyail in the southern half of the outwash fan. Hence, ECs north of Jabal Muraished are generally higher than those to the south of it and the better quality water, even in coastal points, is found on the Kalba than on the Fujairah side of the seaward end of the Ham-Fujairah outwash fan.

The median EC for coastal points, half a km. inland from the shoreline at Sur Kalba, is 1629 mmhos/cm., while the median EC for points the same distance inland from the coast at Fujairah is 3859 mmhos/cm. In both places, there is heavy agricultural activity along the coast with date farming dominating, although there is some mixed farming. Groundwater abstraction in the whole outwash fan is heavy but as Fujairah, in the northern half of the outwash fan, is away from the concentrated southeasterly groundwater head, seawater intrusion is more pronounced in the northern half at Fujairah than in the southern half at Kalba.

ECs in Kalba are better as far as 2 km. from the shoreline and average 600-700 mmhos/cm., but only in wells drilled within the main wadi outflow channels. In Fujairah, ECs average 2000-3000 mmhos/cm. especially west of Jabal Aqabat. At a point 2.5 km. from the coast at Fujairah (Madhab, analysis 1, Table 6.35, location 1 in Fig. 6.26) the EC is 6930 mmhos/cm. due to seawater intrusion as far as that point inland. At the seaward end of the seawater intrusion tongue at Al Ghurfah (analysis 2, Table 6.35; location 2, Fig. 6.26), the EC is 9674 mmhos/cm.

Zonally, there is a distinct increase in the concentration of all determined major ions towards the north in the Ham-Fujairah outwash fan,

Chemical analyses of groundwater in the Wadi Ham-Fujairah alluvial fan

In meq/l

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Al Madhab	6930	5198	8.7	-	3.75	63.6	2.00	5.60	20.63	44.73	1.18	12.4	C_4 S_2
2. Al Ghurfah	9765	7324	8.4	-	3.75	95.11	2.87	6.70	46.83	48.38	0.76	9.4	C_4 S_1
3. "	3255	2116	9.0	1.58	2.68	11.05	19.00	3.37	15.53	14.14	0.96	4.6	C_4 S_1
4. "	2520	1638	9.8	1.47	5.25	18.38	2.14	2.25	12.72	11.87	0.41	4.2	C_4 S_1
5. "	4725	3071	9.2	2.14	4.28	40.95	2.11	1.68	14.65	32.52	0.53	11.4	C_4 S_2
6. Al Rughailat	2700	2835	8.7	-	3.75	22.10	2.20	1.68	10.13	15.96	0.23	6.6	C_4 S_1
7. Sur Kalba	1439	935	8.9	-	3.93	9.34	0.75	1.89	5.15	6.85	0.13	3.6	C_3 S_1
8. "	1575	1024	8.9	0.70	2.51	10.24	0.75	1.96	5.25	6.85	0.14	3.6	C_3 S_1
9. Wadi Assam (Kalba)	1050	683	8.8	0.60	2.68	5.99	1.26	1.24	5.17	4.11	0.08	2.3	C_3 S_1
10. Falaj Al Farfar	3150	2048	10.0	0.70	4.36	10.68	2.41	2.48	9.34	6.22	0.16	2.6	C_4 S_1
11. Al Fujairah, near the Hilton	12705	9529	8.6	-	3.21	128.63	3.11	11.23	37.11	85.58	1.07	17.4	C_4 S_4
12. Above Wadi Ham Dam 9kms from Fujairah	820	533	8.1	-	2.00	2.80	1.80	1.00	4.00	1.70	0.20	1.1	C_3 C_1
13. Below Wadi Ham Dam 7kms from Fujairah/ 1km east of J. 'Uqaibat	853	555	8.0	-	2.10	4.80	2.30	1.20	4.30	3.80	0.16	2.3	C_3 S_1
14. Near filling station/ entrance of Fujairah	552	395	8.2	-	1.35	2.40	1.63	0.74	2.73	2.00	0.11	1.5	C_2 S_1
15. Fujairah new wellfield	1462	950	7.9	-	3.57	12.90	1.30	2.59	4.00	11.02	0.20	6.1	C_3 S_1
16. Fuj. Ruler's Palace	2344	1542	8.2	-	5.72	21.60	2.10	2.90	2.80	23.00	0.73	13.6	C_4 S_2
17. Pvt farm, off channel/Irrig. return	5055	2386	8.1	-	12.32	68.12	3.30	13.70	27.02	42.70	0.64	9.5	C_4 S_2
18. On distributary of W.Ham behind gov't house.	911	592	8.0	-	2.22	5.80	1.29	0.95	3.80	4.55	0.14	3.0	C_3 S_1
19. Open well/date gdn within Fujairah town	1969	1280	7.9	-	4.80	17.70	2.60	2.30	11.70	12.20	0.24	4.6	C_3 S_1
20. Date gdn north of Jabal Muraished	1432	931	8.0	-	3.50	11.30	2.10	1.27	7.90	8.10	0.19	3.8	C_3 S_1
21. MAF nursery	833	542	7.8	-	2.00	5.37	1.76	0.95	4.22	4.40	0.09	2.7	C_3 S_1
22. Ceramic and rock wool factory	620	403	7.9	-	1.50	4.05	1.23	0.79	1.90	4.10	0.11	3.5	C_2 S_1

EC in mmhos/cm. at 25°C; TDS in ppm.; ions in meq/l. Year of analysis 1988.

/ cont. from previous page.

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
23. Off Fujairah airport runway	631	410	8.0	-	1.60	4.05	1.39	0.79	2.80	3.50	0.12	2.6	C_2 S_1
24. Date gdn in Rughailat	1159	754	8.1	-	2.83	8.34	1.63	1.40	5.00	6.20	0.16	3.5	C_3 S_1
25. Date gdn in Ghurfah	911	592	8.3	-	2.20	5.10	1.91	1.20	4.02	4.32	0.17	2.7	C_3 S_1
26. On channel of trib. of W.Ras in Sur Kalba	725	471	7.9	-	1.77	3.27	1.47	1.00	3.20	2.40	0.12	1.7	C_2 S_1
27. Off channel of W. Ras / date gdn.	2260	1469	8.1	-	5.51	20.40	4.29	3.90	12.80	13.10	0.57	4.5	C_4 S_1
28. Tawi Mahdoomah in Misyal Al Shiekh	1341	872	8.0	-	3.27	9.40	3.40	2.90	7.40	6.00	0.14	2.6	C_3 S_1
29. In Misyal Sha'arah	1830	1131	8.1	-	4.24	14.90	3.30	3.00	9.16	10.00	0.30	4.1	C_3 S_1
30. Bithnah	1030	669	7.9	-	2.86	3.68	1.37	1.10	4.40	3.95	0.16	2.4	C_3 S_1
31. Balaidah	1300	845	8.0	-	2.22	9.54	1.38	1.18	6.50	5.40	0.17	2.8	C_3 S_1
32. Daftah	460	299	8.0	-	1.68	2.20	1.32	0.42	2.80	2.00	0.11	1.6	C_2 S_1
33. Ghurah	410	267	8.0	-	1.49	1.96	1.17	0.37	2.40	1.80	0.09	1.5	C_2 S_1

EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Year of analysis 1988.

Table 6.35.

Chemical analyses of the groundwater of the Wadi Ham-Fujairah alluvial outwash fan - 1988 (Fig.6.26).

The flow of the bulk of groundwater southeastwards, following the main surface flow channels of Wadis Ham, Al Farfar and Al Hiyail, is a controlling factor of groundwater quality in the Wadi Ham-Fujairah outwash fan. The other, secondary, controlling factor is the occurrence of both permeable Quaternary and less permeable Tertiary alluvium. Groundwater quality in the Quaternary deposits is better than that in the compact Tertiary deposits. As a result, the outwash fan may be subdivided into a northern (Fujairah) section with groundwater of brackish to saline quality (analyses 1-12) because of the weaker fresh water inflow head away from the main flow channels and the presence of larger proportions of finer deposits; and a southern section with comparatively good quality water maintained by the stronger fresh water inflow head towards Kalba (analyses 21, 22, 23, 25 and 26).

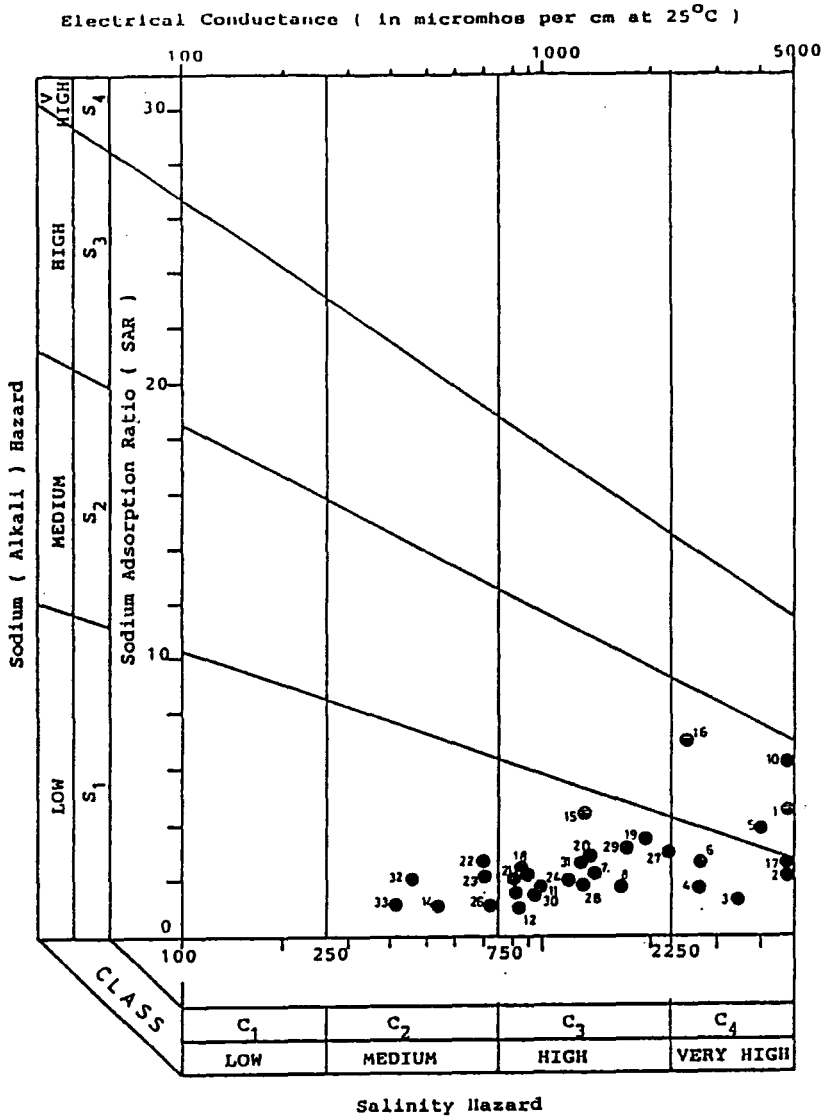


Figure: 6.27.

Irrigation water class of the waters of the Wadi Ham-Fujairah outwash fan on the east coast.

The bulk of irrigation water is of the C_3 S_1 and C_4 S_1 classes, which are the classes for water from wells mostly located on the main groundwater flow lines within the southern half of the Ham-Fujairah outwash fan towards Kalba. The C_2 S_1 irrigation water class for waters in wells located upstream in Wadi Ham (e.g., analyses 32 and 33 for Daftah and Ghurah). Irrigation water of the C_4 S_1 or C_4 S_2 classes is from wells located near the seaward end of the outwash fan where there is mixed fresh and seawater in a transitional groundwater zone as a result of seawater intrusion.

(The numbers in the figure refer to the water samples in Table 6.35)

especially along the coastal zone between Kalba and Fujairah, and can be attributed to two reasons. The first, is the excessive abstraction of groundwater in the Fujairah sector of the outwash fan than in that of the Kalba sector; the second, the renewal of groundwater supply in the southern half by the concentration of inflow towards Kalba, but limited inflow and replenishment towards Fujairah. Na and Cl are the dominant ions, followed by Mg, which appears to be of moderate occurrence in waters higher up the outwash fan (analyses 10 and 12, Table 6.35), where it is derived from the magnesium-rich ophiolites of the catchments to the west. However, Mg is of a high concentration in waters of the coastal aquifer where it is largely of marine origin.

The zone with the lowest ion concentration is that along the Wadi Ham main flow channel which extends as far as Kalba on the coast. The fresh water inflow within the main wadi channel helps dilute the minerals in the water. In the low salinity waters of Wadi Ham and the southeastern part of the outwash fan, the sodium chloride character is maintained, although Mg has equally high values. This attests to both the recharge characteristics of the groundwater from the replenishing inflow from the west (Mg), and also the saline water from the intruding seawater from the east (Na-Cl).

The SAR values in the Wadi Ham-Fujairah outwash fan range from 1.1 to 13.6, and irrigation water is mostly of the C_4 S_1 class of the very high salinity and low sodium hazard. Irrigation water in the southeast in Kalba is of the C_2 S_1-C_3 S_2 classes, whereas irrigation water in Fujairah is of the C_3 S_1 or C_4 S_1 classes (Fig. 6.27). The irrigation water classes of points higher up Wadi Ham, in places like Misyal Sha'arah and Ghurah (analyses 29 and 33, Table 6.35) are of the C_3 S_1 and C_2 S_1 classes respectively (Fig. 6.27).

6.5.3. The desert foreland

(Tables: 6.36 to 6.51 Figs. 6.28 to 6.34)

Delineation of the zone: The desert foreland as treated here includes the whole of the sand dune area to the west and southwest of the piedmont plains as far as 3-4 km. from the Gulf shoreline. It thus includes the coastal low dune belt that backs the Gulf littoral. The desert foreland zone is discussed from north to south and is subdivided

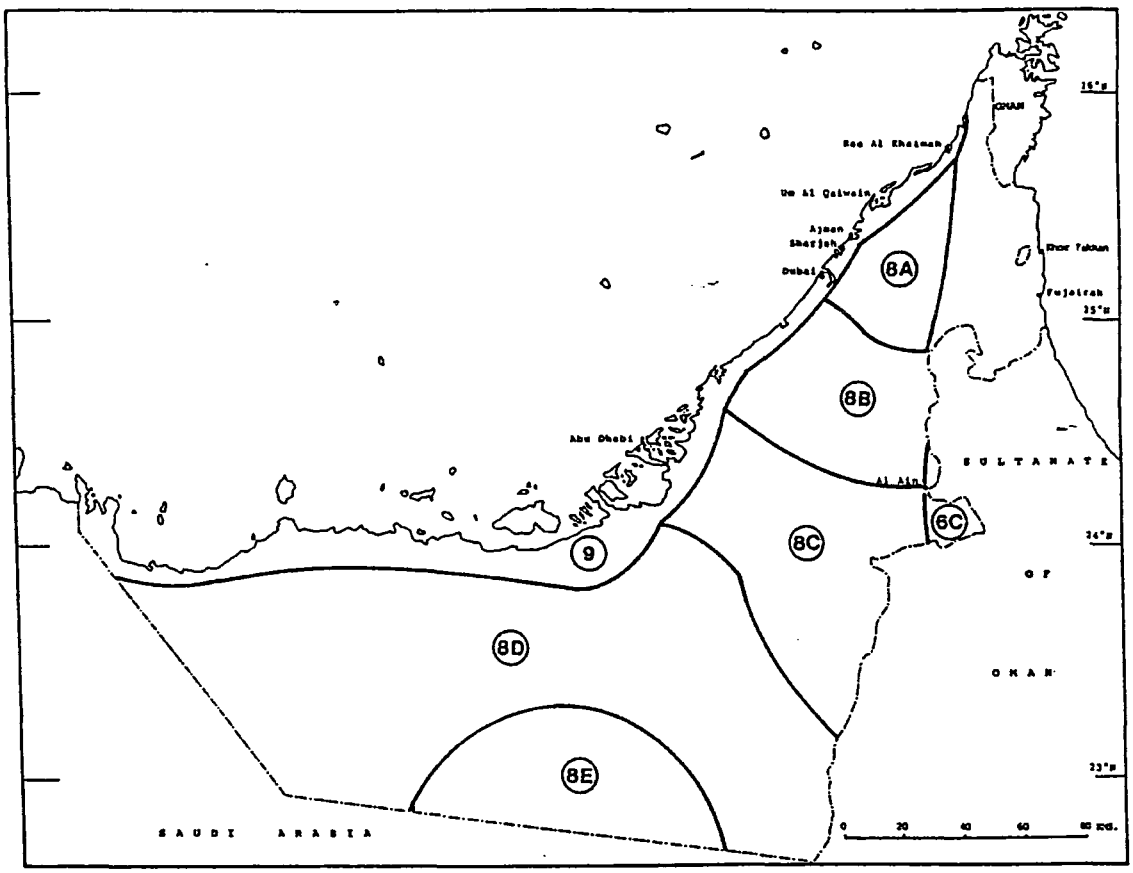


Figure: 6.28.

Subdivisions of the lowland zone of the Emirates showing the subzones of the desert foreland (8 A to E), the southern part of the piedmont plains (Al Ain, 6 C) and the western coastal zone (9) from where water samples were collected and groundwater quality described in the text.

6C) The southern part of the western alluvial piedmont plains (Al Ain).
8A) The desert foreland in the Northern Emirates.
8B) The desert foreland between Tawi Nazwa and Al Faqa'.
8C) The desert foreland between Al Ain and Bu Heeran in the west and Um Ez Zemool in the south.
8D) The desert foreland of central Abu Dhabi.
8E) The southern desert foreland of Eastern and Western Liwa.
9) The western (Gulf) coastal zone.

into the following subzones:

(i) The desert foreland triangle of the Northern Emirates from Tawi Haremlah in Ras Al Khaimah to Al Faqa' on the interemirate border between Abu Dhabi and Dubai in the south (marked 8 A in Fig. 6.28).

(ii) The part of the desert foreland within Abu Dhabi emirate from Tawi Al Faqa' to Um Ez Zemool (in the extreme southeast of the Emirates), and the whole area to the northwest as far as Al Ya'eeliyyah in Al Dhafrah and Bu Remramah and Bu Heeran on the Abu Dhabi-Al Ain highway as far northwestwards as Al Taff and the Tareef road (marked 8 B and C in Fig. 6.28).

(iii) The whole part of the desert foreland to the west and southwest of a line from Um Ez Zemool to the Tareef road, which embraces Manader Arrabbadh, Al Dhafrah, Bida' Zayed, Bujair, Bu Hasa, Bida' Al Areedh up to Ghayathy in the west (marked 8 D in Fig. 6.28), and both eastern and western Liwa (marked 8 E in Fig. 6.28).

Several factors affect water quality in the desert foreland. These include:

(i) Proximity of the eastern parts of the desert foreland, especially in the Northern Emirates, to the recharge zone of the piedmont plains where the quality of groundwater is better than locations further west nearer the coast.

(ii) The presence of wedge-like buried wadi channels that are in effect old wadi courses extending beyond the existing piedmont (gravel) plains, in channels concealed beneath the sands of the desert foreland and providing extensions of good to marginal quality groundwater in areas in the heart of the desert foreland that are otherwise producing brackish to very saline groundwater.

(iii) The presence of a highly permeable thick aeolian cover that provides ideal sandy fresh water aquifers in which good quality water practically floats over the extremely saline water of the underlying sabkha.

(iv) Contamination by seawater intrusion or groundwater residence in evaporite formations at locations further west near the coast, as well as those in inland sabkhas within the desert foreland.

(v) Perhaps the most important factor is the occurrence of the Gachsaran or Lower Fars evaporites formation beneath the aeolian and alluvial mantle in most of the desert foreland, but more so in the part of the desert foreland in the emirate of Abu Dhabi; and the Maastrichtian Juweiza flysch of clastics and shale in the Northern Emirates. These water-bearing sequences, which are thick and are in many areas close to the surface, adversely influence the quality of groundwater in the desert foreland.

6.5.3.1. Groundwater chemistry and quality in the desert foreland of the Northern Emirates (Tables 6.36 and 6.37; Area 8 A in Fig. 6.28; Fig. 6.29)

Two main surface flow wadi channels cross the desert foreland triangle of the Northern Emirates (Area 8 A, Fig. 6.28). The first is Wadi Lamhah, which is basically the main outflow channel into which collect the Wadis of Dhaid, Khadhrah, Ashwani, Sfini, Shawkah and others, after crossing the piedmont plains, to flow northwards and northwestwards as far as Jazeerat Al Hamrah on the Ras Al Khaimah coast. The second main wadi flow channel is that of Wadi Sumaini-Yudaiy'ah which flows from Oman, crosses Al Madam Plain, bypasses Jabal Fayah, and flows northwestwards and then northwards to end up in the inland sabkha of Seih Mussannad near Saja'ah in Sharjah.

These two main wadi flow channels are important groundwater recharge

arteries. They affect groundwater quality by providing a relatively better quality groundwater beneath their courses (ECs 2000-3000 mmhos/cm) in an otherwise poor quality groundwater in the surrounding desert foreland (ECs 3000 mmhos/cm. and more). The waters in the desert foreland of the Northern Emirates are of the sodium-chloride-bicarbonate type. SO_4 increases westwards towards the Gulf coast, and HCO_3 increases eastwards towards the recharge areas of the piedmont plains. The high HCO_3 value in Tawi Al Buhuth and Tawi Nazwa (analyses 21 and 28, Table 6.36) are derived from the Maastrichtian limestone in these two localities affecting the composition of their waters by increasing the HCO_3 value. Tawi Al Buhuth is near the Fayah-Mileiha anticline, and Tawi Nazwa is near Qarn Nazwa, both of which are limestone outcrops.

The high groundwater salinities, as indicated by the ECs in Khareejah (5768 mmhos/cm.), Sirrah (4227 mmhos/cm.), Al Hibab (5250 mmhos/cm.) and Tawi Wuhoosh (5408 mmhos/cm.) are all attributed to the locations of these points in inland sabkhas whose fine-grained deposits contain large quantities of Cl in solution (analyses 3, 5, 20 and 29, Table 6.36). These chloride-rich sabkhas are not necessarily exposed sabkha tracts but are concealed by dune sands as at Al Wuhoosh and Sirrah. At Tawi Khareejah, the sabkha is exposed and is with a hard crusted surface.

ECs range from 1200 mmhos/cm. in Wadi Sumaini near Qarn Nazwa (an isolated direct EC measurement, not included in Table 6.36) to 7550 mmhos/cm. at Al Helew in Ajman to the south of Tawi Sirrah (analysis 32, Table 6.36). At Al Aweer wellfield (analysis 18, Table 6.36), which is the oldest public supply wellfield in the Emirates, ECs range from 1800 mmhos/cm. in the southeastern part of the wellfield (in its upgradient part), to 6500-7000 mmhos/cm. in the main producing area in the centre, while in the fringes of the wellfield the ECs average 2200 mmhos/cm. (1988). At Al Khawaneej (analysis 12, Table 6.36), 5 km. to the northwest of Al Aweer, ECs of 5000 mmhos/cm. are common; while at Al Badea', only 2 km. away from Al Khawaneej, they are even higher (analysis 26, Table 6.36). In all these localities, overpumping of the aquifers has resulted in severe upconing and the drawing up of saline water from the underlying less transmissive strata and also by attracting seawater through the wedge-like channels on which the main wellfields of Dubai and Sharjah are located (more than 21 km. from the coast).

Chemical analyses of the groundwater of the Desert Foreland of the Northern Emirates (AREA 7 A)

In meq/l

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Tawi Haremlah	2853	1452	7.5	-	3.71	16.68	2.79	1.45	3.92	17.83	-	10.9	$C_4 S_2$
2. Tawi Khadeejah	3760	2019	7.6	-	3.51	24.11	5.15	2.00	5.98	24.72	-	12.4	$C_4 S_2$
3. Tawi Khareejah	5768	3317	8.5	-	2.40	34.73	10.19	7.60	7.94	31.78	-	11.4	$C_4 S_2$
4. Tawi Mughawirah	2678	1514	7.9	-	4.15	18.28	4.29	4.17	4.33	17.04	-	8.3	$C_4 S_2$
5. Tawi Sirrah	4227	2456	7.8	-	5.21	27.86	6.31	1.95	5.67	28.79	-	14.8	$C_4 S_2$
6. Tawi Muhaideb	3708	1844	7.8	-	4.33	23.07	2.06	2.45	6.17	20.43	-	9.8	$C_4 S_2$
7. Tawi Bayatah	3873	2009	7.8	-	4.33	26.98	1.39	3.00	8.25	22.35	-	9.4	$C_4 S_1$
8. Tawi Shunuf	3049	1735	7.8	-	3.38	19.09	4.88	1.90	5.50	20.00	-	10.4	$C_4 S_2$
9. Zubair	3265	1973	7.8	-	4.74	20.59	5.58	2.25	6.83	21.61	-	10.2	$C_4 S_2$
10. Nebibeg	1921	1236	7.9	-	4.33	10.45	3.85	1.45	5.42	11.57	-	6.3	$C_3 S_1$
11. Falah	2472	1463	7.7	-	3.29	14.65	4.83	2.45	4.92	15.00	-	7.8	$C_3 S_1$
12. Al Khawaneej	2142	1231	7.8	-	3.29	11.18	4.73	2.45	4.74	11.22	-	5.9	$C_3 S_1$
13. Tawi Al Eiyailah	4553	2657	7.7	-	6.59	30.53	5.38	1.45	2.75	37.04	-	25.6	$C_4 S_3$
14. Tawi Nadd	2524	1597	7.8	-	7.21	12.19	3.54	1.60	2.30	18.69	-	13.4	$C_4 S_2$
15. Mushref	3584	1998	7.7	-	3.92	20.76	6.56	2.60	4.67	23.43	-	12.4	$C_4 S_2$
16. Hamad Bin Hilles	3796	2173	7.5	-	3.30	23.94	6.98	2.75	4.15	27.30	-	14.7	$C_4 S_2$
17. Tawi Marghum, near the oilfield	1813	1030	8.4	-	4.28	11.52	3.23	1.80	5.60	11.65	-	6.1	$C_3 S_1$
18. Tawi Aweer	3502	2163	7.9	-	6.85	17.41	6.44	2.55	4.58	23.35	-	12.4	$C_4 S_2$
19. Tawi Saja'ah	4725	3444	7.8	6.71	0.42	34.80	7.00	2.74	3.40	42.00	-	24.0	$C_4 S_3$
20. Al Hibab	5250	3604	7.8	4.72	0.63	30.91	14.62	4.42	5.96	39.90	-	17.5	$C_4 S_2$
21. Tawi Al Buhuth	3255	1878	8.2	-	7.14	16.73	8.05	1.37	1.31	28.35	-	24.4	$C_4 S_3$
22. Tawi Murrah	3790	2464	7.7	-	8.28	19.25	9.34	1.59	1.52	32.89	-	26.3	$C_4 S_3$
23. Tawi Bel Khabees	3570	2258	7.8	-	4.41	22.72	7.88	2.64	3.40	28.62	-	16.5	$C_4 S_2$
24. Tawi Rashed(Dubai)	2310	1491	8.1	0.42	4.61	13.60	5.25	2.32	6.38	14.70	-	7.0	$C_4 S_1$
25. Badee'at Ghurbash	2730	1752	7.8	-	4.61	15.95	7.88	2.64	5.47	19.72	-	9.8	$C_4 S_1$
26. Al Badea'	5670	3849	7.4	-	8.50	31.00	19.47	8.55	8.11	41.21	-	14.3	$C_4 S_2$
27. Al Rafee'ah	4725	2940	7.7	0.63	6.30	28.84	10.90	3.21	7.88	35.69	-	15.1	$C_4 S_2$
28. Tawi Nazwa	3000	1950	8.3	-	6.58	10.78	4.21	2.99	4.42	13.88	-	7.2	$C_4 S_1$
29. Tawi Wuhoosh	5408	3712	8.1	-	4.86	30.84	17.32	4.55	6.14	41.11	-	17.8	$C_4 S_2$
30. Tawi Lamhah/Bayata	2756	1542	8.1	-	6.11	17.17	5.30	2.59	8.75	16.59	-	7.0	$C_4 S_1$
31. Tawi Al Bareer/ Falah	2173	1240	7.9	-	3.76	13.44	1.77	2.61	5.21	15.90	-	8.0	$C_3 S_1$
32. Tawi Al Helew (AJ) near T.Muhaideb	7550	5285	7.8	-	3.44	62.00	21.88	5.35	15.83	66.39	-	20.4	$C_4 S_3$

EC in mmhos/cm at 25°C, TDS in ppm. All ions in meq/l. Year of analysis 1988.

Table: 6.36.

Chemical analyses of groundwater in AREA 8A (Fig. 6.28) of the desert foreland in the Northern Emirates (1988).

The waters of the desert foreland of the Northern Emirates are generally of the Na-Cl-HCO_3 type. SO_4 increases towards the coast, while HCO_3 increases towards the recharge areas of the piedmont plains and the foothills. The HCO_3 in analyses 21 and 28 for Tawis Buhuth and Nazwa is derived mostly from the Maastrichtian limestone of the nearby anticlinal ridges of Fayah-Mileiha-Qarn Nazwa. Seawater intrusion is evident in the increasing groundwater salinities in Al Aweer (analysis 18), Al Hibab (analysis 20) and Al Badea' (analysis 26). In Al Aweer, the ECs increased between 50-100% since 1963 despite the reduced production from the wellfield since 1980. Na and Cl are the dominant ions in the these desert foreland waters of the Northern Emirates and may occur in concentrations of up to 10 times the maximum allowable limits for drinking or poor irrigation water. The irrigation water class is of the C_4 (very high salinity hazard) and S_1-S_2 (low to medium sodium hazard) class.

Two wells within Al Aweer wellfield, that had been mentioned by the Parsons Report (1963) as having shown an increase in salinity of 10-15% between 1960 and 1963, were investigated for the present study in 1988 and their ECs were measured. As shown in Table 6.37 the salinity for Well 103 increased by 54% and that for Well 43 by 109% between 1963 and 1988. The SWL was found in 1988 to be 20m. lower than that of 1963.

Well	Electrical conductivity (EC) (mmhos/cm at 25°C)	
	1963	1988
No. 103 (Al Aweer)	2600 (at present within Shaikh M. Bin Mana's garden)	4010
No. 43	2050	4300

Source for the 1963 ECs is the Parsons Report (1963).

Table: 6.37.

Deterioration in groundwater quality (EC) in Wells 103 and 43 in Al Aweer wellfield between 1963 and 1988.

The deterioration in the EC between 1963 and 1988 ranged from 50-100%. The deterioration would have been more if it were not for reducing production from the wellfield since 1980 when desalinated water started to contribute to most of Dubai's daily water requirement.

The observation by the Parsons Report (1963) of the presence of a tongue of fresh water stretching northwestwards from Tawi Aweer could not be confirmed by the investigation for the present study, despite the analysis of a wide variety of water samples and direct EC-TDS measurements. This is because excessive groundwater abstraction, for more than a quarter of a century since the Parsons study, has exhausted most of the fresh groundwater in the Quaternary aeolian and alluvial

deposits, and the cones of depression, that have subsequently developed, have attracted more saline water from outside the wedge-like alluvial tongues. There may have existed a difference in groundwater salinity within the reported fresh groundwater tongue and the surrounding brackish groundwater areas in 1963. At present, the wellfield areas of Al Aweer, Al Badea', Al Wuhoosh and Al Hibab are an extensive cone of depression area where the pump-levels of most of the wells are below MSL.

Agricultural groundwater abstraction in Al Khawaneej to the northwest of Al Aweer is equally intense. The result is that the northwest trending 'tongue' of relatively better quality water is no longer identifiable at present (1988 when the EC measurements were taken). Groundwater salinity is rising so rapidly in the public supply wellfields of Dubai and Sharjah, that some wells in these wellfields match those away from the wedge-like discreet wadi channels on which the wellfields are located. The effect of heavy abstraction has been the mixing of coastal with desert foreland groundwater and has made the waters in Al Aweer, Tawi Tai, Tawi Al Badea' and Tawi Oad Al Matinah almost identical (ECs varying between 3000-4500 mmhos/cm.).

Wells within the flow channel of Wadi Lamhah, which crosses the desert foreland from Falaj Al Mualla to the Gulf coast at Bathat Al Ali, exhibit lower ECs than those to the northwest and southwest of the channel. ECs average 2000-3000 mmhos/cm. in wells within the dry wadi channel, and 3000-4000 mmhos/cm. away from the channels on either side. Points such as Tawi Qarn (EC 2678 mmhos/cm.) and Tawi Al 'Uyaiyah (EC 2630 mmhos/cm.) are within the wadi channel, with the latter close to the coast; while points such as Al Yammah (EC 3870 mmhos/cm.) and Um Al Judu' (EC 3680 mmhos/cm.) are located away from the wadi channel on the southwestern and northwestern sides respectively (These are direct EC measurements not included in Table 6.36).

Ca values in this zone are not as high as those for Mg. The latter is located on the eastern part of the desert foreland nearer to the piedmont plains. The Ca-Mg ratio varies from 1:1 in the western (Tawi Khareejah, analysis 3, Table 6.36) to 1:3 (Tawi Nazwa, analysis 28, Table 6.36). The high Mg value for Al Helew (analysis 32, Table 6.36), nearer to the coast, is largely derived from intruding seawater. The

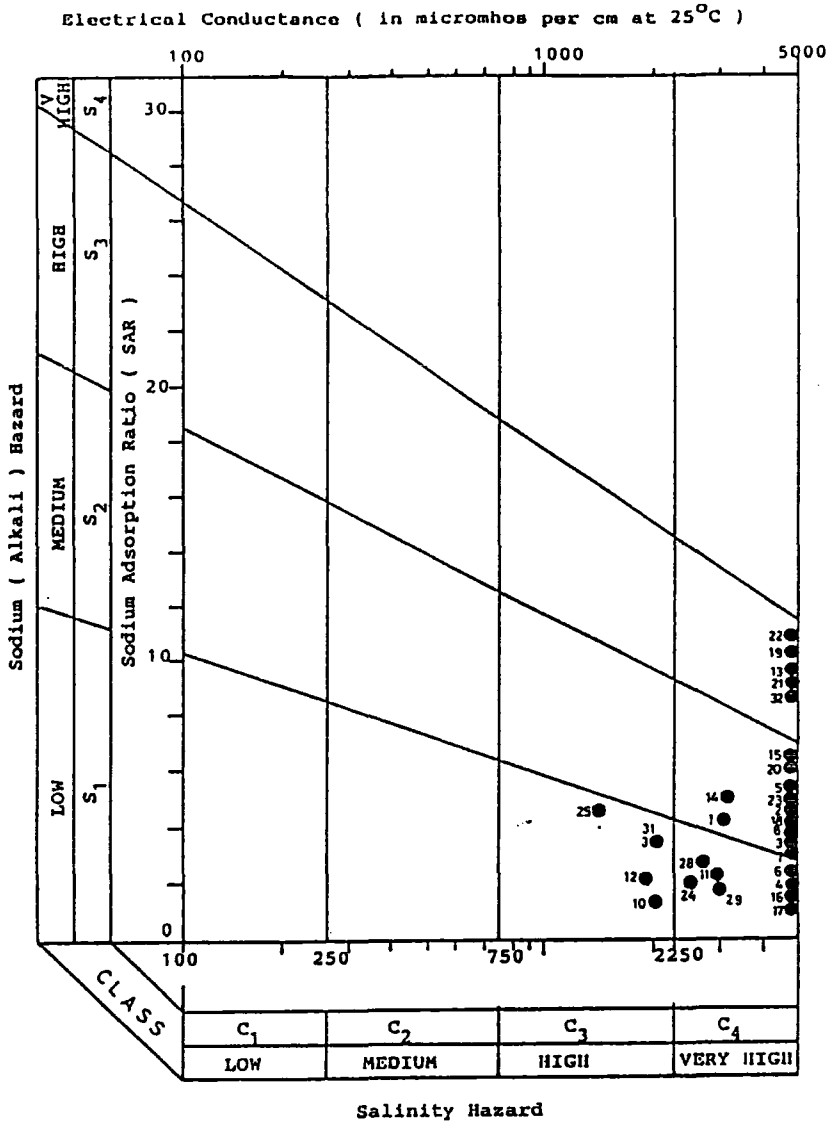


Figure: 6.29.

Irrigation water class of waters in the desert foreland zone in the Northern Emirates (marked 8 A in Fig. 6.28) (see also Table 6.36)

The waters in this relatively narrow part of the desert foreland, by comparison to the wider part further south in Abu Dhabi, are markedly of the C_4 S_1 to S_3 classes in wells away from the recharge zone at the piedmont plains and the foothills. Waters of the C_3–C_4 and S_1–S_2 classes are from wells on the eastern margins of the desert foreland close to the piedmont plains.

(The numbers in the figure refer to the water samples in Table 6.36)

high HCO_3 values in the analyses for this zone are attributed to concentration by evaporation in desert basins or sabkhas, as is the case in most of the locations in which values of more than 5.0 meq/l occur. Examples of this are Al Badea' (8.50 meq/l) and Saja'ah (6.71 meq/l); the latter place is actually situated on an extensive sabkha. Na and Cl are the dominant ions with values exceeding the allowable limits for drinking and poor irrigation water by nearly 10 times. SO_4 values appear to correlate with the Na and Cl values. In Al Hibab and Al Badea' public supply wellfields, SO_4 values are 3 and 4 times the maximum allowable limit for drinking water, respectively.

The SAR values range from 6.1 to 26.3 and the irrigation water class is of the very high salinity hazard (C_4) in about 90% of the analyses, and of the low to medium sodium hazard (S_1 - S_2), putting most of the waters in the desert foreland of the Northern Emirates in the poor class for irrigation (Fig. 6.29).

6.5.3.2. Groundwater quality in the desert foreland south of Tawi Nazwa as far as Al Ain

(Tables 6.38 and 6.39 ; Areas 8b and 8C in Fig. 6.28; Fig. 6.30)

ECs in this zone of the desert foreland to the south of Tawi Nazwa, as far as Al Ain, range from 2000 to 31000 mmhos/cm., with ECs in the majority of the shallow wells averaging 4000-8000 mmhos/cm. Na is the dominant cation and Cl is the dominant anion, followed by SO_4, which reaches high values of up to 70 meq/l and more in wells located in sabkhas (analyses 17-19, Table 6.39). The high content of these three ions in the waters of this zone renders them hazardous for both human and agricultural use. In a well in Tawi Al Ruwaiyyah (in Dubai), to the north of Al Faqa', the EC measured in 1988 54000 mmhos/cm. (a separate analysis not included in the Table 6.39). The well was drilled in the Lower Fars evaporite formation to a depth of 244m. The average SWL in this area is 25-30m. There is a clay aquiclude beneath the sands occurring at a depth of 52m. below which is the thick evaporites sequence. ECs in the upper part of the water-bearing strata are between 14000-16000 mmhos/cm., increasing to very high levels with depth.

Groundwater in Al Faqa' is not of potable quality and all the drinking needs of that vicinity are met by supplies brought by road tankers from Kashoonah, 12 km. to the east. The single well that was operated by WED Al Ain was abandoned in 1984 due to rising salinity that reached 6415 mmhos/cm. that year. The same well at Al Faqa' was reported by the Gibb Report (1970) as having an EC of 1782 mmhos/cm. Table 6.38 presents a comparison of the water chemistry of the same well for 1969 and 1988.

Location	EC	TDS	pH	HCO_3	SO_4	Cl	Ca	Mg	Na
1969	1782	1320	8.2	3.31	3.21	12.94	1.77	2.13	15.17
1988	6415	4752	7.1	11.92	11.56	46.58	6.37	7.67	54.61

EC in mmhos/cm. at 25°C; TDS in ppm; all ions in meq/l.

Source of data for 1969 is the" Water Resources Survey of Abu Dhabi", by Alexander Gibb. The 1988 analysis is for a sample collected for the present study.

Table : 6.38

Comparison of the water chemistry of a well in Al Faqa' for 1969 and 1988.

6.5.3.3. **Groundwater quality in the desert foreland zone extending from Al Ain to Bu Remramah, Bu Heeran and Al Ya'eeliyyah in the west, and Um Ez Zemool in the south**
(Table 6.39; Area 8 C in Fig. 6.28; Fig. 6.30)

With the exception of a few points, such as Bu Samrah, Bu Herma, Al Hayer, parts of Al Sulaimat (the airport) and Raknah (analyses 9, 33, 26, 29 and 40 in Table 6.39), where good quality water is tapped from the sand dune aquifer, ECs are all above 3000 mmhos/cm. (Table 6.39). The ECs are everywhere high and it is not easy to distinguish zones according to difference in EC. There is, however, a marked increase in

groundwater salinities westwards along the Al Ain-Abu Dhabi highway, with maximum EC levels being reached in Al Khaznah and Al Jiniyyah where they range from 18000-23000 mmhos/cm (analyses 10 and 17 in Table 6.39). Similarly, in Bu Heeran and Bu Remramah, along the same highway, the ECs range from 10000-23000 mmhos/cm. (analyses 19 and 20 in Table 6.39).

Groundwater occurrence in this zone is influenced by the alternating clay-marl-evaporite-sand lithologies that give rise to widespread occurrence of perched water bodies. As a result, the ECs in many areas vary widely in wells close to one another in the same locality (in Lusaili, to the south of Suwaihan, ECs range from 4000-13000 mmhos/cm.). Um Al Banadeq has relatively better quality groundwater of 4000-7700 mmhos/cm. (analysis 16, Table 6.39); while in al Khadher Nassasah salinities range from below 4000 mmhos/cm. to more than 24000 mmhos/cm. In Al Ya'eeliyyah (a forestry project site, analysis 22, Table 6.39), 60 km. to the west of al Wagn, the EC range of waters in shallow wells is 4000-11000 mmhos/cm.

To the west and southwest of Jabal Hafeet, in sabkhas like Seih Bin Ammar, Seih Al Rawdhah, Seih Gharabah, Seih al Miyah and Seih Sabrah, ECs range from 4000-13000 mmhos/cm (analyses 6, 7, 8, 24 and 32 in Table 6.39). In all these sabkhas, close to Al Ain, salinity increases rapidly with pumping. South of Al Qoa', as far as Um Ez Zemool, ECs reach their highest values of well over 25000 mmhos/cm., from shallow wells of a mixed dune and sabkha groundwater, but can be even higher in deep wells (analyses 47 and 49, Table 6.39).

The waters in this part of the desert foreland are of the sodium-chloride-sulphate type where all the values of these three constituents are extremely high. Ca and Mg are derived from the limestones, anhydrites and gypsum that constitute the Lower Fars sequence that underlies the whole area. Despite their widespread use for irrigation, the waters in this zone are mostly of the very high salinity hazard (C_4) and of the low to very high sodium hazard (S_1 to S_4)(Fig. 6.30). Such waters cause adverse effects on even the non-saline non-sodic sands of the desert foreland if applied for several years, as is taking place in the forestry projects (Chapter 2, Section 2.4.).

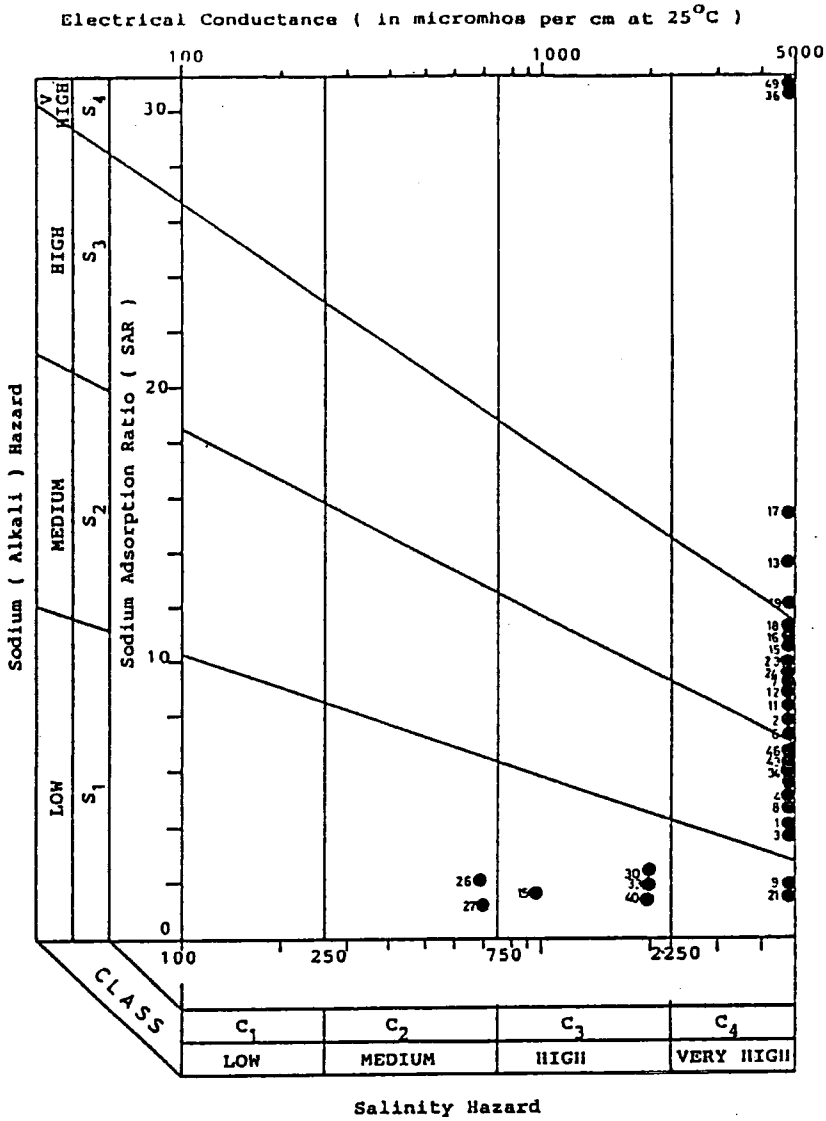


Figure: 6.30.

Irrigation water class in the forestry wells of the desert foreland zones 8 B and C (the desert foreland to the west of Al Ain as far as 10km. west of Al Khaznah) (Table 6.39).

The irrigation water here is mostly of the very high salinity (C_4) and medium to high sodium (S_1-S_2), hazard. The C_2-C_3 and S_2-S_3 waters are from the dune aquifers as at Al Hayer (analysis 26, Table 6.39). The bulk of the waters elsewhere are of the C_4-S_2 to S_4 classes.

(The numbers in the figure refer to the water analyses in Table 6.39)

Chemical analyses of groundwater used in the Forestry Projects in the eastern region of Abu Dhabi (Al Ain), the desert foreland as far west to a point 10 kms. west of Al Khaznah.

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Seih Al Baitar	6927	4850	7.7	-	5.90	60.55	25.00	17.00	22.00	52.00	0.33	11.8	$C_4 S_2$
2. Al Khadher Nassas	12350	9500	7.6	-	3.20	107.50	48.60	27.00	31.00	99.80	1.00	18.5	$C_4 S_2$
3. Al Lissili(5)	5650	3700	7.4	-	3.10	40.50	17.30	8.50	14.00	38.40	-	11.5	$C_4 S_2$
4. Al Ghuwailat(5)	13200	9250	7.7	-	2.90	99.00	44.10	35.00	32.00	78.00	0.60	13.5	$C_4 S_2$
5. Bu Toaq(3)	7930	6100	7.7	-	2.20	74.00	25.80	34.00	14.50	52.90	0.60	10.8	$C_4 S_2$
6. Seih Al Miyah(5)	5200	3380	7.7	-	3.40	50.00	19.80	7.00	11.50	55.20	-	18.2	$C_4 S_2$
7. Seih Gharabah(3)	11100	7770	7.6	-	6.40	70.00	34.40	12.50	18.50	80.80	-	20.5	$C_4 S_3$
8. Seih Sabrah	6143	4550	7.7	-	1.50	57.50	11.50	10.00	13.00	47.90	0.60	14.1	$C_4 S_2$
9. Busamrah	3300	2150	7.6	0.20	3.30	16.50	13.90	5.50	7.00	21.40	-	8.6	$C_4 S_1$
10. Al Khaznah	9500	6175	7.7	-	4.30	48.50	43.80	15.00	7.50	73.40	0.30	21.9	$C_4 S_3$
11. Ramah	3200	2100	7.7	0.20	4.20	16.00	12.00	3.00	3.50	25.80	-	14.3	$C_4 S_2$
12. Abu Jawabi(4)	10900	7630	7.7	-	1.30	53.50	40.20	35.00	7.50	55.50	0.80	12.0	$C_4 S_2$
13. Bida' Al Ajam(5)	6300	4100	8.0	-	4.60	35.50	24.00	6.00	5.00	53.10	-	22.6	$C_4 S_3$
14. Um Ghafah(2)	760	500	8.0	0.20	4.20	2.60	0.20	2.00	2.00	3.10	-	2.2	$C_3 S_1$
15. Halibad(3)	870	565	7.9	0.20	4.00	3.00	1.10	1.50	1.00	3.90	-	2.6	$C_3 S_1$
16. Um Al Banadseq(4)	7345	5650	7.6	-	3.00	64.00	35.30	13.50	12.00	78.60	2.00	22.0	$C_4 S_3$
17. Al Jinniyyah(5)	20500	15400	7.5	-	2.20	175.00	77.50	32.50	40.00	180.20	1.00	29.7	$C_4 S_4$
18. Al Yadoo'eeyyah(7)	14560	11200	6.9	-	3.40	136.00	82.10	39.50	32.00	149.50	1.50	25.0	$C_4 S_3$
19. Abu Remramah(5)	19500	14600	7.5	-	2.80	153.00	83.20	37.50	36.00	164.80	0.70	27.0	$C_4 S_4$
20. Abu Heeran(8)	15800	11850	7.4	-	2.30	132.00	61.20	39.00	27.00	129.50	-	22.5	$C_4 S_3$
21. Abu Deeb(5)	7500	4850	8.3	0.60	2.10	40.00	36.10	28.00	14.50	35.90	0.40	7.8	$C_4 S_1$
22. Al Ya'eelah(3)	11960	9200	7.9	0.40	1.90	121.00	31.00	28.50	18.50	105.80	1.50	21.8	$C_4 S_3$
23. Al 'Ajeer(3)	9360	7200	7.5	-	2.50	85.00	32.50	19.00	23.00	78.00	1.00	17.0	$C_4 S_2$
24. Al Rawdhah(3)	11000	7700	7.4	-	4.2	75.50	44.30	11.00	17.00	95.00	-	25.4	$C_4 S_3$
25. Al Sad(6)	3300	2150	7.0	0.20	1.40	15.00	14.80	4.00	6.00	21.40	-	9.6	$C_4 S_3$
26. Al Hayer(2)	675	500	8.1	0.40	3.30	3.50	0.50	1.50	2.60	3.70	-	2.6	$C_2 S_1$
27. Al Hudood(Boundary Nursery)	690	450	8.3	0.30	2.50	3.00	1.20	1.00	3.50	2.50	-	1.7	$C_2 S_1$
28. Al Hilli	3600	2350	7.6	-	4.40	21.00	9.30	0.40	10.00	23.70	-	10.4	$C_4 S_2$
29. Al Sulaimat(the airport)	1013	750	6.5	-	4.00	6.00	1.60	1.00	3.50	6.40	0.20	4.3	$C_3 S_1$
30. Al Sulaimat	2050	1333	7.8	-	3.00	10.50	7.10	2.50	5.00	13.00	-	6.7	$C_3 S_1$
31. Al Maqam(3)	9900	6450	7.8	-	3.20	71.00	31.70	12.8	18.50	73.50	0.40	18.4	$C_4 S_2$
32. Seih bin Ammar(3)	12200	8550	7.4	-	3.10	94.00	33.20	8.50	21.50	99.50	0.80	25.5	$C_4 S_3$
33. Bu Herma	1958	1450	8.1	0.60	4.40	12.50	4.80	1.50	6.00	15.30	-	7.9	$C_4 S_1$

EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Year of analysis 1988.

34. Nassasah	11180	8600	7.0	-	2.00	106.00	55.20	23.00	42.00	97.50	1.10	17.1	C_4 S_2
35. "	12350	9500	7.6	-	3.20	107.50	48.60	27.00	31.00	99.80	1.00	18.5	C_4 S_2
36. "	31200	24000	7.0	-	3.40	289.00	108.00	54.00	68.00	278.00	1.10	35.6	C_4 S_4
37. Ain Al Faydhah	8645	6650	7.4	-	2.10	99.00	6.70	31.00	13.00	62.60	1.20	13.4	C_4 S_2
38. "	9815	7550	7.2	-	2.90	111.50	7.20	33.00	14.00	73.00	1.40	15.1	C_4 S_2
39. "	14300	11000	7.2	-	2.00	176.00	8.00	54.50	22.00	107.60	1.90	17.4	C_4 S_2
40. Raknah	1755	1300	7.6	-	5.70	8.50	5.90	2.50	6.50	11.10	-	5.2	C_3 S_1
41. Azz'ubah	9490	7300	7.6	-	3.30	81.00	34.00	15.00	23.50	79.00	0.80	18.0	C_4 S_2
42. Al Qattaar	7735	5950	7.6	-	2.70	46.00	44.10	10.20	7.20	75.00	0.40	25.5	C_4 S_3
43. Al Mimran	8190	6300	8.0	-	3.00	54.00	43.70	13.20	19.20	76.30	1.00	16.7	C_4 S_2
44. Al Shubaisi	8320	6400	7.8	-	1.50	75.80	71.10	23.20	24.20	100.00	1.00	20.5	C_4 S_3
45. Al Qaseemah	12805	9850	7.4	-	2.90	97.00	59.00	22.50	21.00	115.30	0.60	24.7	C_4 S_3
46. Al Ghozlan	3200	2100	7.7	-	4.40	17.00	10.70	3.00	3.50	25.60	-	14.0	C_4 S_3
47. Al Waqn	10630	7441	7.9	-	0.50	87.25	22.79	18.64	17.59	73.54	0.77	17.3	C_4 S_2
48. Al Qoa'	9282	7140	6.9	-	0.57	98.59	25.75	21.06	19.88	83.10	0.87	18.4	C_4 S_2
49. Um ez Zemool	25000	17500	6.9	-	1.52	493.31	37.88	98.95	100.50	332.10	0.90	33.20	C_4 S_4

Bracketed figures denote number of samples averaged.
EC in mmhos/cm at 25°C, TDS in ppm. All ions in meq/l. Year of analysis 1988.

Table 6.39.

Chemical analyses of groundwater used in the forestry areas of the Al Ain region of Abu Dhabi in the desert foreland AREAS 8 B and C as far as Al Khaznah in the west and Um Ez Zemool in the south (1988) (Figs. 6.28 and 6.30).

With the exception of a few points, such as Bu Samrah, Al Hayer, parts of Al Sulaimat and Raknah (analyses 9, 26, 29 and 40), where water of potable quality occurs, ECs are all above 3000mmhos/cm. The highest ECs in this desert foreland zone are found in Al Khaznah and Al Jinniyyah where they range between 18000 and 23000mmhos/cm. (analyses 19 and 20). These high ECs are the result of groundwater contamination by the salts of the clay-marl-evaporite lithologies that underlie the vast desert foreland of Abu Dhabi. In the sabkhas to the west and southwest of Al Ain (analyses 6, 7 and 12), groundwater ECs range between 4000 and 13000mmhos/cm. and they worsen as pumping proceeds. The waters in this zone are generally of the Na-Cl-SO_4 type in which all the values of these ions are extremely high (e.g., analyses 2 and 19). Despite the widespread use of these waters for irrigation in the forestry projects, they are mostly of the C_4 (very high salinity hazard) and S_1 to S_4 (low to very high sodium hazard) irrigation water class.

6.5.3.4. **Groundwater quality in the desert foreland zone of central Abu Dhabi** (Tables 6.40 to 6.42

Area 8 D in Fig. 6.28; also Figs. 6.31 and 6.32)

This zone extends from Habshan in the north to Al Dhafrah and Manader Arrabbadh in the southeast, Ghayathy in the west and Al Qafa (north of Liwa) in the south.

ECs vary from 1500 mmhos/cm. in wells in the sand dunes to 24000 mmhos/cm. in wells in the evaporites of the sabkha. Examples of the former range of EC are Al Helew (1200-1800 mmhos/cm.) and Bida' Rashed (1800-2500 mmhos/cm.) (analysis 14, Table 6.42); examples of the latter range of EC are Bida' Al 'Areedh (analyses 1-8, Table 6.41)(3500-20000 mmhos/cm.), Bida' Zayed (analyses 9-20, Table 6.41) (5800-13000 mmhos/cm.) and Al Azeeziyyah (analyses 35-39, Table 6.40) (16000-18000 mmhos/cm.).

In the good quality sand dune water areas, such as Bujair, Bida' Khalfan and Al Helew (all of which are public supply wellfields of WED Abu Dhabi) (analyses 11-13, Table 6.42) there are also forestry wells that tap the sabkha and gypsum aquifers/aquitards where the waters are of poor quality. In Bujair, for example, the EC in the public supply wells range from 1700 to 2200 mmhos/cm., while in the forestry wells the ECs range from 3000 to 10000 mmhos/cm. In both cases the wells are tapping groundwater from about 30-40 m. depth, relative to either the dune or sabkha ground surface.

The waters are of the sodium-chloride-sulphate type in which the first two ions are the most dominant. The SO_4 content in the public supply wellfields in central Abu Dhabi reaches 21.00 meq/l for potable water and more than 30.00 meq/l for brackish irrigation water (the latter value is for Jaww Al Oad based on data from WED Abu Dhabi, 1987) (also refer to Table 11.2, Chapter 11).

The brackish waters of Jaww Al Oad (analyses 1-4, Table 6.42) lie between two areas of very saline water: the one in Ghayathy to the northeast (analyses 5, 8 and 10, Table 6.40), and the other in Bida' Al Matawa'ah to the southwest (analyses 67 and 68, Table 6.40). There is a wide variation in the brackish and saline water in this part of the zone

In agricultural and forestry locations in the Desert Foreland to the west and south of Al Khaznah (of the Agriculture and Forests Sections of Abu Dhabi Municipality).

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. 'Aarfah(Baynoonah)	6012	4017	7.4	-	0.93	46.00	16.99	11.33	6.49	44.29	1.44	14.9	$C_4 S_2$
2. Hadwaniyyah(Marfa)	3986	2472	7.3	-	1.03	28.29	10.82	4.84	3.72	31.31	0.82	15.1	$C_4 S_2$
3. Qurun Anna'am (1)	3677	2266	7.8	-	0.92	22.96	12.88	5.41	3.41	27.29	0.82	13.0	$C_4 S_2$
4. " (2)	5150	3348	8.0	-	0.93	32.93	21.11	5.97	3.71	43.67	0.82	20.0	$C_4 S_3$
5. Ghayathy	4223	2678	7.5	-	1.75	36.11	2.88	8.24	20.60	11.33	0.41	3.0	$C_4 S_1$
6. Bead' Salb	8611	5459	10.8	0.93	5.45	66.85	19.11	17.11	2.49	71.69	1.24	22.9	$C_4 S_3$
7. Aasila' (Ba'ya)	6613	4629	7.5	0.72	4.01	31.83	42.23	37.29	9.58	29.97	1.59	6.2	$C_4 S_1$
8. Ghayathy(Military school)	13287 4m/WT	9991	7.3	-	1.24	103.32	59.74	34.81	21.84	104.75	3.29	19.7	$C_4 S_3$
9. Habshan	19570	13802	6.8	-	0.93	169.59	62.80	47.17	23.99	159.91	2.06	26.8	$C_4 S_4$
10. Ghayathy(Green belt)	25338	19467	7.0	-	1.49	218.03	100.25	39.24	28.84	241.84	1.34	41.5	$C_4 S_4$
11. Bida' Zayed (date gardens)	10609	7159	7.6	-	0.93	87.72	37.08	25.54	10.71	78.28	1.48	18.4	$C_4 S_3$
12. Al Babha (B.Zayed)	8649	5614	7.8	-	0.82	61.76	27.81	19.98	5.67	63.86	1.24	17.8	$C_4 S_2$
13. Atturuq Military Camp in B. Zayed	11500	7700	6.9	-	0.41	90.02	40.17	32.75	12.36	83.06	1.44	17.5	$C_4 S_2$
14. Bida' Saif	2328	1442	7.8	-	1.34	15.60	6.44	1.03	0.51	21.53	0.31	24.5	$C_4 S_3$
15. New Gardens in Bida' Zayed	10900	7500	7.4	-	0.70	86.90	40.00	36.65	14.42	76.12	0.75	15.1	$C_4 S_2$
16. Garden north of camp/B.Zayed	8971	6180	7.1	-	0.41	67.95	32.95	23.89	10.30	65.92	1.44	16.0	$C_4 S_2$
17. Pvt farm/B.Zayed	10403	6500	6.9	-	0.72	79.15	32.45	26.68	12.88	71.69	1.24	15.9	$C_4 S_2$
18. Al Babha Nursery	12257	8219	7.3	-	0.62	90.02	92.49	30.28	13.69	85.49	1.96	18.6	$C_4 S_2$
19. "	13493	9528	7.7	-	0.62	110.10	47.38	33.27	15.76	108.20	1.65	21.9	$C_4 S_3$
20. Madinat Muhammad	6499	3914	7.1	-	1.49	49.44	12.88	9.99	6.01	47.02	0.96	16.6	$C_4 S_2$
21. Bida' Al 'Ajooz	4687	2936	7.9	-	1.34	33.45	12.88	5.97	4.74	35.84	0.93	15.7	$C_4 S_2$
22. Kumaisah	3914	2369	8.0	-	1.13	25.75	11.33	4.23	2.47	31.31	0.84	17.1	$C_4 S_2$
23. Al Dhafrah (a)	9136	6438	7.2	-	3.35	60.61	41.20	30.49	10.61	59.33	1.44	13.1	$C_4 S_2$
24. (b)	7210	4944	7.7	-	0.41	50.89	29.97	23.69	9.48	47.11	1.03	11.6	$C_4 S_2$
25. (c)	9672	6770	6.9	0.72	0.82	74.57	38.11	25.11	11.33	74.98	1.24	17.6	$C_4 S_2$
26. (d)	9538	7107	6.8	-	0.82	138.91	62.75	35.95	100.73	64.11	1.44	7.8	$C_4 S_2$
27. (e)	10187	7262	6.7	-	1.13	70.94	47.38	34.81	11.23	66.74	1.34	13.9	$C_4 S_2$
28. (f)	11742	8498	6.2	-	0.67	88.87	54.59	40.38	14.04	80.97	1.55	15.5	$C_4 S_2$
29. (g)	10012	7416	7.1	-	0.72	70.57	45.32	32.55	12.46	70.16	1.44	14.8	$C_4 S_2$

30.	(h)	12051	8034	6.6	-	2.88	79.72	47.38	35.84	15.35	76.98	1.65	15.2	C_4S_2
31.	(i)	10506	7107	7.6	0.10	0.82	71.99	43.26	33.68	13.29	67.16	1.65	13.9	C_4S_2
32.	(j)	14729	10815	7.5	0.21	0.31	112.11	60.77	26.88	15.88	127.62	2.81	27.6	C_4S_4
33.	(k)	11845	8240	7.6	-	0.72	84.87	48.41	32.65	14.42	87.34	1.44	18.0	C_4S_2
34.	(l)	11412	7989	6.0	-	0.66	84.87	46.35	30.90	15.45	84.56	1.39	17.6	C_4S_2
35.	Al 'Azeeziyah (1)	16068	10712	7.2	-	1.03	138.84	40.19	26.68	19.36	132.15	2.25	27.5	C_4S_4
36.	(2)	18540	12257	7.1	-	1.03	159.87	46.32	31.11	24.51	150.07	2.06	28.5	C_4S_4
37.	(3)	24617	17098	6.9	-	0.82	231.54	56.65	39.96	28.53	217.28	2.58	37.1	C_4S_4
38.	(4)	19158	14317	7.1	-	0.82	153.72	78.28	42.18	34.81	154.50	2.37	24.9	C_4S_3
39.	(5)	18334	12669	7.6	-	0.82	154.29	54.59	35.54	19.98	151.81	1.96	28.8	C_4S_4
40.	Al Khatm (1)	10218	7622	7.7	-	0.72	66.95	55.62	39.14	15.86	67.89	0.93	12.7	C_4S_2
41.	" (2)	15347	11639	7.3	-	1.55	103.00	82.40	30.59	28.43	123.19	1.67	22.7	C_4S_3
42.	" (3)	18231	13905	7.2	-	1.03	126.07	94.86	32.65	33.78	151.77	2.37	26.3	C_4S_4
43.	" (4)	12978	9476	7.4	-	0.82	84.87	67.98	35.02	20.70	97.44	1.59	18.5	C_4S_3
44.	" (5)	25029	20394	7.2	-	1.75	200.64	127.97	35.02	45.11	250.23	2.68	39.5	C_4S_4
45.	" (6)	15450	11948	7.3	-	1.78	105.47	85.49	32.75	28.36	126.48	1.79	22.9	C_4S_4
46.	" (7)	6891	5562	7.2	-	0.82	30.90	54.08	31.11	13.69	40.01	0.72	8.5	C_4S_1
47.	" (8)	7983	6385	7.2	-	0.72	42.23	56.14	31.62	13.18	53.77	0.82	11.4	C_4S_2
48.	" (9)	12154	9064	7.9	-	0.83	62.27	80.34	28.53	20.60	91.67	1.24	18.5	C_4S_3
49.	" (10)	6870	5562	7.2	-	0.62	33.99	41.96	35.02	9.27	30.54	0.76	6.5	C_4S_1
50.	" (11)	15038	11330	8.2	0.31	0.52	107.50	75.20	40.69	26.68	114.23	1.85	19.7	C_4S_3
51.	Dahan-N (12)	7622	5974	6.8	-	0.62	39.04	54.59	30.18	11.95	52.59	0.82	11.5	C_4S_2
52.	Dahan-N (13)	9219	6798	6.7	-	0.62	49.34	56.65	34.09	14.01	57.06	1.13	11.7	C_4S_2
53.	" (14)	7622	5974	6.8	-	0.62	39.04	54.59	30.18	11.95	50.37	0.82	11.0	C_4S_2
54.	" (15)	8034	6438	6.8	-	0.52	41.16	50.17	31.83	3.81	54.89	0.93	13.0	C_4S_2
55.	" (16)	10290	7725	6.9	-	1.13	61.70	59.84	36.77	16.48	68.29	1.24	13.2	C_4S_2
56.	" (17)	6973	5665	6.7	-	0.62	35.02	53.02	34.10	9.71	43.67	0.74	9.3	C_4S_1
57.	Abu Assalf	25235	17922	6.7	-	1.34	237.60	69.01	38.21	70.04	199.31	2.78	27.1	C_4S_4
58.	Mulch Project (Al Khatm)	27501	21115	7.4	-	1.29	267.50	86.62	48.82	49.65	253.23	3.81	36.1	C_4S_4
59.	Dahan-N	13390	10403	7.7	-	0.85	87.45	75.22	35.54	19.98	105.27	1.67	20.0	C_4S_3
60.	Al Khatm	5480	3399	7.1	-	4.22	28.35	6.18	10.40	9.58	17.72	0.53	5.6	C_4S_1
61.	Suwaihan	6056	4120	7.6	0.41	2.37	28.84	33.48	5.36	6.18	47.50	0.82	19.8	C_4S_2
62.	"	7148	5047	7.4	0.31	2.27	40.17	35.11	7.52	7.42	61.80	0.97	22.6	C_4S_3
63.	Abu Remramah	15759	11845	7.6	-	0.86	79.00	82.40	32.65	25.13	122.75	2.47	22.8	C_4S_3
64.	Abu Assalf	19673	14214	7.8	-	1.34	174.89	58.71	35.95	50.16	146.41	1.99	22.3	C_4S_3
65.	Al Khaznah	20188	15141	7.2	-	1.24	118.24	91.77	35.54	32.96	145.76	1.85	24.9	C_4S_3
66.	Al Sad	6252	4017	7.5	-	2.06	48.41	16.48	7.21	14.42	44.81	0.75	13.6	C_4S_2
67.	Bida' Al Mataw'ah	11040	7590	7.2	-	0.98	134.99	44.87	26.16	17.11	136.25	-	29.5	C_4S_4
68.	Bida' Al Mataw'ah	16905	10810	6.8	-	0.98	134.99	44.87	26.16	17.11	136.25	-	29.5	C_4S_4

EC in mmhos/cm at 25°C, TDS in ppm. All ions in meq/l. Year of analysis 1988.

Table: 6.40.

Chemical analyses of groundwater used for irrigation in the agricultural and forestry locations in central and western Abu Dhabi in AREA 8 D of the desert foreland (1988) (Figs. 6.28 and 6.31).

ECs of the waters in this area of the desert foreland range from 2000mmhos/cm. in wells in the sand dunes (analysis 14) to more than 24000mmhos/cm. in wells in the evaporites of the sabkhas (analyses 10, 57 and 58). Groundwater in the whole zone is generally of the Na-Cl-SO_4 type in which Na and Cl are the dominant ions. SO_4 content in the public supply wellfields of central Abu Dhabi is high reaching 21.0meq/l in potable water and more than 30.0meq/l in brackish irrigation water. The irrigation water class is of the very high salinity hazard (C_4) and low to high sodium hazard (S_1-S_3). Such waters are applied to agricultural and forest land throughout this zone. The Na, Cl and SO_4 content is several times the maximum allowable limits of even poor irrigation water.

Variation in groundwater chemistry in single aquifers or parts of them in the Desert Foreland of central Abu Dhabi

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Bida' Al 'Areedh	(1) 3378	2009	7.5	-	0.92	21.61	9.79	5.13	3.63	23.29	0.77	11.1	C_4S_2
2.	(2) 3657	2266	7.7	-	0.77	24.00	11.49	5.11	3.44	26.42	0.89	12.8	C_4S_2
3.	(3) 4017	2472	7.7	-	0.98	27.27	10.82	5.67	2.96	29.56	0.87	14.2	C_4S_2
4.	(4) 4666	2936	8.0	-	1.08	31.39	14.94	6.49	3.72	36.27	0.98	16.1	C_4S_2
5.	(5) 5243	3193	7.7	-	0.57	37.05	14.94	6.44	5.31	39.41	0.94	16.3	C_4S_2
6.	(6) 7890	5047	7.7	-	0.93	57.62	25.21	8.60	6.37	67.17	1.03	24.5	C_4S_3
7.	(7)10073	6592	7.9	-	0.93	76.12	29.89	12.93	8.47	85.11	1.45	26.0	C_4S_3
8.	(8)19982	13287	7.1	-	1.34	169.93	55.86	32.24	21.20	170.17	1.95	32.9	C_4S_4
9. Bida' Zayed	(1) 5892	3657	6.9	-	1.69	46.31	12.36	7.62	5.92	45.23	0.87	17.4	C_4S_2
10.	(2) 6633	4223	6.7	-	0.77	46.38	20.11	16.27	8.27	41.87	1.24	12.0	C_4S_2
11.	(3) 7179	4584	7.2	-	1.03	58.67	16.48	10.71	3.77	62.22	1.11	23.1	C_4S_2
12.	(4) 7591	4841	7.4	-	0.93	60.69	20.53	11.28	4.27	60.46	1.07	21.7	C_4S_3
13.	(5) 8755	5974	7.6	-	0.57	70.83	30.41	26.06	9.69	65.16	1.14	15.4	C_4S_3
14.	(6) 9219	5923	7.2	-	1.03	72.01	23.71	16.38	7.28	72.77	1.14	21.2	C_4S_3
15.	(7) 9991	6695	7.3	-	0.72	78.19	30.41	21.94	10.64	76.13	1.32	18.3	C_4S_3
16.	(8)10249	7004	7.5	-	1.24	87.21	34.01	25.13	9.53	84.25	1.27	20.3	C_4S_3
17.	(9)10712	6798	7.3	-	0.52	82.21	27.83	25.80	13.73	70.53	1.70	15.9	C_4S_3
18.	(10)11330	7828	7.3	-	0.67	84.87	42.25	27.45	13.13	85.09	1.49	18.9	C_4S_2
19.	(11)12463	8549	7.1	-	0.62	92.58	47.40	31.68	14.59	91.80	1.43	19.1	C_4S_3
20.	(20)12978	9270	6.9	-	1.08	100.30	50.40	33.27	14.76	103.00	1.43	21.0	C_4S_3
21. Wadi Al Riyoom	(1) 2740	1638	7.9	0.10	1.02	17.50	7.47	1.13	1.02	23.51	0.29	22.6	C_4S_3
22.	(2) 3420	2060	7.7	0.10	2.11	21.68	7.73	1.69	0.04	29.11	0.37	31.3	C_4S_4
23.	(3) 3863	2369	6.7	0.10	2.16	30.27	7.99	2.22	5.23	32.24	0.45	16.7	C_4S_2
24.	(4) 4419	2678	7.4	0.10	1.55	36.88	10.82	2.82	2.56	33.36	0.50	20.3	C_4S_3
25.	(5) 5150	3296	6.6	-	1.69	39.10	13.91	2.78	3.12	43.44	0.52	25.3	C_4S_3
26.	(6) 5335	3296	7.3	-	1.91	40.13	11.59	3.88	3.34	41.89	0.42	22.1	C_4S_3
27.	(7) 5799	3502	7.8	-	1.71	43.20	11.85	3.80	3.69	49.04	0.61	25.3	C_4S_3
28.	(8) 6716	4069	7.4	0.21	2.74	50.34	12.88	4.89	4.21	56.56	0.69	26.6	C_4S_4
29.	(9) 7540	4790	7.7	-	2.52	58.64	17.53	10.20	7.42	60.46	0.88	20.4	C_4S_3
30.	(10) 7900	5047	7.3	0.72	0.82	59.68	19.59	10.76	9.02	60.46	0.87	19.2	C_4S_2
31.	(11) 8920	5562	6.9	-	1.34	68.94	21.14	8.86	7.16	73.89	0.85	26.1	C_4S_3
32.	(12) 9958	6077	7.6	-	1.03	77.18	22.17	10.92	10.13	78.37	0.92	24.2	C_4S_3

33. Kumaisah	(1) 2987	1700	7.9	-	0.88	18.03	7.47	3.80	2.61	18.80	0.72	10.5	$C_4^4 S_2^2$
34.	(2) 3780	3718	7.9	-	0.88	25.74	9.79	5.08	2.98	27.32	0.83	13.6	$C_4^4 S_2^2$
35.	(3) 4810	2884	8.0	-	1.13	34.42	12.88	4.35	3.14	40.18	0.82	20.7	$C_4^4 S_3^3$
36.	(4) 5037	2936	7.3	-	0.93	33.95	12.36	5.15	3.39	38.96	0.73	18.6	$C_4^4 S_3^3$
37.	(5)11742	8137	7.1	-	0.93	84.87	47.40	34.76	14.33	82.61	1.85	16.7	$C_4^4 S_2^3$
38. Al Dhafrah	(1) 5974	3966	7.7	-	0.52	39.11	24.74	18.79	7.34	38.11	0.94	10.5	$C_4 S_2$
39.	(2) 9033	6323	6.4	-	0.83	61.71	42.25	32.59	10.04	59.69	1.11	12.9	$C_4^4 S_2^2$
40.	(3)11536	7416	4.9	-	0.77	74.59	43.28	33.68	13.30	70.53	1.52	14.5	$C_4^4 S_2^2$
41. Al Khatm	(1) 4862	2987	7.2	-	4.22	39.08	6.18	7.93	7.62	32.47	0.52	11.6	$C_4 S_2$
42.	(2) 5480	3399	7.1	-	4.22	46.31	6.18	10.35	9.61	36.95	0.52	11.7	$C_4^4 S_2^2$
43.	(3) 6582	5326	7.8	-	0.31	30.87	50.49	30.13	12.10	38.51	0.71	8.4	$C_4^4 S_1^2$
44.	(4) 9373	7468	7.8	-	0.36	54.52	63.39	31.20	15.79	71.65	0.87	14.8	$C_4^4 S_2^1$

EC in mmhos/cm at 25°C, TDS in ppm. All ions in meq/l. Year of analysis 1988.

Table: 6.41.

Chemical analyses of groundwater in AREA 8 D of the desert foreland of central and western Abu Dhabi to show the spatial variation in the chemistry of brackish and saline groundwater in whole aquifers or parts of them (1988) (Figs. 6.28 and 6.31)

These water chemical analyses are for samples from wells in the Tertiary clastics and evaporites of the sabkhas of central and western Abu Dhabi. The general depth of the wells is 20-60m. below the surface. Several analyses are presented for each locality. These analyses are for wells that are not far from one another and the different EC values show the variation in groundwater quality in a small area (the figures in brackets denote the EC to be a mean value of the number of analyses cited). Such variation is repeated in all the six areas for which water analyses are presented in Table 6.41. (Bida' Al 'Areedh, Bida' Zayed, Wadi Al Riyoom, Kumaisah, Al Dhafrah and Al Khatm). The widest variation occurs in Bida' Al 'Areedh and Bida' Zayed. The depths of the wells are identical, and the likely explanation to this spatial variation in groundwater quality is in groundwater occurrence in isolated localized lenses of 'perched' water bodies as well as in the varied evaporite-clay-gypsum water-bearing strata.

Chemical analyses of groundwater for potable and agricultural use in central and western Abu Dhabi parts of the Desert Foreland

LOCATION	EC	TDS	pH	F	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Jaww Al Oad 1/1	3623	2536	7.8	0.17	5.56	25.88	12.03	13.91	8.90	31.83	0.95	9.4	C_4 S_1
2. Jaww Al Oad 1/2	3686	2580	7.9	0.33	5.13	27.63	15.31	13.54	8.71	31.96	0.97	9.6	C_4 S_1
3. Jaww Al Oad 2/2	4169	2919	8.0	0.21	33.00	33.27	21.88	20.50	27.80	40.92	1.23	8.3	C_4 S_1
4. Jaww Al Oad 2/8	4673	3271	7.9	0.22	7.98	39.09	21.90	19.95	12.77	39.47	1.18	9.8	C_4 S_1
5. Al Mariyah (Liwa)	1738	1218	8.0	0.35	6.79	10.50	16.88	16.99	10.87	12.92	0.39	3.5	C_3 S_1
6. Al Mariyah (Liwa)	1843	1292	8.1	0.21	2.52	10.20	5.28	6.30	4.03	9.75	0.38	4.3	C_3 S_1
7. Attarq (Liwa)	2363	1654	8.0	0.30	5.78	13.90	8.75	10.50	6.72	17.11	0.51	5.8	C_3 S_1
8. Khanoor (Liwa)	3308	3215	8.1	0.25	4.20	25.14	10.39	10.50	6.65	25.92	0.93	8.9	C_4 S_1
9. Dhafeer (Liwa)	5975	4184	7.9	0.39	12.60	44.10	26.79	21.50	15.20	53.24	1.63	12.4	C_4 S_2
10. Huwailah (Liwa)	7644	5350	7.8	0.22	14.70	69.21	28.43	30.75	18.52	65.13	2.56	13.1	C_4 S_2
11. Bujair 2	2018	1463	8.6	-	0.63	11.77	5.03	1.58	1.01	14.48	0.43	12.7	C_3 S_2
12. Bujair 3	1749	1267	8.5	-	0.92	11.29	4.38	2.31	1.48	12.66	0.38	9.2	C_3 S_1
13. Bida' Khalfan	1410	1083	8.7	-	0.57	7.05	4.23	1.41	0.98	8.45	0.29	7.8	C_3 S_1
14. Bida' Rashed	1775	1365	8.6	-	0.71	8.03	5.36	1.76	1.24	10.65	0.36	8.7	C_3 S_1
15. Qurun Ann'am in Wadi Bu Hasa	3557	2417	7.8	-	1.68	27.38	12.23	8.75	7.80	24.00	0.70	8.3	C_4 S_1
16. Muzeire'ah	1794	1300	8.0	-	0.70	8.80	5.40	1.80	1.26	10.80	0.36	8.7	C_3 S_1
17. Bida' Mubarak	1615	1170	8.1	-	0.63	7.52	4.66	1.62	1.13	9.72	0.32	8.3	C_3 S_1
Along the road to Muzeire'a:													
18. Sha'abiat Al 'Awamer in B. Zayed	7286	5100	7.6	-	1.76	53.01	16.89	12.08	5.16	52.91	1.11	18.0	C_4 S_2
19. Al Babha	9187	6431	7.9	-	1.69	63.30	30.83	20.07	10.49	63.15	1.48	16.2	C_4 S_2
20. Bida' Muhammad	4900	3185	7.9	-	0.97	25.56	26.31	20.35	5.47	24.85	0.64	6.9	C_4 S_2
21. Military Camp	7630	5341	7.6	-	1.52	39.93	41.11	31.79	8.55	42.39	1.00	9.4	C_4 S_1
22. Al Kindi's Garden	5300	3445	7.8	-	1.34	34.88	36.21	28.03	7.54	37.43	0.88	8.9	C_4 S_1
23. Bida' Bin Hareesh	6010	4207	7.7	-	1.20	31.14	32.33	25.03	6.73	32.81	0.79	8.2	C_4 S_1
24. Sh. Khalifa's Gdn.	4601	2991	7.9	-	0.92	23.07	24.58	19.11	5.14	24.28	0.61	7.0	C_4 S_1
25. Addahs Nursery	5960	4172	7.8	-	1.14	29.59	30.73	23.77	6.40	31.23	0.76	8.1	C_4 S_1
26. Bida' Saif Bin Muhammad Bin Butti	4700	3008	7.7	-	0.90	23.00	24.00	18.72	5.04	23.80	0.60	6.9	C_4 S_1
27. Razeez	7600	4864	7.8	-	1.26	54.60	22.50	14.04	4.28	58.80	1.00	19.4	C_4 S_3
28. Muraifej	8100	5670	7.6	-	1.34	57.88	23.85	14.88	4.54	63.39	1.10	20.3	C_4 S_3

EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Year of analysis 1988.

Table: 6.42.

Chemical analyses of potable and agricultural groundwater in AREAS 8D and E of the desert foreland of central and western Abu Dhabi (1988) (Figs. 6.28 and 6.31).

The potable groundwater of analyses 5-6, 11-14 and 16-17 are from hydraulically connected fresh Quaternary aeolian and brackish Tertiary clastics aquifers. The wells from which the samples for these analyses were taken draw water more from the clastics and evaporites than the dune sands as confirmed by isotopic investigations that found out that the waters in the above analyses were of pre-1954 thermonuclear year age (IAEA, Chapter 7, Section 7.7.3.). The medium EC waters (2500-5000mmhos/cm.) occur in the firmer Tertiary clastics (analyses 1-4 and 23), while the high EC waters (of above 5000mmhos/cm.) occur in sabkha or Oligo-Miocene Lower Fars evaporite formations (analyses 18, 19 and 28). Only those waters abstracted from Bida' Khalfan, Bida' Rashed, Bida' Mubarak and Muzeire'ah (analyses 13, 14, 16 and 17) are used for drinking, the rest are brackish waters largely applied to agriculture and are mostly of the C_4 (very high salinity hazard) and S_1-S_3 (low to high sodium hazard) class.

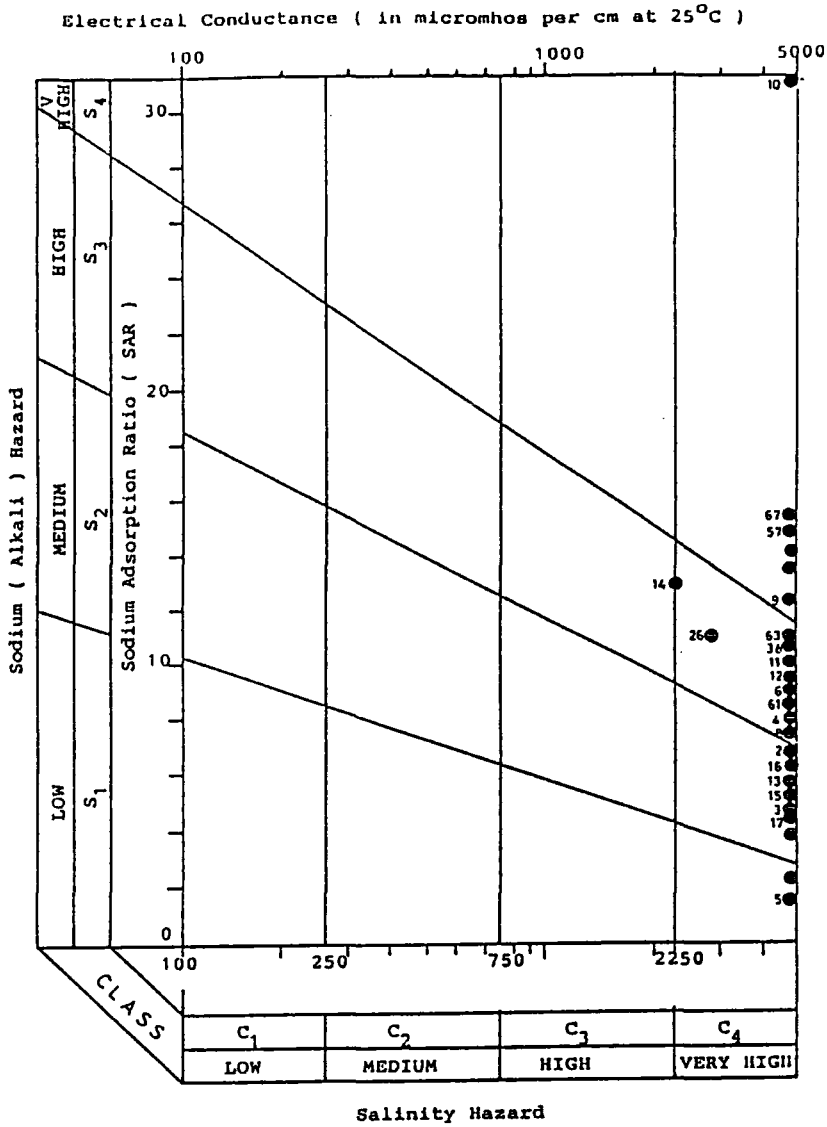


Figure: 6.31.

(combined for selected analyses in Tables 6.40 and 6.41)

Irrigation water class for selected analyses in Tables 6.40 and 6.41 of wells in the desert foreland zone 8 D.

Irrigation waters in this desert foreland zone are of the poorest quality (C_4 S_2-S_4) as they are derived from the Lower Fars evaporite formation.

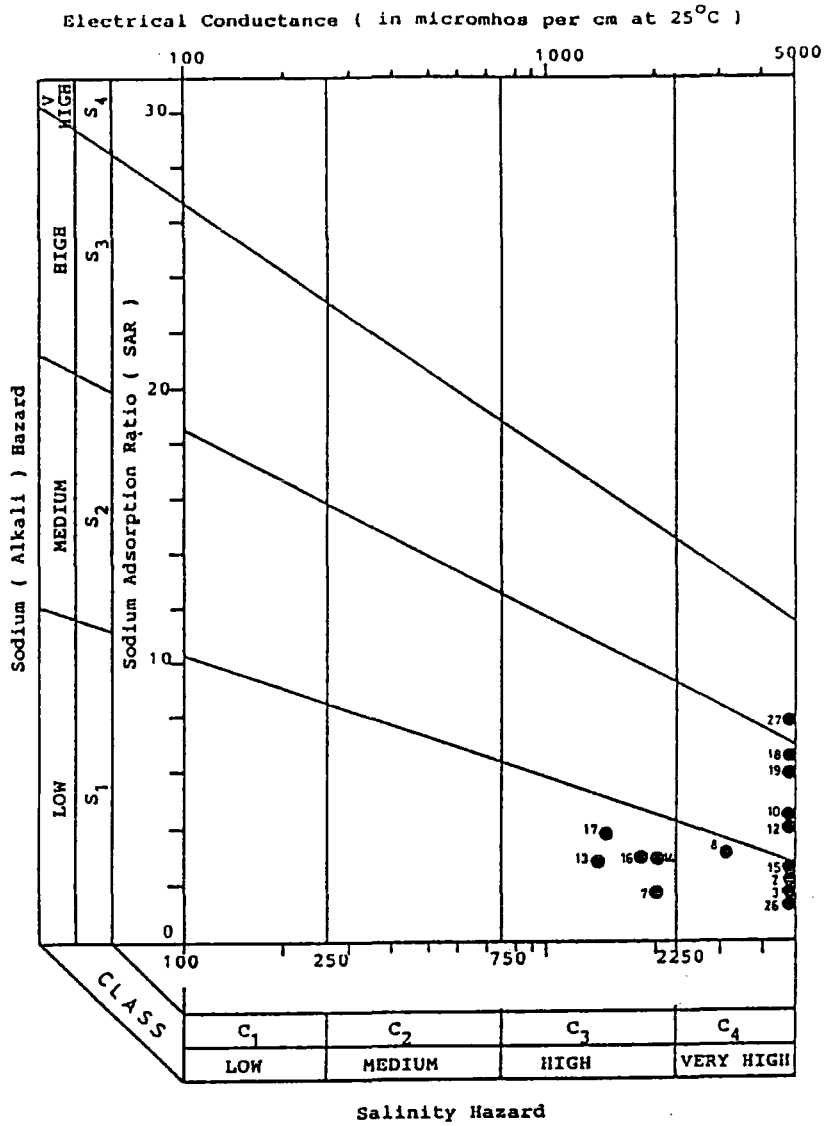


Figure: 6.32.

Irrigation water class in the desert foreland zone of central Abu Dhabi (Zones 8 D and E) (Table 6.42)

Waters of the C_3-S_1 class are from wells of the domestic public supply of WED Abu Dhabi (analyses 11-14 and 16-17, Table 6.42). The rest of the waters in these two desert foreland zones are of the C_4 and S_1 to S_4 classes (very high salinity and low to high sodium hazard).

(The numbers in the figure refer to the water analyses in Table 6.42)

due to groundwater occurrence in isolated lenses of varying vertical and lateral extent (refer to map of direct EC measurements in Appendix 9).

The SAR values are above 15.00 (Tables 6.39 to 6.41). The irrigation water class is of the very high salinity hazard (C_4) and low to high sodium hazard (S_1-S_3)(Figs. 6.31 and 6.32). The waters are applied to forest plants and are used for agriculture in places like Bida' Zayed and Ghayathy. The Na, Cl and SO_4 content is several times over the maximum allowable limit even for poor irrigation water.

6.5.3.5. **Groundwater quality of the shallow and deep water wells of the Abu Dhabi Company for Onshore Operations (ADCO) in the areas of the oilfields in the desert foreland of central Abu Dhabi**
(Tables 6.43 to 6.47)

The shallow water wells in central Abu Dhabi are both for domestic (for use in the personnel camps of the oilfields) and industrial (for oil operations). Because they tap sand dune aquifers, some of these shallow wells have fresh to marginal groundwater quality, as in some of the water wells of Bu Hasa (Well Bu Hasa 252, analyses 10 and 11 in Table 6.45). The deep water wells in central Abu Dhabi have supersaline waters (brines) some of which are used for mixing purposes to optimize their application for injection into oil wells to pressurize oil extraction; some of these waters are even useless for that end because of their corrosive composition.

The shallow water wells of the oilfields in ADCO's concession areas in central Abu Dhabi derive their waters from the same aeolian shallow aquifer that are tapped elsewhere by the public supply wellfields of WED Abu Dhabi (Bida' Khalfan, Bujair and Al Helew). The TDS in these shallow wells range from 960 ppm., as in Well BU-250 in Bu Hasa (analysis 11, Table 6.45), to over 62000 ppm., as in Well Asab J-29 (analysis 15, Table 6.45). In both these wells the average depth of the SWL is 60m. The Shah and Asab rig-wells (analyses 22-25 in Table 6.45) have extremely high salinities of up to 146000 ppm. (analysis 22 in Table 6.45) from a shallow depth of 50m. or even less.

Waters of deeper wells (other than those of the deep carbonate aquifers of the Simsima, UER and Dammam) vary in TDS from 8000 to 250000 ppm.

LOCATION/ WELL No.	TDS	pH	Na	Ca	Mg	Cl	SO_4	HCO_3	OIL CONTENT %
WELL BU HASA-229	2900	7.3	38.40	6.00	1.800	35.00	7.3	3.80	0.05
12.00 hrs.	3000	7.0	40.30	6.00	1.50	36.00	7.30	4.00	0.18
	3350	7.5	45.00	6.00	3.90	44.00	9.30	1.70	-
	3400	7.2	39.90	9.00	2.70	35.00	8.20	9.00	0.31
	3450	7.7	41.00	9.50	2.60	35.50	7.80	9.50	0.73
	3550	7.8	42.00	9.50	2.70	35.80	7.70	10.80	4.11
14.00 hrs.	4050	7.4	56.50	3.90	0.80	40.50	7.30	13.50	6.11
	6450	8.3	82.40	11.00	1.97	55.00	15.60	23.90	1.90
	6900	7.8	77.50	20.00	3.00	60.00	13.30	29.00	1.90
	7200	7.6	91.30	15.00	2.00	70.00	12.00	27.00	1.20
	7800	8.3	87.10	22.00	3.00	55.00	14.30	40.20	0.02
	8300	7.2	95.00	26.00	5.00	83.00	14.30	29.20	33.00
18.00 hrs.	10250	7.4	135.20	25.00	6.00	138.00	13.00	16.30	83.00
	10600	6.6	135.00	26.00	5.00	128.00	14.00	26.10	51.00
	11000	7.0	152.20	21.00	3.00	148.00	10.20	19.00	70.00
	11150	6.4	128.00	41.00	6.00	138.00	13.00	27.20	0.72
	11700	6.6	142.00	37.00	4.00	148.00	15.00	25.00	5.50
	17200	6.6	201.00	55.00	9.00	243.00	18.00	21.00	1.82
24.00 hrs.	27700	7.7	366.00	87.00	17.00	450.00	8.10	12.50	38.00
	44400	6.6	572.20	159.00	30.00	745.20	12.10	6.80	45.00
	47100	6.8	604.00	169.00	33.00	785.00	14.00	11.00	0.80
	53700	7.4	683.00	204.00	39.00	908.00	12.10	6.20	75.00

Table: 6.43.

Bu Hasa Well BU-229 in the Bu Hasa/Shuaiba-Thamama Group of Lower Cretaceous aquifers (with a total depth of 2601m) illustrating stratification of groundwater salinity with continued pumping.

WELL ASAB-136	199600	6.1	2520.00	860.00	80.00	3451.00	6.00	5.60	3.30
	207700	6.3	2841.00	665.00	80.00	3563.00	14.00	9.00	0.80
	210200	6.3	2833.00	690.00	115.00	3620.00	11.50	8.20	3.80
	219900	8.3	3257.00	450.00	75.00	3745.00	32.00	4.60	0.01
WELL BU HASA-252	1633	7.6	24.00	1.30	0.90	18.50	6.00	1.90	-
	1889	7.6	28.00	1.50	0.90	22.00	6.00	2.30	-
	1876	7.9	28.00	1.50	0.90	22.50	5.80	1.90	-
WELL ASAB-132	29200	7.6	388.00	55.00	51.00	423.00	70.00	1.30	-
	62700	7.6	874.00	90.00	113 00	1000.00	76.00	0.90	
WELL SAHIL-28	21670	7.2	288.00	41.00	32.00	270.00	88.00	1.00	-
	27838	7.2	374.00	48.00	43.00	360.00	103.00	1.10	
	32264	7.0	401.00	88.00	65.00	490.00	64.00	0.80	
WELL SHAH- 9	46244	7.0	618.00	93.00	83.00	270.00	74.00	0.80	
	69775	7.0	1012.00	87.00	98.00	1110.00	87.00	0.90	

Source: Abu Dhabi Company for Onshore Oil Operations. TDS in ppm, ions in meq/l

Table: 6.44.

Groundwater salinity stratification in other shallow and deep aquifers in the oilfield areas of central Abu Dhabi for Asab Wells-136 and 132, Bu Hasa Well 252, Sahil Well-29 and Shah Well-9.

(Commentary on both TABLE 6.43 and TABLE 6.44.

There is a marked groundwater salinity stratification in the saline wells of central Abu Dhabi. In WEll BU-229 (Table: 6.43) salinity increases with continued pumping from 2900ppm at 12.00hrs. to 53700ppm at 24.00hrs. The same is true with the rig wells BU-252, ASAB-136, SAHIL-28 and SHAH-9. Water from the these wells is mostly used for injection into oil wells,

Chemical analyses of potable (shallow wells) and saline (deep rig wells) in the vicinities of the oilfields of the Abu Dhabi Company for Onshore Operations (ADCO) in the desert foreland of central Abu Dhabi.

LOCATION/ WELL No.	pH	TDS	Na	Ca	Mg	Cl	SO_4	HCO_3
1. Bu Hasa BU-231	7.5	1900	27.00	2.40	1.30	23.00	5.50	1.80
2. " BU-229 (2601m)	7.4	53700	683.00	204.00	39.00	908.00	12.10	6.20
3. BU-226 (76m)	7.6	3450	46.00	6.10	4.10	45.00	9.80	1.80
4. BU- 99 (67m)	7.8	1880	27.00	1.70	1.40	23.00	4.80	2.30
5. Bu Hasa No. 3 Personnel camp	7.7	2659	37.00	5.00	1.70	34.00	8.50	1.30
6. Bu Hasa No. 2	7.7	2511	35.00	4.70	1.80	32.00	8.40	1.30
7. Bu Hasa No. 1 (61m)	7.7	3495	48.00	6.00	3.10	44.00	12.00	nil
8. Bab Bb-163	6.7	147978	2221.00	131.00	208.00	2484.00	76.00	0.48
9. Bab Bb-147	7.2	255243	3718.00	311.00	425.00	4420.00	33.00	0.40
10. Bu Hasa BU-252	7.9	1876	28.00	1.50	0.90	22.00	6.00	2.00
11. Bu Hasa BU-250	7.8	960	12.00	1.90	1.20	10.50	3.40	1.40
12. Bu Hasa BU-242	8.0	2154	31.00	1.70	1.70	25.00	7.90	1.80
13. Asab Sb-115	7.5	18850	236.00	46.00	34.00	255.00	59.00	1.20
14. Asab Sb-114	8.7	19300	247.00	43.00	32.00	263.00	58.00	0.36
15. Asab J29/Sb-132 65m & 107m	7.7	62700	874.00	90.00	113.00	1000.00	76.00	1.00
16. Asab Sb-118	7.6	14850	181.00	45.00	21.00	195.00	52.00	0.75
17. Asab Sb-5	7.6	15479	188.00	48.00	21.00	190.00	66.00	1.00
18. Asab Sb-136	7.1	18353	224.00	55.00	32.00	255.00	55.00	0.70
19. Asab Sb-135	7.8	14253	178.00	37.00	17.00	155.00	73.00	3.00
20. Asab Sb-138	7.2	10650	130.00	31.00	19.00	148.00	31.00	1.00
21. Asab J-31/40	7.3	17991	220.00	52.00	33.00	248.00	56.00	0.60
22. Asab Sb-135	7.0	146166	2126.00	310.00	83.00	2481.00	31.00	10.00
23. Asab Sb-139	8.0	51489	425.00	273.00	225.00	839.00	78.00	0.70
24. Shah Sy- 10	6.5	96523	1306.00	104.00	161.00	1548.00	112.00	0.90
25. Shah Sy- 9	6.9	46244	618.00	93.00	83.00	720.00	74.00	0.80
26. Shah Sy- 8 (55m)	7.3	1975	102.00	102.00	162.00	2151.00	89.00	0.90
27. Sahil Sa- 26	7.3	27985	356.00	60.00	61.00	400.00	76.00	0.60
28. Bab Bb-109	7.7	37800	528.00	52.00	56.00	543.00	92.00	1.44

Source: Abu Dhabi Company For Onshore Oil Operations(ADCO).
TDS in ppm, ions in meq/l

Table: 6.45.

Chemical analyses of potable and rig groundwater from shallow and deep boreholes in the vicinities of the oilfields of the Abu Dhabi Company for Onshore Operations (ADCO) in the desert foreland of central Abu Dhabi.

The relatively low TDS groundwater of Wells BU-99, BU-231, BU-250 and Sy-8 are used for domestic purposes in the personnel camps of the oilfields of central Abu Dhabi. The high TDS groundwater of Wells Bb-163, Bb-147, Bb-138 and similar wells are used for the injection process in the oil wells.

Well BU-229 is a good example of a relatively medium salinity rig-well tapping water from various lithologies down to 2601m. (Table 6.43; and analysis 2, Table 6.45). The range in salinity in ADCO's water wells is given in Table 6.46.

Stratification of groundwater salinity is clearly demonstrated in Table 6.45 for some shallow wells in central Abu Dhabi, and also in Table 6.43 for Well Bu Hasa 229 deep water well. In Well Bu Hasa 229 salinity increased during 12 hours of pumping from 2900 ppm at 12.00 hr. to 53700 ppm at 24.00 hr. (July 1982) (Table 6.43).

Field	Depth (m)	TDS range mg/l
Asab	46 - 98	3500 - 28000
Bad	43 - 122	6500 - 47000
Bu Hasa	40 - 79	1000 - 6700
Sahil	31 - 53	6000 - 30000
Shah	1 - 59	27000 - 135600

Source: Internal Memo by J.P. Struik, Chief Reservoir Geologist, ADCO, December, 1980.

Table: 6.46.

The range in salinities in ADCO's water wells in the oilfields areas of central Abu Dhabi.

Fresh groundwater is only restricted to the surface dune sands and practically floats over the highly saline waters in the Lower Fars evaporites. Overabstraction of groundwater sources leads to suction of extremely saline waters from the evaporites sequence. Note the high water salinities (brines) in such shallow depths as at Shah.

6.5.3.6. <u>Groundwater chemistry and quality in Eastern and Western Liwa</u>

(Tables 6.47 to 6.49; Area 8 E in Fig. 6.28)

(Figs. 6.33 and 6.34)

Groundwater in Liwa is of shallow occurrence because the Liwa oases stand on the edges of sabkha troughs into which collects subsurface flow from all directions, and where, close to or at ground level, the soil is saturated with highly saline water that rises continuously by capillary action. Ditches are excavated to expose pools of groundwater (whose levels stand at 1-2m. from the surface), from where it is pumped to gardens. There is also a better quality water in the dune sands, especially in the Al Qafa region to the north of the Liwa arc of oases. A total of 68 water samples were collected from both Eastern and Western Liwa and the chemical analyses for these water samples are presented in Tables 6.48 and 6.49.

ECs generally range from 2000 to 10000 mmhos/cm. in Western Liwa, and from 4000 to 26000 mmhos/cm. in Eastern Liwa. The waters in both Liwas are of the sodium-chloride-sulphate type. By comparison with those in central Abu Dhabi (Section 6.5.3.5.), the waters in Liwa contain more Ca and Mg but less SO_4. When the water analyses of both Western and Eastern Liwa are compared (Tables 6.48 and 6.49), besides the high Na and Cl values in both, Ca and Mg values are less in Western than in Eastern Liwa. On the other hand, the SO_4 content in the waters of Eastern Liwa is so high that in some places it exceeds the content of either Cl or Na, which are the major ions (in Al Huwailah, analysis 2; and Taroofa, analysis 8, in Table 6.48).

The quality of groundwater in newly drilled wells in Liwa may sometimes be less than half the salinity of the waters in nearby older wells until pumping proceeds and salinities in the new wells increase to equal those in the older wells. Table 6.47 compares the values of Cl and SO_4 ions in 9 boreholes in Liwa. In 7 out of the 9 water samples, the SO_4 exceeds in value that of Cl. The last three Sareet analyses in Eastern Liwa (Table 6.47) have higher values of SO_4 than those of Cl by between 50-200%, and the SO_4 content makes up between 20-60% of the TDS of the water. A possible explanation for this is the recirculation of decomposed organic matter from the date palms of the Liwa oases but,

most importantly, from the preponderance of gypsum in the water-bearing strata.

Only the groundwater abstracted from the dune aquifers, especially in Al Qafa, is potable. The irrigation water class in both Eastern and Western Liwa is of the very high salinity hazard (C_4). It is in the sodium hazard that irrigation water in Eastern Liwa is slightly 'better', with mostly low sodium hazard (S_1), but also medium to high sodium hazard (S_2-S_3)in some of the samples (Fig. 6.33). In Western Liwa, the sodium hazard is of the medium, high and very high groups (S_2, S_3 and S_4) (Fig. 6.34). Such waters are used on all the Liwa farms to irrigate date palms and a host of table-crops on sandy gypsiferous soils. Salinities in both the irrigation water and soils in Liwa are increasing to intolerable levels and the accumulation of salts hardens the soils and reduces their drainage capability.

			meq/l	
Location		**TDS (ppm)**	**Cl**	**SO_4**
Nashash	(1)	1360	10.98	9.16
	(2)	2660	27.21	12.13
Dhafeer		4423	50.00	17.71
Qu'aisah		2864	33.01	26.04
Tarq	(1)	1516	10.99	10.42
	(2)	1379	9.01	8.75
Sareet	(1)	3767	26.39	46.88
	(2)	2435	14.51	30.63
	(3)	3400	27.01	33.83

Source: Shah Field Area shallow aquifers, Al Mardhi Basheer, ADCO, 1988.

Table: 6.47

Comparison of Cl and SO_4 content in groundwater of some boreholes in Liwa.

SO_4 content in these analyses is high and can reach up to 3 times that of Cl and forms up to 20-60% of the TDS of a water sample.

Chemical analyses of groundwater in Eastern Liwa in the southern parts of the Desert Foreland.

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
E- 1. Hafeef	7800	5460	7.9	-	1.73	15.89	31.53	10.22	5.25	32.89	1.21	11.9	C_4S_2
E- 2. Al Huwailah	7644	5351	7.9	-	1.69	15.57	30.89	10.02	5.21	32.23	1.19	11.7	C_4S_2
E- 3. Al Ghaitain	5660	3962	7.9	-	1.33	12.23	24.25	7.86	4.04	25.30	0.92	10.4	C_4S_2
E- 4. Al Salimee	2787	1812	8.1	-	2.22	16.78	2.87	1.89	1.15	18.36	0.46	14.0	C_4S_2
E- 5. Al Ruwaiq	6300	4410	8.0	-	1.48	13.58	26.92	8.72	4.48	28.10	1.02	10.9	C_4S_2
E- 6. Nafeer	8700	6090	8.0	-	2.04	18.74	37.15	12.03	6.18	38.78	1.41	12.8	C_4S_2
E- 7. Qarmadah	9330	6531	7.9	-	2.18	20.11	39.75	12.87	6.61	41.49	1.51	13.3	C_4S_2
E- 8. Taroofah	9600	7620	7.9	-	2.25	20.71	40.94	13.26	6.81	42.73	1.56	13.5	C_4S_2
E- 9. Qaraidah	7255	5078	8.0	-	1.71	15.74	31.11	10.11	5.18	32.47	1.19	11.7	C_4S_2
E-10. Burr	4963	3226	8.1	-	0.92	8.49	16.99	5.46	2.79	17.53	0.64	8.6	C_4S_2
E-11. Tarfah	6000	4200	8.2	-	1.11	10.27	20.32	6.61	3.38	21.21	0.77	9.5	C_4S_1
E-12. Al Mail	5700	3990	7.8	-	1.35	21.66	22.46	15.15	7.66	21.68	0.91	6.4	C_4S_1
E.13. Shah	10000	7000	7.6	-	2.36	37.91	39.31	26.51	13.41	37.94	1.59	8.5	C_4S_1
E-14. Al Wahaidah	8700	6090	8.1	-	2.01	32.22	33.41	22.53	11.39	32.25	1.35	7.8	C_4S_1
E-15. Naseebat	8100	5670	8.0	-	1.87	29.96	31.11	20.95	10.59	29.99	1.26	7.6	C_4S_1
E-16. Al Huwaitain	8300	5810	8.0	-	1.91	30.56	31.73	21.37	10.80	30.59	1.29	7.6	C_4S_1
E-17. Sareet	9900	6930	7.6	-	2.22	35.45	36.81	24.79	12.53	35.48	1.49	8.2	C_4S_1
E-18. Ruqai'ah	7500	5250	7.9	-	1.69	26.94	27.98	18.84	9.53	26.96	1.13	7.2	C_4S_1
E-19. Assabkhah	11000	7700	7.9	-	2.19	35.02	36.37	24.49	12.39	35.05	1.45	8.2	C_4S_1
E-20. Al Hadee	8400	5880	8.0	-	1.75	28.11	29.11	19.95	9.91	28.04	1.16	7.1	C_4S_1
E-21. Mushaiqer	7750	5425	8.0	-	1.61	25.86	26.78	18.35	9.12	25.79	1.07	7.0	C_4S_1
E-22. Atharwaniyyah	6300	4410	7.9	-	1.29	20.69	21.42	14.68	7.29	20.63	0.86	6.2	C_4S_1
E-23. Nashash	7300	5110	8.0	-	1.49	23.54	24.85	17.03	8.46	23.93	0.99	6.7	C_4S_1
E-24. Jabbanah (N)	5500	3850	8.1	-	1.19	18.83	19.88	13.62	6.77	19.14	0.79	6.0	C_4S_1
E-25. Jabbanah (S)	6900	4830	8.1	-	1.43	22.59	23.86	16.34	8.12	22.97	0.95	6.6	C_4S_1
E-26. Dahen	10520	7364	8.0	-	2.10	64.11	18.60	14.64	11.34	57.07	1.65	15.9	C_4S_2
E-27. Jarrah(av. of 5)	5812	4069	8.1	-	1.16	35.26	10.23	8.05	6.24	31.39	0.91	11.8	C_4S_2
E-28. Watheel(av. of 2)	8000	5600	7.9	-	1.47	44.78	12.99	10.22	7.92	39.87	1.16	13.3	C_4S_2
E-29. Al Khais	5000	3250	8.0	-	0.93	28.21	8.18	6.44	4.98	25.12	0.73	10.5	C_4S_2
E-30. Mosel Bu Rahmah	4210	2737	8.1	-	0.78	23.69	6.87	5.41	4.18	21.11	0.61	9.6	C_4S_2
E-31. Q'aisah	7000	4900	7.8	-	1.09	33.17	9.49	7.57	5.85	29.55	0.85	11.4	C_4S_1
E-32. Bu 'Uwanah	7850	5495	7.9	-	1.21	36.82	10.53	8.41	6.49	32.81	0.94	12.0	C_4S_2
E-33. Hameem	7500	5250	7.9	-	1.16	35.34	10.11	8.11	6.23	31.49	0.90	11.8	C_4S_2
E-34. Jurairah	9000	6300	7.8	-	1.35	41.35	11.83	9.49	7.29	36.84	1.11	12.7	C_4S_2
E-35. Tawi Sehab	11000	7700	7.2	-	1.65	130.45	18.43	15.58	8.89	124.94	1.35	35.7	C_4S_4
E-36. Bu 'Arba'een	13900	9730	7.1	-	2.08	171.57	15.18	19.63	11.20	156.62	1.70	39.9	C_4S_4
E-37. Bu Qafa	21200	14840	6.9	-	2.79	313.18	24.36	26.30	15.00	295.87	2.28	65.2	C_4S_4
E-38. Um ez Zumool	25800	18060	6.8	-	3.29	390.51	28.74	31.03	17.70	371.53	2.69	75.2	C_4S_4
E-39. Um ez Zumool	15100	9815	7.3	-	1.94	250.1	5.80	18.31	10.27	229.30	-	60.7	C_4S_4

EC in mmhos/cm at 25°C, TDS in ppm. All ions in meq/l. Year of analysis 1988.

Table: 6.48.

Chemical analyses of groundwater in the oases of Eastern Liwa in AREA 8E in the southern part of the desert foreland of Abu Dhabi (Figs. 6.28 and 6.33)

(Comparative commentary on the water chemical analyses of both Eastern and Western Liwa is given below Table 6.49 next page)

Chemical analyses of groundwater in Western Liwa in the southern parts of the Desert Foreland

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
W- 1. Muzeire'ah	4477	2910	8.0	-	1.67	29.30	3.42	3.10	2.10	28.12	1.10	17.3	$C_4 S_2$
W- 2. Waheedah	7318	5123	8.0	-	1.64	55.70	9.60	3.46	2.14	60.27	1.14	36.1	$C_4 S_4$
W- 3. Dhafeer	9768	6838	7.9	-	1.65	78.41	13.73	8.27	3.80	80.35	1.38	32.7	$C_4 S_4$
W- 4. Al Mariyah	7012	4908	8.0	-	1.25	63.62	5.33	3.92	2.53	62.56	1.19	34.8	$C_4 S_4$
W- 5. Al Mariyah (E)	8226	5758	8.0	-	2.49	49.10	13.31	8.17	3.99	51.65	1.11	20.9	$C_4 S_3$
W- 6. Al Haif	6357	4450	8.2	-	3.19	44.11	8.47	3.18	3.24	48.21	1.12	26.9	$C_4 S_3$
W- 7. Addhuwaiher	5597	3917	8.0	-	2.49	34.32	7.34	5.34	3.25	34.44	1.12	16.6	$C_4 S_2$
W- 8. Shadq Al Kalb	6100	4270	8.1	-	2.69	37.11	7.93	5.77	3.51	37.20	1.21	17.3	$C_4 S_2$
W- 9. Qutoof	9726	6808	7.8	-	2.22	59.40	14.36	8.35	6.12	60.27	1.21	22.4	$C_4 S_3$
W-10. Waset	4890	3179	7.7	-	3.36	46.39	9.91	7.21	4.39	46.50	1.51	19.3	$C_4 S_3$
W-11. Al Hoamanah	3876	2519	7.9	-	1.52	24.02	1.19	2.62	3.11	20.11	0.96	11.9	$C_4 S_2$
W-12. Lateer	4240	2756	8.0	-	1.58	27.75	3.24	2.94	2.00	26.63	1.00	17.0	$C_4 S_2$
W-13. Kayyah	4002	2601	8.1	-	1.67	22.58	6.01	4.54	1.33	23.53	0.86	13.8	$C_4 S_2$
W-14. Um Al Qareen	5360	3752	8.0	-	2.17	29.35	7.81	5.90	1.73	30.59	1.12	15.7	$C_4 S_2$
W-15. Moaqab	3700	2405	7.9	-	1.46	22.78	1.15	2.94	2.52	19.10	0.95	11.6	$C_4 S_2$
W-16. Bu Saddain	5312	3718	7.6	-	0.97	26.40	19.43	7.90	2.67	35.01	1.14	15.2	$C_4 S_2$
W-17. Raknah(Bait Mana' Sa'eed Al Utaibah	6442	4509	7.4	-	1.99	35.15	3.75	5.22	3.25	31.24	1.21	15.2	$C_4 S_2$
W-18. Atteraq	4042	2830	8.1	-	3.42	25.12	9.46	4.75	2.32	30.26	1.31	16.1	$C_4 S_2$
W-19. Al Heyailah	3675	2573	8.1	-	3.11	22.84	5.42	1.59	2.11	25.96	1.19	19.1	$C_4 S_3$
W-20. Khanoor	8820	6174	8.0	-	3.78	62.21	9.11	4.98	4.11	63.91	1.49	30.0	$C_4 S_4$
W-21. Hamroor	7938	5557	8.0	-	3.40	59.11	8.21	4.73	3.91	60.71	1.42	21.8	$C_4 S_3$
W-22. Ar Rudoom	9060	6342	7.9	-	1.52	56.70	16.89	13.27	4.40	56.24	1.21	18.7	$C_4 S_3$
W-23. Hisan(for. Himar)	9801	6861	8.0	-	2.89	55.82	18.48	7.13	3.69	63.96	2.43	27.5	$C_4 S_3$
W-24. Al Mariyah (W)	3907	2540	8.0	-	2.53	19.15	10.14	3.11	1.48	26.40	0.88	15.3	$C_4 S_3$
W-25. Al Edd	2640	1716	8.0	-	2.49	15.58	3.41	1.29	0.91	18.93	0.34	18.0	$C_4 S_2$
W-26. Ar Ruqai'ah	5000	3250	8.0	-	4.01	25.11	5.41	2.11	1.46	30.48	0.54	22.8	$C_4 S_3$
W-27. Um Al Qataa	6283	4398	8.0	-	5.11	31.64	6.94	2.66	1.84	38.41	0.68	25.6	$C_4 S_3$
W-28. Al Kharees	7100	4970	8.1	-	5.77	35.75	7.84	3.11	2.11	43.40	0.77	26.8	$C_4 S_4$
W-29. 'Aradah	6336	4436	8.0	-	4.45	27.69	6.10	2.41	1.63	33.61	0.84	23.7	$C_4 S_3$

EC in mmhos/cm at 25°C, TDS in ppm. All ions in meq/l. Year of analysis 1988.

Table: 6.49.

Chemical analyses of groundwater in the oases of Western Liwa in AREA 8 E in the southern part of the desert foreland in Abu Dhabi (Figs. 6.28 and 6.34)

(COMMENTARY ON BOTH TABLES 6.48 and 6.49 FOR EASTERN AND WESTERN LIWA)

Groundwater in both branches of Liwa is of shallow occurrence in the sabkhas or the lower slopes of the giant dunes. ECs range from 2000 to 10000mmhos/cm. in Western, and from 4000 to 26000mmhos/cm. in Eastern, Liwa. The waters are generally of the Na-Cl-SO_4 type. Besides the high Na and Cl content in the waters of both Liwas, Ca and Mg are less in Western than in Eastern Liwa. SO_4 content in the waters of Eastern Liwa is so high that in some places it equals the content of either Cl or Na. Only the fresh dune groundwater in Al Qafa (north of the Liwa arc of oases) is potable, but all the waters used extensively for irrigation in both Liwas are of the very high salinity hazard. It is in the sodium hazard that irrigation water in Eastern Liwa is slightly 'better', with mostly low sodium (S_1), but also medium to high sodium (S_2 and S_3) hazard in some water samples. In Western Liwa, the sodium hazard is of the medium to very high groups (S_2 to S_4). Such waters are used to irrigate sandy gypsiferous soils.

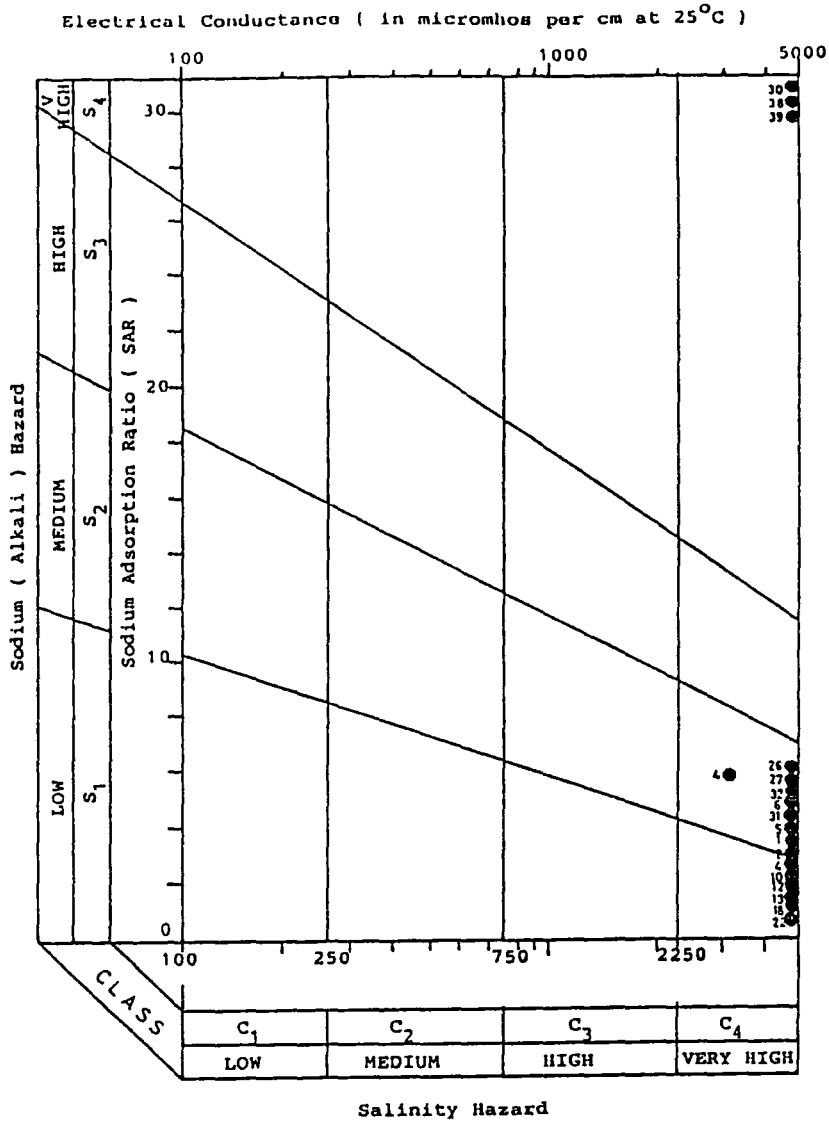


Figure: 6.33.

Irrigation water class of the waters in Eastern Liwa in the desert foreland 8 E zone (Table 6.46).

The irrigation waters in Eastern Liwa are generally of the C_4 and S_1 to S_2 (very high salinity and low to medium sodium hazard) classes. It is only in the sodium hazard that the waters of Eastern Liwa are slightly poorer than those of Western Liwa (Fig. 6.34)

(The numbers in the figure refer to the water analyses in Table 6.48)

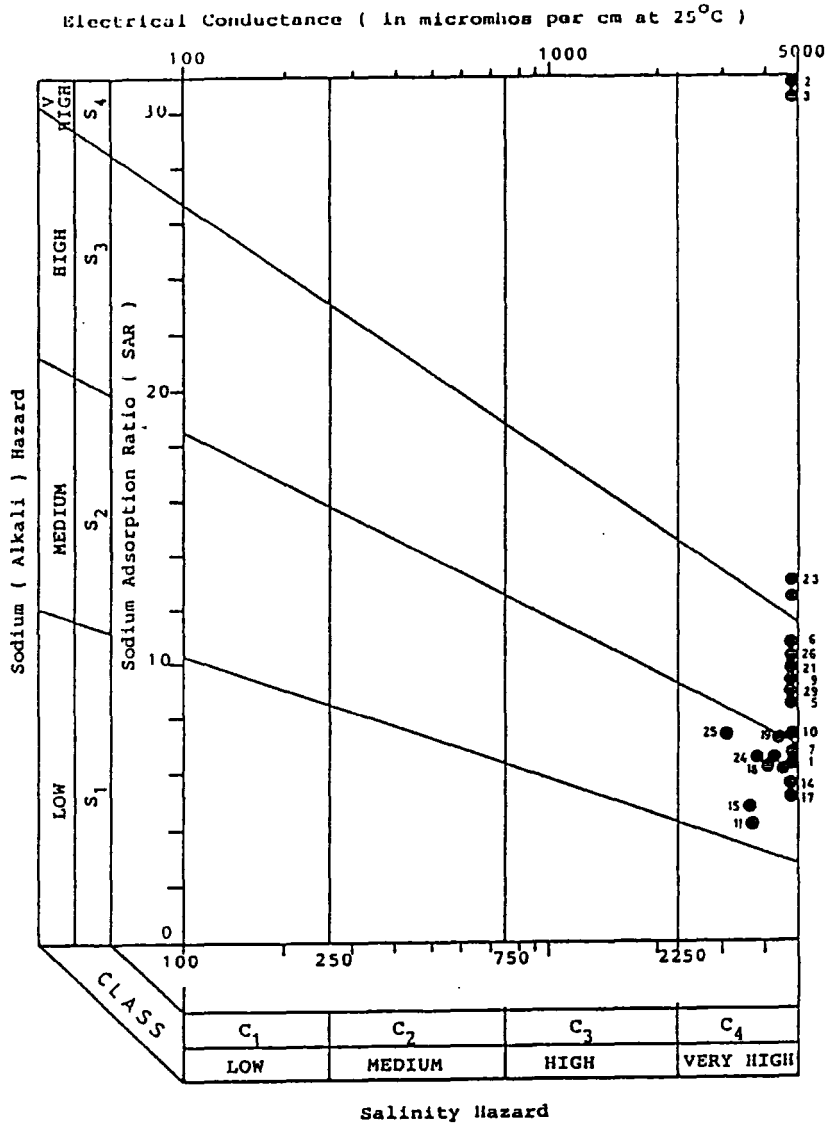


Figure: 6.34.

Irrigation water class of the waters of Western Liwa in the desert foreland 8 E zone (Table 6.49).

The irrigation waters in Western Liwa are generally of the C_4-S_3 to S_4 (very high salinity and low to very high sodium hazard). Only in the sodium hazard the waters of Western Liwa are of a slightly better quality than the waters of Eastern Liwa.

(The numbers in the figure refer to the water analyses in Table 6.49)

6.5.3.7. **Groundwater chemistry and quality of the deep Tertiary carbonate aquifer system**

(Tables 6.50 to 6.51)

Waters of the deep carbonate aquifers of the Simsima, UER, Dammam and the Sahil (the last one is the Miocene clastics and evaporites) are brines with very high TDS values several times those of Gulf seawater. They are useless for both human and agricultural applications, though they have their limited industrial usefulness in the injection process in oil operations. Even with regard to this use, the Dammam brines are preferred alone in the injection process because the iron sulphide reacts with the waters of the other deep carbonate aquifers (Um Er Radhmah and Simsima). This chemical reaction leads to serious plugging of the injection boreholes. Similarly, the high bicarbonate content in the brines of the Simsima Formation requires these waters to be mixed with those of Um Er Radhmah for the injection process to minimize borehole plugging. However, all the brines of the deep carbonate aquifers possess highly corrosive properties that cannot even be ameliorated by the mixing of these brines from the different deep aquifers.

Table 6.50 gives the chemistry of the Simsima, UER and Dammam brines in the oilfields areas of central Abu Dhabi, while Table 6.51 gives the water chemistry of 4 deep wells in Al Sila' in the Dammam-UER Formations, and one in Al Maida'ah (on the Abu Dhabi-Dubai interemirate border). The data in both Tables are included in this discussion of the hydrochemistry of the waters of the Emirates for completeness.

6.5.4. **Groundwater quality in the western coastal zone**

(Table 6.52; Zone 9 in Figs. 6.1. and 6.28; Fig. 6.35)

The western coastal zone extends for 3-4 km. inland from the shoreline along the coast from Sha'am in the northeast to Ba'yah near Al Sila' in the west. ECs for points in the part of this coastal zone in the Northern Emirates range from 1800 to 8000 mmhos/cm., while those from Tawi Addhba'ah and Seih Shu'aib (analyses 9 and 10, Table 6.52) range from 10000 to 21000 mmhos/cm. The relatively lower ECs for the section of the coastal zone in the Northern Emirates are due to proximity of the coastal zone to the mountains in the east; while the high ECs in the

AQUIFER/BOREHOLE	TDS	pH	HCO_3	Cl	SO_4	Ca	Mg	Na
D A M M A M								
Asab-37	185277	5.5	1.74	3286.00	13.60	805.00	538.00	1971.00
Bab-13WS 1	177021	5.6	1.20	3081.00	26.92	511.00	355.00	2252.00
Bu Hasa- 82	186692	5.7	4.20	3266.00	25.17	620.00	444.00	2241.00
Bu Hasa-121	172400	7.1	1.23	1253.49	21.56	217.40	172.75	860.13
Sahil- 5WS	187945	7.1	0.70	3336.00	12.88	848.00	536.91	1977.00
U M E R R A D H M A H								
Asab- 4WS	131988	5.2	1.10	2296.96	9.00	511.00	162.11	1640.13
Asab- 23WS	254959	5.5	1.00	4454.11	5.83	996.00	322.17	3155.61
Bab- 16WS	253126	6.2	0.90	4424.14	7.02	903.80	346.42	3193.11
Bu Hasa- 68	159834	7.0	3.28	2788.73	7.92	520.00	283.33	2009.11
Sahil- 5	260470	6.5	0.75	4553.97	7.10	1046.10	330.25	3197.00
S I M S I M A								
Asab- 33WS	254742	5.5	1.28	4454.11	5.63	994.85	332.25	3144.78
Bab- 13WS2	245090	6.1	2.31	4284.31	7.81	1094.20	310.00	2899.43
Bu Hasa- 68	235854	6.0	3.28	4114.53	7.67	1004.00	249.17	2879.17
Sahil- 1	255277	5.7	2.25	4500.00	9.29	1120.00	526.50	2879.39

Source: "Tertiary and Upper Cretaceous Aquifers of Onshore Abu Dhabi, ADCO, 1981. Also the "Partex report" , 1983. TDS in ppm, ions in meq/l

Table: 6.50.

Water chemistry of the Upper Cretaceous and Tertiary.deep carbonate system aquifers of the Simsima, Um Er Radhmah and Dammam (1983).

Waters of the deep carbonate aquifers of the Simsima, Um Er Radhmah and Dammam as well as the Oligo-Miocene Sahil clastics and evaporites, are brines with very high TDS content several times the salinity of Gulf seawater. The waters are useless for both human and agricultural applications, and only have their limited industrial usefulness in the injection process into oil wells to pressurize oil extraction. These brines are generally highly corrosive and cannot be used singly on their own but are mingled to offset the plugging of boreholes during injection.

LOCATION/WELL	TDS	pH	HCO_3	Cl	SO_4	Ca	Mg	Na
Abu Dhabi Municipality								
1. Sila' Well-29 Depth 378m	82250	6.1	47.00	1504.00	353.00	387.00	115.00	1400.00
2. Sila' Well-30 Depth 384m	91700	5.2	52.00	1578.00	393.00	354.00	283.00	1400.00
3. Sila' Well-31 Depth 386m	88200	5.5	50.00	1607.00	378.00	365.00	325.00	1340.00
ADCO								
4. Sila' Well- 3 Depth 305m	30900	6.3	1.39	515.11	18.33	85.98	45.00	403.85
5. Maida'ah 0- 92m Depth 915m 92-238m 238m +	39000 20200 17400	6.0	1.50	608.00	23.00	101.00	51.00	485.00

Sources: 1,2 and 3 Abu Dhabi Municipality. 4 and 5 Abu Dhabi Company For Onshore Oil Operations(ADCO)
TDS in ppm, ions in meq/l.

Table 6.51.

Chemistry of the groundwater of other deep wells in Al Sila' (in northwest Abu Dhabi) and in Al Maida'ah (near the Abu Dhabi-Dubai interemirate border)(1983-85).

These wells were drilled in the Dammam and Um Er Radhmah formations and their waters are virtual brines in which Na and Cl are the dominant constituents. There is salinity stratification in the Maida'ah deep well (analysis 5) in which groundwater salinity gets relatively better in the lowest (deepest) part of the water-bearing strata.

Western coastal zone from Sha'am to Sila' — In meq/l

LOCATION	EC	TDS	pH	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SAR	CLASS
1. Sha'am	1916	1185	7.7	-	2.89	13.63	2.48	2.25	4.92	11.65	-	6.1	C_3 S_1
2. Dhahiyah	3399	2225	7.9	-	3.85	20.13	6.23	2.50	4.50	23.10	-	12.4	C_4 S_2
3. Al Rafa'ah	3657	2204	7.9	-	4.13	22.83	4.10	2.45	6.20	22.43	-	10.7	C_4 S_2
4. Al Salmah	3708	2390	7.5	-	3.38	23.60	6.77	2.15	4.00	27.53	-	15.7	C_4 S_2
5. Al Satwah	1895	1380	7.6	-	7.62	7.99	3.00	2.06	4.92	11.69	-	5.1	C_3 S_1
6. Madinat Lootah	1890	1380	.6	-	2.06	9.86	4.00	2.06	4.33	9.17	-	5.4	C_3 S_1
7. Hameediyyah	3245	1952	7.6	-	4.82	21.10	4.73	2.50	6.58	21.48	-	10.1	C_3 S_1
8. Buhuth Rawiyyah(330m)	7844	4749	7.9	-	1.27	35.63	38.64	12.10	26.55	36.78	-	8.4	C_4 S_2
9. Tawi Addhaba'ah	11200	7840	7.8	-	4.41	61.97	48.92	39.79	13.25	62.28	-	12.1	C_4 S_2
10. Seih Shu'aib	10700	7490	7.9	-	2.88	63.19	49.87	40.57	13.51	60.95	-	11.7	C_4 S_2
11. Abu Muraikhah	14320	10024	7.6	-	4.04	86.62	69.95	56.90	18.95	84.68	-	13.8	C_4 S_2
12. Al Samhah	12750	8925	7.8	-	3.70	81.24	64.12	52.86	17.37	78.79	-	13.3	C_4 S_2
13. Maled	16000	11200	7.4	-	4.53	99.29	78.37	63.85	21.64	96.64	-	14.8	C_4 S_2
14. Burkat Bu Marawha	15700	10990	7.5	-	4.45	97.65	77.08	62.90	24.88	91.24	-	13.8	C_4 S_2
15. Shames	18410	12887	7.3	-	5.30	112.35	92.62	75.35	25.48	109.48	-	15.4	C_4 S_2
16. Al Hidiyah	19800	13860	7.1	-	5.61	118.09	97.21	79.24	26.43	114.94	-	15.8	C_4 S_2
17. Al Lajeelah	21100	14770	7.2	-	5.98	131.29	103.33	84.30	26.48	129.49	-	17.4	C_4 S_2
18. Al Ghuwaifat	13200	8723	7.6	-	3.74	82.08	64.77	52.79	17.85	79.86	-	13.4	C_4 S_2
19. Annahdain	20900	12628	7.6	-	2.57	161.70	83.07	70.94	30.96	145.37	-	20.4	C_4 S_3
20. Habshan	14500	10150	7.8	-	1.88	106.22	55.55	48.82	21.15	93.79	-	15.8	C_4 S_2
21. Sila'	15600	10920	7.6	-	2.00	114.78	59.98	52.55	22.78	101.01	-	16.5	C_4 S_2
22. Bay'ah	18500	12950	7.6	-	2.41	136.59	70.78	62.56	27.12	120.25	-	18.0	C_4 S_2

EC in mmhos/cm. at 25°C; TDS in ppm; ions in meq/l. Year of analysis 1988.

Table: 6.52.

Chemical analyses of groundwater in the western (Gulf) coastal zone (marked 9 in Figs. 6.1 and 6.28) from Sha'am in the north to Al Sila' in the west.

Groundwater ECs for points in the western coastal zone in the Northern Emirates range from 1800 to 8000mmhos/cm., while those for Tawi Addhaba'ah and Seih Shu'aib (analyses 9 and 10) range from 10000 to 21000mmhos/cm. The relatively lower ECs for the section of the coastal zone in the Northern Emirates are due to proximity of the coastal zone to the mountains in the east; while the high ECs in the section lying within Abu Dhabi emirate reflect the greater distance from the mountains. All ions show high values, but Cl, Na and SO_4 are the most abundant. The high Ca and Mg values for points in the coastal zone of Abu Dhabi (analyses 10-12) are derived from marine waters and sediments. Apart from the groundwater at Sha'am (analysis 1) because of the nearness of Sha'am to the catchment area, all the waters of this coastal zone are unpotable. The irrigation water class is of the very high salinity and medium sodium, hazard (C_4 S_2). Such waters are being widely used in the forestry projects of Al Baynoonah in Abu Dhabi.

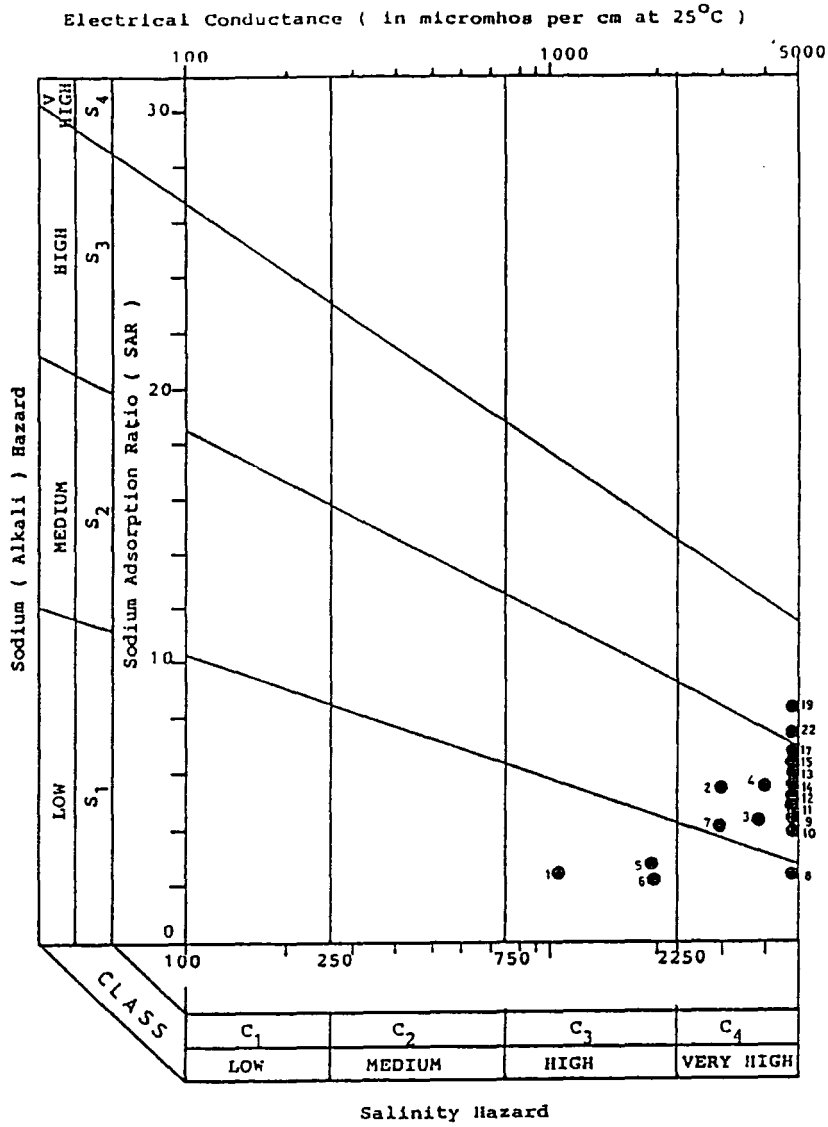


Figure: 6.35.

Irrigation water class of waters in the western (Gulf) coastal zone (marked 9 in Figs. 6.1 and 6.28) (Table 6.52).

The waters of the western coastal zone are of the C_4 S_2 (very high salinity and medium sodium hazard) class. The C_3 S_1 class waters are for points nearer to the foothills of the catchment areas (Sha'am, analysis 1, Table 6.52).

(The numbers in the figure refer to the water analyses in Table 6.52)

section lying within Abu Dhabi emirate reflect the greater distance from the mountains. Groundwater is abstracted from the edges of inland sabkhas and desert foreland dunes in their western periphery where overabstraction leads to seawater intrusion, which explains the extremely high salinities, especially in the Abu Dhabi coastal zone.

All ions show high values, but Cl, Na and SO_4 are the most abundant ions. The high Ca and Mg values, particularly for points in the Abu Dhabi coastal zone (analyses 10-22 in Table 6.52) are derived from marine waters and sediments.

Apart from the groundwater at Sha'am, which is of potable quality (analysis 1, Table 6.52), only because of the nearness of Sha'am to the catchment area, all the other waters are unpotable. The irrigation water class is of the very high salinity and medium sodium, hazard (C_4 S_2) (Fig. 6.35). Such waters are being used in the forestry projects of Al Baynoonah in Abu Dhabi.

6.6. Synopsis

In parallel with Chapter 5, this chapter has included an introductory section on water chemical analysis and the presentation of results, together with a discussion on water quality and data availability in the Emirates. This has been followed by a comprehensive description of the groundwater chemistry and quality for every relevant geological and geomorphological unit throughout the country. For every such unit where there is abstraction, the suitability of the groundwater for various uses has been assessed.

CHAPTER SEVEN

ENVIRONMENTAL ISOTOPES

7. ENVIRONMENTAL ISOTOPES

7.1. Introduction

The environmental isotopes, discussed in the context of natural water (rain, surface and ground water), include the stable isotopes of oxygen (^{18}O) and hydrogen (deuterium (^{2}H)) and the radioactive isotope of hydrogen, tritium (^{3}H), which all form a part of the water molecule; and also the radioactive carbon (^{13}C and ^{14}C) isotopes carried as dissolved carbonate in water. Variation in the concentration of these isotopes can be used to classify waters into types, to examine the mixing or salinity stratification of waters and provide some indication of their age (since they were recharged), or their residence time in the aquifer.

However, the interpretation of isotopic data is often complex and the results have limitations. Such results may not be absolute, but provide important information, which supplements that already provided by the hydraulic and chemical data-base. The limitations concern both the initial stage of sample collection for isotopic analysis and the final stage of interpretation of the results. Three problems exist in this regard:

1) The problem of whether the sample collected for isotopic testing definitely represents a specific type of water body in a single well-defined water-bearing stratum. Such indefinite sampling occurs in most localities especially in the piedmont plains and the western areas of the Emirates, where a sample collected may be for two or more different but hydraulically connected aquifers. Such a sample, therefore, would represent a mean of two or more of these waters of different origins.

   Another common situation in aquifers in the Emirates is the salinity stratification within the same aquifer, and samples are taken from water that is pumped out from considerable saturated

thicknesses. Thus, a single sampling, as is true with all the International Atomic Energy Agency (IAEA) samples collected in the Emirates, relates to a water specimen of unknown mix and origin and the result is, therefore, a mean value depending on the hydraulic properties of the aquifer at the sampling point.

Similarly, to correlate two results from apparently similar boreholes requires great caution. Therefore, any additional available information, particularly that from chemical analysis, has to be used in the interpretation. That is why with each water sample dispatched to the IAEA in Vienna for isotopic analysis, another water sample from the same point, analyzed for its chemistry, is prepared in the MEW laboratory at Sharjah and the chemical result is attached to the water sample destined for the IAEA.

2) The problem of imprecise knowledge concerning the input characteristics of water at the time of recharge, which may spread over a period of up to 10,000 years or more. Although these characteristics may be inferred from isotopic measurements, such interpretations remain of a very limited scope.

3) While the stable isotopes of oxygen-18 (18_O) and deuterium (hydrogen-2 or 2_H), and the radioactive tritium (3_H) are component parts of the water molecule and are, therefore, not subject to direct chemical reaction, the carbon isotopes (the stable isotopes $^{13}C/^{12}C$ and the radioactive ^{14}C) and carbonate species, are part of the complex groundwater chemistry. They have to be used therefore as part of the general hydrochemical system.

Because isotopic investigations are important to groundwater studies by helping to clarify the type, movement and age of groundwater, an understanding of these investigations, their usefulness and limitations, is deemed necessary in the present appraisal of the water resources of the Emirates.

The most important aspects of isotopic investigations for groundwater resources are tritium (^3H) and carbon-14 (^{14}C) detections, provided they are carried out on a more intensive basis than hitherto by the

IAEA. The first of the two radioactive isotopes, tritium, would clarify groundwater aspects related to recharge and movement; the latter, carbon-14, would date the residence time of the groundwater body. Such determinations would give the warning signal that very old groundwater, though it may be of potable quality, is 'fossil' and unreplenishable. Therefore, isotopic investigations require a home-based laboratory and training of local staff, similar to what has taken place in Jordan, to save time that is usually wasted between the UAE and the IAEA headquarters in Vienna. This also would make the role of the IAEA, that of 'transfer of technology', more meaningful.

7.2. Principles of isotope techniques

Oxygen consists primarily of the stable isotope oxygen-16 (^{16}O) with a small component of a heavier isotope, oxygen-18 (^{18}O) (approximately 1 part in 500). Hydrogen is principally the isotope mass 1 (^{1}H) with deuterium (^{2}H) in the concentration of approximately 1 part in 6,400. The mean isotopic composition of environmental water is entitled Standard Mean Ocean Water (SMOW), and it is against this standard that the small changes of composition of individual water samples are measured. Measurements are expressed as deviations from the standard (δ) in parts per thousand (o/oo).

Deviations from SMOW occur throughout the hydrological cycle and are caused by evaporation and condensation processes, the lighter isotopes evaporating more readily and the heavier ones condensing preferentially, in a process called isotopic fractionation. The degree of fractionation is controlled by temperature and humidity conditions, and such conditions at the time of recharge may be inferred from variations in the isotopic composition of groundwater. However, an absolute time scale cannot be deduced from isotopic measurements alone and other aids, such as archaeological and palynological determinations, are used to construct tentatively palaeoclimatic conditions that prevailed at the time of recharge.

The access of stable isotopes to groundwater is via precipitation, either directly by rain falling simultaneously over the whole terrain or indirectly through surface runoff. Individual rainstorms vary in

isotopic composition according to the climatic conditions which produce the rain. As described in Chapter 3 (Climate), in the Emirates, these rainstorms occur in two main rainfall regimes:

1) A Mediterranean type, which is widespread in incidence over the whole country in winter but also with simultaneous strong monsoonal incursions from the north Indian Ocean and the Arabian Sea.

2) The totally monsoonal rains of the spring, summer and early autumn experienced mostly on the east (Batinah) coast.

Table 7.1 shows values of the stable isotopes of oxygen and deuterium (^{18}O and ^{2}H) and the radioactive tritium (^{3}H) for some rain events in the Northern Emirates as determined by the IAEA for the Ministry of Electricity and Water. In principle, there is a change in the stable isotopic content of precipitation, with more depleted values occurring during the winter months (the season during which the Emirates receives most of its rainfall), and equally depleted values at higher altitudes. In general, precipitation at higher altitudes in the mountains has more depleted values than precipitation in coastal and desert foreland areas; inland locations also have more depleted values than those nearer the sea.

Table 7.1. shows the variation in the isotopic content of rain water collected during the winter months and also that for the rain of late spring and summer. This is evident in the rainfall for Sharjah of 17-02-88 with depleted values of ^{18}O and ^{2}H and enriched values of the same station for the rainfall of 5-04-87. Inland locations or those in high altitude do not seem to show markedly depleted stable isotopes. This is because the peninsula of the Northern Emirates is not wide enough to experience continental conditions, and localities show general winter depletion and summer enrichment trends except for the rainfall event of 20-07-88 in Al Beeh in Ras Al Khaimah, where the stable isotope values are highly depleted, contrary to the rule for summer values. Deuterium values are even more depleted than those for the same site for the winter rain event of 24-02-88 (Al Beeh analyses for 24-02-1988 and 20-07-1988, Table 7.1).

Locality	Date of rain event	Rainfall* total of event mm	^{18}O (o/oo) vs SMOW	^{2}H (o/oo)▲ vs SMOW	^{3}H TU
Sahwat	10-12-84	5.4	- 0.5	+ 3.0	-
Khatt	11-12-84	4.4	- 1.20	+ 0.4	3.9
Sahwat	06-12-86	10.8	- 1.62	+ 6.0	3.6 ± 0.3
Dubai	06-12-86	73.0	- 2.70	- 0.3	3.5 ± 0.3
Al A'badilah	07-12-86	19.2	+ 0.26	+10.6	3.3 ± 0.3
Dhaid	06-12-86	20.0	- 1.40	+ 0.60	5.2
Burairat	29-03-87	25.4	- 2.86	-15.2	5.4 ± 0.3
Sharjah	29-03-87	15.0	+ 0.40	+17.3	3.7 ± 0.3
Shunuf	05-04-87	9.6	+ 0.51	+15.4	5.2 ± 0.3
Khatt	05-04-87	3.2	+ 1.08	+19.6	4.8 ± 0.3
Al Beeh	05-04-87	1.8	+ 0.75	+13.1	4.8 ± 0.3
Sharjah	05-04-87	2.6	+ 7.07	+43.7	5.8 ± 0.3
Al Qawr	06-04-87	34.2	+ 2.27	+43.7	5.8 ± 0.3
Dhuhuriyyeen	06-04-87	3.6	+ 2.90	+20.8	4.9 ± 0.3
Sahwat	06-04-87	3.6	+ 3.64	+23.9	4.9 ± 0.3
Dhuhuriyyeen	17-02-88	75.0	+ 0.12	+11.7	3.4 ± 0.5
Sharjah	17-02-88	120.0	- 2.32	- 3.6	2.5 ± 0.8
Al Beeh	24-02-88	13.5	- 2.53	-10.9	5.4 ± 0.8
Al Qawr	24-02-88	21.2	- 2.64	- 5.8	3.2 ± 0.8
Sahwat	24-02-88	17.6	- 2.31	- 8.2	3.5 ± 0.8
Al A'badilah	24-02-88	23.0	- 2.54	- 6.2	3.5 ± 0.8
Shunuf	24-02-88	7.8	- 0.58	+ 4.2	3.7 ± 0.8
Al Beeh	26-04-88	16.4	- 1.45	+ 4.8	5.2 ± 0.8
Um Al Qaiwain	26-04-88	23.0	+ 4.26	+25.3	5.7 ± 0.8
Shunuf	26-04-88	14.0	+ 0.51	+ 9.4	4.5 ± 0.8
Khatt	26-04-88	20.8	+ 7.57	+40.6	5.8 ± 0.8
Al Beeh	26-04-88	16.4	+15.54	+75.2	5.6 ± 0.8
Sahwat	26-04-88	30.6	+11.74	+53.6	5.6 ± 0.8
Dhuhuriyyeen	26-04-88	30.6	+14.54	+64.1	5.6 ± 0.8
Al Beeh	20-07-88	23.6	- 5.48	-30.9	11.7 ± 0.6

Source: Ministry of Electricity and Water/International Atomic Energy Agency

* Source: Daily rainfall records of the Ministry of Agriculture and Fisheries (unpublished)

▲ vs SMOW= versus Standard Mean Ocean Water in parts per 1000.

Table: 7.1.

Isotope content of rain events in the Emirates for 1984-88.

In principle, there is a change in the stable isotope content of precipitation with more depleted values occurring during the winter months and equally depleted values at higher altitudes. In general, precipitation at higher altitudes in the mountains has more depleted values than precipitation at lower altitudes in coastal and desert foreland areas. Inland locations also have more depleted values than locations nearer the sea. The table shows the variation in isotopic content of rain water of the winter, late spring and early summer. The stable isotopes are depleted in purely Monsoonal rain events (Al Beeh on 20/07/1988), enriched for rain events from a purely Mediterranean source (the rainstorm of 26/04/1988) and a median value of these two extremes for the heavy winter rain events when both Mediterranean and Monsoonal influences interplay, with the influences from the latter being more effective (Sharjah, 17/02/1988). Tritium values in rain water vary from 2.5 TU (Tritium Units) for a heavy Mediterranean rain event (Sharjah 17/02/1988) to an average of 5.4 TU (for all stations) for the purely Mediterranean rain event of 26/04/1988, and finally to 11.7 TU for the purely Monsoonal rain event of 20/07/1988 (Al Beeh).

The values for the rain water of 20-07-88 at Al Beeh were for a rainfall caused by a monsoon storm from the southeast, lasting for less than 3 hours, and following a narrow path from Dibba on the east coast to Sha'am on the west coast. On the other hand, values for rain events, in localities in the same northern limestone region of Ru'us Al Jibal, were caused strictly by a late purely Mediterranean type of rainfall striking the western parts of the region from the west and northwest. Although the stable isotopes are understandably high considering the time of the year the rainstorms took place (26-04-88), they appear to contradict those for the July 1988 storm at the peak of the hot summer season, but originating as a monsoon event. It, thus, appears that the stable isotopes are depleted in purely monsoonal rainfall (Al Beeh 20-07-88) and enriched in rainfall events from a purely Mediterranean source (event of 26-04-88). For heavy winter rain events, where both Mediterranean and monsoonal influences interplay, with the influence from the monsoon being more effective (Sharjah, 17-02-88; Table 7.1), a median of these two extreme values is attained.

Tritium values in rain water vary from 2.5 TU (Tritium Units) for a heavy Mediterranean-monsoonal rain event (Sharjah on 17-02-88) to 5.4 TU (average for all stations) for a purely Mediterranean event (of 26-04-88) and, finally, to 11.7 TU for a purely monsoonal rain event of 20-07-88 (Al Beeh) (Table 7.1). This appears neatly in line with the established fact about tritium concentrations in rain water whereby maximum values occur in late spring-early summer and minimum values in winter. However, the high tritium value of 11.7 TU for the July 20th. 1988 rain event, may also have been the result of the interaction of cosmic-ray-produced neutrons in the upper atmosphere with nitrogen atoms, which may be responsible for tritium concentrations in rain water of 5-20 TU.

7.3. Tritium (^3H)

Tritium is a radioactive isotope of hydrogen with a mass of 3 units and a half-life of 12.43 years. It is naturally produced in the earth's upper atmosphere by cosmic ray bombardment, which maintains a natural level of 2 to 5 Tritium Units (TU). The atmospheric concentration of tritium increased after the advent of thermonuclear testing in 1954 reaching a peak value in Bahrain of 971.3 TU in 1963 Table (7.2).

Year	Precipitation mm	^{3}H TU
1961	113	205.0
62	15	372.9
63	35	971.3
64	113	370.3
65	25	172.2
66	36	158.5
67	28	97.0
68	74	62.3
69	166	42.2
70	9	97.6
71	45	106.0
72	85	34.4
73	13	32.1
74	146	24.3
75	42	33.7
76	233	17.3
77	83	20.6
78	19	28.7
79	22	6.1
80	93	5.2
81	25	6.5
82	121	5.6
83	56	6.9

Source: WMO, IAEA, MEW (UAE).

Table: 7.2.

Tritium content in rainfall at the WMO/IAEA station at Bahrain.

The natural level of tritium (^{3}H) in the atmosphere is 2-5 TU (Tritium Units). The atmospheric concentration of tritium increased after the advent of thermonuclear testing in 1954 reaching a peak value of 971.3 TU in Bahrain in 1963. Tritium concentrations have been receding since 1971, and in 1988, in Bahrain, they ranged between 5 and 6 TU. Because of the comparatively short half-life of tritium (12.43 TU), groundwater recharged before 1954, shows tritium concentrations of below 2-4 TU.

Tritium concentrations have been lessening since 1971, and in 1988 at the same station, values ranged between 5 and 6 TU. Because of the comparatively short half-life of tritium, groundwater recharged before 1954, shows tritium concentrations below 2-4 TU. Table 7.2 shows tritium values in rainfall in Bahrain, the nearest WMO/IAEA monitoring station to the Emirates, from 1961 to 1983.

In recent years, tritium has been more difficult to use in hydrological investigations, partly due to the ever-reducing concentrations since 1970, but mainly due to the increasingly widespread use of tritium in industry. Tritium has replaced radium as the radioactive source incorporated in luminous paints, watches and other products. The amounts used in these gadgets are many orders of magnitude greater than those present in groundwater. Thus, water samples handled by personnel where tritium may occur, are liable to become contaminated, giving misleading hydrological results if the data are not interpreted with care and with due consideration to other factors, such as the carbon-14 content of the water sample. Also, isolated positive tritium results should always be interpreted with even more care if there is no other supporting evidence to show that the water could be less than 25 years old (the full life of tritium (^{3}H)).

7.4. Carbon isotopes

Carbon-14 (^{14}C) is an isotope with a half-life of 5,730 years. It is present in the carbon dioxide of the atmosphere, being produced by the action of cosmic rays on the nitrogen atoms in the upper atmosphere, maintains a constant rate. Unlike the stable isotopes of hydrogen and oxygen, carbon is subject to chemical reactions as it moves with groundwater in the lithosphere. Changes in the carbon-14 concentration are partly due to its radioactive decay, but also due to the chemical behaviour of bicarbonate. Carbon-14 in recharge water is associated with other stable carbon isotopes, ^{12}C and ^{13}C, which are normally distinct from that of rock carbonate. ^{13}C content in water is not expressed as an absolute value but as a deviation from the internationally recognized standard of Pee Dee Belemnite (PDB) (*'Peedee Formation Belemnite'* **(PDB)=** the standard for ^{13}C measurement referring to the geological formation of Upper Cretaceous in North Carolina, USA).

The ^{12}C and ^{13}C ratio of a certain fossil belemnite has been taken as the fixed point from which all other ratios would differ as, for example, with the Standard Mean Ocean Water (SMOW) of 9.2, and is expressed in parts per thousand (o/oo).

Any changes in the concentration of carbon-14, not due to radioactive decay, also occur proportionately in the value of the isotope ^{13}C. The ^{13}C concentration thus can be used to evaluate the losses of carbon-14 due to causes other than radioactive decay.

Carbon-14 (^{14}C) itself is present in water as various types of dissolved inorganic carbon. The main input of these carbon types into groundwater takes place in the unsaturated (vadose) zone where the amount of carbon dioxide produced by plant root respiration and decay is greater than that available in precipitation. The input of the isotope ^{13}C values of components entering the water-carbon cycle is as given in Table 7.3.

Material	^{13}C o/oo
Carbon dioxide	-7 approx.
Marine Limestone	+1 to -1 "
Plant humus:	
a) C 3 Calvin cycle (Temperate)	-26 "
b) C 4 Hatch Slack Cycle (Arid)	-13 "
Fossil humic material in limestone	-25 "

Source : Wigley, 1976.

Table : 7.3.

^{13}C values of carbon sources in groundwater.

The input of carbonate species at source is a complex process critically dependent on hydrological and humic conditions before and during water infiltration. The classical chemical reaction producing the bicarbonate ions in groundwater is:

H_2O	+	CO_2	+	$CaCO_3$	=	$Ca(HCO_3)$
(Recharge)		(Biogenic)		(Rock)	=	(Bicarbonate dissolved in groundwater)

The dating of residence time of groundwater with carbon-14 (14_C)is limited to a time span of between 1,000 and 30,000 years and is, thus, applicable to waters of confined occurrences. Its application to water-table (unconfined) aquifers, or to those of mixed groundwater bodies of different ages, leads to results of up to 40% inaccuracy, with the dating being less than the actual age of these waters (Table 7.10, Section 7.7.3.4.).

^{14}C and ^{13}C measurements are useful in dating old water devoid of tritium. This would entail additional work on the physical and chemical composition of the water relating to its pH, alkalinity, and dissolved CO_2. In the case of water with a low pH of below 4.0, a large volume of a water sample would be required to carry out the tests (150 litres).

7.5. Sulphur-34 (^{34}S)

Sulphur-34 is the heavy isotope of normal sulphur (Sulphur-32). The ratio of these two isotopes is expressed as parts per thousand deviations from a standard, which is the sulphur mineral, triolite, found in the Canyon Diablo Meteorite.

Sulphur-34 occurs in the atmosphere, biosphere, rocks, the sea and groundwater. Concentrations of the isotope depend on processes of fractionation. Changes taking place involve the oxidation of sulphide to sulphate, or the reduction of sulphates to sulphides. Sulphur-34 concentration in evaporite deposits has altered throughout geological time. Modern sea water has a value of $+20^{o}/oo$, Palaeozoic sea water, as determined from evaporite deposits, had a value of $+25^{o}/oo$, while Mesozoic seawater, the lesser value of +10 to $+15^{o}/oo$. Such data can be used to determine the source of the sulphate dissolved in the water. They also can be used to identify changes in the sulphur cycle within the aquifer.

The sulphur-34 isotope ratio of the sulphides in shales is negative

(-15°/oo), but the ratio in evaporite deposits is positive. Although positive ratios vary for different deposits according to their geological age, this ratio averages +17°/oo. The difference in isotopic ratios between these two sedimentary rocks, makes it possible to identify a single or mixed source of sulphates in groundwater.

The marginal, brackish and saline groundwater of central and western Abu Dhabi, and also in Ruwaiyyah in Dubai, have very high sulphate values several times more than the maximum allowable limits for drinking and poor quality irrigation water (300 and 500 parts per million). The sulphate content of the water in Jaww Al Oad, in western Abu Dhabi, is 1000 ppm. and in Dhafeer and Huwailah, both in Liwa, it is 1225 ppm. and 1300 ppm. respectively (WED Abu Dhabi, unpublished internal memo, 1988). Yet, no sulphate-34 investigations have been carried out by the IAEA-MEW or any other organization in those parts of the Emirates.

7.6. Application of isotope techniques

There are two different approaches to the application of isotope methodology. One, is to attempt an overview of water characteristics and behaviour over a wide region by a broad or contour approach; the second, is to study in detail smaller localities, individual aquifers and the interactions and flow mechanisms of these, attempting to determine the residence time and movement of groundwater of up to 30,000 years of age.

In either case, the sampling and isotopic analysis should be intensive and regular to derive even a general picture. The frequency of sampling points required for a zone, such as the piedmont plains, would even be denser in view of the heterogeneous nature of the groundwater bodies. The IAEA investigations, todate, have been directed at random sampling with results for widely spaced points that offer, in view of such a heterogeneous hydrogeological setting in the piedmont plains, limited assistance to the assessment of groundwater resources of the Emirates that the "IAEA Technical Cooperation" programme initially set out to achieve. (Isotope investigations as a tool for regional hydrological studies in the UAE, IAEA-MEW, 1988).

7.7. Summary of the results of isotopic studies carried out in the United Arab Emirates (1980-1989)

7.7.1. Environmental isotope measurements in Wadi Al Baseerah (Al Shimal) by the Japan International Cooperation Agency (JICA) 1980-81.

The first isotopic study, though limited to a single wadi basin, was the one carried out during the Water Resources Survey of Wadi Al Baseerah by the Japan International Cooperation Agency (JICA) in 1980-81. 14 wells were selected for isotopic sampling in the wadi plain to determine the age and flow mechanism of groundwater in the basin. The measurements were carried out between June 1980 (dry season) and January 1981 (rainy season) with 3-month intervals between sampling.

The investigations included the isotopes tritium (^{3}H), oxygen (^{18}O) and Radon-222 (^{222}Rn, a radioactive noble gas occurring abundantly in water with a half-life of 3.8 days). Since no rainfall event had taken place prior to the time of isotopic measurement noted above, no change in the concentration of the isotopes could be detected, and, therefore, no comparisons could be made between the expected concentrations in the dry and wet seasons, especially in the case of ^{18}O, which is essential for such comparisons.

In the case of tritium (^{3}H) and ^{222}Rn, regional differences were observed with the change in aquifer characteristics in upstream and downstream sections of the wadi floor. Tritium (^{3}H) concentrations in the groundwater of Wadi Al Baseerah were tentatively classified by JICA into 3 groups:

Groups 1 and 2:

Characterized by low ^{3}H values of below 15.0 TU in the recent wadi-bed deposits.

Group 3:

Showed high values of ^{3}H of more than 15.0 TU corresponding to the areal distribution of the lower terrace deposits.

^{222}Rn concentrations tended to coincide with those of ^{3}H in distribution, increasing in areas where ^{3}H concentrations were high and decreasing where they were low. The high ^{3}H values of group 3 could possibly be due to the upstream location, where groundwater had been recharged a short time before measurement. Likewise, the high ^{222}Rn content, with values of over 30 Bq (becquerel= unit of radio activity)(1), was associated with upper terrace or talus deposits. The low concentration of group 1 downstream was explained by the mixing of recent with old stagnant and circulating water containing little or no tritium.

The effect of recent rainfall on groundwater was reflected in the low electrical conductivities at the confluence of tributary wadis flowing into the main stream of Wadi Al Baseerah, especially those of Wadis Al U'yaiynah and Al 'Abadillah (upstream of Wadi Al Baseerah basin). The extent (width) of this channel, or zone of low conductivity groundwater, shrank in the dry season, and with it also narrowed the area of ^{3}H concentration.

This low EC zone, extending down to the coast, suggested the fast flow of fresh water, from rainstorms occurring over the surrounding mountains, reaching the coast within a few days. The groundwater, that is being pumped in the wadi flood plain and terraces, comprised old, stagnant water of over 100 years of residence in the compact Tertiary wadi terraces, together with recirculating water of several years of age, in the downstream parts of Wadi Al Baseerah.

An interesting observation made by JICA was that ^{3}H concentrations tended to increase, while ^{222}Rn decrease, throughout the summer around the producing wells. These significant isotopic fluctuations were attributed either to recharge in the vicinity of the wells from recent summer monsoon rains prior to isotope measurement, or to other limited, youthful circulating water forcibly sucked in by the accelerated pumping. Table 7.4 summarizes the results of the isotopic study by JICA in Wadi Al Baseerah basin (1981).

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(1) 'becquerel' (Bq)= the unit of radioactivity, defined as: the quantity of any radioisotope which decays at the rate of one disintegration per second (dps).

Well	^{3}H (TU) Sept. 1980	Jan. 1981	^{222}Rn (Bq) Sept. 1980	Jan. 1981	^{18}O (‰ vs SMOW) Sept. 1980	Jan. 1981	Aquifer
TW- 1	4.9	-	0.1	-	-		Recent wadi-bed
TW- 3	0.0	7.0	3.9	3.2	-	-2.4	Recent wadi-bed/upper terrace deposits
TW- 4	4.4	2.4	3.2	-	-	-2.5	"
TW- 5	2.1	5.0	1.2	1.8	-	-2.6	Lower terrace deposits/ upper terrace deposits
TW- 6	-	16.2	34.0	53.0	-	-2.8	Upper terrace deposits/ bedrock
TW- 8	21.7	19.4	35.0	39.0	-	-2.6	"
TW- 9	32.2	30.8	8.4	2.9	-	-3.4	Talus deposits/bedrock
TW-10	24.4	23.5	28.0	30.0	-	-2.7	Upper terrace deposits/ bedrock
L-18	-	18.1	-	1.5	-	-2.7	Recent wadi bed
L-38	-	15.4	3.9	0.5	-	-2.7	"
L-39	-	11.4	4.7	1.9	-	-2.6	"

Source: Wadi Al Baseerah Basin Water Resources Project, feasibility report, vol. III, JICA, 1981.

Table: 7.4.

Summary of the results of the environmental isotope study in Wadi Al Baseerah by the Japan International Cooperation Agency (JICA), 1981.

Tritium (^{3}H) and ^{222}Rn showed regional differences in upstream and downstream sections of Wadi Al Baseerah flood plain. JICA tentatively classified ^{3}H concentration in the groundwater in Wadi Al Baseerah into waters characterized by low ^{3}H values of below 15.0 TU in Recent wadi deposits and those of more than 15.0 TU corresponding to the areal distribution of the lower terrace deposits. Both ^{3}H and ^{222}Rn coincided in occurrence. The high ^{3}H values for upstream locations suggested recent recharge from rainfall in the highland parts of the Baseerah catchment. The low concentrations of ^{3}H values in downstream locations was explained by the mixing of recent with old stagnant water. JICA also observed that ^{3}H concentrations tended to increase, while ^{222}Rn to decrease, throughout the summer around the producing wells. These significant isotopic fluctuations were attributed either to recharge in the vicinity of the wells from recent summer Monsoon rains prior to isotopic measurement or to a localized circulation of fresh water forcibly sucked in by accelerated pumping.

7.7.2. Isotopic measurements by Geoconsult as part of the Deep Wells Project, 1982-86.

The isotopic investigations carried out by Geoconsult as part of the Deep Wells Project (1982-86), involved 18 boreholes from which samples were collected to specifically determine the age of groundwater. 12 out of the 18 samples were from boreholes in the piedmont plains (refer to location map of the GP series of deep wells in Fig. 5.29, Chapter 5), 4 from the Al Ain region, 1 from Gulfa near Hatta and 1 from Ras Al Khaimah. The samples were analyzed in the University of Groningen, Holland, for tritium (^{3}H), oxygen (^{18}O) and carbon-14 (^{14}C). The results of these analyses are presented in Table 7.5.

Although nearly 70% of the samples were for the piedmont plains, all the 18 analyses provided a limited representation of the groundwater of the area. The piedmont plains should have had a greater intensity of sampling considering the importance of the project and the contribution isotopic investigations may add to the understanding of the complexities of the origins, types and movement of groundwater in that zone of recharge and fresh water potential. The results and conclusions were, therefore, tentative and added little to what had already been known about the piedmont plains, except for the dating of groundwater.

There appears to be a correlation between the electrical conductivity and the age of groundwater. The degree of salinization is largely influenced by the circulation, time of residence in the aquifer and evaporation from the surface and the subsurface, causing further mineralization by the leaching of salts. Geoconsult used this general hypothesis to work out a tentative estimate of the age of groundwater and continue the tendency of the isochrone lines in areas where no isotope data were available, as can be seen in Fig. 7.1. This technique was applied between wells GP-17 (southwest of Dhaid) and GP-11 (east of Jabal Fayah) on the map.

From their isotope data, Geoconsult recognized the existence of 3 fronts of relatively fast groundwater flow (marked +1 to +3 in Fig 7.1). These were, from north to south:

Well	^{14}C o/oo vs SMOW	^{13}C o/oo vs SMOW	^{3}H TU	^{18}O o/oo vs SMOW	Apparent ^{14}C age /years	Corrected ^{14}C age / years	EC uS/cm	HCO_3 meq/l
GP-1	65.85+/-0.79	-11.28	<2.5	-1.6	3455	2860	723	2.60
GP-2A	58.01+/-0.53	-	-	-	4503	3503 (2)	1018	3.07
GP-2B	61.67+/-0.57	-	-	-	3997			
GP-7	52.61+/-0.65	-	-	-	5312	4628 (3)	3730	2.63
GP-8	30.54+/-0.84	-	-	-	9809	8086 (1)	3230	-
GP-8A	22.20+/-0.50	- 9.83	<3.9	-1.62	12447	10332	3110	3.50
GP-10	25.69+/-0.39	-11.20	<2.2	-1.87	11239	9774	2460	3.88
GP-11	73.10+/-0.82	-11.74	<2.4	-0.91	2591	2094	15500	7.00
GP-12	53.90+/-0.70	- 8.98	<3.8	-2.46	4979	3884	3350	3.25
GP-15	25.00+/-0.60	- 9.98	<4.2	-1.7	11140	9352	2390	3.25
GP-16A	72.70+/-0.80	- 9.57	<2.7/1.3	-1.49	2637	1895	596	3.00
GP-17	49.20+/-0.90	-7.21	<2.4	-1.37	5866	4058	2230	3.51
WM-1	-	-	<1.7	-2.65	-	-	10630	0.50
WM-1A	-	-	<1.2	-2.74	-	-	9400	1.25
WM-2	3.60+/-0.33	-	<2.4	-2.29	27491	19167 (3)	8730	1.50
AA-3	-	-	-	-1.86	-	-	925	3.50
Gulfa	99.56+/-0.94	-	-	-	36	RECENT	-	-
RK-15	5.00	-	6.1±1.3 4.5±0.9		10000	-	-	-

Source: MAF; Deep Wells Project, Final Report, Geoconsult Vol. II (1985), Iwaco Vol. I, (1986).

Table: 7.5.
Results of the isotopic analyses of the Deep Wells Project by Geoconsult (1982-86)

Although nearly 70% of the groundwater samples for isotopic analysis were collected from the piedmont plains (12 out of the 18 samples), these analyses provided a limited representation of the groundwater of the area. The piedmont plains should have had denser sampling. The results revealed that the age of the waters in the piedmont plains ranged from 2000-10000 years. Whether of low EC (GP-1 and GP-16A) or high EC (GP-11 and GP-7) the waters are far from being recent in age.

1) A groundwater front north of Idhn fed by Wadis Naqab, Idhn, Samah, Tuwaiyyain, Riyamah, Khabb and Al Beeh. The general direction of groundwater flow, after leaving the mountain front, was northerly. To stress that groundwater had always followed the same path, an example was given concerning the age of water in Well GP-8, situated at the western end of the piedmont plains near the dune sands, as 10,332 years; and that in Well GP-12, in the piedmont plains of Hamraniyyah, as 3,884 years. It was assumed, the older age of water in the former well was probably due to ponding of inflow by faulting or folding in the underlying geology. Whether these were apparent or corrected ages of the waters in GPs-8 and 12, they seemed too low in relation to the existing modest tritium values of 3.9 TU and 3.8 TU for the same wells respectively, which were similar to those for modern waters. This, it was noted by Geoconsult, indicated intermixing with recent post-1954 thermonuclear waters (Table 7.5).

2) A groundwater front to the west of Manama, between Wells GP-3 and GP-14, with groundwater flow rates along the profile A-B (Fig. 7.1) decreasing from 13m/year in GP-1 near the foothills at Manama, to 2m/year near GP-2 in the western fringes of the piedmont plains. The wadis that fed this front were Sfini, Siji, Thoban and Tuwaiyyain. Conductivities were relatively low, ranging from 595 mmhos/cm. in GP-16 near the foothills, to 1018 mmhos/cm. in GP-2, 12kms. further downgradient to the west. The age of the waters here was also somewhat low: 1895 years for GP-16 and 3503 years for GP-2, suggesting slow but constant input over the ages.

3) A front between GP-7 and GP-10 extending in a northwesterly direction to GP-17 and fed by Wadis Al Buraq, Al Mudainah, Mansab, Shawkah, Al Hinnah and Nassas. Geoconsult avoided elucidating on this front, apparently because of the hydrological and isotopic anomalies that did not offer a basis for generalization similar to the previous two fronts. GP-6 and GP-7, that were upgradient, had electrical conductivities of their groundwaters of 2350 and 3730 mmhos/cm. respectively. These ECs were higher than that for GP-17, downgradient in the dune sands, of 2230 mmhos/cm. Also, the corrected age of the water at GP-17 of 4058 years, made the water here of a younger age than that of 4628 years for GP-7

(upgradient). The probable explanation was that both wells drew water from the clay-shale Juweiza formation in which groundwater movement was negligible owing to the low transmissivities; therefore, the somewhat higher conductivities. The lower water conductivity in GP-17 may have been due to hydraulic connection with recent waters of the overlying alluvium. The stronger head of inflow in a narrow zone was in the vicinity of GP-17, fed by wadis Shawkah and Sfini more than the other wadis to the south, which were dammed behind the Fayah-Mileiha anticline. The resulting subsurface ponding and, therefore, longer residence of groundwater, depleted tritium (GP-11, near GP-7, had a value of 2.4 TU) and increased chlorides (Cl, in GP-11, was 116 meq/l, or 4118 mg/l).

These 3 zones of relatively fast groundwater flow were interspaced with 3 zones of slow flowing, or almost stagnant, groundwater (marked -1 to -3 in Fig. 7.1). These were:

1) The zone between Wells GP-4 and GP-13 with high groundwater salinities of 2000-5000 mmhos/cm. and low water-bearing capability. GP-13 was even found totally dry down to a depth of 270m. below ground level.

2) The zone south of Al Dhaid, in the vicinity of GP-15 and GP-10, with moderate to high groundwater salinities of 2000-3000 mmhos/cm. and old groundwater age (9,500 years). The tritium value of 4.2 TU for GP-15, higher than the values hitherto met, pointed to mingling with post-1954 waters or even from recently infiltrating runoff water. Pumping in GP-15 may be attracting old and recent water from several levels. Although this zone seemed to have good water-bearing capabilities, the high carbon-14 age determinations suggested infrequent replenishment.

3) The zone to the south of Well GP-11, which was between the main mountain front and Jabal Fayah covering parts of the Ghareef Plain, where the isochrones did not correlate with the EC contours. This was probably due to localized heterogeneity in

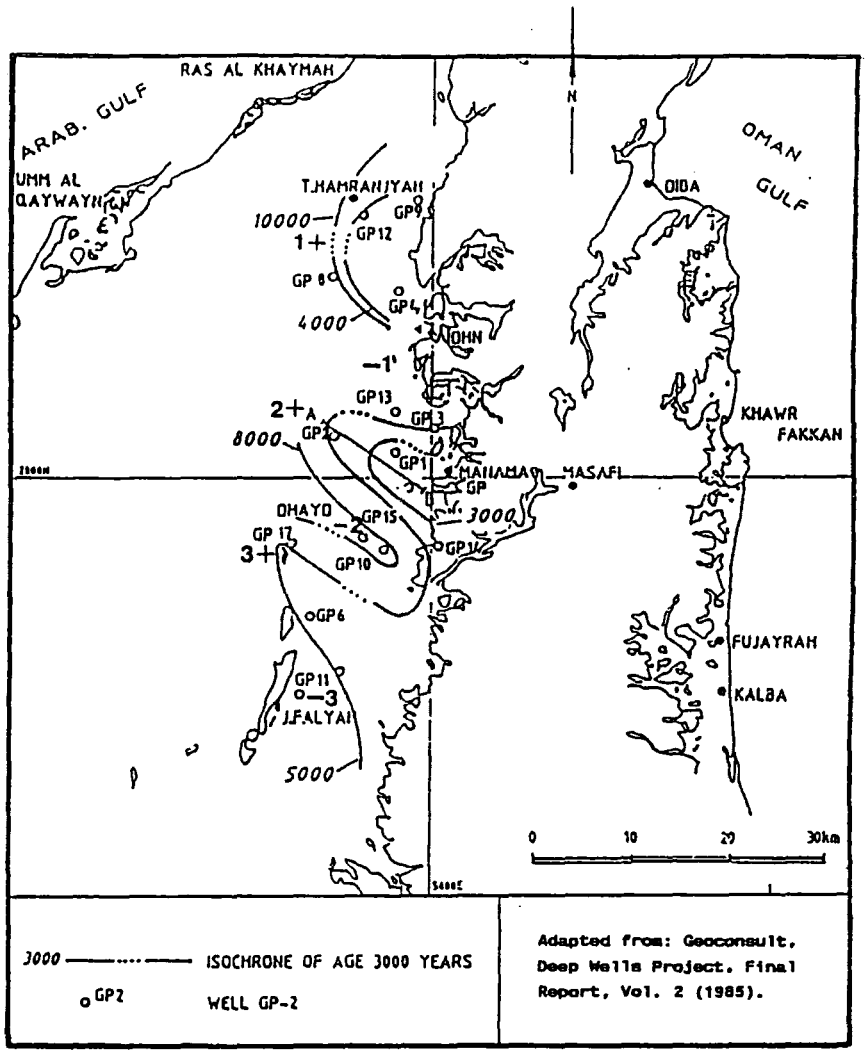


Figure: 7.1.

Groundwater movement and age from isotopic deductions by Geoconsult (1985).

From its isotopic data, Geoconsult surmised the presence of 3 fronts of groundwater flow in the northern piedmont plains (marked +1, +2 and +3). The first front (+1) is in Hamraniyyah in Wells GP-8 and GP-12 where groundwater age was given as 10,332 and 3,884 years. The second front (+2) is west of Manama in Wells GP-3 and GP-14 where groundwater velocities decreased from 13m/year in GP-1 near the foothills at Manama to 7m/year in GP-2 on the western fringe of the piedmont plains. The age of water in this front was given as 1895 and 3503 years in GP-16A and GP-2A respectively. The third front is between Wells GP-7 and GP-10 extending to the northwest where groundwater age was given as 4058 years in GP-17 and 4628 years in GP-7. The 3 fresh groundwater movement fronts are interspaced by 3 fronts of slow groundwater movement(marked -1, -2 and -3): the front between wells GP-4 and GP-13, the front between GP-15 and GP-10 and the front south of GP-11. The age of groundwater in these slow fronts varied from 3000 to 10000 years. Groundwater ECs in the fast groundwater movement fronts ranged from 500-4000mmhos/cm., while the ECs in the slow groundwater movement fronts ranged from 2000-15000mmhos/cm.

aquifer lithologies that impaired groundwater movement and increased the mineralization of groundwater; and also because of the intermixing of waters of different origins. The whole zone was characterized by a somewhat lower age of its waters (2,094 years for GP-11) and very high salinities of 10-15,000 mmhos/cm.

The remaining localities from which samples were collected for isotopic analysis, outside the piedmont plains, were Al Wagn, Al Qoa' and Um Ghafa in the Al Ain region. The corrected age of the water in Well WM-2 in Al Qoa' was 19,167 years and the tritium value was 3.60 +/-0.33. The high tritium value in Well AA-3 in Um Ghafa, of 16.0 +/-1.4TU, suggested recharge in this locality on the alluvial wadi channel of Wadi 'Ajran.

7.7.3. Summary of the isotope investigations by the International Atomic Energy Agency (IAEA) (1984-)

Being a subscribing member of the IAEA, the Emirates invited this international organization in 1984 to carry out an investigation "with the objective of examining the application of isotope techniques, within the framework of the IAEA Technical Cooperation Programme, in the groundwater resources assessment", similar to investigations carried out in other countries for which data are published in IAEA publications. Up to June 1988 a total of 274 samples had been collected for both rain and ground water. The isotope analyses were carried out in the headquarters of the IAEA in Vienna, while back-up chemical analyses were done by the MEW laboratory in Sharjah.

7.7.3.1. Results of the stable isotopes of oxygen-18 and deuterium (^{2}H)

Generally, the stable isotope of oxygen (^{18}O) and deuterium or hydrogen-2 (^{2}H) are used in investigating the origins and mixing of groundwater and the connection of the latter with surface water, largely responsible for present-day recharge, which is detectable by enriched heavy (stable) isotopes. Conversely, recharge of palaeowaters, under different climatic conditions to those prevalent at present, is recognizable by the depleted stable isotopes.

In general, the stable isotopes of ^{18}O and ^{2}H in groundwater are more depleted in all the regions in the Emirates (Table 7.6.) than those for

precipitation (Table 7.1.). Table 7.6. presents selected isotope data from those available to date for various localities, grouped in geomorphic regions and the period during which samples were collected for isotopic analysis. Table 7.7. presents mean values for all the isotopes. The most depleted values of ^{18}O are in the northern limestone mountain block of Ru'us Al Jibal where they range from -2.11 to -3.84 $^{o}/oo$ vs SMOW. These depleted values are followed by those for the central ophiolite mountain zone, where they range from -0.30 to -3.43 $^{o}/oo$ vs SMOW.

Depleted stable isotopes also occurred in both the western and eastern (Batinah) piedmont plains where the ^{18}O values ranged in the former from -0.62 to -2.45 and in the latter they ranged from -1.17 to -2.73 $^{o}/oo$ vs SMOW. Apart from the lowest recorded value for ^{18}O of -4.44 $^{o}/oo$ vs SMOW at Bayatah (Table 7.6.), ^{18}O values for the desert foreland ranged from +2.38 to -1.95 $^{o}/oo$ vs SMOW. The best (highest) measured value was at Sha'arah, from a borehole drawing water from the ophiolite fractured zone downstream of the Ham dam (+5.89 $^{o}/oo$ vs SMOW). Deuterium (^{2}H) is also depleted in the northern limestone mountains with values ranging from -15.0 to -30.9 $^{o}/oo$ vs SMOW. Next in the order of deuterium content were the western piedmont plains with values of between -0.6 and -21.9 $^{o}/oo$ vs SMOW. The values were relatively better in the eastern piedmont plains where they varied from +35.3 to -8.1 $^{o}/oo$ vs SMOW; and in the central ophiolite mountains and desert foreland, where the values ranged from +2.50 to -5.00 in the former, and +4.0 to -9.4 $^{o}/oo$ vs SMOW in the latter.

The somewhat more enriched stable isotopes and the lower chloride content of groundwaters of the desert foreland, than is the case with those of the limestone mountains in the north, were attributed to distance from the coast. In the eastern parts of the western piedmont plains, nearer to the foothills of the central mountains (the main recharge zone), the rapid percolation of surface flow causes dilution of groundwaters and, therefore, depletion of the isotopes.

Again, in the eastern piedmont plains (in the Batinah), the stable isotopes were even more depleted than in the desert foreland, but were

Locality and well number	^{18}O o/oo vs SMOW	^{2}H o/oo vs SMOW	^{3}H TU	^{13}C o/oo vs SMOW	^{14}C % pmc	EC mmhos/cm	Cl mg/l
Northern Limestone Mts. (1984-87 samplings)							
Dhuhuriyyeen # 3	- 3.43	-10.3	6.1	- 7.74	34.7	4000	1025
Dhuhuriyyeen # 1	- 3.31	- 5.6	4.2	-	-	1375	295
Sahwat # 4	- 3.54	- 7.7	6.7	- 8.36	44.8	3200	840
Burairat # 1	- 3.79	-11.0	3.6	-	-	6300	1825
Burairat # 10	- 3.66	-11.4	2.8	-	-	7600	2215
Burairat # 21	- 3.58	-10.6	4.2	-	-	4100	1100
Khatt Spring	- 3.00	- 9.3	2.1	-	-	2390	555
Al Beeh # 14	- 3.86	-10.8	0.9	-	-	2700	625
Al Beeh # 9	- 3.78	-10.4	1.8	-	-	1840	440
Al Beeh # 10	- 3.84	- 9.8	0.7	- 6.32	7.1	2900	735
RK- 6Deep Well(Al Beeh)	- 3.65	-10.0	1.5	- 7.67	18.5	820	100
RK-16Deep Well(Idhn)	- 2.53	- 9.4	9.9	-	-	1590	295
RK-15Deep Well(Idhn)	- 2.32	-12.2	0.5	-	-	5060	1320
Idhn (Hand-dug old well)	- 2.11	- 3.3	12.1	-11.95	86.2	-	-
(1988 samplings)							
Sahwat # 4	- 3.33	- 6.3	4.7	-	-	6550	1900
Dhuhuriyyeen # 3	- 3.51	-11.0	3.5	-	-	5570	1620
Khatt Spring	- 3.07	-15.0	1.6	-	-	-	-
Al Beeh (Dam water)	- 5.08	-30.9	7.9	-	-	-	-
Central Ophiolite Mts. (1984-87 samplings)							
Masafi (Gov't well)	- 2.39	- 4.6	2.7	-	-	530	80
Masafi (Pvt. well)	- 2.11	- 4.1	9.8	-	-	450	75
Masfut (Pvt. well)	- 3.43	- 1.9	11.3	-11.37	93.4	1410	340
Munai'ee (Pvt. well)	- 1.98	- 5.3	13.5	-13.66	109.6	970	112
Huwailat (Falaj)	- 0.78	- 0.4	10.1	-	-	-	-
Wuraia'ah(Spring)	- 2.15	- 4.4	3.0	-	-	510	74
Wuraia'ah(Spring)	- 0.30	- 1.9	3.0	-	-	460	84
Subaigha (Pvt well)	- 0.30	- 1.0	6.1	-12.96	90.8	5800	-
(1988 samplings)							
Al Hiyail (Pvt well)	- 2.19	- 5.8	8.0	-	-	2070	1130
Siji (Dam water)	- 0.38	2.5	8.9	-	-	-	-
Western Piedmont Plains (1984-87 samplings)							
Dhaid # 5	- 1.68	- 3.2	7.6	-11.47	82.4	2900	505
Dhaid # 6	- 1.70	- 3.3	10.4	-	-	1200	210
Dhaid (Pvt deep well)	- 2.45	-21.9	0.1	-	-	-	-
Dhaid # 2	- 1.70	- 3.8	12.4	-	-	1160	220
Dhaid # 1	- 1.49	-	3.8	-	-	3950	-
Manama # 5	- 1.29	3.1	6.4	-11.82	56.0	2100	495
Manama # 2	- 1.45	-	9.9	-	-	890	165
Manama # 4	- 1.53	- 0.6	4.7	-	-	870	150
Falaj al Mualla# 2	- 1.49	- 5.0	0.0	-10.66	77.9	4100	1000
Al Madam (New well)	- 1.72	- 3.0	0.5	-	-	-	-
Al Madam (Falaj)	- 0.62	7.0	0.5	-	-	3090	1015
Al Madam (Deep well)	- 2.20	- 5.9	0.4	-	-	-	-
Ashwani GP-10 (Deep well)	- 1.73	- 7.6	0.7	-11.3	48.3	-	-
Al Awha # 2	- 1.58	- 3.4	0.7	-	-	3000	685
Al Shuwaib # 4	- 1.74	- 5.0	1.3	-	-	-	-
Kashoonah # 2	- 1.50	- 5.5	0.3	- 6.33	51.9	1085	-
(1988 samplings)							
Dhaid # 1	- 1.42	- 5.4	2.7	-	-	3990	2365
Dhaid # 5	- 1.59	- 3.4	7.0	-	-	2260	1010
Dhaid (AL Qasimi pvt well)	- 0.94	- 7.5	0.7	-11.27	2.0	3480	2040
Dhaid Deep Well	- 2.24	- 2.0	10.3	- 8.82	0.0	-	-
Dhaid (Pvt well)	- 1.81	-11.1	0.7	- 9.67	21.8	-	-

Cont./p.2

Locality and well number	^{18}O o/oo vs SMOW	^{2}H o/oo vs SMOW	^{3}H TU	^{13}C o/oo vs SMOW	^{14}C % pmc	EC mmhos/cm	Cl mg/l
Eastern Piedmont Plains							
(the east coast)							
(1984-87 samplings)							
Kidnah (Well A)	- 1.17	-	6.5	-	-	-	-
Kidnah (Well B)	- 1.55	-	9.8	-	-	-	-
Fujairah # 10	- 2.41	- 7.6	1.2	-10.57	69.6	2600	735
Fujairah # 9	- 2.16	5.6	3.4	-	-	2700	807
Fujairah # 5	- 2.08	- 1.5	10.2	-	-	1740	445
Fujairah # 8	- 2.39	- 6.1	12.2	-	-	1060	225
Sur Kalba # 5	- 2.33	- 4.7	20.3	-	-	1680	430
Sur Kalba # 7	- 2.68	- 2.3	14.1	-13.94	82.0	1250	265
Sur Kalba # 10	- 2.64	- 5.5	11.7	-12.53	91.3	1100	210
Sur Kalba # 4	- 2.46	- 3.9	13.9	-	-	720	85
Dibba # 2	- 2.68	- 7.1	4.2	- 9.92	36.9	800	160
Dibba # 1	- 2.73	- 8.1	1.5	-	-	1030	150
Khor Fakkan # 2	- 2.16	- 2.9	10.1	-	-	660	200
Khor Fakkan # 1	- 2.50	-	11.3	-11.32	92.6	600	75
(1988 samplings)							
Qidfa' # 5	- 2.18	- 3.8	3.3	-	-	-	-
Fujairah # 2	- 2.08	- 5.2	16.0	-	-	-	-
Sur Kalba # 4	- 2.17	- 5.0	11.1	-	-	-	-
Sur Kalba # 7	- 2.25	- 5.9	9.8	-	-	-	-
Sha'arah (Wadi Ham)	+ 5.89	+35.3	5.8	-	-	395	250
Desert Foreland							
(1984-87 samplings)							
Shunuf # 3	- 1.55	- 5.4	0.2	- 8.01	66.4	2700	565
Tawi Rashed # 24	- 1.85	-	0.7	-	-	2500	485
Tawi Rashed # 1	- 1.68	- 3.8	0.3	-	-	3800	874
Khawaneej(Pvt well)	- 0.66	- 1.3	1.2	-10.30	99.7	9000	4176
Bayatah (Pvt well)	- 4.44	- 9.4	1.4	- 7.00	83.0	4900	1170
Al Sad (Pvt. well)	- 0.70	- 0.7	0.6	- 7.19	40.9	7100	1150
Al Hayar (Pvt.well)	- 0.68	- 0.9	0.3	-	-	5170	-
Seih Sabrah (Pvt. well)	- 1.84	- 8.0	0.0	-	-	7300	2100
Margham (Pvt. well)	- 0.78	- 1.2	0.4	-	-	3000	500
Al Faqa' (Pvt. well)	- 1.06	- 1.6	0.6	-	-	4100	925
Al Khadher Nassas	- 0.05	-	0.5	- 3.54	30.3	5900	-
Al Khadher Nassas	- 0.80	-	0.5	-	-	3340	-
Al Kara' #108	- 1.15	-	0.4	- 9.85	68.0	625	-
Bujair # 6	1.70	-	0.3	-	-	2070	402
Al Helew # 4	- 1.93	6.0	0.3	-	-	4400	1015
Jaww Al Oad-1# 4	- 1.52	-	0.0	-	-	2708	580
Bida' Khalfan# 3	- 1.95	-	0.0	- 1.97	15.3	1540	292
Al Muzeirea'	2.38	3.8	0.2	- 2.08	-	2000	372
Al Tarq (Liwa)	2.10	4.0	0.0	-	-	2470	430
(1988 samplings)							
Sirrah # 24	- 1.46	- 5.2	-	- 7.71	59.5	4000	2395
Bujair # 7	+ 2.17	3.7	-	- 0.28	3.6	-	-
Bujair # 6	+ 1.56	0.0	-	- 4.38	1.8	-	-
Bujair # 2	+ 2.23	2.7	-	+ 0.57	-	-	-

Source: Ministry of Electricity and Water/International Atomic Energy Agency 1984-88

Table: 7.6.

Selected results of isotopic investigations in the Emirates by the International Atomic Energy Agency (IAEA) (1984-88).

In general, the stable isotopes ^{18}O and ^{2}H in groundwater are more depleted in all the regions of the Emirates than those for precipitation (Table 7.1). The most depleted values of ^{18}O are in the northern Hajar mountains of Ru'us Al Jibal where they range from -2.11 to -3.84 °/oo vs SMOW. These depleted values are followed by those for the central ophiolite mountain zone, where the values for ^{18}O range from -0.30 to -3.43 °/oo vs SMOW. The highest value of + 5.89 °/oo is for Sha'arah on the east-flowing Wadi Ham. Deuterium (^{2}H) is also relatively depleted in the northern limestone mountains where the values range from -15.0 to -30.9 °/oo vs SMOW. Deuterium values in the western piedmont plains range from -0.6 to -21.9 °/oo vs SMOW. Values on the east coast (the eastern piedmont plains) are relatively enriched (+35.3 to -8.1 °/oo vs SMOW). The enriched stable isotopes and the lower chlorides in the groundwater of the desert foreland than those in the northern limestone mountains is attributed to distance from the coast. In the eastern parts of the western piedmont plains, where recharge water percolates rapidly, salinities are diluted and the isotopes are depleted. On the east coast, the stable isotopes are even more depleted than in the desert foreland suggesting the youthful nature of the waters.

Region	^{18}O o/oo vs SMOW	^{2}H o/oo vs SMOW	^{3}H T U	^{13}C o/oo vs SMOW	^{14}C o/oo vs SMOW	EC % samples below 1600 mmhos/cm
Northern Carbonate Mountains	- 2.11 to - 3.84	-15.0 to -30.9	0.5 to 12.1	- 7.67 to -11.95	7.1 to 86.2	2 0
Central Serpentinite Mountains	- 0.30 to - 3.43	+ 2.5 to - 5.8	2.7 to 11.3	-11.37 to -12.96	90.8 to 109.6	7 5
Western Gravel Plains	- 0.62 to - 2.45	- 0.6 to -21.9	0.3 to 12.4	- 6.33 to -11.82	0.0 to 82.4	3 0
Eastern Gravel Plains	- 1.17 to - 2.73	+35.3 to - 8.1	1.2 to 20.3	- 9.92 to -12.53	36.9 to 92.6	8 0
Desert Foreland	+ 2.39 to - 4.44	+ 4.0 to - 9.4	0.0 to 1.4	- 0.28 to -10.30	3.6 to 99.7	1 0

Source of data: Report on Isotope Investigations as a tool for regional hydrological studies in the UAE, IAEA-MEW, 1988.

Table 7.7. (To be used in conjunction with Table 7.6.)

The range of mean values of the stable and radioactive isotopes in the 5 topographic regions of the Emirates (1984-88).

The most depleted ^{18}O values are in the northern limestone massif of Ru'us Al Jibal where they range from -2.11 to -3.4 °/oo vs SMOW. The next region in isotopic depletion is the central serpentinite (ophiolite) mountain block where the ^{18}O values range from -0.30 to -3.43 °/oo vs SMOW. Depleted stable isotopes also occur in both the western and eastern piedmont plains, where the ^{18}O values range from -0.62 to -2.45 °/oo vs SMOW in the western and -1.17 to -2.73 °/oo vs SMOW in the eastern, piedmont plains. The higher ^{3}H values in the central serpentinite mountains (the catchment area of the Emirates) of 2.7 to 11.3 TU reflect youthful, recently recharged waters, while the depleted values for the desert foreland suggest older groundwater.

slightly better than those in the northern limestone mountains, which suggested relatively younger waters. This was further confirmed by the comparatively high tritium values. Chloride content in groundwater here was the lowest, especially after the winter rains, but the chlorides increased in the summer because of heavy groundwater abstraction.

In the eastern region of Abu Dhabi, to the west of Al Ain, and also in the dune areas of southern Abu Dhabi (Liwa and Addhafrah), the stable isotopes are enriched by the slow infiltration and, in places the ponding, of precipitation. The high chloride content here was thought to be the result of both the leaching of salts from the surface and solution of the evaporite-anhydrite-halite that form most of the water-bearing Lower Fars formation. The excessive evaporation in the Liwa troughs (sabkhas) is a major factor in the enrichment of the stable isotopes.

The high increase in chloride content can be the result of two causes : sea-water intrusion (Table 7.9); and the increase, in situ, by long residence or contamination, of chloride from the chloride-rich sedimentary formations (Table 7.8). Two examples were cited by the IAEA-1988 report in this connection and these were:

a) Dhuhuriyyeen Wellfield (MEW) Well No. 3

The data for this well were longer (3 years) than those for Sahwat (1 year)(Table 7.9). The increase in chloride content was three-fold in as many years but the ^{18}O values remained stable. This salinization, the IAEA report suggested, was "not due to salt water intrusion but possibly to the dissolution of soluble salts in the soil during ... infiltration" (IAEA, Isotope Report, 1988, p.22). Data about this well for the three years 1984-86 are given in Table 7.8.

Year	^{18}O °/oo vs SMOW	EC mmhos/cm	Cl mg/l
1984	- 3.47	2400	620
1985	- 3.43	4000	1015
1986	- 3.51	6000	1958

Source: 1988 IAEA Isotope Report and MEW Water Chemistry Yearbooks.

Table 7.8.

Salinization (in situ) in Well No. 3 in Dhuhuriyyeen Wellfield (1984-86).

b) Sahwat Wellfield (MEW) Well No. 4 (seawater intrusion)

On the other hand, the rapid 5-fold increase in chlorides in one year in Well No. 4 in Sahwat Wellfield (Table 7.9), coupled with isotopic enrichment and the reduction of tritium from 6.7 TU to 3.7 TU in the same period, suggested a mixing of fresh and sea water. Such an extreme increase in the chloride content was the result of seawater intrusion caused by overpumping at a rate of 1500m^3/d, or three times the pumping rate in Dhuhuriyyeen wellfield.

	1985	1986
EC	3200 mmhos/cm	15070 mmhos/cm
^{18}O	- 3.54°/oo vs SMOW	- 2.89°/oo vs SMOW
Cl	840 mg/l.	5400 mg/l.

Source: 1988 IAEA Isotopes Report and MEW Water Chemistry Yearbooks.

Table 7.9.

Salinization of groundwater due to seawater intrusion in Well No. 4 in Sahwat Wellfield (1985-86).

A 5-fold increase in chloride in only 1 year.

7.7.3.2. **Tritium results**

A total of 197 samples had been analyzed for tritium ^{3}H for the whole country up till June 1988. Tritium results for rainfall have already been discussed and the values ranged between 2.5 and 5.8 TU, which seemed in line with the values of the WMO/IAEA station at Bahrain in the last few years. The high tritium value of 11.7 TU for Al Beeh for 20-07-88 was an exception (Table 7.1). However, tritium in rest of the analyses of groundwater ranged from 0.0 to 20.3 TU (Table 7.6).

The IAEA Report (1988) classified groundwater, for convenience, according to tritium content as follows: groundwater with more than 10.0 TU, groundwater with between 5.0 and 10.0 TU and groundwater with less than 5.0 TU. Groundwater containing more than 5.0 TU must have been recharged, partially or totally, in post-1954 (thermonuclear year) times. Groundwater containing less than 5.0 TU, was possibly in hydraulic contact with older, mostly deeper sources water, as was true with groundwater in Tawi Rashed near Shunuf (0.3 and 0.7 TU) (Table 7.6) and that of the thermal spring at Khatt in Ras Al Khaimah (1.6 to 2.1 TU) (Table 7.6).

In the desert foreland (which, according to the IAEA report (1988) included the piedmont plains), high tritium values occurred in Al Dhaid in Well No. 5 (7.6 TU), No. 6 (10.4 TU) and No. 2 (12.4 TU) and in Manama in Well NO. 2 (9.9 TU), all of which were in alluvial aquifers close to the foothills from where they were intermittently being recharged (Table 7.6). Besides suggesting the youthfulness of groundwater, these high tritium values hinted also to the possibility of fast groundwater flow. Contrary to this, in the desert foreland proper (to the west of the piedmont plains), tritium content in groundwater was least, with values mostly below 0.1 TU as noted above for Tawi Rashed. These low values suggested either the lack of any hydraulic connection with fresh waters of the alluvium of the plains to the east, or the sudden change of facies caused by regional and localized faulting. The sudden appearance of the dominantly shaly Maastrichtian flysch of the Juweiza (eroded carbonates and silicified shales) was due to this faulting. The westward groundwater flow was slowed by the low permeabilities of these dominantly clay-shale-silt strata.

The general statement by the IAEA Isotope Report (1988) that recharge in the desert foreland was pre-1954 may be true for groundwater taken from the depths the IAEA collected its samples (40-60m below the surface). For groundwater in the aeolian formations above, the statement is debatable because there are shallow fresh water wells in the dune sands that have been recharged in recent times. Such recharge is possible as proved by Dincer et al (1974), in a similar aeolian environment in the Dahna region in eastern Saudi Arabia, who used environmental isotopes in a simple infiltration/evaporation model based on the annual rainfall of about 80mm. where 20mm. (or 25% of the annual total) infiltrated. As the intake level in boreholes in these parts of central Abu Dhabi emirate from which the IAEA took the samples average 40-60m., then any post-1954 recharge might not have reached this depth yet (due to widespread overpumping from the sand dune aquifer and the presence of denser saline groundwater in the Lower Fars Gachsaran strata from where water was being pumped) if the universally acknowledged vertical infiltration rate is 1m/year (Hamill and Bell, 1986).

Groundwater along the whole length of the eastern piedmont plains (the Batinah coast) had high tritium values (1988), with the highest values being in the main distributaries of Wadi Ham flowing from Kidnah (upstream) to Sur Kalba on the coast. In the former point, values ranged from 6.5 to 10.0 TU, and in the latter the values ranged from 10.0 to 22.0 TU. The values for Sur Kalba attested to recent recharge and fast groundwater flow possibilities in the southern , more than the northern, half of the Wadi Ham outwash fan. This was also evident in the lower ^{3}H values of between 1.2 and 10.0 TU for wells in Fujairah (Table 7.6).

Further north along the east coast, in Well No. 1 (Dibba), tritium was 1.5 TU (this is Well UAE-89 in the MEW-IAEA inventory) or Well No. 2 (Dibba)(UAE-90 in the MEW-IAEA inventory), with 4.2 TU, as mentioned by the 1988 Isotopes Report, were low values, especially the value of the former. This low tritium content was explained by the IAEA 1988 report as follows:

" this well (i.e., Dibba Well No. 1) is situated at the foot of the central mountains and therefore it is probable that the well is discharging older water from the limestones of the central mountains. "

(Isotope investigations as a tool for regional hydrogeological studies in the United Arab Emirates, IAEA, 1988)

The most likely explanation is that the aquifer, from which the Dibba Wells Nos. 1 and 2 are drawing their water, is in old, compact terrace gravels of the Pleistocene or even Late-Tertiary, in which transmissivities are low and movement of groundwater is negligible to stagnant. The residence time of groundwater was suggested by JICA as being more than 100 years old (1981). The ' central mountains ' referred to by the IAEA statement, with limestones emanating groundwater to the vicinity of the well(s), is inaccurate. The nearest limestones are more than 15kms. in either direction to the north and west, with a 10-15km. wide complex geology of the Hawasina volcanics and metamorphics filling the ' Dibba Corridor ', between the limestone outcrops and the wells. The wells are practically at the foot of Jibal Al Husoon range of hills, which are the northernmost part of the ophiolite ultrabasics (mostly peridotites), that are totally impervious but alluvial wadi-fill of which contains groundwater of good quality that flows in the wadi deposits to the lower part of the Baseerah basin, where the two (IAEA) wells are located. There appears to be no hydraulic connection with the compact terrace alluvium; therefore the low tritium values can thus be explained.

Tritium content in the groundwater of the mountain wadis of the central ophiolite block is understandably high as this is the collecting zone (the catchment area) of precipitation that flows as runoff on either side of it. Tritium values were higher in the southern part of the mountains, as at Huwailat (10.1 TU), Munai'ee (13.5 TU), Masfut (11.3 TU), Al Hiyail (8.0 TU) and Siji (8.9 TU) (Tables 7.6 and 7.10). The value for the private well at Subaigha (near Masfut) was for groundwater from the shallow Quaternary alluvial aquifer (6.1 TU). The two values for the Masafi government and private wells, of 2.7 TU and 9.8 TU, respectively, suggest deep and old groundwater in the former derived from the lower, compact alluvium of this intermontane basin; and modern, replenishable groundwater from the upper recent alluvium in the latter (Tables 7.6 and 7.10).

An interesting isotopic result is that of the Al Wurai'ah Spring (also called the Falaj, or the Waterfall, of Al Wurai'ah), where the tritium value was 3.0 TU, and the fluctuating but depleted stable isotope values for the two Wurai'ah samples (-0.30 to -2.15 $^{o}/_{oo}$ for ^{18}O, and -1.9 to -4.4 for ^{2}H), shown in Table 7.6., do not suggest recently recharged groundwater. Such low isotopic values, besides the fact that the spring continues to flow during the greater rainless part of the year, point to a mixed water supply from sources of different age and lithology. These conditions are provided by the presence of Tertiary conglomerates, old Pleistocene alluvium and recent wadi-bed alluvium.

These three types of deposits grade upwards away from the present stream course on the wadi sides towards the foothills, or downstream underlying the current loose deposits of the active wadi channel (see Fig. 5.27, Chapter 5). The old alluvium is consolidated and may contain old water, that is gradually being released to the Wurai'ah Spring. This groundwater either makes up the whole flow of the spring during the rainless months, or part of it by mixing with recently infiltrated water from runoff during the rainy months.

Finally, the IAEA analyses depicted no tritium in the groundwaters sampled in the vast desert foreland region to the west of Al Ain as far as Liwa, including the 'sand sea' or giant dune area north of Liwa. The conclusion by the IAEA 1988 Isotope Report was that groundwater abstracted in this region was a pre-1954 water. The Liwa area, in particular, is an inland sump or sink for sabkha waters, which are very old, supersaline, slow-moving and subjected to high evaporation on the sabkha surface. It must, however, be noted that the samples collected by/for the IAEA in this region were from wells pumping water from depths of 34-70m and, therefore, any post-1954 recharge in the dune sands above such levels cannot be detected.

7.7.3.3. Carbon-14 (^{14}C) of TDIC (Total Dissolved Inorganic Carbon)

Carbon-14 determinations of the Total Dissolved Inorganic Carbon (TDIC) were attempted by the IAEA to help derive the time of residence of groundwater. Table 7.10 presents the results of Carbon-14 of TDIC. Determinations on the dissolved inorganic carbon in groundwater involve detecting the decay of soil CO_2, acquired largely from vegetated soils

by the percolating water on its way to the aquifer. This, assumes that the groundwater system is isolated from the atmosphere, and that only decay would alter the ^{14}C content of the dissolved carbon. Determinations do not yield direct water ages, as do those from tritium, and the decay is expressed as a percentage of modern carbon (pmc)(1), which is the standard.

As seen in Table 7.10, there is a wide variation in the ^{14}C values ranging from 3.5 pmc for Bujair in the desert foreland north of Liwa, to 109.6 pmc in Munai'ee in the central serpentinite mountains. Where the values of Carbon-14 of TDIC are low, they suggest an older age of groundwater, as is true with waters of the limestone country of Ru'us Al Jibal or the metasediments of the Dibba Corridor. In the latter area ^{14}C values range from 7.1 to 44.8 pmc, and the age of the waters here vary from 5600 to 17000 years BP (Biochemical Production)(2). Wells in Al Burairat and Al Beeh fall in this group. The water in Al Burairat Well No. 2 is of 9.5 pmc (14000 +/- 3500) and Al Beeh Well No. 10, the value is 7.1 pmc (17000 +/- 4000 years).

The interpretation given for these two results in the IAEA 1988 report that " groundwaters are trapped in stagnant conditions which in part explains the high salt content " is simplistic and general, with little specific relation to this situation with convincing geological data.

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(1) *'Percentage of modern carbon'* (pmc)= results of carbon-14 measurement are expressed in percent with respect to the so-called 'modern carbon', which is supposed to represent the specific activity of the atmospheric CO_2 before any significant dilution by fossil combustion has occurred. For practical purposes the activity of modern carbon is 0.95 of the specific activity of the carbon of the oxalic acid supplied by the National Bureau of Standards (Washington, DC, USA), which is at the point of being exhausted. (Dating of groundwater, J.-Ch. Fontes in 'Guidebook on Nuclear Techniques in Hydrology', (1983),Technical Series No. 91, IAEA, Vienna.

(2) *'Biochemical Production'* (BP) = a measure of the rate of the dissolved inorganic carbon in the lithosphere, particularly that concerning the dissolved carbon from biogenic CO_2 and solid carbonate, which gives an age estimation of the Total Dissolved Inorganic Carbon (TDIC) other than that by using modern carbon activity (that is 100 per cent of modern carbon (pmc)).

There are two possible explanations for this. The first possibility, concerns older sea water trapped in the vast wadi floor deposits of Wadi Al Beeh (where both locations referred to by the IAEA report are situated) left behind by the receding seas and the gentle emergence of the land (in the last 20,000 years; Chapter 2, Section 2.2.8.) especially in the northeast above the present sea level. The second possibility, is that groundwater movement, in the massive Mussandam and Elphinstone limestones and dolomites of the northern limestone mountains, is limited to bedding planes and cavernous karstification does not seem to be developed as is evident in exaggerated drawdowns and recoveries of water-tables within minutes during pumping tests (Chapter 5, Section 5.3.2.2). Any westward movement of groundwater along the tilted bedding planes is slowed, or even blocked, by faulting and dislocation. This terminates the western mountain front of Ru'us Al Jibal abruptly, placing it against the flysch of eroded carbonates and silicified shales of the Upper Cretaceous Aruma Group, the so-called Juweiza Formation. This is a rock formation of low transmissivity containing bands of evaporites, besides the predominance of its shale matrix, which both help build up the salt content (Chapter 5, Sections 5.4.2.1., 5.4.2.4. and also Fig. 5.38).

The highest ^{14}C values, which denote younger groundwater ages, were obtained from points in the central ophiolite mountains, varying between 93.4 pmc and 109.6 pmc. The latter value was in Munai'ee for groundwater in mountain wadi alluvium, which generally has a high infiltration capacity, absorbing flood water that subsequently trickles into base-flow.

In the eastern piedmont plains (the Batinah coast), as discussed for the high tritium values (Section 7.7.3.2.), ^{14}C percentages are also high. The most modern groundwater here was found in Sur Kalba into which discharges the main inflow in the Wadi Ham outwash fan (91.3 pmc), and in Dibba where the 36.9 pmc was for water of an age of between 7000-10000 years contained in old wadi terrace gravels.

The situation in the western piedmont plains, as far as Carbon-14 dating values were concerned, was more varied. Whereas generally the age of waters here ranged from modern to about 6000 years, with ^{14}C values varying from 51.9 pmc to 82.4 pmc, there were also the extremely low

Location and well number	^{18}O o/oo vs S M O W	^{2}H o/oo vs S M O W	^{3}H T U	^{13}C o/oo vs SMOW	^{14}C pmc	Age in years BP
Northern Limestone Mountains						
Dhuhuriyyeen # 3	- 3.36	- 5.74	5.5	- 7.40	34.7	5600 ± 3000
Sahwat # 4	- 3.51	- 8.20	6.6	- 8.36	44.8	4000 ± 3000
Burairat # 2	- 3.69	-10.33	3.8	- 6.29	9.5	14000 ± 3500
Al Beeh #10	- 3.86	-10.10	1.3	- 6.32	7.1	17000 ± 4000
RK-6 Deep Well	- 3.65	-10.00	1.5	- 7.67	18.5	10000 ± 3000
Idhn Old hand-dug well	- 2.11	- 3.30	12.1	-11.95	86.2	Modern
Central Serpentinite Mountains						
Masfut Pvt well	- 1.45	- 1.90	11.3	-11.37	93.4	Modern
Munai'ee Pvt well	- 1.98	- 5.30	13.5	-13.66	109.6	Modern
Subaighah Pvt well	- 0.30	- 1.00	6.1	-12.96	90.8	Modern
Western Piedmont Plains						
Dhaid # 5	- 1.68	- 3.20	7.6	-11.42	82.4	Modern
Manama # 5	- 1.29	+ 3.10	6.4	-11.82	56.0	5000 ± 2000
Falaj Al Mualla # 3	- 1.30	0.00	0.0	-10.60	77.9	Modern
Ashwani GP-10 Deep well	- 1.73	- 7.60	0.7	-11.30	48.3	6000 ± 2000
Kashoonah #. 2	- 1.50	- 5.50	0.3	- 6.53	51.9	Modern
Dhaid Pvt well	- 1.08	- 7.50	0.7	-11.27	2.0	Not available
Dhaid Pvt well	- 1.28	- 5.00	1.3	-11.63	38.6	Not available
Dhaid Deep well	- 2.39	-20.00	10.3	- 8.80	1.0	Not available
Dhaid Pvt well	- 1.80	-11.10	0.7	- 9.67	21.8	Not available
Eastern Piedmont Plains (East Coast)						
Sur Kalba #10	- 2.54	- 5.50	11.7	-12.53	91.3	Modern
Khorfakkan # 1	- 2.50	-	11.3	-11.32	92.6	Modern
Dibba # 2	- 2.68	- 7.1	4.2	- 9.92	36.9	7000 ± 3000
Desert Foreland						
Tawi Rashed #12	- 1.65	- 2.3	0.0	- 9.12	83.7	Modern
Shunuf # 3	- 1.55	- 5.4	0.2	- 8.10	66.4	Modern
Al Khawaneej Pvt well	- 0.66	- 1.3	1.2	-10.30	99.7	Modern
Al Aweer Pvt well	- 0.92	- 5.9	0.0	- 6.42	51.4	Modern
Sirrah Pvt well	- 1.52	- 5.6	0.0	- 8.69	67.1	Modern
Bayatah Pvt well	- 2.44	- 9.4	1.4	- 7.00	83.0	Modern
Al Maqam Pvt well	- 0.70	- 0.7	0.6	- 7.19	40.9	Modern
Race Course Deep well	- 0.70	- 4.2	0.8	- 8.10	11.8	15000 ± 3000
Al Khadher # 1	- 0.05	-	0.5	- 3.54	30.3	Modern
Tawi Al Shaiba	- 0.68	- 7.3	0.0	- 4.65	17.6	8000 ± 4000
Al Karaa' #108	- 1.15	-	0.4	- 9.80	68.0	Modern
Seih Al Miyah # 5	- 1.53	- 6.5	0.0	- 3.97	30.6	Modern
Bida' Bint Sa'ud # 1	+ 2.29	+ 6.2	0.0	- 1.72	14.0	3500 ± 600
Bujair # 6	+ 1.70	+ 2.7	0.0	- 2.47	3.5	39000 ± 5500
Bida' Rashed # 7	+ 1.91	+ 2.9	0.0	- 2.18	9.8	8600 ± 1000
Bida' Rashed #11	+ 1.99	+ 3.0	0.0	- 2.28	24.9	Modern
Jaww Al Oad # 6	+ 1.50	-	0.0	- 1.92	15.3	2500 ± 6000
Sirrah #24	- 1.58	- 5.2	0.0	- 7.71	59.5	Not available
Bujair # 2	+ 2.23	+ 2.7	0.0	+ 0.57	1.8	Not available
Bujair # 7	+ 2.36	+ 3.7	0.0	+ 0.28	3.6	Not available

Source: Ministry of Electricity and Water/International Atomic Energy Agency 1984-89

Table: 7.10.

Carbon-14 (^{14}C) determinations in pmc (percentage of modern carbon), and groundwater age in years (1984-88).

The tritium (^{3}H) values in the groundwater of the mountain wadis of the serpentinite (ophiolite) mountain block is understandably high as this is the catchment area. Tritium values are higher in the southern part of this mountain block, as at Munai'ee (13.5 TU) and Masfut (11.3 TU) than the northern parts, as at Al Beeh (1.3 TU) and Dhuhuriyyeen (5.5 TU).

The highest ^{14}C values, which denote younger groundwater ages, were obtained in points in the central serpentinite mountains varying between 93.4 and 109.6 pmc. The lower ^{14}C value of 9.5 pmc for Wadi Al Beeh Well-2 is 14,000 +/- 3500 years old, while the 7.1 pmc for Al Beeh Well-10 was 17,000 +/- 4000 years. The most modern groundwater was found at Kalba (91.3 pmc), while the 36.9 pmc for Dibba related to older water, of 7000-10,000 years, resident in indurated terrace gravel. The oldest water ages were recorded at Bujair Well-6 with a value of 3.5 pmc or 39,000 +/- 5500 years, followed by the waters of the northern limestone mountains of Ru'us Al Jibal of 7.1-18.5 pmc (10,000-17,000 years).

values of 2.0 pmc and 1.0 pmc for both, the ordinary boreholes of down to 200 m. depth and the deep wells of more than 350 m. depth, in the predominantly shaly Juweiza Formation.

^{14}C values in the desert foreland had an even wider range, from 1.8 pmc to 99.7 pmc, with the modern waters occurring in wedge-like extensions from the western piedmont plains to the east, in old buried gravel wadi channels, or simply from accumulated infiltration from direct rainfall taking place through the highly permeable coarse dune sands. Older waters were associated with sabkhas on the surface or buried under thick sand deposits, such as in the northern dune area of Al Ain where the water of the public supply wellfield of Bida' Bint Saud was found to be about 3500 years old (14.0 pmc). In the high dunes area of Al Qafa, to the north of the Liwa oases, the lowest ^{14}C values were obtained from Bujair Well No. 6 with 3.5 pmc (or about 39000 years of age). As noted earlier, these results were for water samples taken from pumping depths of between 34-70 m., and do not represent the recharge waters in the dune sands above.

Finally, the westward movement of groundwater can only be inferred from the diminishing ^{14}C values towards the coast in the absence of adequate and reliable lithostratigraphical and hydrological data.

7.7.3.4. Origins of groundwater from isotopic deductions

Recharge to the groundwater system takes place by direct infiltration from precipitation over a wide surface, involving wetting the saturated zone and, if rain persists, wetting the unsaturated zone. Equally important, though less in volume, is the recharge from runoff in definite wadi channels that coalesce on their debouchment on to the piedmont plains from the hardrock catchment areas. The wadis flow westwards and northwestwards across the plains, losing their way within the dune sands of the desert foreland surficially, though they may continue as inflow in buried channels of semi-consolidated alluvium. Mountain wadis are therefore highly transmissive arteries of recharge waters containing substantial tritium and high Carbon-14 percentages, but depleted stable isotopes.

Although it is not possible to use stable isotopes for groundwater

dating, as is possible with Carbon-13 and Carbon-14 (^{13}C and ^{14}C), the isotopic composition of a groundwater body can give an indication of the origin of the water and the season of recharge. The source of all groundwater in the Emirates is the exceptionally intense and short-lived rainstorms, whether of the frontal Mediterranean type striking from the west and northwest, the low-level Monsoon type from the east and southeast, or the localized convectional storms centring on parts of the piedmont plains and the mountains. As discussed in Section 7.2, each rainstorm would have its own distinctive isotopic composition, making it difficult to use isotopes as indicators for recharge, as is possible in humid regions where there may be one dominant type of precipitation. Despite this, stable isotopes act as general geochemical tracers of groundwater, and variations in their values help in the identification of different groundwater masses within a whole or part of an aquifer. Backed by a thorough chemical analysis for the same water sample analyzed for isotopic content, stable isotopes can offer a better understanding of the hydrogeological characteristics of an aquifer with its homogeneous or heterogeneous lateral and vertical composition of water masses and their origin.

Chemical analyses, themselves, concern the dissolved load of a water mass, suggesting the chemical processes that made this load, but cannot trace its source or its extent. The stable isotopes ^{18}O and ^{2}H, on the other hand, are direct tracers of the source of a water mass in which the chemical reactions are taking place. It has already been shown that the Mediterranean type of precipitation contains high ^{18}O and ^{2}H (Table 7.1), for the wholly Mediterranean precipitation of 26 April 1988. Precipitation of a mixed Mediterranean and Monsoon type had less stable isotope content, as in the rain events of the 17th. and 24th. February 1988 (Table 7.1). For a solely Monsoon precipitation type, for which there is only one measurement for the Al Beeh rain station for 20th. July 1988, the stable isotopes were markedly depleted (Table 7.1).

Detection of the stable isotopes in groundwater, on the other hand, is not as straightforward. In the northern limestone mountains, where most precipitation is of the Mediterranean type, any recharge from such rainfall mingles with older waters in the Hajar aquifer; hence, the depleted isotope values can be explained. Such mixing of waters of different origins can also be deduced from tritium values of these

waters ranging from 3.0-7.0 TU. Conversely, on the east coast, mixing with older waters is limited to remaining sections of old wadi terrace gravels, as discussed earlier for Wadi Al Baseerah (Section 7.7.1.), and any recharge from precipitation of a Monsoon type, mostly experienced along this coast, can be deduced from the depleted stable isotopes characteristic also of water from monsoon precipitation. The majority of tritium values are high, mostly above 10.0 TU, and all the ^{14}C percentages are also high, mostly above 80%, attesting to the youthfulness and modern origin of these groundwaters.

Tritium in the recent groundwater in the Quaternary has been so depleted in most of the western piedmont plains that its values are above 5.0 TU in only few samples (samples from boreholes on or not far from ephemeral surface flow channels), with the average for the majority of samples being 1.3 TU, denoting older waters in less transmissive strata (most frequently the clastics-in-shale of the Juweiza formation). The high tritium values for the few sample points (Tables 7.6 and 7.10), for which analyses are available, vary between 6.4 TU and 12.4 TU, pointing more to mixed or contaminated groundwater (or deeper occurrence and older origin) than to replenishable groundwaters (except those waters near or close to surface flow channels noted earlier) with the values for 3 deep wells being below 2.0 TU. Only one deep well showed a value of 10.3 TU (Al Dhaid), which could be due more to water being pumped from the Quaternary strata close to the surface (where the submersible pump was possibly located). This well is located close to an active wadi channel. ^{18}O values were somewhat low, and with the low ^{3}H values, they pointed to the age of the waters ranging from modern to more than 10,000 years old.

In the desert foreland, generally, the stable isotopes are more depleted than they are in the western piedmont plains to the east, and are less depleted for ^{18}O but almost match ^{2}H values of the northern limestone mountains. Both ^{18}O and ^{2}H values are, however, higher for groundwater to the south and southwest of Al Ain, in places like Jaww Al Oad and Bujair, where the waters are either in aquifers within the Lower Fars evaporites or in hydraulic connection with waters in this formation. Tritium values are the lowest in the whole Emirates and hardly exceed 1.5 TU. All this mixed collection of isotopic values reflect groundwater of different sources and origins, ranging from the mixed to

the very stagnant old waters. The latter is evident in the ^{14}C values, which range from 1.8% to 83%, with the bulk of the values ranging between 11-60% or 2000-39000 years of age.

Al Aweer, Al Hibab, Al Badea' and the individual wells of Al Khawaneej, are all situated on a single continuous underflow channel. Being the oldest wellfields in the region, the wells have been deepened several times since 1963. The boreholes in this chain of wellfields, especially at Al Badea' and Al Aweer, draw water from levels below mean sea level. Whereas on the east coast the stable isotope values show salinities similar to those for areas in the desert foreland, tritium content is more in the former than in the latter, suggesting better recharge possibilities.

In the dune sands of the desert foreland, where recharge is mostly from direct rainfall, infiltrating the highly permeable sands, the IAEA Isotope Report (1988) was not certain about the origin and the mechanism of their recharge. Regarding this point, the report noted:

> " the sand dunes are located in the lowest topography in the Arabian peninsula and this makes it a perfect area for the collection of surface runoff. Such a surface runoff would have collected large amounts of salts along its path and the resulting infiltration water would have higher salt content. The dune waters have low conductivities reflecting low salt accumulations. "
>
> (Isotope Investigations in the UAE as tool for regional hydrogeological studies, p. 40. IAEA, 1988)

This is an oversimplification of the situation. The 'lowest topography' is the sabkha line (Fig. 5.32, Chapter 5), which is on a regional scale. In detail, on the local scale, there is the underlying sabkha in large areas of the Emirates. It is not necessarily restricted to the desert foreland, but can be close to the piedmont plains and the hardrock catchment area, such as at Al Ghareef Plain (southeast of Jabal Fayah), between Mileiha and Qarn Al Barr (south of Dhaid), and also in the Jiri Plain in Ras Al Khaimah, to the north (in Hamraniyyah), where such sabkha tracts are hardly 7 kms. from the hardrock catchment mountain front to the east of Al Khatt. In the central and southern parts of the desert foreland in Abu Dhabi, the vicinities of the wells of Bujair, Al

Helew, Bida' Khalfan, Attarq and Huwailah, cited by the IAEA Isotope Report (1988), have somewhat lower conductivities in an otherwise widespread and highly saline groundwater, occurring in Oligo-Miocene Fars evaporites and also higher up in recent anhydrite sabkhas, on which rest the dune sands.

In these localities, particularly in Bu Hasa, the dunes resting over the sabkhas, are very thick, reaching 200m in height; while further north, in the vicinity of Bab oilfield, they are thin, getting thinner northwards until sabkhas form the existing surface. Sabkha waters are highly saline; dune waters are relatively fresh and practically floating on the denser waters of the former.

This situation was well documented by the former Abu Dhabi Petroleum Company (and later by the Abu Dhabi Company for Onshore Operations-ADCO) as early as the 1960s (B.M.Twombley "confidential" memo, August, 1971/A.P. Struik, memo to the GM of ADCO, 30.12.80). The Bu Hasa shallow wells draw water from within the dunes with the close balance of the two water bodies carefully monitored to avoid depletion and pumping saline sabkha waters from underneath.

In other areas, such as Shah, Asab and Bab the dunes are thin or non-existent, and the waters abstracted there, are of mixed origins, and are brackish to extremely saline (Chapter 6, Sections 6.5.3.5. and 6.5.3.6.). The somewhat low chloride content of the waters cited by the IAEA 1988 Isotope Report, though from boreholes at 34-70m. depth, hint at the possible hydraulic contact with fresher waters from the sands above.

Also, dune waters are not as low in total dissolved solids as waters of the central ophiolite mountains, and the salts are acquired through long periods of evaporation and surface crystallization of salts, which are then leached down the sandy profile to the water-bearing layer, enriching its salt content. Fine siltation on the dune surface, sides and also in the deflation basins at the foot of the dunes, cause ponding after rainstorms leading also to isotopic enrichment before percolation.

Carbon-14 dating of TDIC for wells higher up in the piedmont plains close to the foothills of the Oman Mountains in the Al Ain region

(Kashoonah, Al Kara', Ghashabah, etc.) have proved from analyses that the waters are modern originating in wadi runoff; while those of the heartland of the desert foreland, from 34-70m. depth, are fossil waters, in places diluted with fresher waters from the overlying dunes, with their age range as shown in Table 7.11. (see also Table 7.10.).

MEW/IAEA Inventory	Location and Well No.	Age in years BP.
UAE-113	Bujair No. 6	39000 +/- 5500
UAE-117	Bida' Rashed No. 7	8600 +/- 1000
UAE-110	Al Helew No. 1	3500 +/- 600
UAE-154	Jaww Al Oad No. 1	2500 +/- 600

Source: IAEA-MEW 1988 Isotope Report

Table: 7.11.

Groundwater age in locations in the central desert foreland of Abu Dhabi.

The older age of groundwater in Bujair Well No. 6 is for fossil water in the Oligo-Miocene Lower Fars evaporites sequence slightly diluted by hydraulic connection with fresher water from the dunes above.

7.8. General conclusions

The traditional techniques of physical hydrogeology and well-testing are used in the development of groundwater resources to show the potential yield and the general characteristics of an aquifer. Isotope techniques, which should be coupled with hydrochemical determinations, are indispensable in complementing the traditional hydrogeological investigations. Isotope techniques have the added benefit of explaining the origin and age of groundwater systems that is undoubtedly important for the planned management of groundwater resources.

It is clear that the recharge contribution to the groundwater system from surface runoff originating in the hardrock catchment areas of the Emirates is small (28.97 MCM/a). The two important recharge zones are on

either side of the mountain divide, in the eastern and western piedmont plains. The eastern piedmont plains have limited area, short wadi runs and direct losses to the sea in times of heavy floods, though this zone accrues most of the surface runoff of the Emirates. On the other hand, the recharge potential is greater in the western piedmont plains, but with extensive agricultural development, encroaching sands from the west and complicated subsurface lithologies limiting its recharge potential. In such a situation, isotopic investigations are extremely important, but such investigations should be undertaken on a consistent, systematic basis, developed into a day-to-day routine, comparable to the traditional hydrogeological activities, to provide satisfactory monitoring of the groundwater system.

Isotope investigations todate in the Emirates allow the following observations to be made:

1) Most of the water samples for isotopic analyses were collected during the two visits by the IAEA officer in charge of the isotope project and not as a regular and continuous process.

2) The sampling points are not clearly logged, many of them are not dated, including nearly all the repeated samples, though these were collected at different times from the first ones. No notes are attached to the samples concerning the type of storm, the total amount of rainfall, its duration and intensity. The same is true for any information concerning the depth or the lithology the sample was collected from, with the result that even in the IAEA 1988 report some well depths were not included.

3) The work is mostly limited to the Northern Emirates, with only sparse sampling from the western and southern areas of Abu Dhabi, based on personal cooperation from individuals in charge in those areas, but not in their official capacity.

4) Neither the intensity nor the basis of sampling has been satisfactory, having been influenced more by the convenience of MEW well location than by the necessity to investigate a certain hydrogeological problem. Values from a few widely scattered samplings meant basically for the isotopic assessment of recharge,

flow and age, can thus be questioned.

5) The relationship between the MEW and the IAEA, with regard to the isotope investigation project, has so far resulted in the reliance of the former on the latter for analyzing and interpreting samples for the major isotopic constituents. The aptitude of the MEW has not been of a satisfactory level in terms of follow-up, self dependence in the interpretation of results and compiling a reasonable volume of hydrogeological data to be useful in such interpretation. The paucity of the latter point was evident throughout the IAEA 1988 Isotopes Report.

6) It was stressed in the IAEA Isotopes Report that the partnership with the MEW was in the context of "technical cooperation" and the "transfer of technology". This meant, among other things, the IAEA could be expected to lend the necessary expertise for this transfer of technology. This assistance is to enable the national partner to set up the required facilities for isotope analysis that would allow many more samples to be handled locally in a much reduced time than now is the case of dispatching the samples to the IAEA headquarters in Vienna. It must be remembered that even the IAEA uses the services of centres such as the University of Groningen in Holland to carry out some isotopic analyses for it. When considering the inadequate number of determinations made in the 4 years between 1984 and 1988, and the delays of samples dispatched to the centre in Amman, Jordan, only a nationally-based laboratory can cope with the growing number of samples from regularly monitored points. The IAEA does not seem enthusiastic about the idea of setting up an independent isotope laboratory, similar to the one established in Jordan (lengthy discussions with Dr. T.T. Akiti, IAEA officer in charge of the isotope project in the Emirates, May 1988).

Water samples for isotope analysis must be taken from all levels in a borehole if it is drawing water from more than one water-bearing stratum. All notes concerning the hydrogeology, history of the well (its deepening stages through different lithologies), complete chemical analysis and any relevant information relating to the borehole, must be attached to the sample. Sample points must be clearly numbered

coinciding with existing numbering of the different water authorities so as to locate accurately points in a study, instead of vaguely describing sample points as "Dhaid private well", "Dhaid deep well", "Al Madam new well", "Idhn old well". The main idea of using isotope determinations is to backup chemical data by pinpointing details that are otherwise concealed, and, therefore, exact locations are vital to the whole concept.

The submersible pump makes it possible to sample water from various levels, though not without the risk of partial mixing from more than one level due to the suction of the pump. The results from such samples would clarify the situation of the groundwater in the dune sands of the desert foreland and also that of the recharge system. The study by Dincer, Al Mughrin and Zimmerman in the Dahna sands of eastern Saudi Arabia (1974), using isotopic investigations, proved that substantial recharge into the aquifer in the dune sands was taking place at the rate of 20mm/a, out of 80mm. annual rainfall (25%). In the absence of recharge determinations into the sands of the vast desert foreland of the Emirates, nearly half the percentage of the annual total infiltrating as recharge, derived by the aforementioned Saudi study, has been adopted by the present study as feeding the existing fresh water dune sand aquifers. Such aquifers are in the belt stretching east-west, north of Liwa, on which are situated the fresh water wells of Bida' Mubarak, Bu Hasa, Bida' Khalfan, Bujair and Al Helew, and also further east, the wells at Qasyoorah, where vast longitudinal sabkhas interspace the fresh water-bearing high dunes. This aspect ought to have been investigated by the IAEA at the outset, and presenting results of samples from 34-70m. depth as representing groundwater in the desert foreland, can unintentionally be misleading.

The acceptable option for the Emirates would be to set up laboratory facilities for isotopic analysis, either in existing chemistry laboratories, such as that of the UAE University, the MAF central laboratory at Al Awha in Al Ain or that of WED Al Ain. The partnership with the IAEA should be clearly defined, so that this international organization should provide guidance from its best expertise, while the local partner (MEW), or any other national water-related institution, should set up a specialized unit within its organization to give the matter its due importance and also maintain continuity of isotopic

investigations should the IAEA cease to operate in the future.

7.9. Synopsis

This chapter has been included in the study to emphasize the importance attached to the development of isotope techniques, which provide unique evidence for water resource appraisal. The main limitations have been identified and the main elements of the principles described. The use of each of the four key isotopes has been discussed as an introduction to a detailed synopsis of all the isotopic studies completed in the Emirates over the past decade.

CHAPTER EIGHT

WATER PRODUCTION, USE AND COST

8. WATER PRODUCTION, USE AND COST

8.1. Introduction

Water production and use in the Emirates is characterized by the following key features:

1) Groundwater abstraction by more than one authority on the regional, the emirate and the local levels.

2) Lack of planning with no targets to aim for and the activity is characterized by ever-increasing drilling of boreholes for an ever-escalating demand.

3) With very few exceptions, there is limited quantity and quality monitoring and maintenance of the system.

4) Demand outpaces the growth of population as a result of uncontrolled use (the more water is made available, the more it is going to be used for the same application at the same place).

Table 8.1 shows the growth in population in each of the seven emirates since 1968. The population increased ten-fold in 20 years, from 179,100 in 1968 to the estimated figure of 1,748,804 in 1988. The increase between 1968 and 1975 was 312%, reflecting the great influx of immigrant workers in the early years of the federal state. Between 1975 and 1980 the increase was 87%, while between 1980 and 1985 it was 56% and, finally, from 1985 to 1988 this increase was 8%. The relatively latter low increase reflected the recession in oil revenues and also the end of the initial construction development in the various emirates.

It is not easy to relate water production figures to trends in population growth, as the former are tentative estimates. The only wellfields of groundwater for domestic consumption that measure their

Emirate	1968+	1975+	1980+	1985+	1988*
Abu Dhabi	46,500	211,812	451,848	670,125	722,108
Dubai	59,000	183,187	276,301	419,104	451,794
Sharjah	31,500	78,790	159,317	268,723	289,683
Ras Al Khaimah	24,500	43,845	73,918	116,470	125,555
Ajman	4,200	16,690	36,100	64,388	69,410
Fujairah	9,700	16,655	32,189	54,425	58,670
Um Al Qaiwain	3,700	6,908	12,426	29,299	31,584
Total	179,100	557,887	1,042,099	1,622,534	1,748,804

\+ Actual census * Estimated by the present study

Note: The 1968 totals are from the Trucial States Census of 1968.
The 1975 and 1985 totals from Ministry of Planning statistical abstracts.
The 1985 totals from newspaper reports after the press release by the Minister of Planning on 13/1/1986 but the census results for 1985 have not been published to date (1990).

Table: 8.1.

Population growth in the Emirates between 1968 and 1988.

The population increased by 87% between 1975 and 1980 during the period of influx of immigrant workers needed for the widespread construction, industrial and agricultural expansion with the resulting heavy demand on water. The increase in population between 1985 and 1988 was only 8% reflecting the recession in oil revenues and the end of the initial period of widespread development in all the emirates of the UAE.

output are the Al Ain wellfields of the northern dune area, and the three Dubai and the two Sharjah wellfields. All groundwater production of the wellfields belonging to the MEW in the Northern Emirates, and also of the public supply wellfields of WED Abu Dhabi in central and western Abu Dhabi, is only estimated and the exact quantities produced are not known.

While it may be possible to relate groundwater production for domestic use to population growth in towns and villages, that produced for agricultural use is not quantified by any means at all. Domestic water production can be monitored and controlled by flow-metering, which is not the case with agricultural water production.

The total groundwater extraction increased from 172 MCM/a in 1968, as estimated by the Trucial States Water Resources Study (Halcrow, 1966-69), of which 95% was abstracted for agriculture and 5% for domestic use, to 3359 MCM/a in 1988 as estimated by the present study, with the same ratio being maintained for both uses (3193 MCM/a for agriculture (95%) and 166 MCM/a for domestic use (5%)).

Groundwater for domestic, agricultural or industrial purposes is produced and supplied by the following organizations:

Domestic and Industrial

- Ministry of Electricity and Water (MEW)
- Dubai Water Department
- Water and Electricity Dept. Abu Dhabi (WED/Abu Dhabi)
- Water and Electricity Dept. Al Ain (WED/Al Ain)
- Sharjah Electricity and Water Dept.
- Ras Al Khaimah Water Dept.
- Abu Dhabi Co. for Onshore Operations (ADCO)
- Armed Forces:
  Central Command (Dubai)
  Western Command (Abu Dhabi)
  Northern Command (Ras Al Khaimah)

Agricultural

- Ministry of Agriculture and Fisheries (MAF)
- Groundwater Department (Al Ain)
- Forestry Dept. (Al Ain)
- Private Dept. (Abu Dhabi)
- Dept. of Agriculture (Al Ain)
- Agriculture Section (Al Ain Municipality)
- Agriculture Section (Abu Dhabi Municipality)
- Forestry Section (Abu Dhabi Municipality)
- Water and Electricity Dept. (Abu Dhabi)
- Armed Forces:
  Central Command (Dubai)
  Western Command (Abu Dhabi)
  Northern Command (Ras Al Khaimah)
- Dubai Water Dept.
- Dubai Municipality
- Owners of private gardens.

Domestic water production and supply throughout the Emirates is managed by the authorities cited above of which only the MEW is a federal water supplying body. The MAF, though a federal water-related institution, only advises on irrigation schemes but does not supply water to any agricultural user. The armed forces are federal though they have localized activities in view of their regional composition. All the rest are strictly local authorities mostly belonging to the local government of the emirate they are serving.

The MEW is the largest of the water developing organizations judged by the number of domestic wells it controls and the villages it is serving in most of rural Northern Emirates. It has no such jurisdiction in the whole of Abu Dhabi, and most of Dubai, emirates.

In Ras Al Khaimah, the MEW operates the reverse osmosis (RO) plant at Burairat, while the rest of the water supply was looked after by the Ras Al Khaimah Government Water Department until August 1990 when activities of this local water department were merged with the MEW because of mounting operational and budgetary difficulties. Although parts of rural Dubai and Sharjah emirates are served by the MEW, the capitals of the two emirates are supplied from wellfields and desalination plants managed by their respective local water departments. In Abu Dhabi emirate the domestic water supply is looked after by WED Abu Dhabi in Abu Dhabi town and a similar department in Al Ain, with little coordination between them, although they are financially linked.

Abstraction of groundwater for agricultural use, on the other hand, is not controlled by any government organization, federal or local. The federal MAF no longer offers the range of subsidies to farm owners it did prior to 1985. This is still the practice throughout Abu Dhabi emirate involving well drilling and pump installation and maintenance. However, the MAF still offers advice regarding well location and design of modern irrigation networks on the individual farms but has no control over well development or abstraction of groundwater. Only those wells drilled and maintained prior to the withdrawal of subsidies are known to the MAF. The majority of wells are drilled privately and, as no licensing is required for drilling a well, a number of such wells go uncounted in the inventory of the MAF, in addition to some wells on the large individual farms.

In this chapter the volumes of groundwater abstracted for both domestic and agricultural use are quantified, together with the volumes produced by the desalination and recycling plants in the major towns. By so doing, not only are the amounts of water involved and their uses presented, data that are not available with any authority, but also a clear picture of the confused uses that involve the application of potable water, or even desalinated water, for agriculture and for application to salt-resistant plants of the forestry projects, is provided.

While measurements of groundwater from the wellfields of Dubai, Sharjah and Al Ain have been reliable, all the other wellfields and single wells of the MEW are not monitored and the exact volumes of groundwater abstracted by them are impossible to quantify with the malfunctioning, or total absence of, flow-meters. The latter have been investigated for the present study in field visits to single wells and wellfields, and inquiries were made with the operators of these boreholes. The well production data for MEW wells presented in Table 8.3. are the best possible estimates attempted for the present study and are based on field investigation. The same is true of the agricultural consumption, which is not metered at all. This gave the present study the incentive to attempt quantification by extensive Emirates-wide well-discharge measurements (Table 8.27).

The production and delivery unit costs of all types of water are calculated for each emirate and an overall unit cost is presented for ground, desalinated and recycled water, to draw the attention to the subsidized cost ultimately paid by the consumer. The unit production or delivery cost of water also helps highlight the economic viability of the use of desalinated or recycled water for large-scale irrigation or artificial recharge to redress the depleting groundwater resources.

8.2. Groundwater production for domestic use

8.2.1. General

Sources of groundwater supply for domestic use from wellfields of more than 8 wells, or from single and dual wells, for the various authorities, are shown in Figures 8.1, 8.2 and 8.3. Figure 8.1 shows

the extraction points for the public supply wells in the Northern Emirates. These include wellfields of more than 8 wells and single or dual wells managed by the MEW, wells belonging to the local water authorities of the emirates of Dubai and Sharjah and also wells managed by the MEW that cater for domestic supply in the emirates of Ajman, Um Al Qaiwain, Fujairah and Ras Al Khaimah.

There are nearly 195 wells (single wells and those in wellfields) belonging to the MEW dotted all over the six Northern Emirates of which 60% are within 38 wellfields (locations with more than two wells). The rest that may be in groups of 1 or 2 wells, but mostly 1 well, provide water to the low-cost housing (lch.) estates and are drilled either on the same lch site or not far away. They may also supply road tankers, which transport water to remote settlements with few inhabitants that do not warrant drilling a well nearby, or where there is no likelihood of finding water.

Every year some wells are abandoned due to silting, collapse, rising salinity or total exhaustion. Most of the wellfields and single wells are located in wadis drawing water from the Quaternary alluvial wadi or outwash fan deposits. The wells are operated for an average period of 10 hours in the wellfields, and for however long it would take to fill the overhead tank of a hamlet or lch. estate in the case of individual wells. The latter are usually operated by a local resident paid for by the MEW.

Since 1982, most of the older diesel-operated pumps have been replaced with electric-operated ones, which, in the case of single wells, are manually operated. In wellfields, they are automatically switched on and off and, in some wellfields, from a central control room. Six of the wellfields (Al Beeh, Dibba, Dhaid, New Idhn, Kidnah and Fujairah) have such control rooms with central control panels. These control rooms were all visited (July, 1988) and were found in disrepair with regard to all the monitoring equipment except for the automatic electric pump-switching facility.

Single wells are of two categories: those wells near or at the site of a lch. estate or hamlet where water is pumped to an elevated tank and a small supply distribution system leads the water to individual

Location	Emirate	Source of supply
Wadi Bajeel	Fujairah	From Riyamah
Wadi Yakel	"	From Wadi Al Sidr (North)
Wadi Khuroos	"	From Riyamah
Wadi Al Sidr (South)	"	From Wadi Al Sidr (North)
Tawi Yakel	"	From Wadi Al Sidr (North)
Wadi Ash	"	From Dibba
Bida' Al Eayaim	"	From Tuway
Al 'Asam	"	From Wadi Al Sidr (North)
Waam	"	From Dibba
Al Ghob	"	From Dibba
Dar Safwa	"	From Dibba
Al Baseerah	"	From Al Halah
Sinnah	"	From Al Halah
Muhtariqah	"	From Dibba
Dhanhah	"	From Dibba
Wu'aib Al Hinnah	"	From Dibba
Al Beerah	"	From Masafi
Fayy Salb	"	From Khalu
Wadi Shuwaiyeen	"	From Fujairah
Makhtanah	"	From Al Manamah
Sharmatah	"	From Al Halah
Ashashah	"	From Al Halah
Jabal Al Teen	"	From Masafi
Eayainah	"	From Al Halah
Tawi Yal	"	From Masafi
Labourah	"	From Marbadh
Lenais	"	From Masafi
Al Kosh	"	From Al Sidr (North)
Balaidah	"	From Fujairah
Al Heyail	"	From Fujairah
Wadi Jabshah	"	From Fujairah
Wa'ab	"	From Dibba
Wadi Kanablah	Ras Al Khaimah	From Wadi Al Beeh
Bithnah	"	From Wadi Al Beeh
Mawared & Khawared	"	From Seih Al Fahlain
Wadi Qulaidi	"	From Khatt
Wadi Al Halah	"	From Shawkah
Tawi Bu Al Qird	"	From Shawkah
Gadf	"	From Gamrah
Diftah	"	From Masafi
Raseesah	"	From Sfini
Hajm	"	From Sfai
Frij Al Ghasham	Sharjah	From Tawi Saif
Khatm Malaha	"	From Kalba
Wadi Bagarah	"	From Sfini

Source: Ministry of Electricity and Water.

Table: 8.2.

Hamlets in the remote areas of the Northern Emirates receiving water supply by road-tankers hired by the MEW (1988).

These remote hamlets are mostly in the mountainous areas of Fujairah and Ras Al Khaimah where either the inhabitants are too few to warrant an independent supply from a borehole in the locality or where hydrogeological limitations inhibit drilling.

households; or those wells operational, but unconnected to a distribution system or fixed consumer, but largely pose as filling points for road-tankers. The first category is in more than 65 lch. estates. The capacity of the elevated tanks range from 5000-20,000 gallons (22-90 m^3), with heights varying from 10-15m. The wells are operated for a maximum period of 7 hours in winter and 10 hours in summer.

Wells in the second category, some of which are still diesel-operated, are only operative on request when water is taken in small containers, barrels or tanker-lorries. Some of these wells were observed running for a long time after the consumer had taken his need of their water. Pumps on these wells have an installed capacity of between 1,500-20,000 gals./hr. (7-90m^3/hr.), but the majority of wells in operation fall within the 14-20m^3/hr. discharge rate, with an average pump operation of 10 hours a day. All the locations and daily production of the wellfields, single and dual wells of the MEW are listed in Table 8.3.

There are still small remote villages that do not have independent stable supplies of water and receive their water by road-tankers. Non-availability of groundwater resources *in situ* is the main reason, but geographical conditions related to the inaccessibility of the village, the limited number of consumers and interemirate politics, are also important factors. The places to which water is delivered by tanker lorries in the Northern Emirates are listed in Table 8.2.

8.2.2. Regional wellfields of the MEW in the Northern Emirates (Fig. 8.1)

8.2.2.1. Ras Al Khaimah groundwater public supply

The area to the north of Ras Al Khaimah town, up to the border with Oman in the extreme north, is served by a number of wellfields which, as discussed in Chapter 5, draw water from the limestone beneath the wadi gravels. The most northerly of these wellfields is **Dhuhuriyyeen Wellfield**, northeast of the coastal town of Sha'am, with 6 wells of an average discharge rate of 55-80m^3/hr. each, pumping water to a 90m^3 overhead tank. The 65 low-cost houses of Dhuhuriyyeen village get their

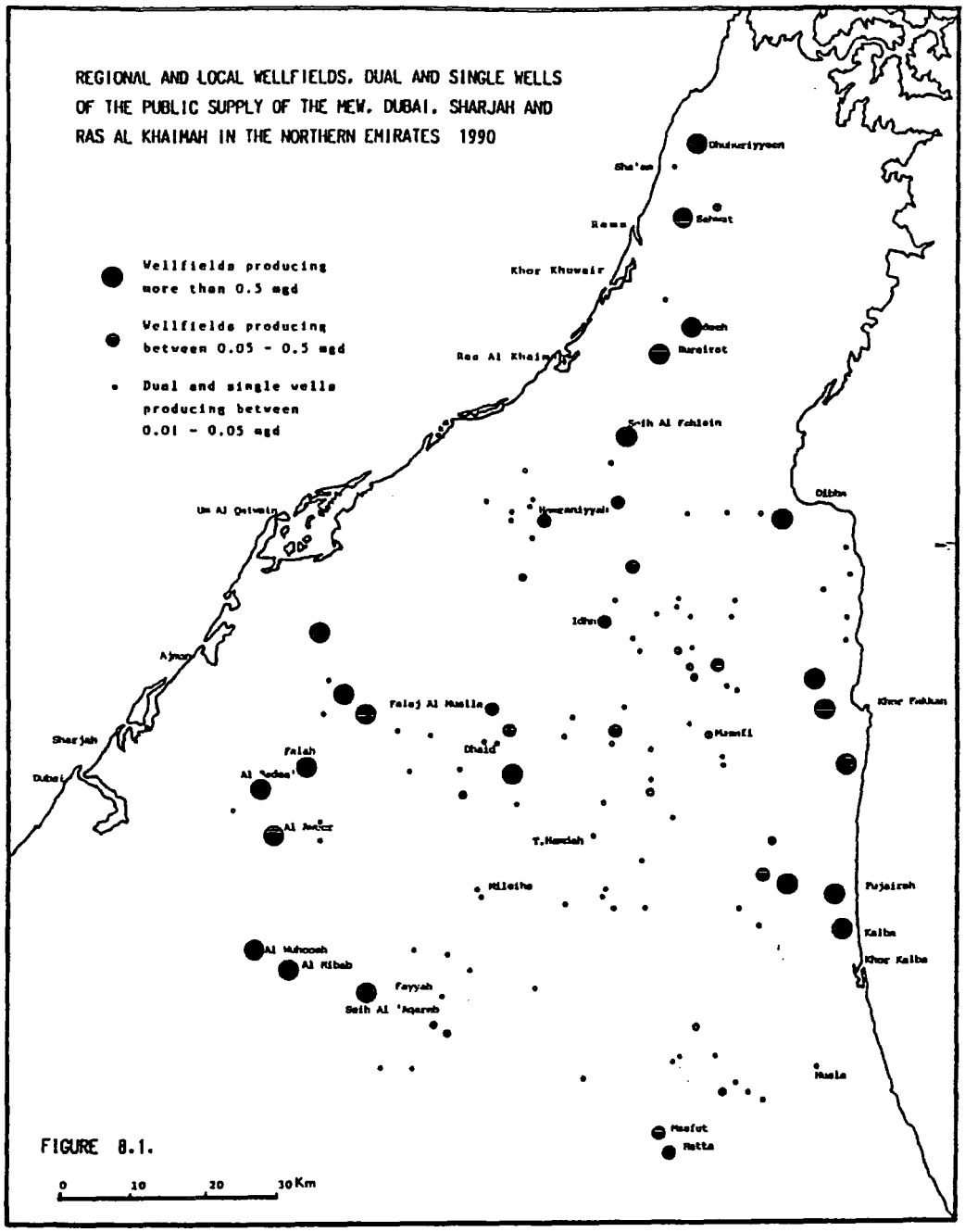


Figure: 8.1.

Regional and local wellfields, dual and single wells of the public supply of the MEW, Dubai, Sharjah and Ras Al Khaimah in the Northern Emirates (1990).

There are about 350 towns, villages and hamlets in the Northern Emirates served by about 300 operating wells managed by the MEW. Of these wells 60% are located in wellfields (locations of more than three wells). Some single wells supply low-cost housing estates and others serve as filling points for road-tankers that transport water to remote villages in the mountains. Regional wellfields include those for Ras Al Khaimah from Dhuhuriyyeen to Seih Al Fahlain and the Fujairah and Al Dhaid wellfields. Wellfields belonging to local departments include the 3 Dubai and the 4 Sharjah wellfields.

supply from this overhead tank before the supply pipeline ends up in the town of Sha'am. Sha'am used to be supplied by the Sha'am-Al Jeer wellfield but this dwindled in output and had to be officially shut down at the end of 1986. Besides Sha'am, Dhuhuriyyeen wellfield also supplies the village of Al Owla with 30,000 gallons a day.

Sahwat Wellfield in Wadi Ghaleelah (drilled in 1982), supplies the Ich estate of Halhool via a $90m^3$ overhead tank. The wellfield is situated 50m. above mean sea level and the supply to the village of Khor Khuwair is by pipeline by gravitational flow. Both Dhuhuriyyeen and Sahwat, especially the latter, are pumping groundwater from levels below that of mean sea level. The rising salinity in Sahwat is becoming acute (Chapter 7, Section 7.7.3.).

The 3 wells in **Hajeel**, and the other 3 wells at **Seih Al Ghob** are of discharge capacities of about $45m^3$/hr each, operating on average for 11 hours a day. Seih Al Ghob itself gets additional water supplies from Al Beeh and Al Burairat wellfields, but Hajeel itself produces about 100,000 gallons/day.

Water supply for the town of Ras Al Khaimah comes mainly from the main old wellfields at **Al Burairat** (the 1.0 mgd. brackish water goes mainly to the R.O. plant near the wellfield to produce 0.5 mgd. of desalinated water) and at **Al Beeh**, which is the newer of the two wellfields and the more upstream. Two more wellfields contribute to the supply of the town and these are: **Seih Al Fahlain**, 27km. to the south of Ras Al Khaimah town, and **Idhn**, more than 40km. to the southwest of it.

The **Burairat wellfield** is the oldest of the four wellfields. It was started in 1974 and from 1977, due to rising salinity, was dedicated to supplying brackish water to the RO plant on the same site. The wellfield is run by the Ras Al Khaimah government and the RO plant by the MEW (1989). Wells are frequently abandoned in this wellfield as a result of increasing salinity attributed to seawater intrusion because the pump intake level in most of the wells is below MSL (Chapter 5, Fig. 5.60 A). In 1989 there were four wells producing about 1.0 mgd., though these are capable of producing up to 2.0 mgd.

Al Beeh Wellfield lies 5km. upstream of Al Burairat wellfield in the same flood plain of Wadi Al Beeh. It has 17 wells in operation with a discharge capacity of 36-82m^3/hr. each and a total daily output of 5.0 mgd. (1989). The wellfield was started by the MEW in 1980 and all the wells are operated from a control room in which all the equipment in the panels is out of order except for the automatic electrical switching gear of the pumps.

Water from both Al Burairat and Al Beeh wellfields is collected in three reservoirs of 2.2 million gallons, 200,000 gallons and 50,000 gallons.

The area to the south of Ras Al Khaimah town, as far as Jazeerat Al Hamrah and Digdaga, is supplied by **Seih Al Fahlain Wellfield**, through a pipeline 27km. long, from the 2.2 million gallon reinforced concrete tank at the wellfield down to Jazeerat Al Hamrah. The fourth wellfield, at **Idhn**, lies 40km. from Al Nakheel in the outskirts of Ras Al Khaimah town and is connected to Ras Al Khaimah town by a 42km. pipeline, which runs parallel to the Manama-Ras Al Khaimah road. It is joined by a branch pipeline to collect water from Seih Al Fahlain wellfield.

8.2.2.2. Groundwater public supply for Um Al Qaiwain (UAQ)

UAQ obtains its groundwater supplies from two sources: the first is of potable water from **Falaj Al Mualla**, the second is of brackish water for the RO plant, which started operation in 1989, from **Tawi Sirrah I and II Wellfields**. The total production from the six wells of Falaj Al Mualla is 0.5mgd. (2300m^3/d), while that from the 24 wells of Tawi Sirrah, is 2.0mgd. (10,000m^3/d). The latter is used in the RO plant in UAQ to produce 1.0mgd. (5,000m^3/d) of desalinated water.

Supplies are transferred by pipeline by gravity to an elevated 1000m^3 tank, at the junction of the Ras Al Khaimah-UAQ highway, feeding the public supply system of UAQ. All the villages along the course of the pipeline from the wellfields are supplied from it. The villages include Falaj Al Mualla, Al Biyata and Al Rashidiyah. The other villages along the Ras Al Khaimah road such as Al Salmah (5km. from the tank) and Al Rafi'ah (26km. from it) are also catered for from the same reservoir.

The old Falaj Al Mualla wellfield (with 8 wells) was drilled by the UAQ government, while the newer wellfield, 500m. away with 9 wells, was drilled by the MEW. The new wellfield is situated a short distance north of the village of Falaj Al Mualla. The **Wadi Fareekh Wellfield**, that once existed, was shut down in 1985 because the wells had dried up. The output from **Tawi Saif Wellfield** also has dwindled and the wellfield has now only one well producing 5,000 gallons/day serving as a water sampling point for the MEW.

8.2.2.3. Groundwater public supply for Ajman

Groundwater supplies for Ajman come from the two wellfields of **Tawi Rashed** and **Riqqat Al Shunuf** (25km. east of the Sharjah-Ras Al Khaimah highway). Water from the two wellfields is collected in two storage tanks of 180m^3 and 900m^3 near Al Hameediyah from where it is boosted to the town of Ajman on the Gulf coast. The villages of Al Helew, Al Hameediyah and Al Zubair, along the road from the wellfield, are also supplied from the same two sources. By 1989 ten new wells had been drilled in Shunuf and the supply was increased by 3.0 mgd. to reach 5.0 mgd. This still falls short of the actual demand of Ajman by 1.5 mgd.

There are 26 old boreholes at Shunuf, of which 11 are in the old, and 15 in the new, sections of the wellfield (1989). All of these wells produce 2.0 mgd., with the newer boreholes having discharge capacities of between 34-68m^3/hr. There are flow meters on some wells but, as these are out of order, the official published quantities are guesstimates. Water from the boreholes of **Tawi Rashed** flows into the public supply system below the flow-meters and, therefore, the actual quantities cannot be determined.

8.2.2.4. Groundwater public supply for Al Dhaid

The 7 wells that had been supplying Al Dhaid, from the old Dhaid wellfield with a control room that had ceased to function many years ago, were running dry by the autumn of 1988. A new set of 11 boreholes was drilled at **Al Bardi**, 14km. northwest of the old wellfield (1988-89). A pipeline was laid down in 1989 to connect the new wells to the

1000m^3 elevated steel tank at the old wellfield, where all the water supply facilities are located.

Water has been almost exhausted in most of the boreholes of the old wellfield and little is found at present even at depths of 95-106m. In the newer wellfield the saturated zone lies between 26-49m. below the surface. The output of the new Al Bardi Wellfield is expected to be 5.0 mgd.(1990).

8.2.2.5. Groundwater public supply of the east coast

8.2.2.5.1. Groundwater public supply for Dibba and Zikt

Water supply for the town of Dibba comes from a wellfield situated in Wadi Al Fayy consisting of 5 wells. Al Halah, in upstream Wadi Al Baseerah, has its own separate supply wells. The daily production from the wellfield is about 1.0 million gallons of acceptable quality water (EC below 1500mmhos/cm.). A 1000m^3 elevated steel tank distributes water by a 400mm. pipeline to the whole area from Dibba Al Husn to Al Rul, south of Dibba.

The wellfield has a central control room in which only the automatic pump switching gear is operating. A booster pumpset with a 12m^3/hr. discharge rate and a 300mm. pipeline supplies water to the villages of Al Gharb and Waam, about 8 km. away across Wadi Al Baseerah.

The village of Zikt has a single well from which it draws its domestic water supplies but there are three other wells, one of which supplies irrigation water. Six new wells have recently been drilled, in what was planned to be a new wellfield to supplement the short supplies of the Zikt-Dibba area. The six wells had been fully equipped and set for public use when they were taken over and included in a newly prepared private plantation (1988). The single well in Zikt is operated whenever the level of water in the 46m. elevated tank becomes low. On average, it operates for 8 hours during a summer, and 3 hours, during a winter, day.

8.2.2.5.2. **Groundwater public supply for Khor Fakkan**

Khor Fakkan had been served, until 6 years ago, by the two wellfields of **Wadi Shi** and **Ahraj (Ahrai)**, when water shortage in the town became acute. A third wellfield was developed in 1985 in **Wadi Al Shamah (Al Wurai'ah)**, 5 km. from the coastal village of Zubarah, from which water is pumped directly into the water supply mains. There are five wells in **Shi** and 7 in **Ahraj**, the latter wells are located near the older wells at Lulaiyyah. A single 300mm. pipeline runs from Ahraj to Khor Fakkan, collecting all the water from the Wurai'ah, Ahraj and Shi wellfields, and supplying all the coastal villages along its course on this stretch of the east coast belonging to the emirate of Sharjah.

8.2.2.5.3. **Groundwater public supply for Fujairah**

The two wellfields, 7km. apart, that supply groundwater to Fujairah, are situated on the Wadi Ham outwash fan and are both on the Masafi-Fujairah highway. The first, is the **Fujairah wellfield**, on the western outskirts of the town with 9 wells controlled from a central control room, which, like the other 5 control rooms in other MEW wellfields, is out of order save for the automatic pump switching facility. Even this is operated manually for most of the time. The second, is the **Kidnah wellfield** which is producing at present (1990) around 100,000 gallons a day, as it has been since 1988. The Jabal Muraished wellfield was shut down in 1987 owing to increasing salinity attributed to seawater intrusion. The present (1990) production from the Fujairah wellfield is 2.0 mgd.

Groundwater output is constantly decreasing and salinity increasing on the east coast in general, but more so in the Fujairah area, despite the exceptionally heavy rains of 1988. As a result, the newly developed wellfield at **Sha'arah** (1989), immediately downstream of the Wadi Ham earth retention dam, had struck no water in the 40m. thick alluvium (mostly gravel) of the Ham wadi fill and was drawing water from the 2m. fractured zone in the ophiolite base (which is of low storage capacity) (1989). 16 wells were drilled in the **Sha'arah wellfield**. At present (1990), 10-12 wells are operating to provide 1.0 mgd. to supplement the public water supply of Fujairah town.

8.2.2.5.4. **Groundwater public supply for Kalba**

The old wellfield at Tareef was abandoned in 1981 because of seawater intrusion. Another wellfield was developed in 1982 at **Sur Kalba**, which at present (1990) has 17 wells with a discharge capacity of $47m^3$/hr. each. The production from the **Kalba wellfield** totals 3.0 mgd.

8.2.2.6. **Total groundwater production for domestic use from MEW wells in the Northern Emirates.**

Water production for the public supply of the villages of the Northern Emirates from MEW single, dual or multiple wells (wellfields) is not monitored and, though some flow-meters were observed fitted at the borehead in several new wells, no readings are regularly taken. Many of these flow-meters are in disrepair, another reason for not reading the discharge of the wells. Thus, quantification of the groundwater volumes involved are, therefore, estimates. Table 8.3. gives the estimated daily output from the wells of the MEW in the Northern Emirates. This is based on field investigation carried out for this study involving enquiries made to pump operators and some members of the staff involved directly with groundwater production. Estimates were also made from discharge rate tests carried out for this study for the whole country, including wells of the MEW, and estimates based on the capacity of the overhead tanks to which water is usually pumped from a well (involving the number of times during a day or week such overhead tanks are filled to supply the consumers). In view of an official absence of discharge measurements, the estimates presented in Table 8.3. are the nearest to the actual amounts produced and help provide a guide to the total volume of groundwater abstracted by the MEW wells. The gross annual volume abstracted from MEW wells in the northern emirates is 36.54 mgd. or **60.63 MCM/a**.

8.2.3. **Sharjah groundwater public supply**

Sharjah had relied totally until 1980, when desalinated water started to contribute to the daily water supply, on groundwater for its domestic use from the wellfields of Al Badea' I, Hamdah, Badea' II (also called Badea' North or Falah) and Wushah. **Badea' I**, situated 20km. to the

Locality		Production Gals./day	Locality		Production Gals./day	Locality		Production Gals./day	Locality		Production Gals./day
Dhuhurtiyyeen	(W)	1,000,000	Tawi Sohailah		30,000	Rul Dhadnah		40,000	Maduk		2,000
Sha'am		30,000	Tawi Bin Ghureir		5,000	'Aqqah		10,000	Wadi Shawkah		40,000
Wadi Ghaleelah		50,000	Idhn	(W)	100,000	Zikt		25,000	Tawi 'Athbah		5,000
Wadi Sahwat	(W)	2,000,000	Al Eayais		30,000	Dhadnah		40,000	Tawi Al Eiyaili		20,000
Wadi Al Beeh	(W)	5,000,000	Al Maname	(W)	150,000	Wadi Al Wurai'ah	(W)	1,000,000	Kidnah		100,000
Wadi Khabb		30,000	Wadi Ashwani		20,000	Al Gamrah		20,000	Bithnah		50,000
Tawi Se'eedi		80,000	Khalu		10,000	Tayyebah		100,000	Al Khabeeb		3,000
Tawi Hamraniyyah	(W)	100,000	Wadi Sidr - North		50,000	'Asimah		50,000	Wadi Mait		20,000
Maghawerah		40,000	Thoban		20,000	Dhawahi		30,000	Darrah		10,000
Hareelah		10,000	Al Eayaim		20,000	Hinyah		30,000	Wadu Sfai		20,000
Khadeejah		10,000	Al Ghail		50,000	Marbadh		25,000	Tuwaimah		5,000
Khuraijah		10,000	Al Fayy		10,000	Khulaibiyah		20,000	Khdhrah		30,000
Tawi Zaidi		20,000	Wadi Al Kub		20,000	Masafi (R.Khatmah)		10,000	Wadi Saham		20,000
Um Al Judu'		5,000	Al Aweer		20,000	Diftah(old village)		10,000	Al Khari		5,000
Mathluthah		7,000	Qata'ah		10,000	Al Halah		40,000	Wadi Mansab		5,000
Seih Al Fahlain	(W)	2,000,000	Nazwah		40,000	Al 'Abadillah		20,000	Wadi Tawah		5,000
Tawi Al Beer		30,000	Tawi Mahrani		5,000	Madak		5,000	Wadi Lamhah		5,000
Khatt	(W)	100,000	Bahayes		50,000	Masafi (Fujairah)		50,000	Fujairah	(W)	2,000,000
Sqail		10,000	Hileiha - North	(W)	40,000	Wadi Khabakheb		5,000	Kalba	(W)	3,000,000
Tawi Saram		20,000	Fareej Al Kindi		20,000	Siji		50,000	Hafrah		20,000
Jaroof		10,000	Fili		50,000	Al Kosh		5,000	Sha'arah	(W)	1,000,000
Jareef		30,000	Hamad Bin Hilles		20,000	Al 'Abadillah (1ch)		10,000	Hamad Bin Sulayyem		30,000
Riyamah		100,000	Tawi Khaidher		40,000	'Amqah		10,000	Wadi Al Qawr		30,000
Sidairah		70,000	Tawi Khalfan		10,000	Badyah		30,000	Huwailat		50,000
Tawi Rashed	(W)	2,000,000	Khatmah		30,000	Khor Fakkan	(W)	2,000,000	Malahah		15,000
Shunuf-old & new	(W)	5,000,000	Tayyah		40,000	Wadi Shi		10,000	Nasfut	(W)	100,000
Tawi Bin Hilles		20,000	Wushah		30,000	Al Quraiyyah		30,000	Sukhaiber		20,000
Al Beer		30,000	Khadheerah		20,000	Sharm		20,000	Munai'ee		50,000
Tawi Sirrah I & III	(W)	2,000,000	Al Bardi	(W)	1,000,000	Qidfa'	(W)	110,000	Muzeire'a		30,000
Tawi Jahili		5,000	Al Nadd		30,000	Tawi Bil Khabees		10,000	Fashgah		15,000
Um Al 'Arj		20,000	Al Madam		50,000	Tawi Khaidher		10,000	Wahlah		20,000
Falaj Al Mualla	(W)	500,000	Rafadah		40,000	Al Helew		20,000	Muslah		15,000
Dhaid	(W)	1,000,000	Ghareefah		40,000	Al Jinaiyyah		5,000	Rafak		20,000
Army camp		100,000	Tawi Thuqaibah		50,000	Kidnah (1ch)		20,000	Margham		30,000
Tawi Saman		80,000	Tawi Khuwailed		10,000	Subaighah		40,000	Al Faqa'		20,000
Tawi Banan		5,000	Um Al Safat		25,000	Munkhulah		10,000	Tawi Ali		10,000
Tawi Nabibeg		10,000	Tawi Fatimah		10,000	Al Ghabah		10,000	Tawi Hamad Al Owais		5,000
Naseem		40,000	Dibba	(W)	1,000,000	Fara'ah		5,000	Tawi Murrah		5,000
TOTAL DAILY VOLUME 36,542,000 gallons/day GROSS ANNUAL VOLUME 60.63 MCM/a											

Table: 8.3.

The daily production of potable groundwater from the public supply wellfields, dual and single wells of the Ministry of Electricity and Water (MEW) in the Northern Emirates (1988).

These daily production figures of MEW wellfields, dual and single wells in the Northern Emirates are the result of field enquiries to pump attendants; observation of the filling time and frequency of supply tanks during a day and from well-discharge rate tests for some of these wells. The volumes are, therefore, the best possible estimates and can be taken as a reasonable guide to the actual daily volume of groundwater abstracted by all the MEW wells in the absence of official quantification due to either the lack of flow-meters on these wells or their state of disrepair, if they exist, as well as their infrequent reading if they happened to be in working condition. The total daily volume of 36.54 mgd. (60.63 MCM/a) is for potable water for the rural areas of the Northern Emirates. Supply of groundwater to the large towns of Dubai and Sharjah is excluded as this comes from separate wellfields managed by the respective local water departments in these two emirates.

southeast of Sharjah town, is still the largest producer of groundwater, though this water is increasingly deteriorating in quality because of rising salinity. The total daily output from this wellfield is 7 mgd. (31818m^3/d.) from 36 boreholes (1988), which is twice the daily safe yield of the wellfield of 3.5 mgd. (15909 m^3/d.). As was shown in Chapter 5, pump levels in 50% of the boreholes are below MSL., and salinity is rapidly increasing as a result of seawater intrusion (conductivities of groundwater are between 3000-3200 mmhos/cm. (1988)).

Hamdah wellfield has 45 boreholes (1988) with a total yield of 3.5 mgd. (15909 m^3/d.). Groundwater conductivities vary from 800-3000 mmhos./cm. 25 out of the 45 boreholes have deteriorated in their rate of discharge down to 14m^3/hr., similar to the boreholes at Wushah. Such continuously reducing discharge rates adversely affect well efficiency and life and also the performance of the submersible pumps. The general gradual deterioration in yields in the whole wellfield, especially since 1986, has put the wellfield in a phased shut down programme. Instead, a new wellfield has been developed at **Seih Al 'Aqareb** (1989), situated between Qarn Mileiha and Jabal 'Aqabah-Buhayes, and started operation by mid-1990 with a possible daily production of 4-5 mgd. Discharge rates of the boreholes at Seih Al 'Aqareb are between 23-36m^3/hr. and the static water level stands at 15-20m. The wellfield is upgradient of that of Al Aweer of Dubai, 15km. to the southwest, and that of Al Hibab, also of Dubai, lying only 7 km. away.

Badea' II (Badea' North or Falah) Wellfield has 31 boreholes in operation with a total yield of 5.0 mgd. With three additional boreholes drilled in 1988, the output reached 5.3 mgd. in 1989. No further development can be expected in this wellfield as the 5.3 mgd. output is the maximum load the 450mm. main pipeline, to the Badea' reservoir, can handle. In 20 out of the existing 34 boreholes the pump intake level is below msl., and groundwater conductivities are between 2300-3200mmhos/cm.

The wellfield at **Wushah**, developed in 1984 near Dhaid, was producing 1.6 mgd. by early 1986. This volume had dwindled to only 0.25 mgd. by March 1988, which dictated the closure of the wellfield by the Sharjah Electricity and Water Dept. 6 months later. Decreasing yields in Wushah and Hamdah result from the fact that both wellfields draw water from

Quaternary deposits close to the foothills where the storage capacity of aquifers is limited. Also groundwater is being abstracted heavily along the whole gradient of groundwater flow, as both wellfields happen to be in the same groundwater flow path. Table 8.4 shows the decrease in yield of the boreholes at Wushah wellfield between 1986 and 1988 (columns 2 and 3), with many of the boreholes being abandoned because of total aquifer exhaustion; while Table 8.5 shows the decline in borehole production in Hamdah wellfield between 1986 and 1988.

Although the decline in output at Wushah wellfield was nearly twice that at Hamdah (87% against 41%), both wellfields are situated, on the same aquifer. Wushah is located on the downgradient part of the alluvial aquifer of Wadi Khadhrah, while Hamdah is located on the upgradient part. The wells of the gardens at Dhaid, which have been dry since 1985, are even more downgradient than Wushah. Thus, the exhaustion of the aquifer started from the downstream point in Dhaid (in the gardens between the two roundabouts in the village of Dhaid) and extended upstream to Wushah as far as Hamdah wellfield, which has been experiencing decline in the productivity of its wells for the past few years. Hamdah wellfield is situated on the outwash alluvial fan of Wadis Khudhairah, Khadhrah, Mansab and Al Halah, 10km. from the mountain front.

Table 8.6. gives the increase in groundwater production from the Sharjah public supply wellfields since the beginning of groundwater development in 1965. Table 8.7 shows the daily production of groundwater from all the Sharjah wellfields for the years 1987 and 1988. Demand on groundwater increased by 32% in 1988 compared with 1987. The average daily groundwater produced in 1988 was 17.89 mgd., against that of 12.10 mgd. produced in 1987 (Table 8.7). The enhanced groundwater production in winter is for compensating for the laying-off of distilling units for maintenance in the desalination plant at Al Llayyah. This is evident in the sharp increase in the output for January 1988 from the wellfields to compensate for the loss of desalinated water from a single distilling unit during its stoppage (Table 8.7.). The total annual groundwater production from the wellfields of Sharjah is 29.7 MCM/a.

Borehole number	Yield in gals/min (25-3-1986)	Yield in gals/min (27-3-1988)	Decrease in yield %	Remarks
1	104	24	77	
2	30	-	100	Abandoned
3	30	-	100	"
4	144	16	89	
5	148	44	70	
6	80	-	100	"
7	30	-	100	"
9	44	-	100	"
10	48	14	71	
11	50	24	48	
12	68	22	68	
13	52	-	100	"
14	100	20	80	
15	48	-	100	"
16	96	-	100	"
Total/Average	1072	164	86.86	8 out of 15 boreholes

Source: Sharjah Electricity and Water Department.

Table: 8.4.

Decrease of production and the number of boreholes (by depletion) in Al Wushah wellfield of Sharjah between 1986 and 1988.

On 25/03/1986, 16 boreholes produced 1,543,680 gallons/day
On 27/03/1988, 7 boreholes produced 236,160 gallons/day
In one year 8 out of the 16 boreholes were abandoned due to aquifer exhaustion as the wellfield is situated on a buried wadi channel in the same groundwater flow path as the boreholes within the gardens in Al Dhaid that also dried up.

Date	Number of producing boreholes	Total output in mgd	Drop %
3-3-1986	60	7,117,920	
26-3-1988	54	4,222,080	41

Source: Sharjah Electricity and Water Department.

Table: 8.5.

Decline in borehole production in Hamdah wellfield, 1986-1988.

Although the reduction in the number of boreholes that ran dry was 10%, groundwater production from the Hamdah wellfield decreased by 60%. Hamdah wellfield, in a low-storage foothill location, is increasingly diminishing in productivity. The development of the new Seih Al 'Aqareb wellfield, to the south, is to supplement the diminishing supplies from Hamdah, which may eventually be shut down. The daily groundwater production from Hamdah in early 1990 was 3.5 mgd.

Year	Producing boreholes	Production in mgd	Wellfield
1965	1	0.3	Badea' I
1967	3	0.75	Badea' I
1970	5	1.15	Badea' I
1971	5	1.50	Badea' I
1972	6	1.81	Badea' I
1973	6	2.05	Badea' I
1974	9	2.90	Badea' I
1975	14	5.45	Badea' I
1976	23	6.20	Badea' I
1977	23	8.20	Badea' I
1978	44	11.00	Badea' I + Hamdah I
1979	64	13.00	Badea' I + Hamdah I & II
1980	67	15.70	Badea' I + Hamdah I & II
1981	86	15.70	Badea' I & II + HamdahI & II
1982	88	15.80	Badea' I & II + HamdahI & II
1983	98	17.50	Badea' I & II + HamdahI & II
1984	105	19.02	Badea' I & II + HamdahI & II + Wushah
1985	114	18.94	Badea' I & II + HamdahI & II + Wushah
1986	-	18.00	Badea' I & II + HamdahI & II + Wushah
1987	-	19.87	Badea' I & II + HamdahI & II + Wushah
1988	112	15.60	Badea' I & II + HamdahI & II WUSHAH WAS SHUT DOWN

Source: Sharjah Electricity and Water Dept.

Table: 8.6.

Development in groundwater production from the Sharjah wellfields (1965-1988).

Notice the decline in output despite the increase in the number of boreholes. Badea' I and II and Hamdah I and II produced in 1983 17.50 mgd. from 98 boreholes; while in 1988 (after Wushah wellfield had been shut down) the same wellfields produced only 15.60 mgd. from 112 boreholes. This decline was due to reducing discharge rates at Hamdah and rising salinity at Badea' I and II.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Daily Av.
1987	11.70	11.50	10.00	12.45	11.20	12.45	12.75	13.00	12.80	12.75	12.32	12.30	12.10
1988	17.32	14.73	14.01	15.09	17.34	20.24	20.43	20.06	20.06	19.62	13.96	10.50	17.89

Source: Sharjah Electricity and Water Dept.

Table: 8.7.

Comparison of the total daily groundwater production of all the Sharjah wellfields for the two years 1987 and 1988 (in mgd.).

The average daily production of groundwater increased by 32% in only one year from 12.0mgd. in 1987 to 17.89mgd. in 1988.

8.2.4. Dubai groundwater public supply

Groundwater demands in Dubai have been met since 1961 by the Aweer (started in 1961), the Wuhoosh (1972) and the Hibab (1977) wellfields, situated on the same wedge-shaped aquifer as Al Badea' I and II wellfields of Sharjah, in the downgradient, and Seih Al 'Aqareb wellfield, also of Sharjah, in the upgradient section of the aquifer.

Production increased from 60,000 gallons/day (276m^3/d.) in 1961 to 19.0 mgd. (86539m^3/d.) in 1979, just before the first contribution of desalinated water from Dubai Electricity (DEC) in June 1979 (7.5 mgd. at the start). From June 1979 to October 1980 groundwater production in Dubai remained stable, with a minor daily variation, at 16.0 mgd. After October 1980, when 3.5 mgd. of desalinated water was made available from Dubai Aluminium Co., (Dubal), wellfield production dropped and remained between 8-8.6 mgd. until the end of 1984. In 1985 it rose again to the 1979 level and the average daily production for the year was 15.34 mgd. (69631m^3/d.). In 1987 it dropped yet again to 11.33 mgd. (51494m^3/d.) following the increase in the production of desalinated water by Dubai Electricity by about 23%. The average daily production from the three Dubai wellfields in 1988 was 10.0 mgd. (45455m^3/d.), or an annual total volume of 16.6 MCM/a.

Table 8.8 presents the groundwater production for domestic use in Dubai in mgd./m^3-d. since 1961. The daily production reached a peak in 1979 but has totalled 10-12 mgd. since 1987. The total daily output from the three Dubai wellfields in 1989 averaged 11.0 mgd. (**18.3 MCM/a**.)

Since the end of 1980 when desalinated water started to contribute to meeting the daily water demand for Dubai, production in each of the 3 wellfields has varied in maximum output, with Aweer and Wuhoosh producing most of the total production, though in 1985 the production of Al Hibab was enhanced to become almost equal to that of both Aweer and Wuhoosh for some months. It was 60% more than that of Aweer and 23% more than that for Wuhoosh throughout that year. As shown in Table 8.9., which gives the daily groundwater production of each of the three Dubai wellfields for 1985, output from Al Hibab was maximized from March to the end of the year, reaching a peak in September. This was because of the failure of Dubai Aluminium Co. (Dubal) to produce what was expected

Year	Total daily production in MGD	(M^3/day)	Wellfield
1961	0.061	(267)	Aweer
1962	0.28	(1,281)	
1963	0.37	(1,667)	
1964	0.48	(2,190)	
1965	0.61	(2,792)	
1966	0.72	(3,274)	
1967	0.88	(3,986)	
1968	1.24	(5,634)	
1969	1.92	(8,714)	
1970	2.91	(13,051)	
1971	3.31	(15,056)	
1972	4.42	(20,097)	Aweer + Wuhoosh
1973	5.55	(25,237)	Aweer + Wuhoosh
1974	7.14	(32,465)	Aweer + Wuhoosh
1975	8.86	(40,277)	Aweer + Wuhoosh
1976	11.17	(50,790)	Aweer + Wuhoosh
1977	14.67	(66,679)	Aweer + Wuhoosh + Hibab
1978	18.81	(85,520)	Aweer + Wuhoosh + Hibab
1979	19.04	(86,539)	Aweer + Wuhoosh + Hibab
START OF DESALINATION PRODUCTION			
1980	17.62	(80,101)	Aweer + Wuhoosh + Hibab
1981	8.12	(36,894)	Aweer + Wuhoosh + Hibab
1982	7.91	(35,938)	Aweer + Wuhoosh + Hibab
1983	7.51	(34,030)	Aweer + Wuhoosh + Hibab
1984	8.65	(39.303)	Aweer + Wuhoosh + Hibab
1985	15.32	(69,631)	Aweer + Wuhoosh + Hibab
1986	12.70	(57,728)	Aweer + Wuhoosh + Hibab
1987	11.33	(51,494)	Aweer + Wuhoosh + Hibab
1988	10.20	(46,364)	Aweer + Wuhoosh + Hibab

Source: Dubai Water Department.

Table: 8.8.

Development in the total daily production of groundwater from the public supply wellfields of Dubai, 1961-1988.

The daily production from the wellfields of Dubai reached a peak in 1979 just before the start of desalinated water production. After that, it reached its lowest output of 7.51 mgd in 1983 when desalinated water was contributing substantially to the daily supply. The increase to 15.32 mgd. was due to the failure of desalinated water to keep up production, especially in the DUBAL plant. The average daily production of groundwater has been fluctuating between 10.0 and 12.0 mgd. since 1986 as desalinated water has become increasingly dominant in the daily supply.

	Al Aweer	Al Wuhoosh	Al Hibab
January	3.90	5.78	3.47
February	4.29	5.62	5.39
March	4.46	5.77	6.62
April	4.57	4.95	5.79
May	3.50	5.02	6.82
June	3.98	4.92	6.43
July	3.21	4.64	6.86
August	3.57	4.86	6.37
September	3.55	4.96	7.13
October	3.88	4.62	6.73
November	3.93	4.74	6.32
December	3.71	4.41	6.10
Average	3.88	5.02	6.14
Source: Dubai Water Department.			

Table: 8.9.

The daily production of groundwater from Al Aweer, Al Wuhoosh and Al Hibab wellfields of Dubai for 1985 (in mgd).

Since desalinated water started contributing to the daily domestic demand of Dubai, groundwater production has been alternating in maximum output between the three Dubai wellfields of Al Aweer, Al Wuhoosh and Al Hibab. When in 1985 groundwater production was maximized due to shortages in desalinated water supply, production from Al Hibab wellfield surpassed that from each of Al Aweer and Al Wuhoosh wellfields, and its output equalled that from both these two latter wellfields during some months in that year.

	Al Aweer	Al Wuhoosh	Al Hibab
1981	3.20	2.70	2.20
1982	3.10	2.00	2.90
1983	3.10	2.40	1.98
1984	2.90	3.40	2.40
1985	3.90	5.10	6.30
1986	3.40	4.70	4.60
1987	3.90	3.97	3.50
1988	3.60	3.60	3.30
Average	3.80	3.95	3.81
Source: Dubai Water Department			

Table: 8.10.

Alternating lead in groundwater production in the three Dubai public supply wellfields, 1981-1988 (in mgd.).

Although the daily average groundwater production in each of the three Dubai wellfields appeared close, the output from Al Wuhoosh wellfield for the same period (1981-88) was slightly more than each of the other two wellfields.

of its plant (as will be discussed in section (8.5.3.)). Table 8.10. shows the alternating lead in groundwater production in the three Dubai wellfields between 1981 and 1988 in mgd. The average daily production for each of the three wellfields was close, although the groundwater production from Wuhoosh for the same period was slightly more than that from the other two wellfields.

Groundwater from the three wellfields is mingled with the desalinated water produced by the 2 main plants at Jabal Ali whose water is stored in a 30 million gallon elevated concrete reservoir. Water flows to the town by gravity in a pipeline that runs parallel to the Dubai-Abu Dhabi highway. Groundwater is then mixed at several points along the course of this pipeline before and after the booster station located behind the cement factory at Al Najmah. There is another 12.0 million gallon elevated concrete tank at Rashidiyah and 3 smaller elevated steel tanks at Burj Al Nahar in Deira. The flow gradient in the main 1200mm. pipeline from Jabal Ali to Dubai town is 1.2m. in 1 km.

8.2.5. Abu Dhabi groundwater public supply

8.2.5.1. Groundwater public supply of the eastern region of Abu Dhabi: Al Ain. (Fig. 8.2)

There are no wellfields near the town of Abu Dhabi. Before the first desalination plant was commissioned at the end of 1970, Abu Dhabi town took its supply from the Al Sad wellfield in Al Ain, situated on the Abu Dhabi-Al Ain highway. The pipeline that transported the water to Abu Dhabi was of a modest 2.0 mgd. capacity. By 1978 the demand of Abu Dhabi had risen 9 fold to become 18.8 mgd. Al Sad is the most western wellfield of potable groundwater in the Al Ain region. All the other public supply wellfields have been developed along the Al Ain-Dubai highway, in the northern dune area, from Ghashabah in the south to Al Shuwaib in the north, in a 50-km. continuous front of wellfields. The remaining wellfield, that of Um Ghafah, lies to the southeast of Al Ain in the southern part of the Al Jaww plain (Fig. 8.2.).

The total number of wells for the public supply managed by the Water and Electricity Dept. (WED Al Ain) todate (1990) is 482 (including the 80

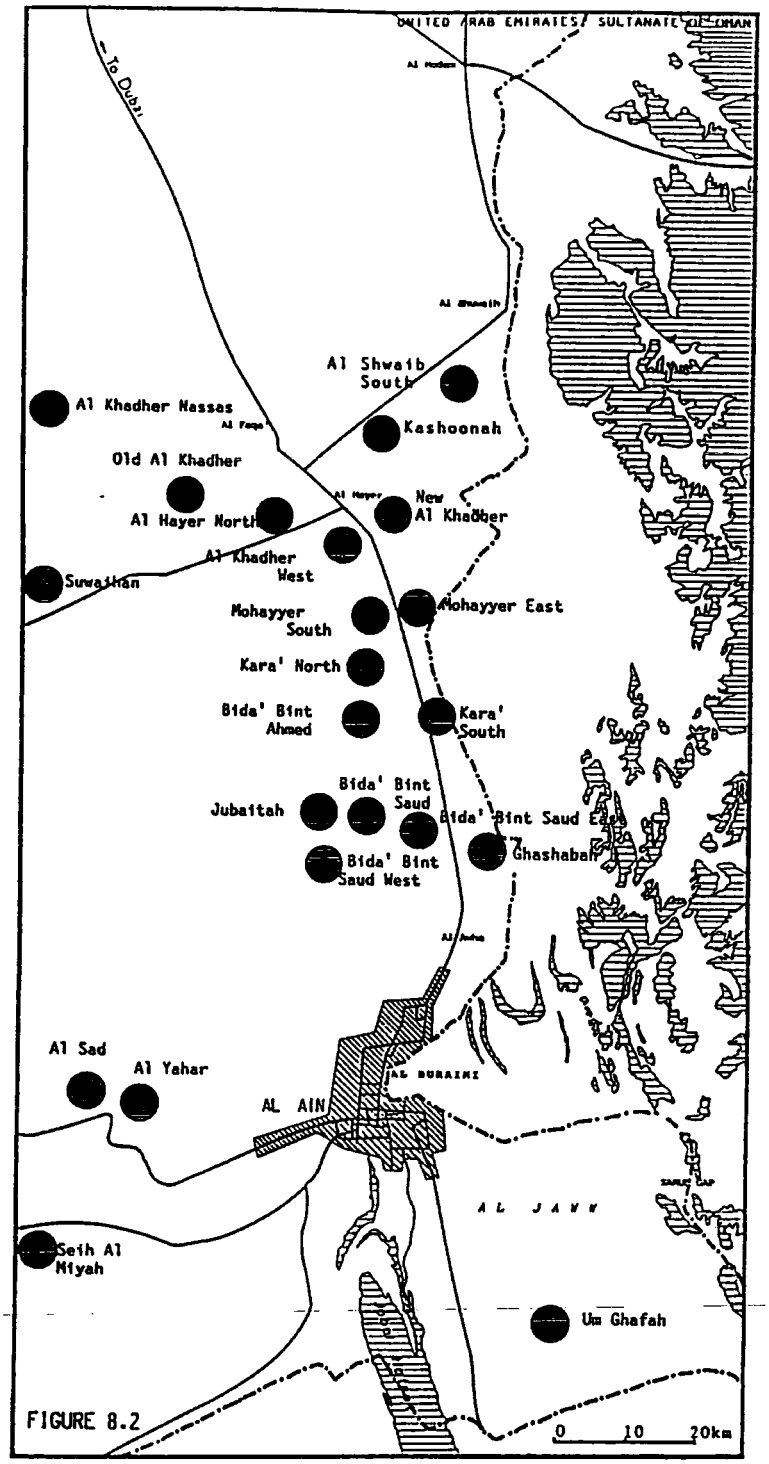


Figure: 8.2.

The public supply wellfields of WED Al Ain. 1990.

Nearly all of the Al Ain public supply wellfields are concentrated in a 50-km. stretch in the northern dune area from Ghashabah to Al Khadher. Um Ghafah wellfield, in southern Al Jaww Plain, is the only potable water wellfield south of Al Ain town tapping inflow from the Zarub Gap. The public supply wellfields of Al Ain are competing for potable water with hundreds of other private and government agricultural wells. A number of vegetable, fodder and dairy farms intersperse the public supply wellfields along the Al Ain-Dubai highway.

Shuwaib boreholes handed over by the Groundwater Department to WED Al Ain in December 1988), of which 447 are operational. Of these wells, 422 are actually pumping groundwater. The available number of wells in each of the public supply wellfields of Al Ain, those wells available for maximum operation and those actually in operation are shown in Table 8.11.

Besides being mostly responsible for the supply of potable water in Al Ain, WED Al Ain is also responsible for supplying brackish water for agricultural use from the two wellfields of **Seih Al Miyah I and III** (mainly for the horticultural projects of Al Ain Municipality). Water of marginal quality from **Al Khadher Nassas wellfield** is relayed by a 160-km. pipeline to the palaces on the Gulf coast at Ras Ghanadhah and Al Shaleelah. Al Khadher Nassas wellfield, besides that of **Kashoonah wellfield** with about 130 wells (80 of which form the recently handed-over Al Shuwaib wellfield, which is the responsibility of WED Al Ain), are managed by WED Abu Dhabi. Although some of the water carried by this pipeline is supplied to the Al Jarf and Al Reef forestry areas and several large users before reaching the coast, the groundwater volumes abstracted from Al Khadher Nassas and Kashoonah wellfields, owing to their location within Al Ain region, are included in the final groundwater balance calculations for the Al Ain region and not for the desert foreland, where Al Jarf and Al Reef are located.

Since the acute shortage in irrigation water of 1988 in southern Al Jaww, owing to the drying up of wells in the farms in Um Ghafah, water of prime potable quality has been supplied to agriculture from the public supply wellfield of Um Ghafah (also from a reservoir of mixed desalinated and potable groundwater of the public supply of WED Al Ain).

Public water supply in Al Ain increased from 2.0 mgd. (3.4MCM/a) in 1975, before the commissioning of the wellfields in the northern dune area, to 34.41 mgd. (57.1 MCM/a.) in 1989 (Table 8.11). As seen in Table 8.11. the bulk of the water produced from the public supply wells of Al Ain (84%) is for potable use, that for brackish water for use on the town's landscaping schemes is 12%, while the remaining 4% brackish water is produced by Al Khadher Nassas wellfield destined for Abu Dhabi.

Wellfield	Total available wells	Operating wells Total	Working	Production in mgd
A. SUPPLYING AL AIN TOWN (POTABLE)				
Ghashabah	18	14	14	1.30
Kara', Kara'(N), Bida' Bint Ahmed	35	35	32	3.95
Mohayyer (E) & Suwaihan Road	22	22	21	
Al Hayer (N) & Seih Al Baitar	56	41	41	7.29
Al Shuwaib	80	80	80	4.00
Bida' Bint Saud & Jubaitah	79	79	75	5.70
Um Ghafah	39	39	30	1.44
Sub-total	329	310	293	23.61
B. SUPPLYING THE VILLAGES (POTABLE)				
Wells in villages	48	45	45	2.93
Al Sad, Al Yahar & Haza' Al Boash	42	36	32	2.30
Sub-total	90	81	77	5.23
C. SUPPLYING IRRIGATION WATER (BRACKISH)				
Seih Al Miyah I	11	7	5	1.40
Seih Al Miyah III	12	11	9	1.94
Al Hamam tanker service	8	8	8	0.60
Sub-total	31	26	22	3.94
D. SUPPLYING AREAS IN ABU DHABI (MARGINAL)				
Al Khadher Nassas	32	30	30	1.65
Sub-total	32	30	30	1.65
Grand total	482	447	422	34.41

Source: Water and Electricity Department (Al Khubaisi, Al Ain)

Table: 8.11.

Groundwater production from the public supply wellfields of Al Ain, 1989.

The total daily potable groundwater supply from the wellfields (groups A and B in Table 8.11) is 28.84 mgd., to which is added between 14-15 mgd. of desalinated water imported from Abu Dhabi. The fact that this quantity of groundwater is obtained from 391 wells shows the delicate balance and careful abstraction that is governed by the limited groundwater resources. Some wells are allowed to rest for more than a month before the resumption of pumping. As these potable supply wells are competing with hundred other uncontrolled private wells over the same groundwater reserves, the careful monitoring by WED Al Ain of its wells is rendered futile.

The development in production and supply of groundwater for domestic use in Al Ain, since commissioning the bulk of the wellfields in 1975, is given in Table 8.12. The table shows a 17-fold increase in the total groundwater production in the Al Ain region between 1975 and 1988 from 3.4 MCM/a to 57.1 MCM/a.

Of the supply to the villages and Abu Dhabi (Table 8.11.), Al Khadher Nassas has been supplying Abu Dhabi since 1982 with between 1.65 mgd. and 3.65 mgd. (2.1-6.1 MCM/a), then Kashoonah in 1985 with 2.5 mgd. (4.2 MCM/a). This latter wellfield, off the Shuwaib road near its junction with Al Ain-Dubai Highway, was primarily developed to supplement the failing supplies from Al Khadher Nassas.

Groundwater is extracted from wells of stage 1 of the development of the Kashoonah wellfield with a total of 31 wells, of which 30 are operational in alternating groups. Stage 2 development of Kashoonah was completed in 1987 with nearly 130 wells drilled at the same time in a small area, the distance between each well being 400-500m. 80 wells of this second group make up the so-called **Al Shuwaib South wellfield** that was handed over by the Groundwater Department of Al Ain to WED Al Ain in December 1988. The total daily output from the Shuwaib South wellfield is 4.0 mgd.

The high density of wells in this area of continuous wellfields is indicative of the poor productivity of the boreholes. Heavy abstraction has led to the consistent decline in groundwater levels (see Chapter 5, Section 5.5.). Wells are being continuously deepened, caving-in is common because some of the wells are developed without casing, and pump rates are intentionally slowed down in order to maintain production and prolong well life.

The fact that there are so many wells in the northern dune area and the output is only 34.41 mgd. (1989, including the 80 wells of Al Shuwaib) is a clear indication of poor aquifer performance and a sign of depletion. With a total of 482 wells under WED Al Ain producing 34.41 mgd., each well discharges 5100 gals./hr. in a 14-hour day ($23m^3$/hr.). The situation of low aquifer performance becomes even clearer if the new Al Shuwaib wellfield is considered on its own. Here, the 80 wells operate simultaneously to produce 4.0 mgd. This gives a discharge rate

of 3571 gals./hr. (14-hour day) or 16m^3/hr. Well pumping tests, carried out for a whole month after WED Al Ain had received the wellfield (January, 1989), established discharge rates from these 80 wells of between 10-16m^3/hr each.

Mohayyer East is the wellfield most affected by the intense abstraction. Lately, that of Um Ghafah, in southern Al Jaww, has been experiencing sharp drops in groundwater levels and even the total drying up of some wells (summer 1988)..

The newly built low-cost housing satellite villages of Al Yahar, Al Hayer and Al Sad depend on single shallow wells and a great deal of the daily demand for water is provided by road tankers. Such a service is a permanent every-other-day ritual in Al Ain town.

Excluding groundwater supplies to the villages, and also the brackish water supplies in general, the groundwater supplies to Al Ain town reached a peak in 1985 when they were 38.5 MCM/a or 23.2mgd. Up to that year, since it had started to flow to Al Ain in August 1983, the import of desalinated water from Abu Dhabi had hardly been more than 1.65 mgd. When in 1986 the supply from this source of water was increased to 5.72 mgd., the output from the wellfields was reduced by 3.0 mgd. and stood at 33.7 MCM/a or 20.3 mgd. Groundwater supply for Al Ain town dropped by nearly 6.0 mgd. from 33.7 mgd. in 1986 to 27.8 mgd. in 1987 (Table 8.12.), reflecting the increase in the imported desalinated water from Abu Dhabi which, throughout 1987, was maintained at 10.86 mgd. This trend, however, did not continue, and again in 1988, despite yet another increase in the volume of imported desalinated water by 31% to become 14.2 mgd. (23.6MCM/a), the groundwater supply to the town increased by 35% from 27.8 MCM/a in 1987 to 41.9 MCM/a for 1988. The overall increase in groundwater production for the whole of the Al Ain region, including the supply to the satellite villages and also that of brackish water, was 40% more for the same period.

The substantial contribution to this general increase in the output of groundwater in whole of the Al Ain region was from the production of brackish groundwater from Seih Al Miyah I and III whose output increased from 0.66 mgd. in 1986 to 3.0 mgd. in 1987 and, finally, to 4.0 mgd. in 1988. This increase in the overall groundwater abstraction, especially

that of brackish water, was brought about by many factors: the failure of wells in many areas, such as Um Ghafah, to maintain the acceptable quantities they had been producing; the increased demand by horticulture owing to large-scale landscaping schemes within Al Ain town during 1988; and, most importantly, the need to augment falaj flow with both potable and brackish water, both of which are supplied by WED Al Ain to Al Ain Municipality, the manager of the aflaj.

8.2.5.2 **Groundwater public supply in central and western Abu Dhabi** (Table 8.13; Fig. 8.3)

Wellfields that have been developed since 1974 in central and western Abu Dhabi emirate are illustrated in Fig. 8.3. These wellfields include:

1. **Al Helew wellfield**: Situated 35km. southeast of Bida' Zayed. There are 30 wells, of which 9 are operational, producing between 0.6 and 1.0 mgd. (1.7MCM/a). It supplies Abu Al Abyadh Island to which it is connected by a pipeline. Groundwater conductivities range from 2000 to 3000 mmhos/cm.

2. **Bujair wellfield (Bujair I, II and III)**: Situated 35km. south of Bida' Zayed. Data are not available for Bujair I, but each of Bujair II and III has a total of 10 and 8 wells respectively, of which 9 and 8 wells are operational producing 0.75 mgd. and 1.0 mgd. respectively (3.0 MCM/a. for both).

3. **Bida' Khalfan wellfield**: Situated 10km. to the southwest of Bujair III. It has a total of 10 wells of which 7 are operational producing nearly 0.75 mgd. (1.2 MCM/a.)

4. **Bida' Rashed wellfield**: 35km. west of Bida' Zayed with 13 wells, 9 of which are operational producing an average of 0.5 mgd. (0.83 MCM/a.).

Groundwater conductivities in all these wellfields range from 1000 and 5000 mmhos/cm. and the water is used for both human consumption and irrigation.

	For Al Ain	For villages	Brackish water for agriculture	Total
1975	1.4	2.0(To Abu Dhabi)	-	3.4
1976	3.0	3.7	-	6.7
1977	7.5	3.5	-	11.0
1978	12.8	5.0	-	17.8
1979	19.8	7.0	-	26.8
1980	22.9	9.1	1.7	33.7
1981	31.0	11.4	1.6	44.0
1982	35.0	11.4	1.0	47.4
1983	33.6	11.6	0.93	46.1
1984	32.3	6.8	1.1	40.2
1985	38.5	7.2	1.1	46.8
1986	33.7	7.9	1.1	42.7
1987	27.8	7.9	5.1	40.8
1988	41.9	8.7	6.5	57.1

Source: Water and Electricity Department, Al Khubaisi, Al Ain.

Table: 8.12.

Groundwater development and use in the Al Ain region, 1975-1988 (in MCM/a).

There was a 17-fold increase in the total volume of groundwater produced by the public supply wellfields since the greater number of them were commissioned in 1975 (when the output was only 3.4 MCM/a, 60% of which went to Abu Dhabi then) and 1988 (when it became 57.1 MCM/a).

Abu Dhabi Water and Electricity wellfields:		Petroleum Companies wellfields:	
POTABLE GROUNDWATER WELLFIELDS		BRACKISH DOMESTIC WELLFIELDS	
Wellfield	Production-mgd	Wellfield	Production-mgd
Al Helew	0.80	Asab	0.60
Bujair I,II,III	1.75	Shah	0.02
Bida' Khalfan	0.75	Bu Hasa	0.84
Bida' Rashed	0.50		
BRACKISH WATER			
Jaww Al Oad I&II	0.50		
Total	4.3 mgd		1.46 mgd

Sources: WED (Abu Dhabi)/ (ADCO)

Table: 8.13.

The potable and brackish groundwater public supply wellfields of WED Abu Dhabi and the oil companies in central, western and southern Abu Dhabi emirate.

Apart from the brackish groundwater wellfields of ADCO, which supply the personnel camps at the oilfields, the potable groundwater wellfields of WED Abu Dhabi are mostly tapping sand dune aquifers in the zone of fresh water in the Al Qafa area north of Liwa from wells with a maximum depth of 30-50m. Brackish water from the Jaww Al Oad, Qurun Al Na'am and Bida' Haza' wellfields supply irrigation water to Ghayathy, Bida' Al Matawa'ah and Sir Bani Yas Island.

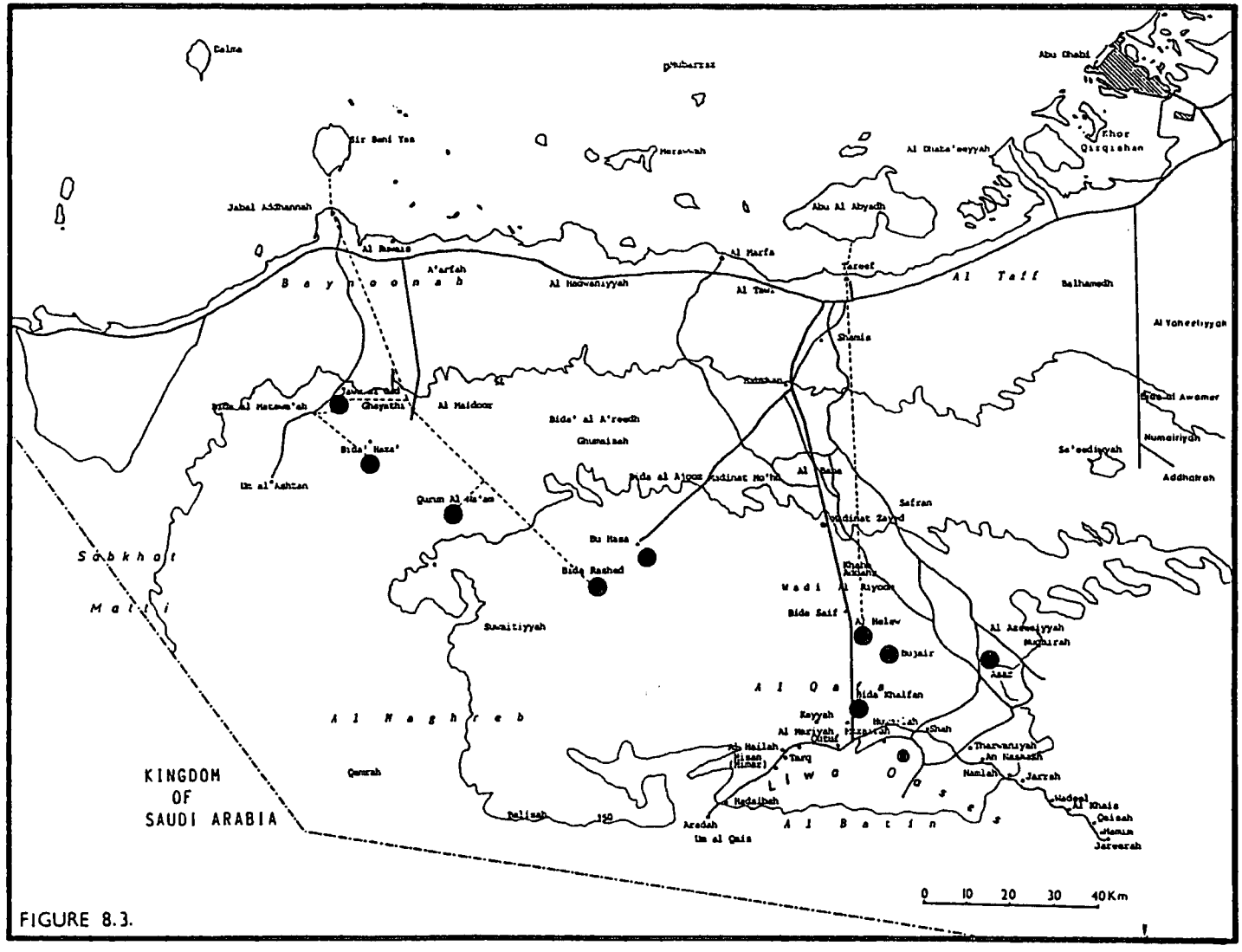


FIGURE 8.3.

Figure: 8.3.

The public supply wellfields of WED Abu Dhabi and the oil companies in central, western and southern Abu Dhabi, 1990.

The potable groundwater wellfields of Al Helew, Bujair and Bida' Khalfan tap sand dune aquifers in the shallow fresh water zone of Al Qafa north of Liwa. Further north, where the sands are less thick, wellfields such as Bida' Rashed, Bida' Haza' and Jaww Al Oad tap brackish groundwater from the sabkha underlying the sand dunes. The water from these last wellfields is used for agriculture and forestry in the region.

In the Ghayathy region in western Abu Dhabi the wellfields of **Qurun Al Na'am**, **Bida' Haza'** and **Jaww Al Oad** are sources of brackish groundwater with conductivities in excess of 3500 mmhos/cm.

There are about 40 wells for domestic supply drilled by WED Abu Dhabi in both Eastern and Western Liwa. They are used for human consumption despite their marginal quality and high sulphate content (Chapter 6, Section 6.5.3.6).

Finally, there are wellfields serving the personnel camps of the oilfields in central Abu Dhabi drilled by the Abu Dhabi Company for Onshore Operations (ADCO) (Table 8.13) and these are:

1) **Asab wellfield**: There are 6 wells drilled in the sand dunes, each to a total depth of 60m. All the wells, together, produce 0.6 mgd. (0.98 MCM/a) of brackish water, of conductivities ranging from 5000 to 9000 mmhos/cm., used by the personnel in the camps of Asab oilfield for domestic purposes (other than drinking).

2) **Shah wellfield**: There are two wellfields: one of which had, until the end of 1989, 10 wells, drilled to a total depth for each of 40-70m., that had silted up and had become totally blocked; the other, also with 10, but deeper, 'rig' wells (wells whose waters are very saline with TDS ranging from 17,000ppm to 150,000ppm. and are used primarily for injection purposes in the oil wells).

   2 wells were drilled in Nashasha in Liwa (near the Shah oilfield) and these at present (1990) supply 20,000 gallons/day to the personnel camp in place of the dried up wells. This amounts to 0.33 MCM/a of groundwater of conductivities ranging from 1800 to 2250mmhos/cm.

3) **Bu Hasa wellfield** : Nearly 400 shallow wells have been drilled in Bu Hasa todate (1990). The waters here are of relatively better quality with conductivities of 1500-9000 mmhos/cm. The total production is 0.84 mgd. (1.4 MCM/a).

8.3. Groundwater production for agricultural use

8.3.1. General

Abstraction of groundwater for agricultural use is taking place almost everywhere, even in those areas of central and southern Abu Dhabi emirate with the most adverse environmental limitations. Traditionally, areas of concentrated agricultural activity were in parts of the piedmont (gravel) plains around Digdaga-Hamraniyyah in the north, Dhaid in the centre and Al Ain in the south. On the east coast, the Dibba coastal zone had, as it still has, the largest single area under the date palm. The other area is Kalba in the southern part of the east coast. Agricultural activity elsewhere was limited to the mountain wadis and basins of Masafi, Masfut and Siji. None of the present widespread agricultural and forestry areas in western and southern Abu Dhabi had any recorded existence prior to 1973.

Groundwater for all these agricultural areas, until the early 1970s, was provided from shallow, hand-dug wells and from aflaj that had been in the past the most dominant sources of communal water supply.

The advent of oil but, most importantly, the formation of the federal state, and the resulting influx of capital into the poorer emirates of the federation and subsequent widespread development, especially of the road network, has led to the expansion in both the construction and agricultural sectors, with the inevitable heavy demand on water on an unprecedented scale. This trend can best be illustrated by the increase in the area under cultivation in the last 15 years as shown in Table 8.14, regardless of whether this cultivation is in the form of economically-based farms or simply recreational gardens, as both compete for the abstraction of groundwater.

In all the towns, widespread development in landscaping has taken place since the mid-1970s, which has exerted pressure on the groundwater supplies of these towns, especially in those towns where there are no desalination and recycling plants that may offer additional water to be used for such an application. Table 8.16 shows the development of acreage under landscaping in and around the town of Abu Dhabi. This

	Central	Eastern	Northern	Western		Total
				Western Abu Dhabi	Al Ain	
1973	2145	2911	5710	-	2128	12,894
1975	2814	2371	6513	-	2870	14,568
1977	3243	1632	7355	-	3108	15,338
1978	3717	3014	7388	2625	3549	20,293
1980	6295	3244	7478	1547	4910	23,474
1981	7847	3244	8134	2175	5515	26,915
1982	8955	3342	7293	1746	5893	27,229
1983	9970	3613	7293	2094	7670	30,640
1984	9970	3613	7293	2732	10,975	34,583
1985	10,867	3801	7390	2811	10,559	35,428
1986	12,053	4434	7605	3161	10,624	37,877
1987	12,660	4531	8120	3938	11,568	40,817
1988	12,931	4600	8203	4025	11,815	41,574
1989	14,324	5051	8666	4121	12,404	45,566

Source: MAF, Al Ain Agriculture Dept., Ministry of Planning and regional agriculture offices.

Table: 8.14.

The development of total agricultural acreage in the Emirates by agricultural region (in hectares), 1973-1989.

There was nearly a four-fold increase in the agricultural acreage in the whole of the Emirates between 1973 and 1989. The greater development in acreage was in agricultural regions most deficient in groundwater resources: the Central Agricultural Region where the increase was seven-fold and Al Ain where it was six-fold. Development was slow or even stagnant in the Central, Eastern and Northern Agricultural regions between 1983 and 1985 owing to a long period of drought (1984-86). Despite the drought, there was a marked increase in the agricultural acreage in the Al Ain (an increase of 27%) and western Abu Dhabi areas. The increase in acreage in the Eastern and Northern Agricultural Regions, both of which suffer from chronic water shortages, has been a relatively modest 5% for the same period.

acreage increased 58 times between 1974 (when it was 26.3 ha.) and 1989 (when it became 1535.5 ha.).

In all regions, there are agricultural areas that use irrigation water of potable quality, others potable and brackish while a third group uses brackish water of varying degrees of salinity.

8.3.2. Groundwater abstraction by agriculture in western and southern Abu Dhabi emirate

There was hardly any agricultural activity in the western and southern regions of Abu Dhabi emirate, namely Bida' Zayed-Ghayathy and Liwa, prior to 1973. Liwa consisted of historic oases, in the so-called chain of sabkha troughs relying on brackish water that is found at or near the surface. Groundwater abstracted in the whole area to the west and south of Al Ain as far as the western and southern borders with Saudi Arabia, is brackish to saline save for a zone of sand dune aquifers in Al Qafa to the north of Liwa. As elsewhere in the Emirates, the introduction of the motor pump to these traditionally shallow, hand-dug well areas, caused an upsurge in the acreage under agriculture. As shown in Table 8.14 there was a 3-fold increase in the agricultural acreage in western and southern Abu Dhabi between 1980 and 1989. The official total number of agricultural wells in Liwa, Ghayathy and Bida' Zayed was estimated in 1988 to be 4620 wells (Western Agricultural Area Office in Bida' Zayed) abstracting altogether groundwater in excess of 482 MCM/a (nearly 291 mgd.) ranging in quality from the potable, as in areas such as Bida' Mubarak and Bida' Khalfan, to the brackish and saline elsewhere in the region (see Section 8.4.2.)..

The marginal to poor quality groundwater in most areas is applied to field crops grown on mostly sandy and gypsiferous heavily fertilized soils, which develop salinities after a few seasons of cultivation (see Chapter 2, Section 2.4).

8.3.3. Groundwater abstraction by forestry in both the western and eastern (Al Ain) regions of Abu Dhabi emirate

Besides the overall expansion in the acreage under agriculture, there is the even more important expansion of the land under forest. The acreage under forest (actually rangeland) has increased, especially in the emirate of Abu Dhabi, by nearly 60% in only 7 years, from 37,999 ha. in 1980 to nearly 59,637 ha. by February 1990. This is shown in Table 8.15, which presents the development of acreage under forest in both the western and eastern regions of the emirate of Abu Dhabi; and Table 8.17, which presents the development of acreage under trees of various kinds, date palms as well as vegetables and fodder managed by the Agriculture Section of Abu Dhabi Municipality. As shown in Table 8.17, the increase in the acreage under agriculture, managed by the Agriculture Section, was 64 times between 1974 (241 ha.) and 1989 (15,524 ha.).

Forestry is the largest single user of groundwater for irrigation in Abu Dhabi where there are 4 authorities involved in the forestry projects. These are:

1) The Forestry Section

2) The Agriculture Section

Both are part of Abu Dhabi Municipality and both manage forestry areas in Al Dhafrah, Bida' Zayed, Ghayathy, Al Baynoonah and Liwa in central, western and southern Abu Dhabi.

3) The Private Department of the Diwan of the Ruler of the emirate of Abu Dhabi: managing forestry areas in Sir Bani Yas Island and the stretch of land between Al Mafraq to the interstate border with the emirate of Dubai. This includes areas in Al Reef, 'Ajban, Al Jarf, Ghantoot, Al Sumaih and Al Maida'ah.

4) The Forestry Department of Al Ain: managing forestry areas up to Al Faqa' in the north, Bu Heeran and Al Ya'eelah in the west and Al Qoa' in the south.

Forestry authority	1981	1982	1983	1984	1985	1986	1987	1988	1989
Forestry Section (Abu Dhabi Municipality)	8403	12182	15907	16103	20005	20113	20000	20769	21573
Agriculture Section (Abu Dhabi Municipality)	8704	6104	8705	10612	11682	13949	14225	15610	16924
Total for western Abu Dhabi	17107	18286	24612	26715	31687	34062	34225	36379	38497
Al Ain Forestry Dept.	NA	NA	13387	14294	14491	16641	19040	20340	21040
Total of acreage under forestry in Abu Dhabi	-	-	37999	41009	46187	50703	53265	56719	59637
Source: Forestry and Agriculture Sections, Abu Dhabi Municipality/ Al Ain Forestry Department.									

Table: 8.15.

The development of acreage under forest in both the western and eastern (Al Ain) regions of Abu Dhabi, 1981-1988.

The acreage under forest in Abu Dhabi increased 1.6 times between 1983 and 1989. The increase in the forestry acreage under the Forestry and Agriculture Sections of Abu Dhabi Municipality was more than 2.5 times during the same period. The forestry activity in Abu Dhabi emirate alone is responsible for abstracting more than 425 MCM/a of groundwater of both potable and brackish quality.

The Forestry and Agriculture sections (Abu Dhabi Municipality), in western Abu Dhabi, control a total of 2600 boreholes (1988) within their forested or agricultural areas. Most of these wells have an average depth (each) of 60m. The average daily discharge of a borehole in the forestry projects is 448m^3/d., at an hourly rate of 28m^3/hr., for a 16-hour well operation day. The Agriculture Section is pumping water from 1800 out of the 2600 wells and, based on the above discharge rates, abstracts 177.4 mgd. or an annual volume of 294.34 MCM/a. The Forestry Section operates 800 such boreholes (1988) discharging a daily volume of 79.0 mgd. or an annual volume of 131.0 MCM/a.

Thus, these two authorities, together, abstract annually **425.34 MCM/a** to irrigate their 59,637 ha. (1989) of forested and cultivated acreage applying water mostly by the drip irrigation method, but also by basin flooding under individual trees (Table 8.15).

In addition to this, the Agriculture Section manages 1692 ha. (1989) of landscaping sites within the limits of Abu Dhabi town (Table 8.16) for which irrigation water is supplied from 17.5 mgd. of recycled sewage water and 3.0 mgd. of desalinated water (see section 8.6.1.).

The forestry areas under the Private Department of the Diwan of Abu Dhabi, extending along the Abu Dhabi-Dubai highway from Al Reef to Al Maida'ah, use both ground and desalinated water (the latter from the desalination plants in Abu Dhabi town) almost in equal daily amounts. The desalinated water is used on salt-resistant plants, which can stand high water salinities, such as the salt-bushes *Zygophyllum spp. (Al Harm)*, *Halopeplis perfoliata (Al Khurrayz)*, *Prosopis spicigera (Al Ghaf)*, *Acacia tortolis (Al Sumar)* and *Prosopis juliflori (Al Ghuwaif)*. The forested localities, managed by the Private Department of the ruler of Abu Dhabi, their acreage, total number of cultivated trees and the type of irrigation water applied (whether ground or desalinated) are given in Table 8.18.

The desalinated water used for irrigation by the Private Department in these areas, which amounts to 1.61 mgd. or 2.7 MCM/a, is included in the total daily output of the desalination plants of Abu Dhabi (Section 8.5.2). The 1.8 mgd. (3.0 MCM/a) brackish water used is produced by **'Ajban wellfield**, situated within the forested area (Table 8.18), while

1974	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
26.3	505.2	652.8	756.6	819.0	869.6	1001.1	1222.1	1278.4	1368.6	1535.5
Source: Agriculture Section, Abu Dhabi Municipality.										

Table: 8.16.

The development of acreage under landscaping in and around the town of Abu Dhabi, 1974-1989 (in hectares).

The acreage under landscaping increased 58 times between 1974 and 1989. This increase became more since 1977 when treated sewage water was made available for irrigating these town reserves.

1974	1977	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
241	880	2998	4904	6166	8803	10741	11818	13159	13721	14710	15524
Source: Agriculture Section, Abu Dhabi Municipality.											

Table; 8.17.

The development of acreage under trees of various kinds, date palms, vegetable and fodder outside Abu Dhabi town managed by the Agriculture Section of Abu Dhabi Municipality, 1974-1989 (in hectares).

The acreage under this diversified agricultural activity increased 64 times between 1974 and 1989. Irrigation water ranging from the potable, through the brackish, to the recycled, is used for irrigation in these areas.

Forested Area	Area (hectares)	Number of trees/type	Irrigation water (gallons/day)	
			Desalinated	Groundwater
Sir Bani Yas Island	30,000	2,750,000	300,000	400,000
Al Reef	9,000	300,000 (Halophytes) 3,000 (Citrus) 3,050 (Date palms)	600,000	-
'Ajban	3,500	50,000 (Halophytes) 15,000 (Citrus) 5,000 (Date palms and grass)	600,000	500,000
Al Jarf		770,000 (Halophytes) 4,200 (Citrus)	-	700,000
Ghantoot	8,000	12,300	-	60,000
Sumaih		8,900	-	50,000
Al Maida'ah		15,000 (Citrus)	-	60,000
Al Qaaimah	3,000	19,800 (Citrus)	30,000	-
Al Salmiyyah	2,000	20,000	30,000	-
Hallat Bahrani	4,000	30,000	45,000	-
Total	59,540		1,610,000 2.7	1,800,000 gals/day 3.0 MCM/a
Source: Private Dept. secretariate				

Table: 8.18.

The forested areas managed by the Private Department of the Diwan of Abu Dhabi, their areas, the the total number and type of trees grown in them and the type of irrigation water used (desalinated or ground water), 1988.

Both desalinated and groundwater are used in almost equal amounts on both forest halophyte plants (Prosopis spicigera = 'Al Ghaf') and citrus (lemon and lime) plants.

another 2.0 mgd. (3.3 MCM/a) of marginal groundwater are taken off the main pipeline carrying water from Al Khadher-Kashoonah wellfields in Al Ain. What is left of the water in this pipeline supplies the large users in Al Jarf and the Gulf coast from Ghanadhah to Al Shaleelah.

The 0.4 mgd. or 0.7 MCM/a of brackish groundwater used for the 2,750,000 trees on Sir Bani Yas Island (Table 8.18) comes from the Ghayathy and Jaww Al Oad wells and forms only 17% of the total volume of irrigation water used on the island. The remaining 83% comes from desalinated water produced by plants on Sir Bani Yas Island itself and also from plants on the mainland (Section 8.5.2) as well as from an unquantified volume of recirculating irrigation water pumped out of excavated ditches all over the island. Table 8.19 gives the breakdown of the source, type and amounts of irrigation water applied to forested areas on Sir Bani Yas Island.

In Al Ain, the development in acreage under forest is shown in Table 8.15. The forested area increased in the 5 years between 1983 and 1989 by 64%. There are more than 105 forestry locations served by a total of 885 wells (1988) of which 225 are of potable and 660 of brackish quality. The former are less productive in terms of discharge and the 225 wells together produce 12.6 mgd. at a discharge rate of $18m^3/hr.$ each for a 14-hour well operation day. This gives an annual volume of 21.1 MCM/a of groundwater of potable quality used for forest salt-resistant plant species (such as those noted earlier), in forestry locations such as Raknah. The other 660 wells, extracting groundwater of marginal to brackish quality, have higher discharge rates similar to those of the wells of the two forestry authorities in western Abu Dhabi. The discharge rate per well is about $27m^3/hr.$ and, with an average daily operation of 14-hours, the total output amounts to 54.9 mgd. or 91.1 MCM/a. Thus, the total volume of groundwater abstracted for the forestry projects in the Al Ain region is 112.1 MCM/a; while the gross volume of groundwater abstracted by the forestry in the whole of Abu Dhabi emirate amounts to 323.94 mgd. or 537.44 MCM/a.

Type of irrigation water	Source	Quantity gallons/day	Total	% of total used
Groundwater	Jaww Al Oad	400,000	400,000	17
Desalinated water	Jabal Addhannah Al Ruwais Sir Bani Yas Is. Other sources	750,000 750,000 300,000 200,000	2,000,000	83
Recirculated	Irrigation return	Unquantified	-	-

Source: Private Dept./WED Abu Dhabi

Table: 8.19.

The actual amounts of desalinated and groundwater used for irrigating forest trees on Sir Bani Yas Island, 1988.

Desalinated water forms 83% of the total irrigation water volume applied to the cultivated parts of the Island that are grown with mostly salt-tolerant forest trees. Groundwater forms only 17% of the total water volume used for irrigation and is supplied from the Jaww Al Oad wellfield on the mainland via an undersea pipeline. A substantial unquantified amount of recirculating irrigation water is pumped out of ditches excavated all over the Island. If the volume of this irrigation return water could be known it would have been deducted from the gross volume of irrigation water initially used.

Source	Type of water	Quantity/day mgd	Quantity/ MCM/a	% of total used
600 wells of which 300 are operating	Potable + Marginal	8	13.3	50
Public supply	Potable	4	6.6	25
Seih Al Miyah	Brackish	2	3.3	12.5
Sewage Treatment Plant	Recycled effluent	2	3.3	12.5
Total		16	26.8	

Source: Al Ain Municipality

Table: 8.20.

The quantities and sources of the types of irrigation water used by the Al Ain Municipality for landscaping, 1988.

The daily volume of irrigation water used for landscaping in Al Ain is made up of 3 types: Fresh/brackish ground, desalinated and recycled water. The 16mgd. supplied still fall short of the actual demand by about 10-20%. Potable water supplied by WED Al Ain forms more than 50% of the total daily volume of irrigation water used for the town's green reserves (1988).

8.3.4. Groundwater production for agriculture in the Al Ain region

The eastern part of Abu Dhabi emirate, the Al Ain region proper, is becoming more and more the area of most severe groundwater mining on an alarming scale. A large volume of groundwater is pumped annually across the whole region up to Al Khaznah in the west, Al Faqa' in the north, Um Ghafa in the southeast and Al Qoa' in the south. The groundwater volumes used by the various sectors involved in all kinds of agricultural activity will be considered in this discussion to try and assess the dimensions of groundwater abstraction by the agricultural sector. The main agricultural users of groundwater in Al Ain are:

i) Private and government farms, either directly managed, or guided by the Al Ain Department of Agriculture.

ii) Al Ain Municipality Horticultural Section.

iii) Large private farms.

iv) The Forestry Department of Al Ain (already discussed in Section 8.3.3.).

The situation can best be understood by the ensuing areal analysis of the production and use of groundwater for irrigation in the Al Ain region.

8.3.4.1. Groundwater abstraction for agriculture in the Al Ain town vicinity and the Al Jaww Plain

There are many private farms and government experimental stations, such as the Qattarah Agricultural Centre and the Um Ghafah Nursery (forestry), as well as several very large private gardens. The main agricultural activity in the Al Ain town area is date farming. The supply of irrigation water for the date gardens is provided by augmented falaj water, amounting to 5.0 mgd., from 3 sources. These are the brackish water from Seih Al Miyah Wellfield (2.0 mgd.), fresh water from the public supply from WED Al Ain (2.0 mgd.) and recycled sewage water (1.0 mgd.). Of these, the contribution from WED Al Ain (2.0 mgd. brackish from Seih Al Miyah, and 2.0 mgd. fresh, water) is included in

the total daily production of the public water supply, and that of recycled effluent with the daily output from that source, in the final water balance calculations (Chapter 10).

The total daily water used by the Horticulture Section of Al Ain Municipality is more than 16 mgd. (26.6 MCM/a, 1988), of which 56% is from groundwater sources from boreholes belonging to this division of the municipality. Nearly 300 boreholes, on average, are in operation daily out of 640 boreholes actually existing. The breakdown of the daily quotas, from each source irrigation water is obtained for the various landscaping projects within Al Ain town, is given in Table 8.20.

Al Jaww plain is one of the most densely drilled areas, similar to that around Kashoonah-Al Shuwaib further north. Boreholes are especially concentrated on the courses of the two wadi channels emanating from the Zarub and 'Ajran gaps, with a particular borehole concentration at Sa'ah and Um Ghafah. The main public supply wellfield of Um Ghafah (WED Al Ain) is situated on the southern wadi channel side by side with two extensive private gardens in Sh'ubat Salma (on Wadi Hamad channel). The 45 small agricultural holdings, belonging to the local inhabitants residing in the lch. village of Um Ghafah (agricultural plots of 120m X 120m with 1 or 2 wells each), are situated slightly away from the wadi channel on its northern bank.

Although the abstraction from the Um Ghafah public supply wellfield is carefully monitored, and the daily production kept at 1.5 mgd., heavy groundwater abstraction in the whole area for agricultural use is causing a major drawdown cone that has lowered groundwater levels away from the main wadi channels, and even extending to the area of the boreholes of the nursery farm of the Forestry Department and those within the small agricultural holdings. This negative trend, which started in 1985, had continued to worsen until the summer of 1988 when boreholes in the small holdings and the nursery ran dry. This necessitated the resort to road-tanker service to irrigate the cultivated areas and uproot all the date palms and transfer them to other areas with payment of compensation to their owners. In December 1988 a pipeline was laid down to transfer water of potable quality from the 600,000 gallon reservoir of WED Al Ain to these drought-stricken areas of southern Al Jaww. 0.54 mgd. (about 1.0 MCM/a) was delivered

every day. This quantity only met 60% of the daily agricultural demand of irrigation water of the small holdings and the forestry nursery (1988).

Abstraction in Al Jaww, in excess of 5.0 mgd. has almost led to the depletion of the Quaternary aquifer, and even of the deeper limestone aquifer in the Um Ghafah-Sa'ah vicinity. The inevitable result will be the eventual deterioration in quality both in the town and Al Jaww Plain areas (already happening) and also to the tragic diminution, or even total exhaustion, of falaj flow (Falaj Buraimi and Falaj Sa'arah in Omani territory). Furthermore, a reversal eastward brackish groundwater flow may occur that may change the quality of the remaining fresh groundwater, as is indicative in the rapid salinity increase, both in space and time, in the area. The estimated daily abstracted groundwater for all uses in Al Jaww is 5.0 mgd., which is apportioned between domestic and agricultural use on the basis of 1:4.

8.3.4.2. Groundwater abstraction for agricultural use in the northern and western dune areas of the Al Ain region

Agricultural centres such as Al Shuwaib, Al Hayer, Al Jabeeb, Al Faqa', Al Awha and Al Khadher-Suwaihan are all situated within the same area of the wellfields for public water supply of WED Al Ain. Agricultural boreholes, therefore, compete for groundwater of potable quality with those of the public supply. Water of the best quality in the region (500-600 mmhos/cm), from Ghashabah, has been used for wheat growing in the government farms at Al Awha since the beginning of wheat farming here in 1977, resulting over the years in a marked deterioration of groundwater quality. Wheat is a crop known to tolerate higher conductivity waters than these of Ghashabah.

As a result, groundwater levels have been rapidly declining in these parts, with an ever increasing percentage of unsuccessful wells in recent drillings. What is left of groundwater in storage is in an aquifer with low storage capacity (see Chapters 5 and 9). Conductivities have risen 4-fold since the development of groundwater resources in this area in the mid-1970s. Water in Al Shuwaib, one of the most recently developed abstraction areas (1988), is already becoming marginal in some

parts despite its close proximity to the Oman foothills. Further west, in Al Sad along the Abu Dhabi highway, apart from abstraction for domestic supply in Al Sad, Al Yahar and Haza' Al Boash, there is the abstraction by both agriculture and forestry. Farms are still being allotted in this area as late as the middle of 1989 when 350 new farms were handed over to owners. Each of these farms has at least one well.

The groundwater situation is delicate in this region because brackish water lies at shallow levels beneath the present aquifer immediately to the west of Al Ain. The failure of the old Al Za'alah wellfield at deeper levels (300/500m.) due to rising salinities, which led to the subsequent raising of the pump levels in the boreholes to higher levels (100-300m.), similar to those in the boreholes of Al Sad not far away, may eventually have serious repercussions by intercepting the westward groundwater flow in the Quaternary deposits from the recharge zone in the east to Al Sad wellfield. Equally, in the longer term, groundwater overabstraction in Al Shuwaib-Kashoonah and the whole eastern wellfields front, might deprive these western points of their slow-moving groundwater replenishment from the Oman mountain front to the east.

Abstraction centres such as Al Ushoosh and Al Khader Nassas are showing rapid deterioration in groundwater quality. The total volume consumed by agriculture in the northern and western dune areas is included in the gross volume of groundwater abstracted in the whole of the Al Ain region. (Section 8.4).

8.3.4.3. Groundwater abstraction for agricultural use in the southern desert of the Al Ain region

Although this area, which runs parallel to the border with Oman, passing through Al 'Arrad, Al Wagn and Al Qoa', is far from the mountain front to the east (150km.), renewable groundwater resources are available, even if of poor quality. Water generally tends to be brackish to saline and already substantial quantities are being used for agriculture. Areas of concentrated abstraction include Al 'Ajeer, Al Wagn (north and south), Seih Um Al Oash and Al Qoa' (formerly Medesees). The last place, is the centre of the heaviest abstraction in this region where more than

60 boreholes are located within an area of 8 km^2. In 1983, the Al Ain 2000 Master Plan (Water Utilities section) reported a total groundwater abstraction in the southern desert of 48.0 MCM/a or 16% of the total volume of groundwater abstracted by agriculture in the whole of the Al Ain region. Areas closer to Al Ain, with groundwater conductivities of more than 4000 mmhos/cm., are being heavily mined. The southern desert is going to be the next area of agricultural and forestry expansion and groundwater exploitation, and may gain more importance as the groundwater resources, potable and brackish, become depleted elsewhere in the Al Ain region.

8.3.5. Groundwater abstraction for agricultural use in the Northern Emirates

Abstraction of groundwater for agriculture is severe in the piedmont (gravel) plains in the traditionally important agricultural areas of Digdaga-Hamraniyyah in the northern, Falaj Al Mualla-Dhaid-Al Madam in the central and Al Ain in the southern, parts. The last area is outside the Northern Emirates and groundwater abstraction for irrigation in that area has already been discussed in Section 8.3.3.

In the recent past, the aflaj used to be suppliers of good quality, though uncontrollable, water (Chapter 4, Section 4.11) At present, apart from a few aflaj in the Northern Emirates such as Falaj Munai'ee, the waters they discharge are artificially augmented from boreholes near the mother well. As discussed in Chapter 4, most of the aflaj of Al Ain at present not only contain potable and brackish water from the public supply, but also a substantial amount of recycled sewage water (Chapter 4, Section 4.10.1). The water from various sources that makes up falaj flow is taken into account in the calculation of the total volumes of their respective sources in the groundwater balance calculation (Chapter 10). In the case of the Al Ain aflaj, these sources are WED Al Ain (potable/brackish water), the Horticulture Section of Al Ain Municipality (brackish/recycled water) and, in the case of Falaj Al Dhaid in the Northern Emirates, the source is the Sharjah Municipality (potable water).

Although the general trend is towards an increase in the area under cultivation, the exploitation of water to the limit is reflected in the shrinking of the cultivated area that was developed in the eastern agricultural region (largely the east coast) in 1975-76 (Table 8.21). The total area dropped from 2370.9 ha. in 1975 to 1632.1 ha. in 1977, in spite of the fact that it was the time when the oil revenues were at a peak. The worst drop was in the northern agricultural region (Ras Al Khaimah) between 1981, when the total acreage was 8133.8 ha., and 1984 when it was 7293.3 ha., and finally 1986 when it became 7604.7 ha. It recovered by 1987, but only to the 1981 level, as seen in Table 8.21, which shows the shrinkage in the total cultivated area due to water shortage and rising groundwater salinities in the northern and eastern agricultural regions in the Northern Emirates.

8.3.6. Natural discharge of the aflaj of the Emirates

As discussed in chapter 4, most of the aflaj at present no longer maintain natural, but artificially augmented, flows from several sources, most of which are from groundwater boreholes. In the Northern Emirates, augmented falaj flows are limited to Falaj Dhaid, but in Al Ain augmentation is widespread (discussed in Chapter 4, Section 4.10.1). Aflaj partly destroyed by floods are no longer repaired with the same speed as that before 1982 because of stringent budgetary measures and acute groundwater level recession.

The overpumping in wadi flood plains, terraces and the piedmont plains at the foothills of the main mountain block, where the larger aflaj used to be, and the eventual consistent decline of groundwater levels, have rendered these traditional means of water supply redundant or, at the best, with greatly reduced and unreliable flow. Table 8.22. illustrates this for a number of aflaj in the Northern Emirates with flow measurements for the years 1985, 1987 and 1988.

Naturally, falaj flow fluctuates widely, affected by both the rainfall received in a particular year or series of years and also by damage to the falaj tunnel by strong floods in exceptionally rainy years. This makes falaj flow measurement impossible. Table 8.23 shows the two characteristics of falaj flow: its extreme fluctuation and severely

	Northern	Eastern	
1973	5711.0	2911.0	
1975	6512.5	2370.9	
1977	7355.4	1632.1*	
1978	7388.0	3013.8	
1980	7478.0	3244.4	
1981	8133.8	3244.4	
1982	7293.3*	3341.7	* years of shrinkage of agricultural acreage in relation to a preceding year
1983	7293.3*	3613.2	
1984	7292.9*	3613.1	
1986	7604.7*	4434.2	
1987	8120.0	4531.0	
1988	8203.0	4600.0	
1989	8666.0	5051.0	(in hectares)
Source: Ministry of Agriculture and Fisheries.			

Table: 8.21.

Shrinkage in agricultural acreage because of groundwater shortage in the Northern and Eastern Agricultural Regions.

The agricultural area receded in the Northern Agricultural Region by 10% between 1981 and 1982, and remained so until 1987 when it returned to the size of 1981. This was due mainly to acute groundwater shortages (coinciding with the period of drought 1983-86) but also to crop failures and the gradual withdrawal of federal farm subsidies. The recession in the agricultural area in the Eastern Agricultural Region by 31% between 1975 and 1977 was also partly due to water shortage problems but mainly due to local farmers leaving the region to join jobs in the federal establishments. The recovery and expansion of agricultural acreage was largely due to inflow of capital by the same farmers from their new jobs. The water shortage problem still remained.

Falaj	1985	1987	1988 (month after the heavy Feb. rains)
Huwailat	0.006m^3/sec	0.089m^3/sec	0.044m^3/sec
Rafak	0.009 "	0.111 "	0.032 "
Shafqa	DRY IN 1985-86	0.043 "	0.041 "
Warrah	DRY IN 1985-86	0.024 "	0.14 "
Sagheer	DRY IN 1985-86	0.007 "	0.021
Masfut Nuslah	DRY IN 1985-86	-	DISLOCATED BY FEB. 1988 FLOODS.
Source: Ministry of Agriculture and Fisheries.			

Table: 8.22.

Dwindling natural falaj flow in some of the aflaj of the Northern Emirates that still have natural flow, 1985-1988.

The overpumping of groundwater and the continuous decline of water-tables have rendered these once traditional means of water supply redundant or with greatly reduced and unreliable flow.

shrinking flow. The latter characteristic is also influenced by receding water-tables, leaving falaj tunnels 'hanging' above static water levels for most of the year, and experiencing limited flows only during the rainy season when there is some base-flow in the wadi deposits in which falaj tunnels are excavated.

The present state of all the aflaj in the Emirates is discussed in detail in Chapter 4 and their actual natural flow is given in Table 4.17. The mean annual natural flow from all the aflaj of the Emirates, including those in Al Ain, total **13.02 MCM/a**.

The MAF is the only source of falaj discharge data. Such data should be handled with caution, especially with regard to the Al Ain aflaj most of which, at present, have artificially augmented flow from boreholes (fresh and brackish), desalinated and even treated sewage water. The data prepared by the MAF make no note of such artificial augmentation and present the total discharge volumes as though they are natural. The 13.02 MCM/a. natural falaj flow volume is included in the final groundwater balance calculation (Chapter 10).

8.4. Quantification of groundwater abstraction for agricultural use

8.4.1. General

In view of the unavailability of groundwater flow measurement from agricultural wells, and also the lack of accurate statistics concerning the total number of such wells, the actual volume of groundwater abstracted for agricultural use is extremely difficult to determine. The attempt made for this study to find out the sources and the quantities of groundwater abstracted from them and also the various types of agricultural application these waters are put to, is only a modest step in the right direction. However, it entailed an immense effort in measuring and observing abstraction points (of more than 900 wells all over the Emirates) and the use of their water.

Two methods of quantifying agricultural abstraction are presented by the present study. These are:

1) That of the gross irrigation requirements of the cultivated acreage, whether agricultural, forestry or recreational.

2) That of the actual borehole discharge measurement in all types of wells (agricultural, forestry and recreational).

8.4.2. Irrigation water requirements

8.4.2.1. Potential evapotranspiration and irrigated crop water requirements

Evapotranspiration and irrigated crop water requirements are important factors in the evaluation of water resources. This is particularly significant when the official national policy is geared towards continued expansion in agriculture, the demand for irrigation water of which increases the pressure on the groundwater resources.

Quantifying both evapotranspiration and crop water requirement presents a number of difficulties. Firstly, the Penman formula used for evaporation is designed to measure potential evapotranspiration with reference to a short green crop for a period not less than 10 days. It is therefore of limited validity when applied to extremely arid conditions. There is also the assumption of unlimited water supply. In practice in arid regions, neither is the water plentiful nor do economics allow optimum growth of crops. The aim is to get maximum yields per unit of water. Furthermore, there is the complication arising from considering optimum economic water use rather than potential evapotranspiration rates as this brings in physiological factors that determine how crop yields respond to water requirements. Experiments relating to crop water requirements have proved that different crop species respond differently to the same irrigation treatment.

Doorenbos and Pruit (1975) adapted Penman's formula by computing the potential evapotranspiration with an appropriate albedo (a measure of the reflected incident radiation from a surface, of about 25% reflection) for a green crop, which took into account the variation in day and night time wind speeds and correction factors based on the prevailing trends of temperature, wind and humidity. With the knowledge

of the growing stages and seasons of local crops, a list of crop factors from FAO's worldwide experience was applied to values of potential evapotranspiration.

This adapted potential evaporation version was tested for 3 years in an arid environment under extreme advective conditions and was found to correspond closely to measured values. When, however, it was applied to irrigated crops in eastern Saudi Arabia, it was found that the formula overestimated potential evapotranspiration by 25% in a 24-hour period. This is not surprising due to the fact that the Penman equation for evapotranspiration was designed for periods of not less than 10 days.

In computing crop water requirements for the Emirates, Prashar and Thanki (FAO, 1978) considered 10-day estimates of potential evapotranspiration for all the regions of the Emirates and applied them to crop irrigation requirements on a 10-hectare farm. Monthly potential evapotranspiration values were used for determining the irrigation requirements. The crop evapotranspiration(1) values were corrected for advection and peak period requirements. The advection correction was warranted due to the distance between the farms in such an arid environment as that of the Emirates. The peak water use correction was to account for the low balancing effect of loamy sand soils. The total water requirements of the main crops grown in the four agricultural regions of the Emirates, prepared by Prashar and Thanki, are given in Appendix 4.

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(1) Crop evapotranspiration is defined as the rate of evapotranspiration of a disease-free crop growing in a large field (of one or more hectare) under optimal soil conditions, including sufficient water and fertilizer and achieving full production potential of that crop under the given growing environment; includes water loss through transpiration by the vegetation, and evaporation from the soil surface and wet leaves; in mm/d.

8.4.2.2. Quantification of groundwater abstraction for agricultural use by the gross crop irrigation requirements

Several tentative attempts to determine the crop water requirements for different crops in the agricultural areas of the Emirates have been carried out by the FAO cooperation programme with the MAF between 1977 and 1984. The estimates of the crop water requirements produced, however, were inadequate owing to the limited period of meteorological data of only 4-8 years (MAF-FAO, Crop Water Requirements in the UAE, Technical Report No. 2, May 1978 p.30). Another attempt was made by the Department of Agriculture in Al Ain, using FAO criteria based on the Penman method, which estimated evapotranspiration from a short green grass assuming availability of water and taking into account the effect of all the meteorological elements of radiation, sunshine hours, humidity and wind speed (FAO, Irrigation and Drainage Paper 24, 1977).

The gross irrigation crop water requirement is defined as:

> "the depth of water required to balance evapotranspiration less the contribution by effective rainfall, groundwater and soil moisture"
>
> (Crop water requirements in the UAE , FAO-MAF, Technical Report No. 2, May, 1978)

These water requirements should be sufficient for normal crop production taking into account leaching, water losses and waste; the gross crop water requirement is expressed in millimetre/ day (mm/d). The calculation of such crop water requirements includes farm irrigation efficiency which, in turn, is determined by considering the effectiveness of the conveyance of irrigation water and its application on the cultivated area. With regard to the latter, the field application efficiency for fully grown citrus trees was determined by the FAO as 0.5 in the case of the traditional open basin and furrow (inundation)irrigation system, and 0.75 in the case of the modern drip, sprinkler and bubbler irrigation methods in Digdaga in the northern piedmont plains (FAO-MAF Technical Report No. 3, 1980). As the agricultural land applying the traditional irrigation methods in the Emirates makes up 90 % of the irrigated acreage, and that using modern

techniques only 10 %, the average farm irrigation efficiency was given as 0.45 (FAO-MAF, Technical Report No. 3, 1980).

Based on the FAO Technical Report No. 7, (1984), which gave crop coefficients (the ratio between crop evapotranspiration and the reference crop evapotranspiration when the crop is grown in large fields under optimum growing conditions) in Digdaga, using the MAF distribution and total area of agricultural land for the year 1987-88 and applying average gross crop water requirements for each of the agricultural regions (with agricultural land under vegetables, fruit trees, field crops and other types, as classified by the MAF statistics), the gross annual volume of crop water requirements has been calculated for this study for each of the 4 agricultural regions as given in Table 8.24.

As seen in Table 8.24, the gross annual crop water requirement for the cultivated areas in the whole of the Emirates is 1788.3 MCM for the agricultural year 1987-88. Of this volume applied on crops, a certain percentage is expected to percolate back to the water-table. For this irrigation return, a value of 8% of the total gross water requirement volume has been used by the present study in the groundwater balance calculations (see Chapter 10). This amounts to 143.1 MCM/a. This is subtracted from the gross crop irrigation water used leaving a net crop water requirement volume for 1987-88 of **1645.2 MCM.**

An attempt has been made by the Agriculture Dept. of Al Ain to quantify the annual crop water requirement for each crop grown in the Al Ain region (which forms the eastern part of the Western Agricultural Region as classified by the MAF) according to the method of irrigation used and based on the total area (in hectares) put under each type of crop for the year 1987-88. The result of this calculation is given in Table 8.25. As seen from the gross annual volumes of irrigation requirements for the same crops by the different irrigation methods in Table 8.25, it is clear that the sprinkler method saves 20%, and the drip 30%, on water that is otherwise applied on the cropped land by the traditional basin inundation method.

The main shortcoming in attempting to quantify the total volume of irrigation water by means of the gross crop water requirements is the accuracy of official statistics concerning the cultivable area and

1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	
10.96	7.74	7.29	8.2	11.01	23.39	16.20	16.03	7.95	4.03	16.98	11.10	MCM/a

Source: Ministry of Agriculture and Fisheries

Table: 8.23.

Fluctuation of Falaj discharge volumes in the aflaj of the Northern Emirates still with natural flow, 1977-1988.

Natural falaj flow fluctuates widely affected by both the rainfall received in a particular year, or series of years, and also by damage to the falaj tunnel by strong floods in exceptionally rainy years that renders flow measurement impossible. Shown in Table 8.23 are the two characteristics of falaj flow: its extreme fluctuation and dwindling flow.

Agricultural region	Total cultivated area (in ha)	Av. daily crop water requirement (mm/day)	Av. annual crop water requirement (mm/annum)	Gross annual volume required (MCM/a)
Northern	8203	9.3	3395	278.5
Eastern	4600	10.7	3906	179.7
Central	12,931	12.1	4417	571.2
Al Ain	11,815	13.0	4754	560.6
Western Abu Dhabi	4025	13.5	4928	198.3
Total/Average	41,574	11.72 (Av.)	4278 (Av.)	1,788.3
		8% percolating into the water-table		143.1
		Net annual crop water requirement		1,645.2 MCM/a

Table: 8.24.

Quantifying the total annual volumes of groundwater used by agriculture in the Emirates on the basis of the gross crop water requirements, 1988.

Calculating the gross crop water requirement needs accurate meteorological and agricultural data, which are not of the satisfactory level in the Emirates, to derive a reasonable figure for the volume of water consumed by agriculture. Calculations made on the basis of the total agricultural land area may lead to a high water estimate; calculations made on the basis of only the cropped area may lead to low water estimates. Still a lot of the water used on the farms, or elsewhere on land classified as agricultural, goes unaccounted for. Furthermore, calculations of the crop water requirements are arithmetic means; what does take place in agricultural water use in reality is different from theoretical calculations and requires only direct measurement in the field.

Crop	Area cropped (hectares)	IRRIGATION METHOD		
		Open basin	Sprinkler	Dripper
		(in million cubic metres/annum)		
A. Field crops:				
Wheat	1877.0	11.70	9.30	0.4
Broad beans	21.5	0.11	0.082	0.65
Maize	120.6	0.93	0.74	0.59
B. Vegetable crops:				
Tomatoes (ordinary)	543.0	6.80	5.40	4.80
Tomatoes (hybrid)	237.0	2.20	1.70	1.50
Aubergenes	150.0	1.50	1.20	1.10
Paprika	45.0	0.50	0.40	0.40
Potato	194.0	0.80	0.60	0.50
Squash	246.0	1.70	1.30	1.20
Musk melon	124.0	1.10	0.90	0.80
Water melon	118.0	1.30	1.20	0.90
Cucumber	55.0	0.41	0.33	0.30
Green chillies	110.0	0.64	0.51	0.59
Pumpkin	9.5	0.064	0.051	0.045
Cabbage	208.0	0.92	0.73	0.65
Cauliflower	211.0	1.21	0.97	0.85
Radish	75.0	0.31	0.24	0.22
Turnip	92.0	0.53	0.42	0.37
Dry onions	160.0	0.94	0.75	0.66
Leek	0.6	0.002	0.002	0.002
Beans	49.0	0.27	0.22	0.19
Black-eye peas	115.0	0.83	0.67	0.59
Peas	14.0	0.08	0.07	0.06
Carrots	142.0	0.89	0.72	0.63
Spinnach	51.0	0.14	0.11	0.10
Lettuce	81.0	0.30	0.24	0.21
Coriander	14.0	0.034	0.027	0.024
Parsley	28.0	0.26	0.21	0.18
Beet	44.0	0.17	0.14	0.12
Chard	49.0	0.41	0.33	0.29
Marsh melow	149.0	1.94	1.56	1.37
Dill	2.3	0.013	0.010	0.009
Water-crest	4.2	0.022	0.020	0.020
Bottle-neck gourd	6.7	0.053	0.42	0.34
Okra	95.0	1.180	0.94	0.75
C. Perennial crops:				
Alfalfa	1542.0	50.26	40.21	35.48
Citrus	187.0	5.52	4.42	3.90
Gross annual volume	7175.1	96.40	76.60	66.70

Source: Irrigation Section, Al Ain Department of Agriculture.

Table: 8.25.

Quantifying the crop water requirements by the traditional open basin (inundation), and the modern sprinkler and drip irrigation methods on the basis of the actual land area under each type of crop grown in the Al Ain region, 1987-88.

Using the Penman method for calculating the crop water requirements, which is based on the assumption of a short green crop supplied continuously with water, this attempt to calculate the crop irrigation requirements by the Al Ain Department of Agriculture by the 3 irrigation methods relied on a short-period climatic data. The calculations revealed that the sprinkler method saved 20% and the drip method 30% on water supplied to the cropped land by the traditional open basin flooding method.

details of the types of crops grown that require different quantities of irrigation water. Calculations made on the basis of crop water requirements using the total agricultural land area, that is the total area of all the agricultural holdings, cultivated or not, per region, may give a high estimate. Conversely, calculations based on the total area under cultivation may lead to a low one. The remaining area of a farm that is not put to either vegetable, fruit, tree or summer or winter field crops does not necessarily remain fallow or unused at all. Neither does it mean that no water of one type of application or another is not used on it.

It was observed that water in some farms was being applied to uncultivated soil to stabilize it, in others grass was grown in lawns to which water was applied by spraying or sprinkling; yet, both cases do not go down in the MAF registers as land under cultivation or, in the case of the former, land where water was being used.

The statistics concerning the area under actual cultivation are prepared by the area agricultural offices at Al Dhaid, Digdaga and Fujairah for the central, northern and eastern agricultural regions respectively. Those statistics for the western agricultural region, namely Al Ain and Liwa/Ghayathy, are prepared by the Al Ain Department of Agriculture and the Agriculture Office in Bida' Zayed, respectively. These data give the type of cultivation and the total area of land under each type. Table 8.26 shows the percentage of the cultivated area out of the total agricultural land for 1987-88 for all the agricultural regions of the Emirates.

The data for the total area actually cultivated for the year 1987-88 were made available for the present study by the regional agricultural offices during field visits. Most of the raw data are usually sent to the Central Computer Centre of the Ministry of Planning in Abu Dhabi and are usually published one year after the end of the agricultural year (October-September). With information from the surveyors' offices of local municipalities concerning gardens and farms allotted to owners during 1987-88, which forms the balance between the 1986-87 and the 1987-88 total of cultivated area, the remainder was added to the 1986-87 total area of farmland in order to calculate the gross volume used on the basis of the total area of the agricultural land (as against that of

Agricultural region	% out of the total agricultural area	
	Cultivated	Uncultivated
Central	64%	36%
Northern	48%	52%
Eastern	73%	27%
Western:		
Al Ain	38%	62%
Western Abu Dhabi	50%	50%

Source: Ministry of Agriculture and Fisheries/ Al Ain Agriculture Dept.

Table: 8.26.

The percentage of the cultivated and uncultivated area out of the total agricultural acreage in the agricultural regions of the Emirates, 1987-88.

The percentage of the cultivated to the uncultivated area clearly reflects the groundwater shortage problem in the Northern Emirates as can be seen from the ratios for both the Northern Agricultural Region where water shortages are acute. The same is true in the Western Agricultural Region of Abu Dhabi where the initially brackish groundwater becomes more saline with pumping, thus limiting sustenance of the same cultivated area for long. In the Al Ain region there has been an 8% shrinkage in the total agricultural area in only 1 year between 1987 and 1988, which affected the acreage of the government projects such as the wheat farms. The main reasons for such a shrinkage of the agricultural land were both depleting groundwater resources and the rising salinity of the irrigation water.

the total area of actually cultivated land).

The gross crop water requirements attempted by the FAO (Technical Report No. 2, 1978) for a 10-day period are arithmetic means of a limited number of years for which meteorological data were available. The longer the meteorological records the more accurate these crop water requirement means are going to be. In addition, a great deal of accuracy in terms of crop types and the exact area of land under them, as well as accurate evaporation and evapotranspiration and soil moisture measurements would be required. All these prerequisites cannot be provided in the Emirates at present, due to the lack of most of the agrometeorological data required, to make accurate crop water requirement calculations.

8.4.3. Quantification of groundwater abstraction by agriculture by borehole discharge measurements (Table 8.27)

The other method of quantifying the total amount of water abstracted by agriculture, carried out for the present study, is by determining the actual groundwater volumes discharged by wells in each of the agricultural regions by averaging well-discharge rates from a large number of wells in farms in an agricultural region. This takes into consideration the duration of borehole operation, which was observed to vary from 4 hours a day in winter to 24 hours a day in summer in nearly all localities. If well-discharge measurement is done properly, it is the correct approach to quantifying the abstracted groundwater volumes since it relates to the actual abstracted amounts without being limited to one form of use. Estimates based on crop water requirements, on the other hand, are strictly arithmetic means limited to the amount of water required by a certain crop. In reality, wells are drilled for several uses and as the farms or gardens are largely recreational (non food-producing), then groundwater from these boreholes may go to various outlets other than agricultural, such as, for example, swimming pools within these farms/gardens.

Groundwater abstraction measured at the well-head is the more acceptable quantification of the two methods. There is, however, an absence of flow-meters on nearly all agricultural boreholes in the Emirates and the

discharge rates, sought to work out an estimate based on well output, were not available. Well discharge test results, that may be available, are for initial stages of well development, and not necessarily accurate or of the required quality in terms of duration of the test (if it took place at all). The discharge rates available with the MAF are for deep exploratory wells (of the Deep Wells Project, 1982-86), which cannot be taken as representative as the majority are deeper than the producing wells in the farms around them.

Measurement of well discharge rates was carried out for this study during the period June to November 1988 using 3in. and 4in. Kent Helix flow-meters to fit the two pipe sizes normally used in the boreholes all over the Emirates. Each time, the flow-meter was screwed onto the threaded end of the borehole galvanized pipe at the flange, then unscrewed to be used on another well. In the absence of a threaded outlet, water flow was measured by filling a 44-gallon plastic barrel. This was repeated several times to reach a stable filling time, or several such filling-durations were averaged to obtain a mean filling time. As this was not a well-test that might require a longer time for measuring the discharge from a well, an hour or so was adequate to establish the rate of discharge per minute or hour for the purpose of deriving the total volume produced from a well in a day. Enquiries were made to farmers, farm labourers ('baidars') or the agricultural area office staff about the possible running duration of pumps. Generally, the daily pump operation for the whole Emirates varied from an average 7-10 hours in a winter, to 12-15 hours in a summer, day; giving a flat average rate throughout the year of an 11-hour well-operation day.

The measurements revealed extreme variation in the discharge rates, in some places in boreholes within the same farm or garden. However, variation over wider distances were well established. In a farm in Al Dhaid there were two boreholes, one was 240m. and the other 300m. deep, and the discharge rates were 39.5m^3/hr. and 15.0m^3/hr. respectively. In another garden, also in Al Dhaid with two wells both 180m. deep, there were discharge rates of 25m^3/hr. and 15m^3/hr. Both pump-sets were of the same brand and power, fitted on 4" galvanized pipes at the two well-heads. However, discharge rates of up to 35m^3/hr. or even 40m^3/hr. were measured in many points in the Central Agricultural Region. In farms not far from Hamdah (Sharjah public supply wellfield) discharge

rates in boreholes measured were as low as $10m^3$/hr. in 5 out of 8 boreholes. Such low discharge rates are typical of boreholes in locations close to the foothills where the alluvial deposits have low storage capacity. Furthermore, although these discharge rate tests were carried out on private wells in the Hamdah area, they conformed with the continuously decreasing discharge rates of the boreholes of the Sharjah Hamdah public supply wellfield discussed in Section 8.2.2. They also conformed with those that had been established in well pump tests in the newly developed Al Shuwaib wellfield in the Al Ain region along the same foothill zone further south.

It was interesting to observe the means followed by operators in farms to measure well discharge by whether the water flow was "with the full pipe" (i.e. water gushing through the full diameter of the 4" pipe solidly) or partial discharge flowing out at three-quarters, half or even less (of the diameter of the pipe) during periods of prolonged drought or near the end of the life of a well, at least at the level in the aquifer from which that well was pumping.

The widest variation in the discharge rates was found in Liwa where low rates of below $13m^3$/hr. were measured in shallow boreholes drawing water from clayey sabkha strata, as at Hisan (formerly Himar) in Western Liwa, and in locations nearer sabkhas. Higher rates in excess of $41m^3$/hr. were measured at Al Mariyah (East) in western Liwa, and $54m^3$/hr. at Dhafeer, a short distance away.

The discharge rates of the wells in each of the agricultural regions were averaged, together with the daily well operation duration. The latter was taken as 11 hours per day as the average well-running time in all the regions, although pumps were observed operating for up to 24 hours in, for example, Liwa, during the summer days. In Liwa and Al Ain wells were operated every day of the year in farms where there were date palms. Wells that might otherwise be allowed to rest for a day or two during the winter months (December to March) were made to run every day to supply water on the basis of one day to crops and the following day to the date palms. Wherever there was alfalfa grown, the wells were worked the whole time, as this crop is the largest single consumer of water in a small acreage in the Emirates (refer to Table 8.25).

	Agricultural Regions				
Parameter	Northern	Central	Eastern	Western	
				Al Ain	Liwa/Ghayathi
Average well discharge rate	25 m^3/h	24 m^3/h	20 m^3/h	24 m^3/h	26 m^3/h
Average running hours per day[1]	11	11	11	11	11
Average daily discharge per well	275 m^3/d	264 m^3/d	220 m^3/d	264 m^3/d	286 m^3/d
Well operation - days in the year	365 days	365 days	365 days	365 days	365 days
Average annual discharge per well	100,375 m^3/y	96,360 m^3/y	80,300 m^3/y	96,360 m^3/y	104,390 m^3/y
Total Number of operating wells[2]	3011	7785	4752	5615	4400
5% more for expected actual number	3162	8174	4990	5896	4620
Average gross annual discharge MCM	317.39	787.65	400.70	568.14	482.28
Gross annual volume abstracted for agriculture from 26,842 agricultural wells is 2556.16 MCM					

(1) Well operating hours range from 4 to 24 hrs. 11 hrs. is a medium between winter min. and summer max. operation
(2) Statistics from Gov't Central Computer Office in Abu Dhabi; Basic data supplied to it from agricultural depts.

Table: 8.27.

Results of the well-discharge tests from irrigation wells in the different agricultural regions of the Emirates, 1988.

These well-discharge tests were carried out using 3" and 4" Kent flow-meters to fit the two typical pipe sizes usually used in boreholes in the Emirates. Only 5% was added to the total number of agricultural wells as there was (and still is) an unknown number of uncounted wells. Thus the volumes of groundwater presented in this table, though they may appear large, are still somewhat underestimates of the groundwater volumes actually abstracted by agriculture. The heaviest groundwater abstraction by agriculture is in the piedmont plains of the Northern Emirates (the Central Agricultural Region), the east (Batinah) coast (the Eastern Agricultural Region) and the Al Ain region of Abu Dhabi or the southern piedmont plains (the Western Agricultural Region), which are all areas of depleted fresh groundwater resources.

Thus, all the days in the year are taken as well-operating days, the total number of wells in each area was used taking into account all the wells as far as possible (MAF, local departments and private agricultural wells). The average results of the flow measurements undertaken in each region are summarized in Table 8.27., which presents the calculated estimates of the gross annual groundwater abstraction by agriculture, based on actual discharge measurements, favoured by the present study and used in the final groundwater balance calculations of the whole Emirates (Chapter 10).

8.5. Desalinated water production and use (Fig. 8.5.)

8.5.1. General

The distillation of seawater has, in the last 8 years, provided the complete daily water needs, domestic and industrial, for the town of Abu Dhabi; about 85% for Dubai and 45% for Sharjah (1989). This has relieved the pressure on the wellfields that would, otherwise, have had to meet the demand. The development in the production of desalinated seawater has been so substantial and successful in both Abu Dhabi and Dubai that the trend seems to be for more development of this sector of water resources throughout the 1990s.

8.5.2. Desalinated water production and use in Abu Dhabi emirate

The first desalinated seawater plant started in Abu Dhabi in 1969 with a total output of 2.0 mgd. Prior to that, a similar amount of groundwater was transported by pipeline from Al Sad in Al Ain to Abu Dhabi. By 1974, 10 mgd. of desalinated water were being produced. In 1977 alone, the production increased between March and September from 15.0 mgd. to 24.0 mgd. following the installation of 4 Sidem distilling units.

This development in desalination had been in the Gas and Steam Turbine Stations in the centre of Abu Dhabi town until 1979 when Um Al Nar (East) came into operation with 3 Sidem distilling units of 5.0 mgd. each, increasing the output to 39.0 mgd. Um Al Nar (West) became operational in 1980 with 4 IHI (ISHIKAWAJI MAHARIMA HEAVY INDUSTRY CO.

(JAPAN) LTD.) distilling units of 4 mgd. each, thus enhancing the capacity to 63.17 mgd. (104.8 MCM/a). In 1984, 2 Weir Westgart units, of 2.0 mgd. each, were retired. Since then, the development has been in the two Um Al Nar Power Stations (East and West) until the total installed daily desalination capacity for Abu Dhabi reached, in January 1988, 97.0 mgd. with an average actual daily production during the summer of 1989 of 83.0 mgd. (137.7 MCM/a).

The development in desalination at present is at Al Taweelah on the Gulf coast, half-way between Abu Dhabi and Dubai. There are two phases to the development: Phase 'A', which was completed in mid-1989, is producing 18-20 mgd. (1990); and Phase 'B', which is to be completed by 1993, would have a capacity of 40.0 mgd. With the commissioning of Phase 'A' at Al Taweelah, the total installed daily desalination capacity of Abu Dhabi has been raised to 117.0 mgd. (early 1990), while the actual daily output throughout 1990 averaged 90.0-93.0 million gallons. The 83.0 mgd produced throughout 1989, like the 93.0 mgd produced throughout 1990, met not only the domestic and industrial water demand of Abu Dhabi and its outlying satellite villages, but also part of the irrigation demand of the horticultural and forestry areas within the town and along the Abu Dhabi-Dubai highway and an export of 14.2mgd to Al Ain. Table 8.28 shows the development in the installed capacity of the Abu Dhabi desalination plants, their type and number of units within each plant since 1970.

The Steam Turbine Station in Abu Dhabi town produced all the desalination water for Abu Dhabi until 1979. Since then the two Um Al Nar Gas and Steam Turbine Stations have been expanding, taking the larger quota of the daily desalinated water production in Abu Dhabi (84%). Table 8.29 gives the production of each desalination plant in its respective power plant, in and around Abu Dhabi, and the percentage of that produced by each plant of the total produced by all the plants for 1987 and 1988. This is also illustrated graphically in Figure 8.4.

The production of the solar energy desalination plant in Um Al Nar (South) is 17,600 gallons/day, and that from the Sa'adiyat diesel station (SDS) is 64,000 gallons/day or 0.02% and 0.06% of the total desalinated seawater output in Abu Dhabi (1988).

Year	Station/ Plant	Manufacturer of evaporator unit	Unit Capacity mgd	Cumulative Capacity mgd
1970	GTS	Weir Westgart	2x2	4
1971	GTS	Weir Westgart	2	6
1973	GTS	Weir Westgart	2	8
1974	GTS	Weir Westgart	2	10
1976	GTS	Weir Westgart	2	12
1977	STS	SIDEM	4x3	24
1979	UNE	SIDEM	3x5	39
1980	UNW	IHI	4x4	55
1981	UNW	IHI	2x4	63
1984	GTS	2 Westgarts retired	-4	59
1984	UNS	Solar	0.02	59.02
1985	UNW	SIDEM	5	64.02
1986	UNW	SIDEM	3x5	79.02
1987	UNE	Italimpianti	2x6	91.02
1988	UNE	Italimpianti	6	97.02
1989	Taweelah 'A'	SIDEM	3x6	117.02

GTS= Gas Turbine Station/ STS= Steam Turbine Station/ UNE= Um Al Nar East/ UNW= Um Al Nar West/ UNS= Um Al Nar South.

Weir Westgart(British), SIDEM(French), IHI(Japanese), Italimpianti (Italian).

Source: WED Abu Dhabi, Power and Desalination Dept.

Table: 8.28.

The development of the installed desalinated water production capacity in Abu Dhabi, 1970-1989.

The installed desalinated water production capacity in Abu Dhabi increased 30 times between 1970 and 1989. Of the units, the French SIDEM evaporators produce 57%, the Japanese IHI 20% and the Italian Italimpianti 15%, of the total daily desalinated water output. The trend in the 1990s will be to concentrate production outside the town limits of Abu Dhabi, as is happening at Al Taweelah 'A' and 'B' phases, which, by 1993, are going to produce 60mgd. or 41% of the total daily volume of desalinated water of Abu Dhabi. This will be on a single site with evaporators of the same manufacturer (SIDEM).

Plant	1987			1988		
	mgd	% of total prod.		mgd	% of total prod.	
GTS	1.47	2.29		0.088	0.11	
STS	10.41	16.21		13.64	16.36	
UNE	20.00	31.13	83%	31.02	37.20	84%
UNW	32.29	50.26		38.58	46.26	
UNS	0.017	0.026		0.014	0.017	
SDS	0.052	0.08		0.053	0.064	
Av. daily prod.	64.24			83.40		
Source: Power and Desalination Dept. Statistical Year Books 1987-88						

Table: 8.29.

The daily production of desalinated water of the 6 plants in Abu Dhabi, and the percentage of each from the total daily output for 1987 and 1988.

The 2 Um Al Nar desalination plants produced in 1988 84% of the total daily desalinated water output. This has been reduced to 60% since 1989 when the Al Taweelah plant started to produce 20mgd. (18% of the daily output of Abu Dhabi).

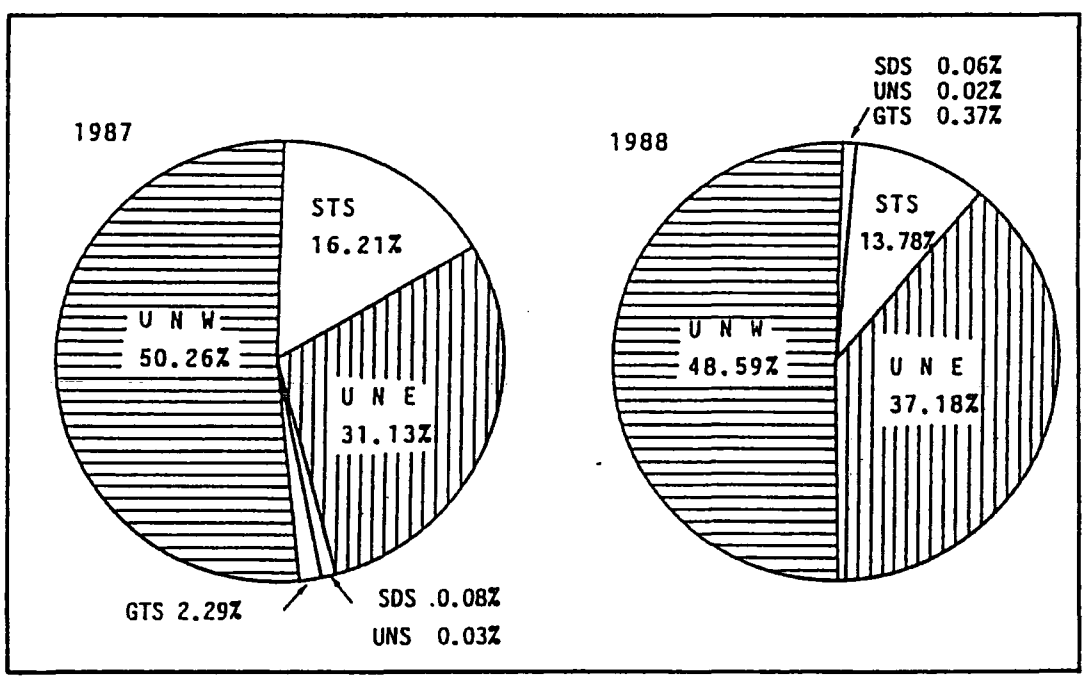


Figure: 8.4.

Graphical representation of the daily production of desalinated water in the 6 power and desalination plants of Abu Dhabi for 1987 and 1988 (as given in Table 8.29).

Nearly all the desalinated water produced is supplied to consumers with only a tiny fraction of the total daily output retained for use within the plants. The most important contribution by the desalination production of Abu Dhabi is the export of such water to Al Ain, which has amounted to between 14-15 mgd. throughout 1989 and 1990. Table 8.30 shows the development of desalinated water production in total output, that which is actually supplied to the distribution system, and that exported to Al Ain (1973-88).

The actual per capita consumption in the town of Abu Dhabi increased from 67 lpcd. in 1974 to 317 lpcd. in 1987. This excludes losses in the distribution system, estimated to be between 10-15%, and water supplied to Al Ain (14.2 mgd.), but includes the output by the Sa'adiyat Island desalination plant.

Table 8.31 presents all the desalination plants in the emirate of Abu Dhabi for 1989. These include the main desalination plants managed by the Power and Desalination Section of WED Abu Dhabi, those in the remote areas, also managed by WED Abu Dhabi, the plants managed by the Abu Dhabi National Oil Co. (ADNOC) and the plants in the eastern region of the emirate (Al Ain) as well as the planned desalination units.

8.5.2.1. Small desalination plants in the emirate of Abu Dhabi

The existing producing desalination plants in the remote areas of Abu Dhabi, managed by WED Abu Dhabi, are included in group 2 in Table 8.31, which gives the location of the desalination plants, the number of units and their production capacity, the manufacturer, the type by the distilling process and the daily total output produced in million gallons per day in each station, whether it has a single or a group of units. All these plants are also shown in Figure 8.5. In Table 8.31 also are the desalination plants serving ADNOC in their oilfield camp sites, petroleum and marine terminal facilities. The total daily output from the 3 plants at Al Ruwais is 11.5 mgd. (19.1 MCM/a) produced by the seawater multi-stage-flash (MSF) process.

Desalinated water produced by the small desalination plants outside Abu Dhabi, managed by WED Abu Dhabi, amounts to 9.1 mgd. (15.03 MCM/a) from

Year	Daily prod. mgd	Daily supply mgd	Net supply to Abu Dhabi town mgd	Export to Al Ain mgd
1973	4.21	-	-	-
1974	5.23	-	-	-
1975	5.64	-	-	-
1976	7.25	-	-	-
1977	10.65	-	-	-
1978	14.50	-	-	-
1979	21.10	20.76	20.76	-
1980	30.04	28.96	28.96	-
1981	35.89	34.38	34.38	-
1982	40.99	39.37	39.37	-
1983	42.50	41.42	41.10	0.321
1984	46.13	44.46	43.10	1.36
1985	49.06	47.80	46.14	1.65
1986	55.83	54.63	49.13	5.72
1987	64.25	53.17	52.30	10.86
1988	73.70	72.61	58.37	14.24

Source: 1988 Operating Results, Directorate of Power and Desalination Plants, WED Abu Dhabi.

Table: 8.30.

The desalinated water production in Abu Dhabi, 1973-1988.

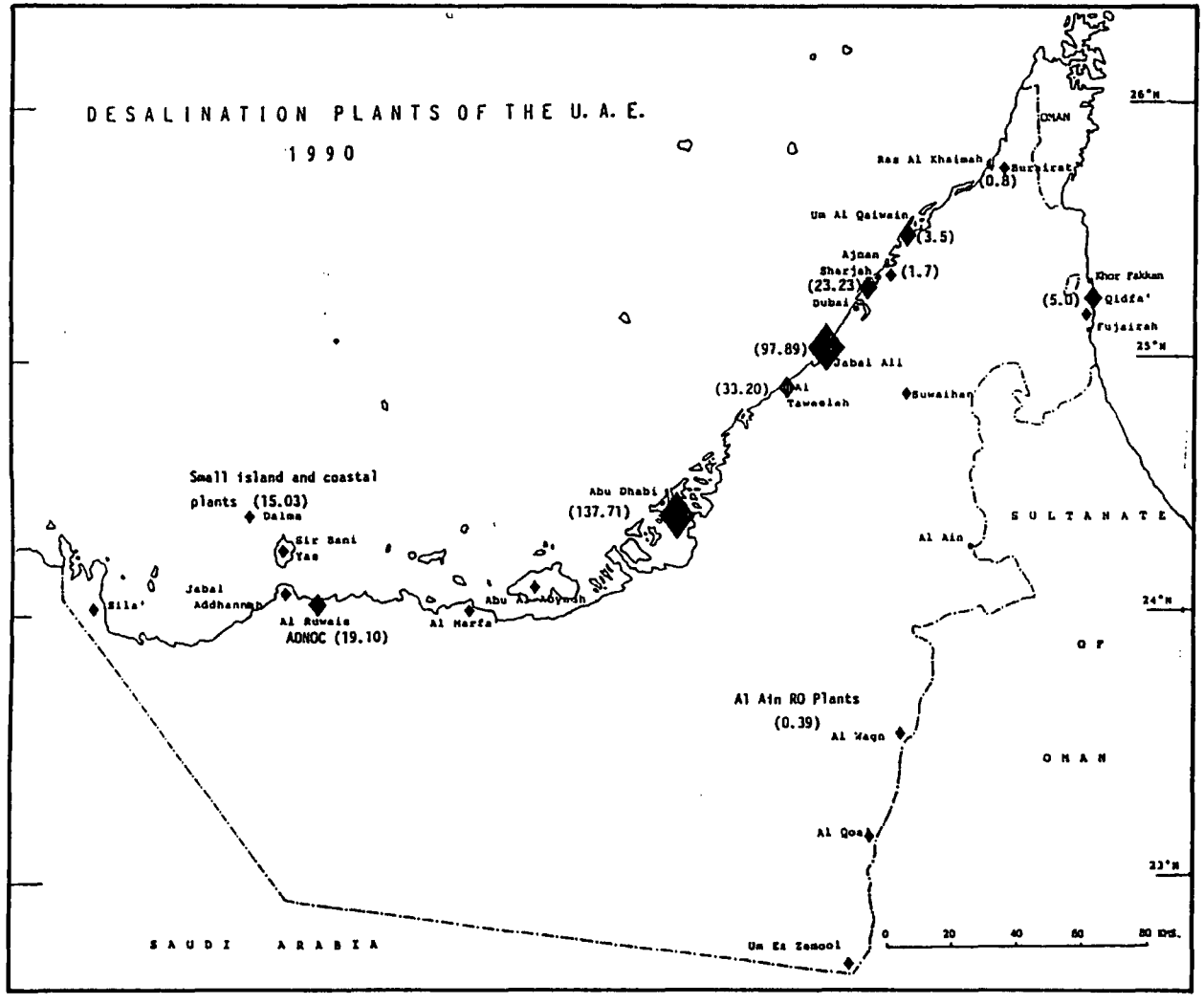
Nearly all the desalinated water produced by the plants is supplied. Only about 1% is retained in some of the large plants for their use. The most important contribution by the desalination industry of Abu Dhabi is the export of 14-15mgd. of desalinated water to Al Ain.

	Plant	Units x installed capacacity mgd	Manufacturer	Type of desalination process	Expected daily output mgd
1.	MAIN PLANTS OF WED ABU DHABI (DIRECTORATE OF POWER AND DESALINATION PLANTS)				
	GTS	4 x 2	Weir Westgart	MSF	8.0
	STS	4 x 3	SIDEM	MSF	12.0
	UNE	3 x 5	SIDEM	MSF	
		3 x 6	Italimpianti	MSF	33.0
	UNW	6 x 4	IIII	MSF	
		4 x 5	SIDEM	MSF	44.0
	UNS	1 x 0.02	Solar	MSF	0.02
	Al Taweelah 'A'	3 x 6.5	SIDEM	MSF	20.0
			Installed capacity in March 1990		117.02 mgd 195.81 MCM/a
			Actual capacity in March 1990		93.00 mgd
2.	SMALL PLANTS IN THE REMOTE AREAS IN ABU DHABI EMIRATE (WED ABU DHABI)				
	Dalma Island	6 x 0.11	Krup	MSF	
		2 x 1.00	Italimpianti	RO(seawater)	2.66
	Sir Bani Yas Is.	4 x 0.11	Krup	MSF	
		1 x 1.00	Italimpianti	RO(seawater)	1.44
	Sila'	2 x 0.11	Krup	MSF	
		1 x 0.50	ESCO	MSF	
		1 x 0.25	ESCO	MSF	0.97
	Al Marfa'	3 x 0.11	Krup	MSF	
		1 x 0.50	ESCO	MSF	
		1 x 0.25	ESCO	MSF	1.08
	Jabal Addhannah	1 x 0.50	TOYO	MSF	
		1 x 0.50	ESCO	MSF	
		1 x 0.25	SERCK	MSF	1.25
	Al Futais	1 x 0.05	SIDEM	MSF	0.05
	Adhubayyah	1 x 0.11	Krup	MSF	0.11
	Abu Al Abyadh	1 x 1.00	Italimpianti	RO(seawater)	1.00
	Al Rumaith (Floating barge)	2 x 0.25	Krup	MSF	0.50
			Installed capacity		9.06 mgd 15.03 MCM/a
3.	PLANTS OF THE ABU DHABI NATIONAL OIL CO. (ADNOC)				
	Al Ruwais	4 x 0.375	SIDEM	MSF	1.50
		1 x 4.0	SIDEM	MSF	4.00
		1 x 6.0	SIDEM	MSF	6.00
			Installed capacity		11.50 mgd 19.10 MCM/a
4.	PLANTS IN AL AIN				
	Suwaihan	2 x 0.0264	BIWATER	RO(brackish)	0.053
	Al Wagn	2 x 0.0264	BIWATER	RO(brackish)	0.053
		1 x 0.11	D.V.T.(Solar)	RO(brackish)	0.060 (actual= 0.06mgd)
	Al Qoa'	2 x 0.0264	BIWATER	RO(brackish)	0.053
	Um Ez Zemool	2 x 0.0264	BIWATER	RO(brackish) 2-Stage	0.053 (actual= 0.009mgd)
			Installed capacity		0.322 mgd 0.39 MCM/a
5.	PLANNED DESALINATION PLANTS				
	Al Marfa'	1 x 1.00	-	RO(seawater)	1.0 PLANNED
	Jabal Addhannah	2 x 1.00	-	RO(seawater)	2.0 PLANNED
	Jablan(Sa'adiyat)	1 x 0.25	-	RO(seawater)	0.25 PLANNED
	Khor Dhubayyat	1 x 0.25	-	RO(seawater)	0.25 PLANNED
	Al Rufaq	1 x 0.25	-	RO(seawater)	0.25 PLANNED
				Total	mgd 3.75 (6.22 MCM/a PLANNED)
6.	PLANNED DESALINATION PLANTS IN AL AIN				
	Al Wagn	4 x 0.25	-	RO(brackish)	1.00 PLANNED
	(product water will be transported to Al Qoa' and Um Ez Zemool).				(1.70 MCM/a PLANNED)
	Sources: The official sources entitled in 1-6.				

Table: 8.31.

All the existing and proposed desalination plants in the Emirate of Abu Dhabi, their units, the installed capacity, the manufacturer, the type of desalination process and the total daily output of each, 1990.

The bulk of the daily output of desalinated water is produced by the main plants in the town of Abu Dhabi and Al Taweelah (1). The desalination plants of the remote areas are low-output plants serving limited communities in the oilfields, oil terminals or construction sites (2 and 3). The Al Ain desalination plants are mostly brackish water ROs (4), and those on the islands are seawater ROs. The installed capacity is taken here as the expected daily output as data of the actual output for all the smaller plants are not available.



◆ Desalination plant (MSF and RO)

(137.77) Bracketed figures refer to the output in million cubic metres/ annum.

Figure: 8.5.

The desalination plants of the Emirates, 1990.

The large coastal desalination plants are of the multi-stage-flash (MSF) seawater type. There are smaller plants of the seawater reverse osmosis (RO) type also (the plants on the islands of Abu Dhabi and the 2 Qidfa' ones on the east coast), but all the small inland plants are brackish water ROs.

all the 9 locations, produced mostly by seawater MSF, but also by reverse osmosis (RO) using seawater, such as the plants at Dalma Island, Sir Bani Yas Island and Abu Al Abyadh Island. Very little of this water meets human consumption requirements and the larger part is used for irrigation purposes (Section 8.3.3), such as the use of desalinated water for irrigation in the forestry projects, especially on Sir Bani Yas Island.

The solar-powered seawater desalination plant in Um Al Nar South is only producing 80m^3/d. (0.03 MCM/a). It is running successfully but, because the volume produced is small, its unit cost is high (see Section 8.7.3.2). There seems to be little enthusiasm to expand this type of seawater desalination.

The solar-operated brackish water RO plant in Al Wagn in Al Ain, on the other hand, has been less successful. From the start, the plant ran into endless difficulties and became half solar-powered (during daytime only) and half electrical-powered (especially in running its boilers during nighttime). As a result the plant is only capable of producing nearly half its rated capacity at very high running cost. Since the summer of 1988, the plant has become totally electric-powered.

Although there are other small plants at Al Qoa' and Um Ez Zemool, but in view of the increasing difficulties in meeting the demand for potable water for the villages in the southern desert of the Al Ain region, aggravated by the recurring breakdown of the Al Wagn 'solar' plant, plans are underway to set up in the next 2 years (by 1992) 4 units of 0.25 mgd. at Al Wagn. Water will then be transported by pipeline to Al Qoa' (30km. to the south) and Um Ez Zemool (130km. further south), instead of setting up separate units that would entail triplication of maintenance costs.

The installed capacity of the existing brackish water RO plants at Al Wagn (2 X 0.0264 mgd. and 1 X 0.11 mgd.), Suwaihan (2 X 0.0264 mgd.), Al Qoa' (2 X 0.0264 mgd.) and Um Ez Zemool (2 X 0.0264 mgd.) is 1460 m^3/d. but the actual daily output is 1060 m^3/d. or 0.39 MCM/a (1989). The shortfall largely lies with the 'solar' plant at Al Wagn, which is only capable of producing between 200-300m^3/d. of its installed capacity of 500m^3/d., and also in the Um Ez Zemool plant where the two units of

120m^3/d. each are only putting up together 40m^3/d. or 0.015 MCM/a. In the latter case the distillation of the same feedwater is carried out twice due to the extreme salinity of groundwater (19,000-35,000 mmhos/cm.). The desalinated water exported daily from Abu Dhabi to Al Ain (14-15 mgd. (1990)) meets about half the daily domestic demand of Al Ain town. Of this, between 4 and 7 mgd. are made available to the public water supply, the rest is used to irrigate extensive alfalfa and grass fields at Al Maqam.

In all these inland desalination plants, brackish feedwater is used in the RO units. The reject brine is discharged into open ponds close to the plants where it is allowed to dissipate either by evaporation, leaving a salt crust, or by infiltrating back to the groundwater system. This is an often overlooked reason for the fast rise in salinities of the borehole feedwater used in the same RO plants.

8.5.3. Desalinated water production and use in Dubai emirate

The wellfields of Dubai reached their maximum output of 21.0 mgd. in 1978. By then, groundwater salinities had risen two-fold since 1963. Dubai then had not undergone the present extensive town landscaping schemes. With this in mind, together with the expected rise in demand in the early 1980s, the two non-conventional water resource options of seawater desalination and sewage water treatment were being considered on a large scale in order to take the pressure off the wellfields and then supplement the supply, which could not continue to be safely met from groundwater resources.

The only two large producers of desalinated seawater in Dubai were established in the mid-1970s in the Jabal Ali area. These were Station 'D' of Dubai Electricity Company (DEC), where desalination is incorporated with electricity generation from steam turbines, and the Dubai Aluminium Company (DUBAL), where desalination makes use of the waste heat left over from bauxite smelting using electricity generated from gas turbines.

In DUBAL, the process is the multi-stage-flash (MSF) distillation of seawater in 6 Weir Westgart evaporators which, in the mid 1970s in Abu

Dhabi exhibited low performance by never exceeding 67% of their design capacity (Lahmayer, 1978: consultants of Abu Dhabi Government then). Each evaporator was designed to produce 4.2 mgd. of product water at low temperature (90^{o}C top brine temperature) and 5.2 mgd. at high temperature (110^{o}C top brine temperature) operation with feedwater at 30^{o}C. One of the 6 evaporators at DUBAL was failing to increase output despite the rise in temperature (November, 1988).

By 1984, the capacity of Station 'D' of DEC had risen to 31.46 mgd. by adding 3 units of 5.72 mgd. with the 225 MW steam turbine plant. Stage 'E', which is to add a further 4 MSF desalination units of 6 mgd. each associated with a 252 MW gas turbine station, will commence production in 1991. The total output of desalinated water from DEC reached a daily maximum of 37.66 mgd. (March 1988) by increasing the brine temperature and so enhancing water production by 6.2 mgd. or nearly 17% more than the low brine temperature installed capacity. Except for April 1988, when the average daily production was 30.91 mgd., all the other months of the year had a daily average desalinated water production of more than 33.0 mgd. A daily average of over 37.0 mgd. was achieved during the months of March, May, September and October (1988). The maximum daily production for DUBAL for the same year was 28.24 mgd. in August, while the lowest was 15.6 mgd. in February when the desalinated water output for DEC was 34.32 mgd. The very low output for DUBAL was partly due to evaporators being overhauled, while maximizing the output for DEC (at this time of the year of low demand) was partly to compensate the deficiency in the public water supply caused by this maintenance of units in DUBAL.

Production from DEC in 1988 made up 48.9% and that from DUBAL 35.6% of the total average daily output for that year of 65.4 mgd. Table 8.32 shows the average daily desalinated water production for both DEC and DUBAL for the years 1987 and 1988. Comparing the two, DEC production in the daily average for the whole year increased in 1988 by 6.92 mgd. to that for 1987, while that for DUBAL decreased by 0.86 mgd. By quota, DEC output increased from 44.49% in 1987 to 48.9%, while that for the DUBAL receded from 37.96% to 35.6% for the same period. When this quota is considered in relation to the total desalination output from both plants, and also to the gross daily output of water including

groundwater, then the percentages were 45.49% for DEC and 36-38% for DUBAL.

The average daily production of both DEC and DUBAL for 1987 and 1988 is given in Table 8.33. The output of DEC increased between 1987 and 1988 by 25%, while that of DUBAL decreased by 3%. Overall, DEC production of desalinated water made up 60% and that for DUBAL 40% of the total daily desalinated water output for 1988.

There does not seem to be any official intention to expand the distilling capacity of DUBAL although there is allowance for 3 more evaporators. As will be discussed later, the unit cost of water produced by DUBAL is more than two times that produced by DEC (Section 8.7.3.3). When DEC Station 'E', due to start operation by 1991, makes available its expected 24.0mgd. increasing Dubai's desalinated water capacity to 92.0 mgd. using the higher top brine temperature, the cost of desalinated water by DEC might become even cheaper. With the yet further expansion planned for DEC in the 'G' station, which had been originally sited at Al Mamzar near Qusais but was then moved to the main DEC complex at Jabal Ali (February, 1990), a further 56.0 mgd. will be added to the total daily desalinated water output (by 1993). By this addition, the actual production capacity of desalinated water in Dubai will be increased to 148 mgd. or 0.7 MCM/d. This will amount to an annual volume of 245.55 MCM/a. As in the case with the use of part of the desalinated water in Abu Dhabi for agriculture discussed in Section 8.5.2., some of Dubai's daily output of desalinated water is also used in outlets other than domestic. Suffice it to note the use of such water of high potable quality to irrigate the grass lawns and fill the fish ponds in the new golf course at Jabal Ali and also irrigating the wind breaks and large gardens at Nadd Al Shaba. These two outlets, together, used up between 3.5-4.5 mgd. or about 7-8% of the total daily output of desalinated water of **59.0 mgd.** in Dubai in 1989.

8.5.4. Desalinated water production and use in Sharjah emirate

Sharjah is the only desalinated water producer among the 3 Gulf coast large producers of the Emirates that still maintains a substantial

Plant	% of the daily desalinated water output in Dubai		% of the gross daily water including groundwater in Dubai	
	1987	1988	1987	1988
DEC DUBAL	58.00% 42.00%	60.21% 39.79%	44.47% 37.96%	48.90% 35.60%
Source: Dubai Water Department				

Table: 8.32.

Percentage of the daily desalinated water produced by either DEC or DUBAL out of the total daily desalinated water production and that of the gross daily water production (including groundwater) in Dubai for 1987 and 1988.

The daily output of desalinated water in DEC was more by 50% than that of DUBAL in 1988. With more desalination development planned for DEC, the output in 1991 will surpass that for DUBAL by 2.5 times, and by 1993 by 5 times.

	DEC		DUBAL	
	1987	1988	1987	1988
January	17.76	34.31	26.22	17.51
February	23.66	34.32	21.64	15.60
March	22.09	37.09	23.77	20.89
April	21.28	30.91	26.15	22.18
May	29.40	37.08	24.12	25.35
June	30.25	35.75	25.86	25.00
July	31.35	36.02	26.43	25.58
August	33.17	33.29	24.61	28.24
September	33.99	37.16	24.67	26.66
October	32.01	37.14	25.41	25.65
November	31.55	33.56	22.35	25.31
December	32.34	35.27	18.34	22.76
Daily Average	28.29	35.21	24.13	23.39
Source: Dubai Water Department.				

Table: 8.33.

The average daily production of desalinated water by DEC and DUBAL for 1987 and 1988.

The output of desalinated water of DEC increased between 1987 and 1988 by 25%, while that of DUBAL by only 3%. Overall, the production of desalinated water by DEC formed 60% and that of DUBAL 40% of the total daily desalinated water output of Dubai.

percentage of its domestic water supply from wellfields. However, there have been many difficulties in recent years with groundwater sources that led to the shutting down of Wushah wellfield due to its shrinking output as well as the rising salinities of the main wellfields of Badea' I and II and the gradually reducing productivity of Hamdah (see Section 8.2.2.). Furthermore, neither the initial design of the desalination plant at Al Llayyah allowed for expansion, nor budgetary constraints at present (1990), permit any increase in the production capacity of desalinated water in Sharjah.

The desalination plant, as part of the steam power station at Al Llayyah in Al Khan, has 4 units of an installed capacity of 4.5 mgd. each. Although the total daily installed capacity is 18 mgd., the actual average daily production fluctuates between 12 and 16 mgd. In 1987 the daily output averaged 12.42 mgd. (i.e. with the plant working at 69% efficiency) and in 1988 the daily output averaged 14.72 mgd.(i.e. with an 82% plant efficiency). The ratio of desalinated water output to that of groundwater in 1988 was 1:1.

The first contribution of desalinated water to the Sharjah water supply was in 1981 with about 3.0 mgd., increasing to 5.0 mgd. the following year and reaching a peak of 15.20 mgd. in July 1987.

Desalinated water is used within Sharjah town with no surplus left for export outside its environs. Although a good deal of the irrigation water for landscaping within the town is provided by treated sewage water, some blended water (ground and desalinated water from the public supply reservoir for potable use) is also used in Al Muntazah Park and in all the household gardens as part of domestic consumption.

Table 8.34 gives the average daily production of desalinated and ground water in Sharjah and the daily total of either on a monthly basis for the year 1989. Figure 8.6, shows the development in the production of both desalinated and ground water in Sharjah since 1981. The annual gross output of desalinated water, taking the 1988 average of 14.72 mgd., is **24.42 MCM/a**.

There is no storage space for the produce water at the desalination plant site at Al Llayyah and all the water produced goes straight to the

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Desalinated water	12.35	11.49	9.79	13.00	14.06	15.82	15.14	15.67	15.80	15.37	13.41	11.97	13.67
Groundwater	17.98	18.14	20.00	19.66	20.87	20.29	19.82	20.12	18.99	18.97	18.99	18.01	19.39
Total	30.33	29.63	29.79	32.66	34.93	36.11	34.96	35.79	34.79	34.34	32.40	29.98	33.06
Source: Sharjah Electricity and Water Department.													

Table: 8.34.

The average daily production of desalinated and ground water and the daily total output of both on a monthly basis for Sharjah town for 1989.

The low desalinated water production in the winter months because of the routine maintenance of the desalination units in the Al Layyah plant, is compensated by the higher output of groundwater. Maintenance is timed for the winter months because of the reduced overall demand on water. In summer, production from both sources is enhanced by 25%, with the daily production from both sources during the period May-October is being maintained at above 34.0 mgd. (1989).

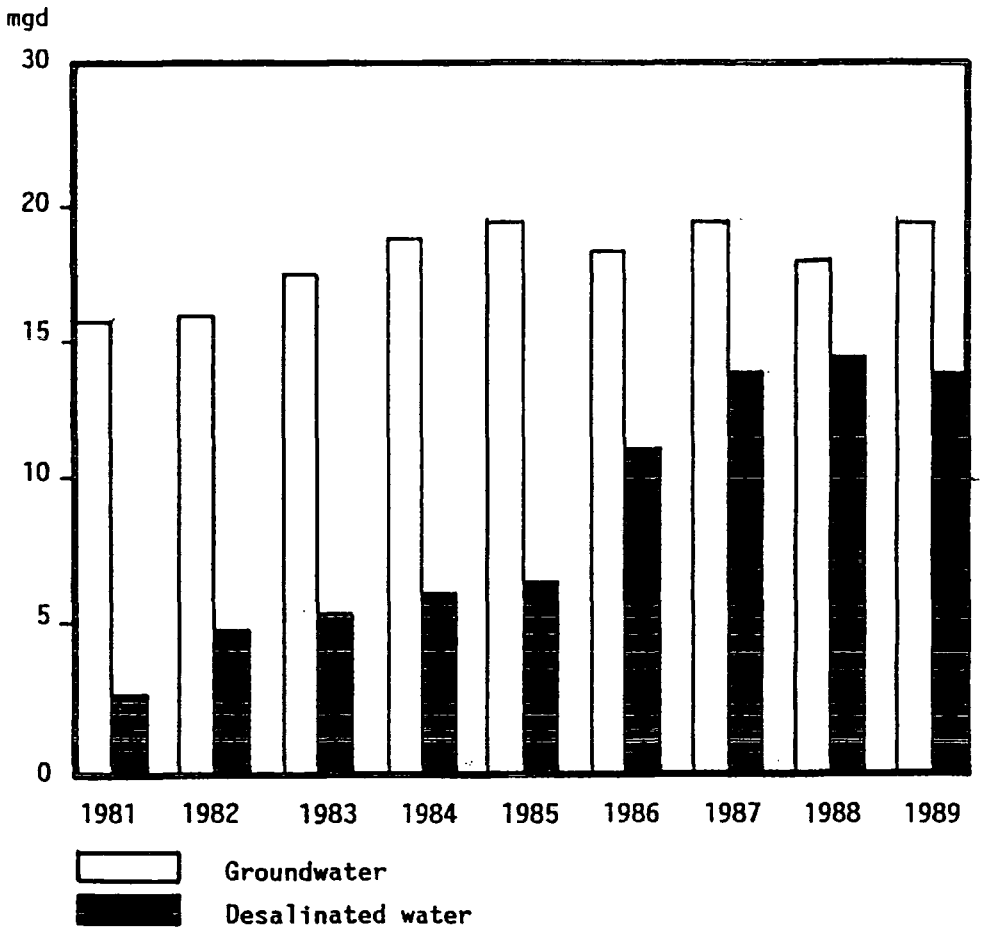


Figure: 8.6.

Development of desalinated and groundwater production in Sharjah, 1981-1989.

Unlike Dubai where groundwater production receded as desalinated water production increased, the enhancement of groundwater production in Sharjah since 1985 has been due to the limited capacity of the Sharjah desalination plant to meet the increasing demand with its 16.5 mgd maximum output, which, as seen in the graph, has never been reached since the start of desalination production in 1980. Added to this inadequacy of desalinated water supply is the problem of reducing outputs from the wellfields leading to the closure of Wushah in 1988. Hamdah wellfield has experienced dwindling output in the past few years forcing the local water department of Sharjah to seek another groundwater source in the new Seih Al 'Aqareb wellfield, which commenced production in 1990.

desalinated-ground water mixing reservoir at Al Falaj in Halwan where also groundwater from Al Badea' and Hamdah is received.

Table 8.34 shows the increased production of desalinated water during the summer months to keep up with the demand, which is always more than what could be supplied. Hence, the shutting and phasing of supplies at various times during the day both in summer and winter (the latter, January-February, 1990). The mixed ground and desalinated public water supply has conductivities ranging between 1,100-1,500 mmhos/cm.

8.5.5. Other desalination plants in the Northern Emirates

The oldest desalination plant in the Northern Emirates is the brackish water RO plant at Al Burairat, in the lower Wadi Al Beeh, which was installed in 1977. The plant consists of 3 reverse osmosis trains, each with a capacity of 2300m^3/d. (0.5 mgd.). The borehole feedwater in the early days of the development of the plant was of a salinity (TDS) around 1700 ppm. and the product distilled water was of 240 ppm. (EC 400 mmhos/cm.) at 90% recovery. Wellfield feedwater has subsequently deteriorated reaching salinities of more than 5000 ppm. (EC 8250 mmhos/cm) and the recovery process decreased to 70%. Due to mounting problems since its inception involving corrosion, rising feedwater salinities, fowling and rapid deformation of plant membranes, the plant was redesigned in the early 1980s. Its recovery capacity was upgraded to 75%, which enabled it to handle brackish feedwater of up to 6000 ppm (above 9000 mmhos/cm.).

The treatment scheme of Al Burairat RO plant comprises:

a) Rapid filtration through 5 sand filters (water flow pressure 5.5 bar) for the removal of suspended solids. Alum (Aluminium sulphate) is not dosed because the feedwater is not turbid.

b) Raw water, after leaving the sand filters, is injected with sulphuric acid (H_2SO_4) of 98% concentration so as to descale the water of its carbonate and bicarbonate content that would otherwise damage the cellulose acetate membrane elements of the plant.

c) The water is then let through 3 cartridge filters having a filtering media of 10 microns. The hardness of the water (the pH) is reduced at this stage from 7.0 to 4.9 and maintained at that level.

d) A 10% solution of sodium hexameta phosphate (SHMP) is injected at this stage. This, and the H_2SO_4 react with the calcium, magnesium, carbonate and bicarbonate, present in the water, and form a non-scaling mixture of water with chemicals such as calcium sulphide, magnesium sulphate and carbonic acid.

After this pretreatment stage,

e) Water is then pressurized to 32 bars with 3 high pressure pumps and admitted to the reverse osmosis membranes. The semi-permeable cellulose acetate membranes process the water and the potable end product collects in a central tube from where it is removed to product water collectors.

f) The concentrated reject or brine is then led away from the plant by a pipeline. This was at first discarded in the immediate vicinity of the wellfield from where the feedwater was obtained, but, then, due to the rising salinity of the groundwater, the brine was led to a point 2 km. away. When this caused a marked contamination of groundwater abstracted by the local farmers, the pipeline was further extended by another 8 km. and, at present (1990), the water is being discharged near a round-about within the Ras Al Khaimah town limits from where it is led to the Ras Al Khaimah creek.

The recovery rate of the plant was 80-85% in 1982 but was only 70% in 1988 because of the ever-increasing salinity of the feedwater. The reject brine was with a salinity of more than 11,000 ppm (1989).

g) The carbon dioxide and carbonic acid that have previously been added with the sulphuric acid and sodium hexameta phosphate are then expelled by a decarbonating process involving the spraying of water from above and blowing air from below.

h) A 10% sodium hydroxide is dosed into the final water so as to upgrade its hardness (the pH value) from 4.6 to 7.5-8.2. Chlorine is finally added to maintain a 0.2 ppm. residual chlorine, after which the water is pumped into the public supply storage tanks.

Although the RO plant was designed with a 1.5 mgd. production capacity, it has only been actually producing 0.5-1.0 mgd. from 2 of the 3 units working at the same time. Throughout 1988, the RO plant was a point of strife between the MEW and the local water authority of Ras Al Khaimah over the financing of chemicals. Twice it was shut down totally during that year, such as the shutting down for 3 months from September to November 1988 adding to the difficulties caused by the endemic water shortages of Ras Al Khaimah. The output of the plant at present (1990) hardly exceeds 0.5 mgd (0.83 MCM/a).

Data concerning all the existing desalination plants in the Northern Emirates are presented in Table 8.35. There are 2 desalination plants in Um Al Qaiwain. The larger of the two plants, is a brackish water RO plant of 2.0 mgd. capacity, but with an actual output of 1.5 mgd. Its feedwater is from Al Sirrah wellfield, which lies 12 km. inland from the plant site with water conductivities averaging 6000 mmhos/cm. The other smaller plant is an MSF seawater plant of 0.5 mgd. capacity. It was completed in early 1988 but has never operated because of institutional disagreements between the donating organization (the local WED Abu Dhabi) and the operating organization (the federal MEW). It is scheduled for dismantling and shipment to be installed elsewhere in Abu Dhabi (1990). The difficulties in such handing over from a local to a federal institution do not only involve securing funds in the federal budget for running the plant, but also staffing it with the qualified personnel that is already deficient in the other desalination plants.

The Ajman seawater RO plant has recently been handed over to the MEW by WED Abu Dhabi. It is the first RO to use seawater in the Northern Emirates and is scheduled to produce 1.0 mgd. of desalinated water before the end of 1990.

In Qidfa', on the east coast, plans of the mid-1970s for a large desalination plant, associated with power generation to supply the whole

Location	Type of plant	Daily output mgd	Annual output MCM/a	Operation year
Burairat (Ras Al Khaimah)	RO/brackish	0.5	0.8 (MEW)	1977
Um Al Qaiwain	RO/brackish MSF/seawater	1.5 0.5	2.5 (MEW) 0.8 (A.Dhabi)	1986 1988
Qidfa' (Fujairah)	RO/beach wells RO/seawater	2.0 1.0	3.3 (Dubai) 1.6 (A.Dhabi)	1990 1991
Ajman	RO/seawater	1.0	1.7 (A.Dhabi)	1990
Total		6.5	10.7 MCM/a	
Sources: MEW and consultants.				

Table: 8.35.

Small desalination plants in the Northern Emirates, 1990.

These small desalination plants in the Northern Emirates are not part of the overall federal plan but are donated piecemeal by the local authorities of either Abu Dhabi or Dubai emirates. The Ajman plant is the first seawater RO in the Northern Emirates. The Qidfa' RO (one of the two plants there) will depend on brackish groundwater from beach wells to maintain the plant's desalination efficiency than would have been the case with the more saline seawater.

coast, have been abandoned. At present (1990), two small plants are under construction. The first, again, financed by WED Abu Dhabi with 1.0 mgd. capacity, is an RO plant designed for seawater feed. The second, financed by the government of Dubai, is an RO brackish feedwater plant (from beach wells) designed to produce 2.0 mgd. Both plants are expected to start production by 1991.

Two other desalination plants are planned for the near future on the Gulf coast of the Northern Emirates. One is in Ajman, a 3.0 mgd. brackish feedwater RO plant that will draw its water from the Dibdiba wellfield. It is scheduled for operation by 1992. The other, in Ras Al Khaimah, a 3-5 mgd. seawater RO, is scheduled for operation by 1993.

8.6. Effluent treatment

Sewage treatment is still limited to the 4 major towns of Abu Dhabi, Dubai, Sharjah and Al Ain. The whole activity has only been in existence for 15 years; the first two old sewage works in Abu Dhabi and Dubai started at almost the same time in the mid-1970s.

8.6.1. Effluent treatment in Abu Dhabi

The initial sewage treatment plant in Abu Dhabi had a capacity of 4,500m^3/d. It had become overloaded by 1974. It was extended in 1976 to treat an effluent flow of 27,000m^3/d. Originally, salinity in the influent was aggravated by illegal pumping into the sewage system by building contractors draining the bases of buildings before laying concrete establishments. Such a practice ceased by 1976 as monitoring of this activity was stepped up. This old plant was gradually phased out as the large new plant in Al Mafraq came into operation in 1983.

8.6.1.1. Al Mafraq sewage treatment plant of Abu Dhabi

The Mafraq sewage plant was opened in August 1983. The old plant had by then been abandoned and all the sewage flow had been diverted to the new plant. The present (1990) average Dry Weather Flow (DWF) is 100,000m^3/d.

The plant was designed on an assumed population for the town of Abu Dhabi of 665,000, with allowances made for industrial and commercial expansion. The ultimate flow of 208,500m^3/d. will be treated in 2 similar modules. The first, the existing one, is already handling between 100,000-114,000m^3/d. for an assumed population of 332,000 (1990). Details of the existing and ultimate performance of the sewage plant are given in Table 8.36.

The ultimate provision of a 2km-wide belt of trees around the site, irrigated with treated effluent water, would minimize the problem of wind blown sand into the sewage settlement tanks.

8.6.1.1.1. **Operation of the Al Mafraq sewage treatment plant**

In the primary sedimentation stage, as much of the settleable solids as possible are removed. Owing to the hot climate, the sludge has to be scraped regularly to prevent the development of gases and a rise in the level leading to overflowing the settlement tanks.

Chlorination of the treated effluent is done twice. The first dose is after the secondary treatment; the second, after the tertiary treatment. The tertiary treatment produces a highly treated effluent water that is directly used to irrigate landscaping schemes in the town, and may be used on non-edible crops or for the artificial recharge of aquifers.

The treated effluent is returned to the town of Abu Dhabi through a 32km-long pipeline for distribution basically to municipal landscaping reserves. The full biochemical and mechanical treatment, through rapid sand filtering, produces a high standard safe effluent. The quality of this product can be seen in the sample analysis sheet presented in Table 8.37, whereby the Biochemical Oxygen Demand (BOD) and Suspended Solids (SS) never exceed 10/10 mg/l, and are even frequently better.

The only consumer of the product treated water is the Agriculture Section of Abu Dhabi Municipality. The daily quantity made available is 17.5 mgd. (1989) which is wholly used up in a summer day, but only half of this quantity is needed in a winter day when an 8-mgd. surplus is released into the sea.

	STAGE I	STAGE II
Population	332,500	665,000
Dry weather flow (DWF)	104,250 m^3/d	208,500 m^3/d
Biochemical oxygen demand (BOD) loading	271,000 m^3/d	542,000 m^3/d
Suspended solids loading (SS)	55 gr/head/d	55 gr/head/d

Capacity of individual units when all are operating

Screens	3 x 90,000 m^3/d
Detritors	2 x 135,000 m^3/d
Primary sedimentation tanks	6 x 45,450 m^3/d
Aeration tanks	8 x 53,650 m^3/d
Effluent tanks	12 x 35,750 m^3/d
Tertiary sand filters	8 x 8.4 $cm^2/m-hr$
Primary sludge digestors	8 x 3,450 cm
Secondary sludge digestors	32 x 160 cm
Sludge drying beds	28 x 750 cm^2

The effluent standard that the works have been designed to achieve is:

5-day BOD	Less than 10 mg/l
Suspended Solids	Less than 10 mg/l
Nitrification	Complete
Coliform/100 ml	Less than 100 in 80% of samples

Source: Information collected during a field visit to the plant.

Table: 8.36.

The design capacity of the Al Mafraq Sewage Treatment Plant of Abu Dhabi.

Although the population of Abu Dhabi town and its outlying settlements in 1990 is not more than the estimated figure in the design of the sewage plant for Stage I, the plant has been handling 114,000 m^3/d, that is at 10% overload, since 1989. The influent is strictly domestic as industrialization is limited. The treated effluent of BOD/SS 10/10 mg/l (25 mgd) is wholly used by the Municipality for irrigating the town's horticultural reserves.

Parameter	Influent	Primary Sedimentation	Tertiary Sedimentation	Effluent
Electrical Conductivity mmhos/cm	3700	3800	3600	3600
pH	7.2	7.2	6.9	6.5
Total Alkalinity as $CaCO_3$ mg/l	230	220	40	20
Total Hardness as $CaCO_3$ mg.l	380	380	360	360
Total Phosphorous as P mg/l	12.8	12.0	9.7	9.8
Total Sulphide as S mg/l	29.5	21.3	0.5	Nil
Suspended Solids mg/l	314	96	7.9	Nil
Ammoniacal Nitrogen as N mg/l	30	29	Nil	Nil
Nitrite Nitrogen as N mg/l	xx	xx	0.02	Nil
Biochemical Oxygen Demand mg/l	260	160	3.3	1.2
Chemical Oxygen Demand mg/l	720	300	40	20
Permanaganate Value (4HR) mg/l	104	61	4.1	1.7
Sodium as Na mg/l	520	525	525	525
Potassium as K mg/l	30	30	30	30
Calcium as Ca mg/l	45.6	45.6	43.2	43.2
Magnesium as Mg mg/l	64.6	64.6	61.2	61.2
Total Iron as Fe mg/l	3.8	2.0	Nil	Nil
Chloride as Cl mg/l	1010	1020	1020	1030
Sulphate as SO_4 mg/l	117	118	182	185
Detergent as Manaxol OT mg/l	21.6	16.8	0.8	0.4
Turbidity NTU	95	100	2.0	1.0
Colour ^oH	130	100	20	5
Odour	Putrescent	Putrescent	Odourless	Odourless
			• M.P.N of Coliform organisms 100ml	1.0
			• Chlorine dosage mg/l	19.3
			• Chlorine consumption Kg/day	1719.0
			• Irrigation and flushing flow	88950 m^3/d
Source: Al Mafraq Treatment Plant, Abu Dhabi				

Table: 8.37.

The physical and chemical specifications of the raw influent and the treated affluent of the Al Mafraq Sewage Treatment Plant of Abu Dhabi.

Table 8.37 above clearly shows the purely domestic nature of the influent not yet contaminated by industrial waste. It also shows the high standard of the treated effluent to 10/10 mg/l BOD/SS. The EC of the treated effluent of 3600mmhos/cm. puts the water in the marginal to brackish water category, and is better in this salinity level than that of the treated effluent of Sharjah (10-11,000mmhos/cm). In 1990 nearly 25mgd. of effluent were pumped to the town of Abu Dhabi for irrigating the horticultural schemes.

There are no exact statistics concerning the quantity of treated water produced. It is known that although the plant was initially set up with a maximum handling daily capacity in its first stage of 104,000m^3/d., it has reached a daily average of influent intake of 100,000m^3/d. (1988). The volume of the daily treated effluent, as given by the management of the plant, is 20.0 mgd. or about 91,000m^3/d.. The Agriculture Section of Abu Dhabi Municipality, the only recipient of the product water, gives the volume as 17.5 mgd. or 80,000m^3/d. Furthermore, the plant management measures the actual inflow into the plant for treatment as having exceeded the designed Dry Weather Flow (DWF) capacity of 104,000m^3/d. for the first stage, and the plant was actually handling throughout 1989 a daily inflow of 114,000m^3/d. or a 10% overload in the DWF design capacity. This amounts to 41.5 MCM/a (which is also applicable for the period up to March 1990). This volume is about half the total treated wastewater volume produced in the Emirates (80 MCM/a).

8.6.1.2. **Effluent treatment in Al Ain**

Situated 25km. to the southwest of Al Ain town, or 7 km. west of Zakher, the sewage treatment plant of Al Ain commenced operation in 1981 with the designed capacity of 27,000m^3/d. (6mgd.), with the provision to double that volume in a second stage. Since Al Ain had no previous sewage treatment facilities, it was less difficult to lay down the new system as had been the case with Abu Dhabi. By 1983, the DWF was about 7,400m^3/d. (1.6 mgd.) or 25% of the designed capacity of phase 1. By 1987 the DWF was 18,000m^3/d. (4.9 mgd.) or 75% of the designed capacity.

The plant is designed on the extended aeration process which processes a treated effluent of a BOD/SS standard of 10/10 mg/l. As is the case with the Abu Dhabi plant, the treated effluent is pumped to the Horticulture Section of Al Ain Municipality to be used wholly for irrigating the road reserves in the town.

Effluent treatment and reuse in Al Ain is on a limited scale compared to both Abu Dhabi and Dubai and also in relation to Al Ain's own daily domestic consumption of 30-34 mgd. Only 2.4 mgd. of treated effluent were available for reuse in 1984 within the sewage works, gardens, lawns, the adjacent compost factory, the zoo and limited areas in Ain Al Faydhah Park.

The plant has been having problems in its operation. These have been acute during the rainy season with the intake of rain water. In 1988, only 3 mgd. (5.0 MCM/a) of treated effluent were made available to the municipality for landscaping irrigation and falaj flow augmentation.

8.6.2. Effluent treatment in Dubai

The old Dubai sewage treatment works at Qarhood started in 1971 to serve a population of 25,000 with a daily capacity of 3,400m^3/d. By that date, the Assabkhah, Iyal Nasser, Addaghayah, Al Ras, the Airport, Al Bastakiyah and the Souq (Bur Dubai) areas had been linked to the plant. Between 1971 and 1976, further areas were linked to the works. These included Reqqa (west), Al Maktoum Road as far as the clock tower (Deira) and Al Mussalah, Al Refa', Za'abeel (east) and large parts of Za'abeel proper (Bur Dubai).

By 1973, the plant had become overloaded and between 1978 and 1979 extensions were carried out enabling it to handle 15,900m^3/d. for a population of 100,000. In 1977 an aeration lagoon was formed to tackle 5,500m^3/d. as an emergency increase, enhancing the total actual handling capacity of the sewage works to 21,400m^3/d., to serve a population of 135,000. The water from the aeration lagoon, treated to the high BOD/SS 10/10 mg/l standard, was used by the municipality for the irrigation of road reserves, Assafa Park and as process water for the cement factory on the Dubai-Abu Dhabi highway.

By 1978, the areas of Al Barahah, Al Safiyah housing complex, the Police Headquarters, Al Qusais housing complex, Al Karamah, Shaikh Rashed housing colony in Al Jafiliyah, Al Hudaibah, the Central Military Command camp and the areas around Al Safa Park, had been linked to the plant. Linkage of other areas to the plant continued, and in one year alone (1979-80), Al Mussalah, Al Mateenah, Reqqa (west), Reqqa proper, Al Butain, Al Murraqqabat, the Trade Centre and Satwa (east) were also connected.

With the advent of desalinated water by the summer of 1980, a more reliable supply of water became available to consumers, the effluent flow into the sewage works by that year had become 22,000m^3/d. from an estimated population of 145,000.

Again, it became necessary to uprate the handling capacity of the plant by a further extension aiming for a population of 190,000. This was completed at the end of 1983 with a capacity of 38,000m^3/d. of which 27,000m^3/d. were to be treated to an affluent standard suitable for irrigation, while the remainder was to be discharged into the sea in Dubai creek.

Between 1981 and 1984 sewage connections were carried out in the areas of Abu Hayail, Port Said, Al Khabeesi, the rest of Za'abeel, part of Al Esbeg, Um Hurair, Al Jumairah from the Guest House to the Grand Mosque, part of Al Wasl Road, the rest of Al Refa' and the food factories along the Abu Dhabi highway.

By 1983, the DWF was 43,000m^3/d. and the population served was 200,000 which was about 60% of the total population of Dubai. Altogether, 26,000 households had been connected and 500 km. of sewer lines and 115 pumping stations had been executed.

When by 1985 the plant had again become overloaded, plans to extend it further were dropped in favour of a new, larger plant to be set up farther inland at Al Aweer. By that time also, the plant site at Qarhood had nearly been engulfed by urban development.

In its first stage, the new plant at Al Aweer started operating at the end of 1989. It has been designed to treat 130,000m^3/d., serving by 1994 an expected population of up to 500,000.

The incoming sewage undergoes mechanical treatment, 2-stage biological treatment and pressurized sand filtration to ensure a high standard irrigation water. 5 major pumping stations pump the influent through a number of rising mains with a total length of 65 km. The final effluent is pumped back to the town for landscape irrigation.

When Hor Al Anz had the problem of rising levels of the contents of domestic septic tanks, owing to the low-lying nature of the ground (at or 0.5m. above msl.) a temporary sewage network and plant were set up in 1985 behind Al Ahli club in Al Mamzar near Al Qusais. When the main treatment plant started operating at the end of 1989, this temporary plant was connected to the rising mains system leading to the new works.

The existing works at Qarhood (the old plant) will eventually be demolished and only the tanks will be retained to handle 1000m^3/d. of excess treated water.

By 1992, all areas within the town will have been connected to the sewage plant. Besides this, it will be necessary by that time to reconstruct some of the pump stations originally installed for the main plant, to duplicate some of the rising mains and sewer lines and to install a system of septicity control in the sewerage network to reduce the smell. All the sewage projects, including Al Aweer plant will have cost 2.5 billion dirhams (800 million US $).

Furthermore, if the population of Dubai increases at the calculated rate, it is expected to reach 610,000 by the year 2005. In that case, it will be necessary to expand the second phase of the existing Al Aweer plant by 1992 to handle 200,000m^3/d. of effluent.

It is unfortunate that the local authorities in the emirate of Dubai do not rate as important storm water (urban runoff), which floods many sectors of the town and is left to pond or is pumped by road-tankers. There is no allowance for leading this water to the treatment plant as these authorities consider that the infrequency of rainstorms does not justify the construction of a combined sewage and surface water drainage system.

As is usual in other towns of the Emirates, the only use for the treated effluent water is for irrigating municipal parks and road reserves. By 1985, 31,000m^3/d. of treated sewage water was available for horticultural use, in addition to 4000m^3/d. of brackish groundwater from Al Mizhar wellfield. Dubai town has been divided into 6 irrigation zones with the aim of making 8% of the total area of the town green. 3 storage tanks for the treated effluent have been constructed to provide the pressure head for the irrigation network.

The new sewage plant of Al Aweer will produce 60,000m^3/d. of treated effluent of a high 10:10 mg/l BOD/SS standard. The average daily output in 1990 was 55,000m^3/d. (12.2 mgd.) or 20.1 MCM/a. Conductivities of the treated effluent range from 2,500 to 3,500 mmhos/cm.

8.6.3. Effluent treatment in Sharjah

Only some parts of the town are linked to the sewage works in Sharjah. These include the centre of the town (the Rolla), Maisaloan, Al Fayha, Al Majaz and half of Al Khan. The greater part of the town is still served by road tankers pumping from soak pits of individual households and emptying their contents in the swamps between Sharjah and Ajman.

The design capacity of the Sharjah sewage plant is 25,000m^3/d. (4.8mgd.) but the plant has been handling for most of 1988 between 32,000-34,000m^3/d.(25% overloading). About 28,000m^3/d. are delivered to the Horticulture Section of Sharjah Municipality and are wholly used for irrigating road reserves. This amounts to 6.2 mgd. or 10.2 MCM/a. The remaining 4-6,000m^3/d. are released to the lagoon in raw form, as is the case with the excess inflow into the works during the rainy season.

8.7. Cost of water in the Emirates

8.7.1. General

The cost of water, whether ground, desalinated or recycled, includes the full cost of the items that go into the production and distribution process. This is either as a direct cost, which includes production and distribution factors, such as the depreciation of installations in wells, desalination and recycling plants, pipelines, maintenance of the assets, energy (fuel, gas or electricity), chemicals and wages paid to the actual labour force directly involved in producing and distributing water; or indirect costs, such as those associated with salaries for administration in the water, energy and desalination plants. The unit cost of water produced from wells, MSF and RO desalination plants, the solar energy plant in Um Al Nar (South), as well as that of sewage recycled water, is discussed here with a presentation of the breakdown of such costs for the various types.

The clearest available accounts concerning the cost of water production are those published by the Directorate of Power and Desalination Plants of WED Abu Dhabi. DEC and Sharjah Electricity and Water Department prepare production cost accounts but are only available on request.

Details of water production costs in DUBAL, like all other water related data on this public utility concerning this company, are veiled in questionable secrecy. The unit cost of water produced by DUBAL, as invoiced every quarter to the Dubai Finance Department, has, however been obtained, and it is sufficient for comparison with the production cost of other producers, especially with that of DEC. The usual unit is that of 1000 gallons; the unit for which the consumer is charged the flat rate of 15 dirhams (dhs.) (US$ 4.0; nearly US$ 1.0 per $1m^3$).

8.7.2. Cost of groundwater

Although the cost of drilling operations has come down since 1982 by at least 40%, it is difficult to derive a fixed tariff for drilling as this is governed, first, by geological considerations and, second, by whether casing and screening or even logging of the borehole are required. As most government wells have, until recently, been cased and screened, the cost per foot (depth) is around 110 dhs. (1988). This can be taken as a basic average cost for all types of wells over a range of varying economic and drilling needs. It is also the cost for a well drilled in gravel or sand strata using the percussion method of drilling. Rotary drilling is slightly higher in cost, and if well-logging is required, then the cost is doubled.

As more of the water departments do their own drilling, in line with the budgetary streaming measures, the cost of developing a well is further reduced. An estimate has been obtained from Dubai Water Deptartment, which has always carried out its own drilling. The cost per foot is about 100 dhs. which includes casing and screening. A private 100-foot well drilled in sands or gravels in Al Ain costs between 10,000 and 13,000 dhs. From records of drilling contracts of MEW wells in the early 1980s, it was clear that the price charged by the drilling contractors to the government was highly exaggerated. The cost of a successful well was estimated in 1982 to be 200,000 dhs., while that of an unsuccessful well was 110,000 dhs. Since the cost of one well was borne by the other in the case of a group of wells drilled in the same project, the average cost of a successful well charged to the government was 253,000 dhs. Table 8.38 illustrates this for MEW wells between 1975 and 1982.

The production cost of groundwater is cheap compared with that from other sources, and is three times cheaper than the cheapest desalinated water from DEC. The production cost of groundwater in Dubai is 3.0 dhs. per 1000 gallons. In the past, when the quantity produced from Al Aweer Wellfield was less and there were 3 booster pumps needed to push the supply to the town, the production cost was as high as 9.0 dhs. Now, water gravitates from the 3 wellfields at 40m. above msl. to its outfall at 15-20m. above msl. The cost of water is kept at a minimum in Dubai, aided, in addition to the energy-saving self movement of conveyance noted above, by the fact that its 3 wellfields are close to one another and its pipeline system is well-established.

The situation is different with the MEW rural supply system. An aggregate length of pipeline, of more than 1,200 km. has been laid down in the past decade to supply all the settlements in the remote areas of the Northern Emirates. 15 years ago, these settlements relied on supplies from hand-dug wells or water cans on donkey back. The varied consumers benefiting from the MEW water supply, ranging from sizeable towns to small hamlets and individuals in remote places, and the high maintenance cost, render the cost of transmission of MEW water supply nearly 3 times as much as the production cost of groundwater per 1000 gallons.

Investment in pipelines by the MEW in the early 1980s ranged from 700,000 to 21,000,000 dhs. a year. The average life-time of a well or a pipeline is estimated to be 15 years. Damage to both wells and pipeline caused by floods led to replacements of both wells and parts of pipelines, which increased the overall capital investment on both. A house water supply connection in the numerous lch. estates cost the MEW 1000 dhs. each and until 1982 21,000 such connections had been made. A house connection to the main supply line has an average life-time of 3 years.

Furthermore, the value of storage tanks has to be considered in the production cost of groundwater. A steel water storage tank has a life of 15 years. An idea of the cost of tanks can be obtained from Table 8.39, which compares the cost of the two types of storage tanks (the elevated steel and the ground reinforced concrete tanks) of the MEW for the years 1982 and 1987.

Year	Number of wells	Initial investment (x 1,000dhs)	Total value (x 1,000dhs)	Value per well (in dhs)
1975	194	49,082	14,725	75,902
1978	16	4,048	2,969	185,563
1979	13	3,289	2,631	202,385
1980	33	8,349	7,236	253,000
1981	45	11,385	10,626	236,133
1982	114	28,842	28,842	253,000
Average cost per well in 1982				253,000 dhs.
Average cost per well in 1988				96,909 dhs.
Source: Ministry of Electricity and Water.				

Table: 8.38.

The cost of MEW water boreholes, 1975-1988.

The cost of water wells charged to the government was highly exaggerated as is seen from the cost of MEW wells in 1982. The cost has come down by nearly 2.5 times in 1988. A typical well drilled in sandy or gravelly strata costs on average 100dhs. per foot, which includes casing and screening if the drilling is carried out by the government department concerned. This is the rate costing Dubai Water Department that has always carried out its own drilling (1990).

Capacity	Type	Average cost in 1982 (dhs)	Average cost in 1987 (dhs)
5,000 gls.	Elevated (steel)	150,000	110,000
50,000 gls.	Ground (concrete)	291,000	183,000
Source: Ministry of Electricity and Water.			

Table: 8.39.

Comparison of the cost of MEW public water supply storage tanks in 1982 and 1987.

The cost of the many storage tanks of the MEW in the villages of the Northern Emirates helps raise the unit cost of MEW groundwater. The elevated steel tanks have a life-time of 15 years and the majority already need replacement (1990).

With regard to the value of equipment of the wells, which includes diesel, electric or submersible pumps, the last two types have a life-time of 5 years, while the diesel pumps can last up to 10 years. Table 8.40 compares the cost of water pumps in 1982 and 1987.

Maintenance, fuel (diesel), electricity, chlorine and insurance are included in the input capital. Chlorine is hardly applied to MEW groundwater. The cost of buildings, control rooms and road-tanker service are also taken into account in the ultimate water cost.

The distribution cost of MEW groundwater amounts to nearly twice the production cost of groundwater itself. While the production cost of groundwater from all MEW wells in the Northern Emirates was 3-4 dhs. per 1000 gallons, the distribution cost added up to about 6 dhs., making the total cost of 1000 gallons of groundwater reaching MEW consumers in the villages about 9-10 dhs. (1989).

In Al Ain, the high investment in well development and management makes the cost of groundwater delivered to the consumer the highest in the Emirates; about 12-15 dhs. per 1000 gallons in 1989 (personal communication with the Director of Al Ain Water Dept., at Al Khubaisi).

8.7.3. Cost of desalinated water

8.7.3.1. General

As noted earlier, the Abu Dhabi Directorate for Power and Desalination Plants is the only water-related organization in the Emirates that publishes and makes available data on its production of desalinated water. Hence the wealth of production unit cost data presented in the present study for the various desalination plants of Abu Dhabi.

Dubai Electricity Company (DEC), produces the cheapest desalinated water in the Emirates at a rate of 8.9 dhs. per 1000 gallons (1988-89) of an average daily bulk desalinated water output of more than 35 mgd. The Gas Turbine Station in Abu Dhabi, on the other hand, produces the most expensive desalinated water at 302.99 dhs. per 1000 gallons but for a

daily output that formed in 1988-89 only 0.27% of the total desalinated water volume produced in Abu Dhabi (1 US$ = 3.65 Emirates Dhs.).

8.7.3.2. Cost of desalinated water in Abu Dhabi

The unit cost of desalinated seawater produced in Abu Dhabi is 18.10 dhs. per 1000 gallons based on the total volume produced in 1988 and 1989 of around 79-83 mgd. by all the 6 desalination plants. Al Sa'adiyat Diesel Station (SDS), the Gas Turbine Station (GTS) and the Solar Plant at Um Al Nar (south), which together produce only 0.33% of the total daily desalinated water output of 83 mgd. (1989), have production costs of 183.99, 302.99 and 56.44 dhs. per 1000 gallons, respectively. For the remaining 99.67% of desalinated water produced in Abu Dhabi the cost averages 18.10 dhs. per 1000 gallons which is higher than the combined DEC-DUBAL production cost per 1000, gallons in Dubai for the same year(12.62 dhs.).

The production unit cost could have been lower had it not been for the varied plant sites, types of units (Sidem, IHI and Weir Westgart) and the quantity produced in each. Production ranges from 35.81 mgd. in Um Al Nar (west) plant to a mere 0.018 mgd. in the Solar Plant in Um Al Nar (south) (1988). The ultimate cost is governed by the 3 factors of fuel, plant operation and the quantity of desalinated water produced. The bulkier the daily desalinated water output, the lower is the unit cost. The multiplication of production sites increases operation and maintenance cost.

The 3 small producing desalination plants of Al Sa'adiyat, the Gas Turbine Station and the Solar Plant are old and their distilling units are of low operation efficiency as is the case with the Gas Turbine Station. Al Sa'adiyat plant is not linked to the public supply system and the island the plant is serving, is itself supplied with desalinated water from the major producing plants.

The desalination plants of the two extremes: the low production-high cost (Sa'adiyat) and the high production-low cost (the 2 Um Al Nars) are shown in Table 8.41. The last plant in Table 8.41 (the Gas Turbine Station), was the first in production bearing all the demands of Abu

	1982	1987
Diesel pumps	110,000 dhs	80,000 dhs
Electric pumps	32,000 dhs	26,000 dhs
Turbine pumps	192,000 dhs	162,000 dhs
Submersible pumps	100,000 dhs	80,000 dhs
Sources: MEW, local water departments and drilling contractors.		

Table: 8.40.

The cost of the various types of pumps installed on boreholes in the Emirates for 1982 and 1987.

Pumps constitute an important cost input component in the calculation of the production unit cost of groundwater. Most of the pumps installed on private and government boreholes are electric ordinary and submersible pumps, which have a life-time of 3-5 years.

Station	Av. daily production mgd	% of daily total	Production unit cost dhs/1000 gals.
Steam Turbine Station	10.16	13.78	22.13
Um Al Nar East (Gas)	27.41	37.18	16.13
Um Al Nar West (Steam)	35.81	48.59	16.08
Sa'adiyat (Diesel)	0.044	0.061	183.99
Um Al Nar South	0.018	0.024	56.44
Gas Turbine Station	0.27	0.37	302.99
Total	73.89	Combined unit cost dhs. 18.10	1000/gals.
Source: Power and Desalination Directorate, WED Abu Dhabi			

Table: 8.41.

The high-output/low-cost and the low-output/high-cost desalination plants of Abu Dhabi, 1988-89.

The production unit cost of desalinated water in Abu Dhabi is 18.10dhs./1000gals. for a bulk output of 73-83 mgd. of which 99.7% is produced by the two Um Al Nar and the Steam Turbine Plants. Bulk production and uniformity in equipment (i.e., units of the same make) in a single location are important cost-reducing factors.

Dhabi town in the early 1970s. Its Wier Westgart evaporators, which have never performed at more than 67% efficiency, even in the early days when they were still new, have just been taken out of service (1990). The 0.27 mgd. they are producing (from 4 units, the other 2 were retired in 1984), is more than 18 times in production unit cost of the water produced at Um Al Nar (East) of Abu Dhabi and more than 34 times that of DEC of Dubai. The similarity in the unit cost between Um Al Nar (East) gas station and Um Al Nar (West) steam station, despite the greater volume of water produced by the latter by 39%, may be attributable to the design capacity of the evaporators. It appears cheaper to run the evaporators in Um Al Nar (West) than those in Um Al Nar (East).

The breakdown of the unit production cost of 5 of the 6 desalination plants of Abu Dhabi for 1988 is given in Table 8.42 (the solar-powered station in Um Al Nar South is excluded). The unit cost breakdown for the same plants since 1980 is given in Table 8.43.

As seen in Table 8.43, there was a noticeable drop in the unit cost from 31.01 dhs. per 1000 gallons in 1985 to 20.02 dhs. in 1986. The main factors leading to this cost reduction were the sharp drop in the cost of fuel from 64.4% (of the total production cost) to 38.2%, the higher depreciation estimate (43.9% for 1986 against 26.0% for 1985) and, naturally, the larger volume of water produced (20.38mgd. against 17.91mgd), which induced the lower overall cost. The drop in cost was again noticeable between 1987 and 1988 from 19.68 dhs. to 18.10 dhs., due also to a reduction in fuel cost by 14%, although there were exceptionally high running costs in the troubled Gas Turbine Station as well as the other two minor, but costly water producers of the solar plant in Um Al Nar (South) and the diesel plant at Sa'adiyat. Labour and fuel costs in the latter were comparatively high offsetting its substantial depreciation rate in 1988. The overall gross increase in total output by 14% in 1988 to the 1987 output helped to reduce the unit cost by 9% from 19.68 dhs. per 1000 gallons in 1987 to 18.10 dhs. in 1988.

Should future development trends in the desalination sector in Abu Dhabi follow the pattern set by the two Um Al Nar plants, then the 18.10 dhs. per 1000 gallons of 1988 could even get lower. As it stood in 1988, this unit cost was more by 43% than that of the combined DEC-DUBAL cost of

Plant	Fuel	Material	Labour	Depreciation	Total cost dhs/ 1000 gals.
	(---------- % of the total cost---)				
GTS	27.18	60.90	130.59	84.32	302.99
STS	6.44	1.97	4.49	9.25	22.13
UNE	4.26	0.58	1.60	9.69	16.13
UNW	4.21	0.58	1.51	9.79	16.08
SDS	65.87	6.10	112.10	-	183.99
Source: Power and Desalination Plants Directorate, WED Abu Dhabi					

Table: 8.42.

Breakdown of elements of the production cost of each desalination plant in Abu Dhabi (the Solar Plant in Um Al Nar South is excluded), 1988.

The highest cost components are in the low-output plants of the GTS (Gas Turbine Station) and the SDS (Sa'adiyat Diesel Station), which only produce 0.03% of the total daily output and where nearly all the cost elements are high, especially that for labour. The lowest production cost is for the two Um Al Nars where the 'labour' and 'material' cost components are the lowest among the plants and where the daily desalinated water production, together with that from the STS (Steam Turbine Station) plant, forms 99.7% of the total volume produced in Abu Dhabi (1988).

Year	Fuel	Material	Labour	Depreciation	Cost dhs/1000 gal.
	(---------- % of total cost ----)				
1980	31.40	11.80	16.10	40.70	22.09
1981	62.10	5.30	9.60	23.00	33.60
1982	63.20	2.90	9.80	24.10	34.54
1983	65.60	4.30	8.30	21.80	32.59
1984	65.50	2.80	8.20	23.50	29.77
1985	64.40	2.30	7.30	26.00	31.01
1986	38.20	4.10	13.80	43.90	20.02
1987	30.74	27.36	47.21	44.54	19.68
1988	26.44	33.09	43.71	49.71	18.10
Source: Power and Desalination Plants Directorate, WED Abu Dhabi					

Table: 8.43.

Breakdown of the components of the production cost of all the desalination plants of Abu Dhabi town (the Solar Plant at Um Al Nar South (UNS) is excluded), 1980-1988.

The unit cost of desalinated water per 1000 gallons reached a peak of 34.54 dhs. in 1982 because of extremely high fuel costs, which made up 63% of the total production cost. There was a marked drop in the production unit cost from 31.01 dhs. to 20.02 dhs./1000gals. between 1985 and 1986 owing to a drop in fuel cost from 65% to 38% and also a sharp rise in depreciation from 26% to 44%, of the total cost. Again, the 18.10 dhs/1000gals. cost for 1988 was because of the large drop in the cost of fuel (26%) and an increase in the depreciation value of the aging plants by 50%.

12.62 dhs. per 1000 gallons and was slightly less than that of DUBAL alone for the same year (18.23 dhs/1000 gals). Uniformity of equipment in a single location is a cost-reducing factor, and it would be interesting to watch the performance of Al Taweelah 'A' plant, with its 3 units of 6.5 mgd. all of which are of the same brand (Sidem) that have only recently commenced production (end of 1989).

8.7.3.3. **Cost of desalinated water in Dubai**

The two seawater desalination plants in Dubai, the Dubai Electricity Company (DEC) and Dubai Aluminium Co. (DUBAL) plants, are in the Jabal Ali zone. Both are seawater MSF plants and are associated with power generation. The larger of the two, DEC, is attached to both steam (commissioned in 1980-84) and gas (in 1981) turbines of station 'D'. 3 more gas turbines are under construction and are expected to be in operation 1990-1991. Desalinated water production associated with these stages of development of power turbines in DEC in Dubai is given in Table 8.44.

As mentioned earlier, the unit cost of 1000 gallons of desalinated water produced by DEC in 1988 was 8.9 dhs. Production is concentrated in one site, with the associated costs minimized. The output of desalinated water was efficiently enhanced by raising the heat from the normal 88^{o}C to 110^{o}C securing a 20% increase in output. As a result, the installed low temperature capacity of 31.46 mgd. was boosted to a maximum of 38.0 mgd. in March 1988 when the average daily desalinated water volume produced exceeded 36.0 mgd. during 5 months in 1988. In DUBAL, on the other hand, one of the evaporators failed to increase output even with the higher temperature of 110^{o}C, and was only producing its usual output at the low temperature of 90^{o}C (1989). Operation cost efficiency has played a key part in the production of desalinated water with the lowest unit cost in the whole Emirates being for the water produced by DEC. The breakdown of the various facets of production costs of DEC is given in Table 8.45(A).

The unit cost of desalinated water produced by DUBAL, as invoiced to Dubai Water Department, can be seen from the 3 invoices obtained for the year 1988 (Table 8.45 B), with the average unit cost for all the 3 invoices being 18.23 dhs. per 1000 gallons.

'D' PLANT	Power (Megawatt)	Desalinating units/ capacity in mgd	Max. daily water output in mgd
1979	340 MW	5 x 3.43 mgd	17.15 mgd
1984	375 MW	3 x 6.86 mgd	20.58 mgd
'E' PLANT			
1991	252 MW	6 x 4.00 mgd	24.00 mgd
'G' PLANT			
1993	460 MW	8 x 7.00 mgd	56.00 mgd
Total capacity by 1993			117.73 mgd (195.33 MCM/a)
Source: Dubai Electricity Company.			

Table: 8.44.

The development of desalination plants in association with power stations in the Dubai Electricity Company (DEC) site at Jabal Ali, 1979-1993.

The volumes for the various stages of desalination development shown in Table 8.44 are for top brine temperature (110°C) desalinated water production, which is approximately 20% higher than that of the lower brine temperature (90°C). Dubai's desalinated water capacity in 1992 (Phases E and G) is going to be 117.73 mgd, which is equivalent to the present-day (1990) capacity of Abu Dhabi with the completion of Al Taweelah 'A' plant.

Cost Item	Unit	Total
Capital depreciation (15 years)	Million dhs	39.45
Additional electricity and fuel costs	Million dhs	37.22
Auxiliary energy costs		
Cost of chemicals	Million dhs	2.89
Staff costs	Million dhs	8.50
Plant maintenance	Million dhs	4.06
Administrative costs (15% of staff costs)	Million dhs	1.28
Total annual costs	Million dhs	93.40
Total water production	Million M^3	47.73
Cost of water per M^3	Dhs/m^3	1.96 (US $ 0.54)
Cost of water per I.G.	Fils/I.G.	0.89
		8.90 dhs/1000 gals.
Average equivalent fuel cost/ I.G.	Dhs/I.G.	0.84
Water supplied to Dubai Water Department	Million I.G./day	28.32
Source: Dubai Electricity Co.		

Table: 8.45 (A)

Breakdown of the estimated production cost components of the desalinated water produced by Dubai Electricity Company for 1988 and 1989.

● Invoice for the period 2/10/1987 to 1/1/1988: 32,407,000 dhs for 1,382 million gallons = 23.45 dhs/1000 gals.
● Invoice for the period 2/1/1988 to 25/3/1988: 27,324,000 dhs for 1,450 million gallons = 18.84 dhs/1000 gals.
● Invoice for the period 26/3/1988 to 15/7/1988: 41,864,000 dhs for 2,741 million gallons = 15.27 dhs/1000 gals.
Average cost = 18.23 dhs/1000 gals.
Source: Dubai Water Dept., Ruler's Diwan.

Table: 8.45 (B)

The actual cost of the desalinated water produced by DUBAL in 1988 as invoiced to the Dubai Water Department.

The unit production cost of the desalinated water produced by DEC is less than half that produced by DUBAL despite the fact that the water produced by the latter is by means of cost-free waste heat. This high production cost of DUBAL, as seen in the actual invoices above, is the main factor behind enhancing desalination schemes in DEC (Phases E, G and H) that by 1993 would increase Dubai's desalinated water output to 148 mgd.

The production unit cost of 18.23 dhs. per 1000 gallons of DUBAL for 1988 was more than twice that for DEC (8.9 dhs./1000 gals.). At the beginning of 1988, the cost was higher (23.45 dhs. per 1000 gallons) (Table 8.54 B). It should be noted that desalinated water produced at DUBAL, unlike that of DEC where gas and liquid fuel are used for its production, is produced by waste heat, which is not taken into account as part of the production cost. It is thus obvious that DUBAL apportions the cost of gas/liquid fuel and electricity, used for the smelting of bauxite in its aluminium plant, between aluminium and water production despite the fact noted earlier that the latter is produced from cost-free waste heat.

It is anticipated that when DEC station 'E', in which waste heat will be used to distil the expected 24.0 mgd. to be produced, comes into operation in 1991, the cost will be reduced even further. The trend for more economic desalinated water production appears to be more concentrated in DEC than in DUBAL, and if the decrease in costs as production is enhanced continues, then further expansion and development in the desalination industry should be concentrated in DEC.

8.7.3.4. **The combined cost of desalinated and groundwater in Dubai**

As has been shown in Section 8.7.2, groundwater has the cheapest production unit cost among the three sources of potable water in Dubai. The other two sources are the desalinated water plants of DEC and DUBAL, with the unit cost of the water produced in the latter twice that of the former. The unit cost of each source, the average daily output and percentage of each from the gross daily output of the 3 sources together, is summarized in Table 8.46.

The combined production unit cost of the 3 potable water sources is 11.19 dhs. per 1000 gallons. To this is added 30% as distribution cost, making the combined overall unit cost of a 1000 gallons delivered to the consumer as **14.55 dhs.** This is almost equal to what the consumer is being charged for 1000 gallons (15 dhs.). Compared to the 18.10 dhs./1000 gallons for Abu Dhabi and the 20.92 dhs./1000 gallons for Sharjah (Section 8.7.4.), this combined unit cost of the water of Dubai, though hardly showing any profit, is relatively better than that of the other emirates.

Source of water	Av. daily output mgd	% of daily total produced	Unit cost dhs/1000 gals.
Groundwater	10.21	14.84	3.00
Desalinated water (DEC)	35.21	51.17	8.90
Desalinated water (DUBAL)	23.39	33.99	18.23
Total	68.81	100.00	Average 11.19
Source of data: Respective water authorities in Dubai.			

Table: 8.46.

The average production unit cost of the 3 sources of water in Dubai (groundwater and the two sources of desalinated water), on the basis of apportionment of water volume produced from each source.

8.7.4. Cost of water in Sharjah

Sharjah produces the most expensive bulk desalinated seawater in the Emirates. The cost of 1000 gallons in 1985 was 42.50 dhs., in 1986 it was 31.97 dhs., in 1987 31.26 dhs., and in 1988 26.76 dhs.. The breakdown of the cost inputs into the production process of desalinated water in Sharjah is given in Table 8.47 for both 1987 and 1988. As seen from Table 8.47, the cost of fuel (gas from the Sharjah Saja'ah field and diesel from the Abu Dhabi National Oil Co. (ADNOC)) made up 59% and 68% of the total production cost in 1987 and 1988.

The unit production cost of the combined desalinated and groundwater in Sharjah is given in Table 8.48. As seen in the Table, the low production cost of groundwater (3.0 dhs./1000 gals.) helped to dilute the high production cost of desalinated water, which was more than 10-fold in 1987 (31,26 dhs/1000 gals.). The combined cost is calculated by apportioning the cost on the basis of the volume of water obtained from either desalinated or ground water, with the latter making up 54-55% of the total daily volume of water produced in 1987-88. As a result, the production unit cost of the combined ground and desalinated water in Sharjah was reduced to 16.09 dhs. and 13.68 dhs. per 1000 gallons for 1987 and 1988, respectively. When nearly 31% is added to this as the distribution cost, the ultimate cost per 1000 gallons reaching the consumer in 1987 was 21.02 dhs., while in 1988 this was 17.78 dhs.

The official estimated distribution cost in Sharjah is put at 30.5% of the combined desalinated and groundwater production unit cost. This is because very little is new in the distribution system, but as the new wellfield in Seih Al 'Aqareb is developed, more new cost inputs in the form of development investment will raise the groundwater unit cost for 1990.

8.7.5. Cost of sewage treated water in the Emirates

None of the 4 sewage treatment plants of the Emirates has prepared an analysis of the production unit cost of treated effluent water. The only available breakdown of production unit cost details is that for the new Dubai sewage treatment plant at Al Aweer contained in its feasibility study (New Dubai Sewage Treatment Plant, Feasibility Study, German

Item	Cost in million dhs		% of total cost	
	1987	1988	1987	1988
Chemicals	1.54	1.58	1.0	1.12
Fuel	89.23	95.48	58.89	67.60
Maintenance	3.87	1.32	2.55	0.94
Administration	3.52	3.22	3.32	2.28
Other operation costs	26.42	22.54	17.45	15.96
Depreciation	26.94	17.10	17.79	12.10
Total	151.52	141.24	100.00	100.00
Average desalinated water produced in 1987 = 13.28 mgd Average desalinated water produced in 1988 = 13.67 mgd				
Production unit cost of desalinated water in 1987 = 31.26 dhs/1000 gls. Production unit cost of desalinated water in 1988 = 26.76 dhs/1000 gls.				
Source: Sharjah Electricity and Water Department.				

Table: 8.47.

Breakdown of the production unit cost of the desalinated water produced at Al Layyah plant in Sharjah for 1987 and 1988.

The production unit cost of the desalinated water of Sharjah is the highest in the Emirates. The high cost of fuel is the main cost-raising factor. The 26.76 dhs/1000 gals. cost of desalinated water in Sharjah for 1988 is 1.5 times that for Abu Dhabi (18.10 dhs/1000 gals.) and is more than double that for Dubai (12.65 dhs/1000 gals.).

Type of water	Av. daily production (mgd)		Unit cost dhs/ per gallon		Unit cost dhs per 1000 gallons	
	1987	1988	1987	1988	1987	1988
Desalinated	13.28	14.46	0.0313	0.0267	31.26	26.76
Groundwater	15.38	17.87	0.003	0.003	3.00	3.00
Combined cost	28.66	32.33	0.0161	0.01362	16.11	13.62
Added to this is 30.46% distribution cost =					20.02	17.77
Source: Sharjah Electricity and Water Department.						

Table: 8.48.

The production and selling unit costs of desalinated and groundwater, and of both combined, as well as the cost per 1000 gallons reaching the consumer in Sharjah, for 1987 and 1988.

The larger volumes produced in both desalinated and groundwater in 1988 than those for 1987 were behind the lower production unit cost per 1000 gallons for 1988. However, the cost was still higher than that for the desalinated water of Dubai (14.55 dhs./1000 gals.) and that for Abu Dhabi (18.10 dhs./1000 gals.). Groundwater in Sharjah formed 55% of the combined desalinated and groundwater daily average production in 1988 (32.33mgd.).

Water Engineers, 1987). There were 3 unit production cost options, all in relation to the location of the plant at Al Aweer from Dubai town. The existing site is the farthest of the 3 from Dubai town. Despite these different locations, the final production unit cost varied only by 4% from 5.10 dhs. to 5.30 dhs. per 1000 gallons (about 0.30 US$ per $1m^3$), all for phase 1 of the plant of the designed capacity of 130,000 m^3/d, although about half of that volume will be treated in the early stages of plant operation. 5.30 dhs. per 1000 gallons is taken by the present study as the reasonable production cost for high-quality treated effluent water in the Emirates. The various inputs to the total production unit cost are given in Table 8.49 which shows the unit cost per 1000 gallons as 5.30 dhs. or 1.5 US$.

Owing to the similarity of the treatment process and identical influent with little or no variety in its almost wholly domestic composition, this estimated unit cost for the new Dubai sewage treatment plant can be taken as applying to all the other plants until estimates for these are prepared in their respective emirates.

Although all the treated effluent from any of the 4 sewage treatment plants of Abu Dhabi, Al Ain, Dubai and Sharjah is totally used for irrigating landscaping schemes in these towns, with no payment for it is made by the municipalities, which are the managers of the sewage plants and their sole consumers, it is useful to derive the production unit cost of this treated sewage water to consider later its economic feasibility as a potential source for artificial recharge of aquifers.

The production unit cost of treated sewage water is, thus, second to that of the consumer-delivered groundwater for the whole Emirates (5.19 dhs./1000 gals.) and nearly half the cheapest cost of desalinated water produced by DEC in Dubai (nearly 12.0 dhs. for desalinated water per 1000 gals. reaching the consumer).

8.7.6. The average cost of water in the Emirates

Table 8.50 compares the production unit cost of the various sources of water derived and cited in the preceding text. It should be noted that the distribution cost (pipelines, booster pumps, storage tanks, tanker

A. RUNNING COSTS (x 10^6 dhs.)		
Power consumption		3.42
Chemicals		3.13
Operating		6.25
Maintenance		4.94
B. AMORTISATION (x 10^6 dhs.)		
Construction		16.05
Pipelines		7.21
Mechanical equipment		14.34
Total amortisation cost		55.34
Annual sewage flow (m^3 x 10^6)		47.45
PRODUCTION UNIT COST (dhs/m^3)		1.17
	US $	0.30
PRODUCTION UNIT COST (dhs/1000 gals)		5.30
	US $	1.50

Source: New Dubai Sewage Treatment Plant, Feasibility Study, Dubai Municipality/German Water Engineers(Consultants).

Table: 8.49.

Breakdown of the cost of the expected production of recycled sewage water from the New Dubai Sewage Treatment Plant at Al Aweer, which commenced operation at the end of 1989.

The production cost of recycled sewage water is nearly half that of the cheapest desalinated water produced by DEC of Dubai and almost equal to the groundwater production cost for the Emirates (5.19 dhs./1000 gals.). It, therefore poses as a potentially important source for irrigation of non-edible crops or for artificial recharge of aquifers.

Source	Av. daily prod. mgd	Cost dhs/ 1000/gals	Combined cost Gnd. & desal. dhs/1000 gals.
GROUNDWATER:			
Al Ain	34.41	8.0	
Dubai	10.21	3.0	
Sharjah	13.96	3.0	
Northern emirates (MEW)	36.54	4.0	
Average production groundwater cost for the whole Emirates:			5.19
DESALINATED WATER:			
Abu Dhabi	73.89	18.10	
Dubai	58.60	12.62	
Sharjah	14.16	31.26	
RO Brackish	-	14.00	
RO Seawater	-	22.00	
Floating desalination plant " Al Rumaith"	-	22.00	
Average production desalinated water cost for the whole Emirates:			21.80
RECYCLED SEWAGE WATER:			
Dubai	13.20	5.30	5.30

Table: 8.50.

Summary of the production unit cost of ground, desalinated and recycled water by emirate or region, and the combined production unit cost of each type of water for the whole Emirates, 1988.

The production costs of groundwater and treated sewage water are about equal. The production cost of desalinated water for the whole Emirates (21.80 dhs./1000 gals.), which is 4 times the cost of either of the two types of water, is rendered high by the high production cost in Sharjah and Abu Dhabi. With such a high average cost, desalinated water seems prohibitively expensive for widespread application as irrigation water.

service and administrative staff directly related to distribution) is higher for ground than for desalinated water from MSF or RO plants. This is particularly so for distribution managed by the MEW all over the Northern Emirates involving longer distances and higher costs as discussed in section 8.7.2. Since the consumer is charged the same flat rate for 1000 gallons for both desalinated and groundwater in the whole Emirates (15 dhs.), it is assumed that the cost of distribution is similar in each of the water producing emirates. However, as has been shown in this chapter, the distribution cost alone is almost double the actual production unit cost of groundwater managed by the MEW, and is about 40% the cheapest unit cost of desalinated water produced by DEC of Dubai.

Whereas both quantification and costing of water supplied for domestic use are possible because both, especially more so with regard to desalinated water, are monitored; that for agricultural use is not. The accurate measurement of quantities and their input costs pursued by the desalination plants, is dictated by the high technology on which the combined electricity-desalination industry is based.

Water abstracted in large amounts for agricultural use, like most agricultural activities, is not linked to economic viability and, motivated by this upsurge of 'greening' the land, is left unquantified and uncosted. In a typical garden in Al Dhaid (600' X 600') in the piedmont (gravel) plains, up to 3 or 4 boreholes may be found with motor pumps operating on average for up to 18 hours with no metering of their discharge and not even a nominal tariff imposed on the water extracted. Thus, agriculture, the larger consumer of groundwater resources, is hardly regularized in terms of both quantity and cost.

From the unit cost derived for the 3 types of water resources in the Emirates (ground, desalinated and recycled water), a tentative estimate has been worked out for the unit cost of water for the whole Emirates, combining all types and apportioning the cost according to the volume produced by each type in an emirate or region as summarized in Table 8.51. The overall production unit cost of all types of water for the Emirates is 12.24 dhs. per 1000 gallons, and for that delivered to the consumer it is 16.03 dhs. per 1000 gallons for 1988 (4.30 US$ per 1000 gals. or 1.0 US$ per $1m^3$). This high cost is made so by the high cost of

Emirate	Daily prod. mgd	Prod. unit cost dhs/1000 gals.	Distribution cost dhs/1000 gals	Cost per 1000 gals reaching consumer
Abu Dhabi	73.89	18.10	5.51	23.61
Al Ain	34.41	8.00	4.00	12.00
Dubai	68.81	11.19	3.36	14.55
Sharjah	27.80	15.36	4.68	20.04
Northern Emirates (MEW)	36.54	4.00	5.50	9.50
UAE Average	241.45	12.24	4.88	16.03

Source: Calculated from data obtained from the respective local and regional water related departments.

Table: 8.51.

The combined unit cost per 1000 gallons of both the produced water and that reaching the consumer for the whole Emirates, 1988.

The combined calculated unit cost of water reaching the consumer in the Emirates is 16.03 dhs./1000 gals.. As the consumer is only charged the flat rate of 15.0 dhs./1000 gals., this all-Emirates water cost is 7% subsidized. It is less by 13% than the cost of desalinated water served to the consumer in Abu Dhabi town (18.10 dhs./1000 gals.) and is cheaper also than the cost of the combined ground and desalinated water of Sharjah by 11% (17.77 dhs./1000 gals.), and also the combined cost of Dubai water by 7%.

It is obvious from the cost of desalinated water in the large bulk producers of Abu Dhabi, Dubai and Sharjah, which ranges from 18-24 dhs./1000 gals., that such a cost is preclusive to widespread application of desalinated water to agricultural use on the uncontrolled scale irrigation is practised at present all over the Emirates.

The desalinated water sold to the consumer in the town of Abu Dhabi (where it is the only source of water supply) at 18.10 dhs./1000 gals. is 13% subsidized; while the cost of the combined desalinated and groundwater in the whole of Abu Dhabi emirate (including Al Ain) of 19.92 dhs./1000 gals. is 24% subsidized. Only Dubai is selling its water at cost without subsidy, which makes it relatively better than the other emirates.

desalinated water produced in plants such as those of Al Llayyah in Sharjah, DUBAL in Dubai and some of the older plants in Abu Dhabi.

Finally, the production unit cost of effluent treated water, which is about 5.30 dhs. per 1000 gallons (1988), is cheaper than the cheapest desalinated water produced by DEC (8.9 dhs./1000 gals.) and is about equal to the groundwater production cost for 1000 gallons for the whole Emirates (5.19 dhs. (Table 8.50)). The total daily volume of treated sewage water amounts to 48.12 mgd. or 80 MCM/a, which is made available for irrigating landscaping reserves in the towns. It thus poses as a potentially important resource for the future. Its unit cost is likely to decrease with the increase in the volume of treated sewage as envisaged by the plan for the new Dubai sewage treatment plant at Al Aweer. The unit cost of treated sewage water in Phase I of the Al Aweer Sewage Treatment Plant (to treat 130,000m^3/d.) will be 5.30 dhs./1000 gallons; while the unit cost for Phase II (to treat 200,000m^3/d.) is likely to drop to 4.50 dhs./1000 gallons.

8.8. General summary

Water production in the Emirates is characterized by continual enhancements in provision of water to meet the increasing demand. There are many water governing organizations on the regional, or federal (MEW), and emirate, or local levels (water departments of the individual emirates). There is no central planning for water development and management, and drilling of wells by official and private bodies is absolutely uncontrolled by any legislation. Any limited planning that does exist is for purely the supply rather than the whole aspects of water resources. Whereas groundwater abstraction for domestic use from the wellfields that serve the major towns, such as Dubai, Al Ain and Sharjah is quantified by metering and careful monitoring, that, also for domestic use for the villages in the Northern Emirates (managed by the MEW), is unmeasured and even unchlorinated. Furthermore, the widespread abstraction of groundwater by the agricultural sector is not metered and its quantity is, therefore, not known exactly. Hence, the undertaking by the present study to quantify agricultural abstraction by well discharge measurements and to average them by area to derive a reasonable value for the volume of groundwater abstracted by agriculture.

Groundwater abstraction increased from 172 MCM/a in 1968 to 3,400 MCM/a in 1988. The ratio of agricultural abstraction to that for domestic use has remained 19:1, or 95% for the former and 5% for the latter, since 1968.

Since the early 1980s desalinated water has grown in importance and has lessened the pressure on groundwater sources. At present (1990), desalinated water meets 100% of the needs of the town of Abu Dhabi, 85% of Dubai and 47% of Sharjah. More small desalination plants are being set up to meet human demand for potable water in Ajman, UAQ, Ras Al Khaimah and Fujairah. Al Ain is already receiving more than 40% of its daily consumption from desalinated water from Abu Dhabi (about 15.0 mgd). Development in the desalination water production sector includes Phases 'A', which started producing 18-20 mgd at the end of 1989, and 'B', which is expected to produce 40mgd. in 1993, both of Al Taweelah Power Station of Abu Dhabi; and Stations 'E' and 'G' of DEC at Jabal Ali in Dubai, which are expected to produce 24.0 mgd (1991) and 56.0 mgd (1993), respectively. This will increase the desalination capacity of Abu Dhabi and Dubai in 1993 to 157 mgd. (260.5 MCM/a) and 148 mgd (245.6 MCM/a), respectively. The desalination capacity on the east coast is going to be 3.0 mgd by 1991. The total desalinated water output for the whole Emirates at present (1990) is 181.0 mgd. or 300.0 MCM/a.

Desalinated water production is likely to gain greater importance during the 1990s with the official expectation of looking to this non-conventional water source for agricultural application, though this is obviously impracticable both quantitatively and economically.

Recycled water production, limited only to the large towns of Abu Dhabi, Dubai, Sharjah and Al Ain totals about 48.22 mgd (80 MCM/a) of treated sewage effluent of a good 10/10 mg/l BOD/SS (Biological Oxygen Demand/Suspended Solids), which is twice chlorinated, but it is totally used for irrigating the landscape schemes in the towns the sewage plants are partially serving. If large-scale sewage treatment is embarked on, coupled with limiting the escalation of landscaping in towns, recycled sewage water could be potentially important as a source for artificial recharge. The plausibility of this lies in the production unit cost of recycled sewage water: 5.30 dhs/1000 gallons, which is almost equal to the cost of potable groundwater reaching the consumer (5.19 dhs/1000

gallons) and less by 40% than the unit production cost of desalinated water produced by DEC.

The detailed synthesis of the water production and use of the three types of water resources developed in this chapter is intended not only to present the problem of shortage in the supplies, but also to highlight the recurring theme in water resource development and management in the Emirates: that of the lack of planning not only at the central but also at the local levels, and the total absence of any conservation measures. These negative aspects are behind the widespread and intense abstraction of groundwater and the escalating production of desalinated water.

It must be pointed out that whatever estimates are made in this chapter concerning groundwater abstraction by agriculture, they are conservative although they may appear huge. The actual number of agricultural wells is not definitely known, nor is the actual long pump running duration used in calculating the discharge from these wells. Means of well discharge rates were used for the total number of agricultural wells by region based on official statistics (Ministry of Planning Central Computer Office, 1988) to which only 5% was added to allow for the uncounted wells, though this allowance, in view of many professionals working in the fields of water and agriculture, should have been more.

With regard to the use of water resources, whether natural (groundwater) or processed (desalinated or recycled water), it has been shown in detail in this chapter that the dominating characteristic is the confused priorities in their use. Examples, include the water of prime potable quality, which is used in Al Ain for irrigating wheat when this crop is known to tolerate water of marginal quality; the application of desalinated water (and also groundwater of potable quality) to salt-resistant forest plants (in Sir Bani Yas Island, Al Reef, Maida'ah and Nadd Al Shaba), the use of desalinated water on lawns and the fish ponds (of the Dubai Golf Course) and of groundwater of marginal to brackish quality with high sulphate and fluoride content for human use in the heart of the desert foreland. Recycled water production is totally diverted to irrigating landscaping reserves in the towns. No plan exists for using this water resource for irrigating even

non-edible crops or for groundwater recharge through natural sand filtration despite its encouragingly low production costs.

It is obvious that the high production cost of desalinated water prohibits its widespread use as irrigation water for agriculture. If such use is to be contemplated, then the agriculture, to which such expensive water is to be applied, should be highly specialized and beneficial in terms of meeting the requirements of national food security.

8.9. Synopsis

In this chapter, the main economic and social factors have been introduced into the study, which has concentrated in the preceding chapters upon the physical. Following a section in which the government departments concerned with water have been identified, the major sources of water have been discussed in the context of their usage. In the section on groundwater for domestic use, all the main wellfields and the supply for every area within each emirate or region have been described. A detailed account has been given of groundwater for agricultural use throughout the Emirates and, in particular, the problems of quantification of consumption. Additionally, the first scientifically-based quantification of the groundwater used by agriculture nationally is given. National provision for desalination and effluent treatment has been analyzed with detailed examples. Finally, taking all the known variables into account, an attempt, that must be described as unique, has been made to calculate water cost regionally, and by water type, to provide a figure for the overall general production and delivery cost of water in the Emirates.

CHAPTER NINE

THE SHARED WATER RESOURCES

9. THE SHARED WATER RESOURCES

9.1. Introduction

The Emirates shares water resources with neighbouring countries as follows:

a) On the regional scale, the brackish to supersaline artesian water of the Simsima, Um Er Radhmah and Dammam deep carbonate aquifer system, of Upper Cretaceous to Eocene age, which is shared with Qatar, Saudi Arabia, and the Dhofar-Hadhramaut region of Oman and the Yemen Republic (The Shared Water Resources in the Gulf States and the Arabian Peninsula, FAO, 1979).

b) On the local scale, the shared water resource areas are:

   i) In both the Quaternary alluvium and the limestone rocks of the Ru'us Al Jibal peninsula, where 60% of the length of Wadi Al Beeh, in its upper and middle courses, lies within Omani territory.

   ii) The shallow fresh water resources of the Quaternary alluvial deposits shared with Oman on the western flank of the mountains, between Filli-Al Madam in the Al Madam Plain in the north, through Al Ain and Buraimi to Um Ghafah in southern Al Jaww Plain in the south. This is the most important region of the shared water resources, which is treated in detail later in this chapter.

There are two more areas of shared fresh water resources on the eastern flank of the mountains at Madhah, south of Khor Fakkan where the isolated mountain Omani territory encloses the upper course of Wadi Madhah and the village of Madhah; and further south, on the east coast

also, where Wadis Al Qawr (East) and Hatta flow to the Batinah coast between Milaha and Shinas.

iii) To the west and south of Jabal Hafeet, the Emirates also shares with Oman the shallow brackish groundwater in the gypsum-clay-marl-sand sequence across the international border to the west of Al Dhahirah.

Figure 9.1. illustrates the regional and local shared groundwater areas with Oman and the other countries of the Arabian Peninsula to the east, south and west of the Emirates.

9.2. The regional shared water resources

Although most of the Emirates lies south of the main east Arabian sabkha line (Fig. 5.32, Chapter 5), where the 'upper' (the Dammam) and the 'middle' (Um Er Radhmah) deep carbonate system aquifers (distinguished by the FAO Report of 1979, 'The shared water resources of the Gulf States and the Arabian Peninsuls') discharge at the 150m. surface contour in eastern Saudi Arabia, the three main deep carbonate system aquifers lie at great depths under central Abu Dhabi, where the sediments are thickest and deepest. Limited recharge at present is taking place in the outcropping upgradient sections of these strata in central Saudi Arabia but the hydraulic gradient is very low. Whereas, naturally, their waters are fresh in Saudi Arabia, Qatar, Bahrain (especially the uppermost of the three aquifers, the Dammam) and are at or near the surface, they are extremely saline in the Emirates in the vicinity of the oilfields of central Abu Dhabi reaching salinities of over 200,000 ppm.

The middle, Um Er Radhmah aquifer, is the most productive of the three deep aquifers and its water, together with those of the upper Dammam and the lower Simsima, is being used for industrial purposes to pressurize oil extraction. The Dammam is at present the subject of water resource coordination, especially between Saudi Arabia, Kuwait, Bahrain and Qatar, under the auspices of the GCC Secretariate. The Dammam outcrops in limited areas in the UAE to the west and southwest of Assila' in northwest Abu Dhabi, where three wells were drilled (Wells Nos. 29, 30 and 31) to a depth of 382m. (Chapter 5, Section 5.3.2.4; and Chapter 6,

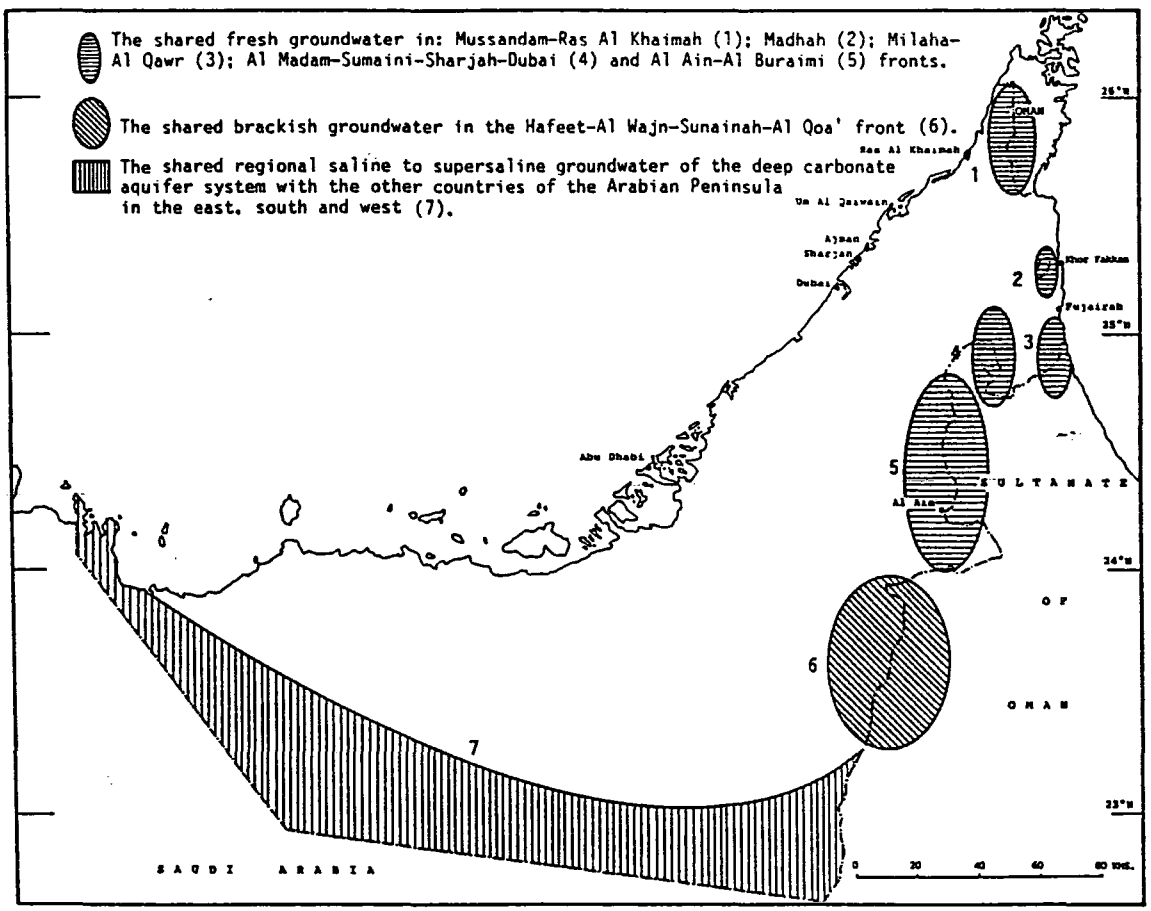


Figure: 9.1.

Fresh, brackish and saline groundwater resources shared with Oman and the countries of the rest of the Arabian Peninsula.

The fresh groundwater resources are shared with Oman in the Mussandam peninsula in the north, where most of Wadi Al Beeh rises and runs in Omani territory, and in the Al Madam-Al Buraimi-Milaha-Madhah in the centre. The brackish groundwater resources are shared also with Oman in the Dhahirah-Al Sunainah-Al Wagn front in the south, where no floods have crossed the common border in living memory but where inflow from Oman feeds the brackish groundwater system in the Emirates. The saline groundwater resources of the deep carbonate aquifer system of the Emirates into which inflow is moving in deep strata from their upgradient sections of the Arabian Peninsula, are shared with Oman, the Yemen and Saudi Arabia.

Section 6.5.3.8) in which the water salinities are between 117,500 and 131,000 mmhos/cm. Such salinities are not much different from those for the deep waters of this aquifer and the other two under the oilfield area of central Abu Dhabi. In central Abu Dhabi salinities of the waters of the Dammam aquifer range from 172,000-188,000 mmhos/cm. rendering any mutual usability of the water resources of this formation from the human and agricultural point of view, as far as the Emirates is concerned, impracticable.

9.3. The local shared water resources

9.3.1. Ru'us Al Jibal peninsula

The western part of Ru'us Al Jibal mountains, lying within the Emirates, is only 15kms. wide, stretching eastwards from the coastal village of Al Rams. Wadis Saham, Ghaleelah, Haqeel and Naqab rise and flow totally within the Emirates side of the border, but the major wadi Al Beeh, flows for most of its course within Oman. Although, in principle, the waters of Wadi Al Beeh may be considered as shared between the Emirates and Oman, much of the water is absorbed by the limestone wadi sides and bedrock of Ru'us Al Jibal as is evident in the less pronounced surface flows compared with those of wadis in the impervious ophiolite zone, such as Wadi Ham. The wadi basin is very wide and its floor is covered with a thick mantle of boulders, gravels and coarse sand interbedded at various intervals with clays and silt, forming the ideal setting for the lens-shaped 'perched' water bodies for which Wadi Al Beeh is famous. Groundwater levels are receding rapidly on both sides of the border and are around 60m. below the surface of the wadi floor at the Al Beeh wellfield of the Emirates (in its downstream section).

9.3.2. Al Shumailiyah mountain enclave of Madhah

Another area of shared fresh water resources is that of the Shumailiyyah mountain enclave of Madhah (Oman), to the west of Qidfa'(Emirates) on the east coast, where the upper half of Wadi Madhah is within Omani territory and the rest within the coastal plain of the Emirate of Fujairah. There are three wells serving Qidfa', where groundwater levels are rapidly falling and well discharge rates are decreasing.

Similarly, upstream in Madhah, where the saturated layer in the wadi gravels lies 7m. below the surface (after the rains) and is about 30m. thick, but is exhaustible, attempts are underway to drill into the ophiolite fractured zone below 37m., and also to tap water from thrust fault zones in both the massive gabbros, which make up the lower half of the enclave, and the peridotites, which make up the upper half.

9.3.3. The area of brackish to saline water: South of Jabal Hafeet as far as Um Ez Zemool, and westwards of this line

Unlike the zone of fresh water further north between Al Ain-Al Buraimi and Filli-Al Madam (Section 9.3.4.), where the international border is about 20-30kms. from the foothills and where groundwater is in highly permeable Quaternary gravels, the border south of Hafeet lies between 100-120kms. from the foothills.

The geology of the area away from the mountains is dominated by the Fars evaporites, which are a succession of limestone clastics, gravels, sand, marl, clay and, most importantly, gypsum, as seen in a drill cutting of a well in Al Wagn drilled down to 567m. (1986) (Fig. 5.23, Chapter 5) Besides the distance from the recharge zone at the foothills and the added mineralization of groundwater as it moves westwards towards the common Emirates-Oman border, this composition of the water-bearing strata has a direct effect on the chemistry of the groundwater.

Surface runoff has never reached the border in living memory in this southern desert to the south of Al Wagn, and all the flow is therefore subsurface. Hydroconsult (1978) estimated the brackish water inflow in this area, between Al 'Ajeer and Um Ez Zemool, as 56MCM/a. Water salinity in the UAE side of the border is so high that the reverse-osmosis plant in Um Ez Zemool is a two-stage desalting plant to handle saline groundwater of up to 30,000mmhos/cm. Um Ez Zemool is the extreme end of the scale of groundwater quality, though the general quality of this brackish water area ranges from 7,000 to 16,000 mmhos/cm. Discharge rates are low and forestry wells in the Emirates side of the border at Al 'Ajeer, Az Zu'bah, Al Ginniyyah, Al Wagn, Al Himran and Al Qoa' have maximum discharge rates of between 20 and 24 m^3/h. Similar well discharge rates are found within Omani territory in Wadi Jafrah, where the agricultural wells have discharge rates of

between $10m^3/h$ and $24m^3/h$. This reflects the poor transmissivity of the strata where silts, clays and gypsum predominate minimizing water movement and enhancing its mineralization. The quality on the other side of the border within Oman is not much different. With little agricultural development in Oman adjacent to the area in the UAE, the extremely poor water quality and discharge rates make the area less important as far as the status of the shared resources between the two countries is concerned.

9.3.4 The fresh water zone of Al Ain-Al Buraimi

This area lies on either side of the Emirates-Oman border between Filli in the north and Um Ghafah and 'Ajran in the south. It is the fresh water zone of the eastern region of Abu Dhabi extending for 115kms. from Filli in Al Madam Plain, through Al Shuwaib, Al Hayer, Ghashabah down to Um Ghafah and Saa' in southern Al Jaww Plain. In its northern part, surface and groundwater flow is channelled through Wadi Sumaini-Yudaiy'ah after being fed by Wadis Mayhah and Khuraimah, across Al Madam Plain in a general northward surface, and north and northwestward subsurface, flow.

In the central part of this front, Wadi Safwan continues the northwestern flow with a channel running west towards the Khadher Nassas and Suwaihan wellfields. Wadi Ma'aisheq flows to the west and then to the southwest; Wadi Kahal to the southwest, and Wadi Ghashabah westwards, spreading out in the Mahdhah outwash fan, and then further west, flows southwestwards towards Al Sad and Sulaimat.

In the southern part of this shared fresh water zone, in the Al Jaww Plain, Wadi Shik and Wadi Al Ain (also known as Wadi Al Wadiyyain) flow westwards through the Zarub Gap; in the southern section of Al Jaww Plain, Wadis Muraikhat and 'Ajran flow south-westwards through the 'Ajran Gap.

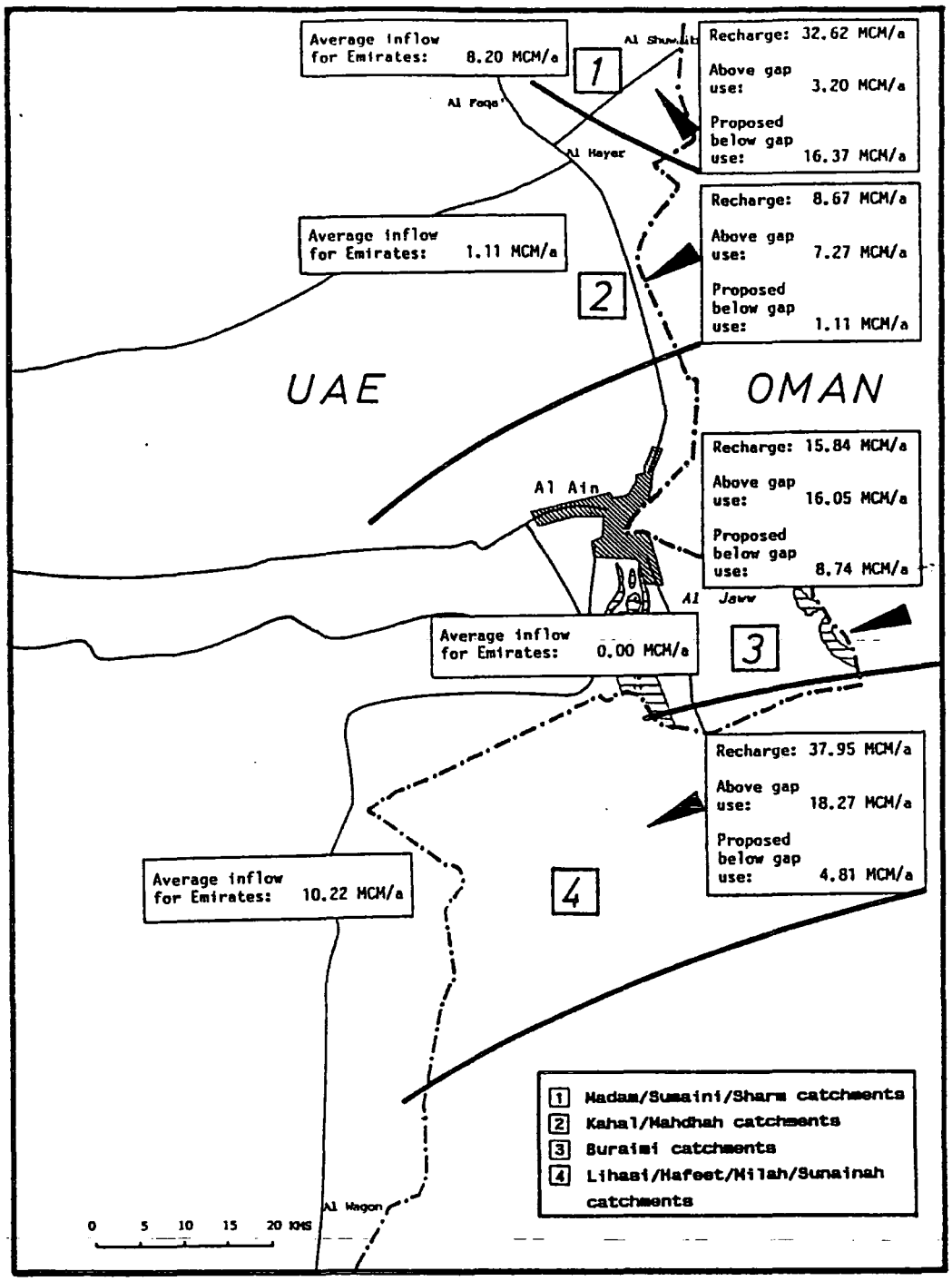
In the northern part of the front the border runs half way across Al Madam Plain in a vast outwash fan formed by Wadis Scharab, Khuraimah, Mayhah and Sumaini, and in the central part it runs across the lower part of the Mahdhah alluvial outwash fan. In the extreme southern part of the zone the border engulfs the whole piedmont plain of Al Jaww,

an area of 400 km^2, to the west of Jabals Hamar, Zarub, Malaqet and Mundassah. The border to the north of the Mahdhah fan and Wadi Kahal runs along the northern dune area of Al Ain, which is part of the sandy desert foreland and the permeable gravels here are about 10kms. to the east in the outwash fan of Wadi Safwan. There is limited storage in the alluvium of the foothills described in the interpretation of the hydrographs, especially those for Ghashabah, Al Madam and Um Ghafah (Chapter 5, section 5.5.2). The parts of the alluvial outwash fans of the foothills within Omani territory, are also known to have very low storage capacities as have the wadis, which are the transporting channels from the bare catchments in the east to the gravel and sandy plains in the west.

The catchments and their runoff output, and the wadis and plains and their groundwater storage and availability on the Omani side of the border, have been well studied by the water authorities in Oman and their quantification over the past eight years has provided a good data-base for design and practical purposes. This is coupled with cautious and limited agricultural development in all the upper and middle reaches of the wadis in Oman that eventually cross the border into the eastern region of Abu Dhabi (Al Ain) in the Emirates.

Estimates of recharge crossing the border into the Emirates as subsurface flow for the various wadis, overland courses of which coincide with the general groundwater movement westwards and southwestwards and also north- and northwestwards, are shown in Fig. 9.2.

Extraction of groundwater for both potable and agricultural use on the Emirates side of the border is extensively developed (Fig. 9.3.). Groundwater development has reached such critical levels in overexploitation that, in nearly all areas, groundwater has been mined from storage in volumes exceeding replenishment by several times (Table 9.7.). Apart from recharge into the aquifers shared by both the Emirates and Oman in the form of subsurface flow from the upper reaches of the wadis and their entire catchments, whether this groundwater flow is directed north and northwestwards under Al Madam Plain into the Northern Emirates, or westwards and southwestwards into the northern dune area and desert foreland of the Al Ain region, replenishment into



Source of estimates: Regional Water Management Plan (1987),RDC, Oman.

Figure: 9.2.

Estimates of groundwater from Omani catchments underflowing the Oman-UAE border into the Al Ain region in the land front from Al Madam to Al Wagn.

The groundwater inflow in parts 1, 2 and 3 of the front is fresh, while that in part 4 is brackish to saline. Notice the minimal annual inflow from the Kahal-Mahdhah, and hardly any flow in the Buraimi, parts, where in adjacent areas in the Emirates there is heavy groundwater abstraction. With the planned agricultural development in Oman, inflow into the Emirates would be wholly intercepted.

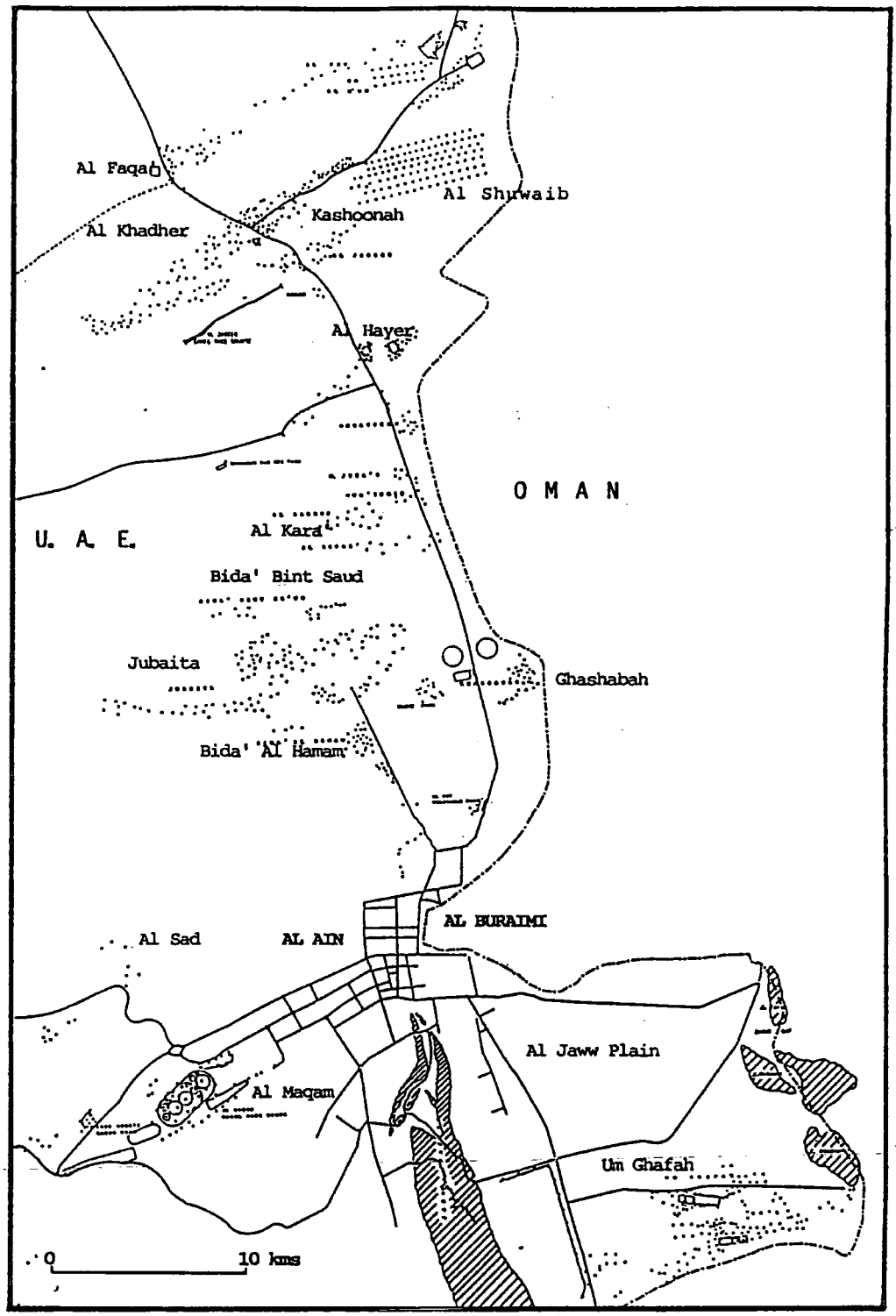


Figure: 9.3.

Groundwater abstraction points on the Emirates side of the international border with Oman in the Al Ain-Al Buraimi shared fresh groundwater front.

With such an intensively developed groundwater abstraction in a 50km. long and 20km. wide front on the Emirates side of the border with Oman, it is most likely that all the inflow available for the Emirates underflowing the border is intercepted and pumped out (See also Table 9.7 presenting the groundwater balance of the Al Ain region).

the aquifers is also taking place from direct rainfall as well as from surface flow that develops in the wadis on the Emirates side of the border. The rate of such infiltration is in the range of 20-28% in the loose sands of the Al Khadher Nassas wellfield to the northwest of Wadi Al Jabeeb (Chapter 10, Section 10.3.7.2).

Outside Al Jaww Plain, the only limited stretch of alluvium is in the lower part of the Mahdhah outwash fan, falling within Emirates territory on which is located the Al Awha government wheat farm. Infiltration rates in alluvium, such as that of Al Jaww Plain, can be as high as 20% of the total annual precipitation. Recharge from direct infiltration of rainfall over the area is discussed in Chapter 10, Section 10.3.7.1., together with recharge from subsurface flow through the mountain gaps within Oman (Table 9.1). The volume of replenishment to the shared aquifer within the Emirates is 28.13 MCM (Table 9.6). Recharge estimates for the part of the aquifer within Oman for the whole front are given in Table 9.2, and recharge estimates by several previous studies for the Sumaini-'Ajran front are given in Table 10.7 (Chapter 10).

9.3.4.1 Recharge potential and groundwater availability on the Omani side of the border in the Al Ain-Buraimi region.

Across the border in Oman, the fractured bedrock groundwater zone underlying the alluvial aquifer, whether it is in the ophiolite, Hawasina metasediments or the Tertiary (Maastrichtian) limestones, holds little potential and discharge rates are less than $1m^3/d$. However, the Maastrichtian limestones, in the public supply wellfield of Bida' bint Saud in the Emirates, is highly transmissive (with values of $200-650m^2/d$ and storage coefficient of 0.03) and the discharge rates have been found by Gibb (1974) to be between 26 and $80m^3/h.$, but are at present maintained at $371m^3/d$ or between 22 and $24m^3/h$. The wellfield is the largest single contributor to the public water supply in the northern dune area, producing nearly 25% of the total output from all the seven fresh water wellfields of WED Al Ain.

In the upper Mahdhah outwash fan the alluvial deposits are about 15-20m. thick underlain by the Lower Jurassic to Lower Cretaceous flysch of carbonate clastics and silicified shales of the Juweiza Formation.

	Madam Plain	Sumaini Basin	Sharm Basin	Kahal Basin	Mahdhah Basin	Buraimi Basin	Lihasi Basin	Hafeet Basin	Wadi Milah	Sunainah Basin
Catchment Area in Km^2	449	274	265	127	257	525	87	301	352	511
Average estimated recharge in MCM/a	15.91	9.21	7.50	2.33	6.34	15.84	1.90	10.21	11.29	14.55
Upstream Users in MCM/a	0.40	1.58	1.22	2.94	4.01	9.10	0	1.81	0.25	0.86
Av. Groundwater Available below the gaps in MCM/a	15.52	7.63	5.91	-0.43	2.50	9.30	1.86	9.10	11.15	10.43
Existing downstream users in MCM/a	0	0	0	0	0.32	6.95	-	6.52	0.93	8.17
Proposed additional down-stream users in MCM/a	7.74	0	4.95	0	0.61	8.74	-	1.33	3.37	0.11
Average unused flow remaining in MCM/a	7.74	7.63	1.0	-0.43	1.54	-6.39	-	1.22	6.85	2.15
Proposed expansion in acreage in ha.	254	0	231	15	20	(183)	-	40	111	0

Source: Oman Regional Development Council - Regional Water Management Plan, 1987

Table: 9.1.

Groundwater availability and use by drainage basin (wadi catchment) in the Al Buraimi region of Oman adjoining the Al Ain region of the Emirates.

The total inflow into the Emirates from Omani catchments in the whole land front from Al Madam to Sunainah is 28.13 MCM/a. Of this 59% (16.47 MCM/a) is destined for the Omani part of the Al Madam Plain after which it spreads out into the Northern Emirates. 36% of this inflow (10.22 MCM/a) is for the part of the land front south of Hafeet. Only 5% (1.54 MCM/a) actually remains for the part from Kahal-Mahdhah to 'Ajran where the whole groundwater abstraction of the Al Ain region is concentrated (56.5 MCM/a for the public supply; agricultural abstraction in the same area is unknown).

	Total Recharge	Consumption by u/s users	Consumption by d/s users (below gaps)	Remaining underflow into UAE	
Al Madam to Sunainah 160-km front	95.10	22.17	22.89	28.13	Into N.Emirates Al Ain and southern brackish water dune area
Al Madam to A'jran 120-km front	57.13	19.25	7.27	17.91	Into N. Emirates and Al Ain area
Sumaini to A'jran 80-km front	41.22	18.85	7.27	10.17	Into Al Ain area
Lihasi to Sunainah 40-km front	37.95	2.92	15.35	10.22	Into southern brackish water dune area.
All volume units in million cubic metres per annum					

Source: Regional Development Plan, Regional Development Council, Oman.

Table: 9.2.

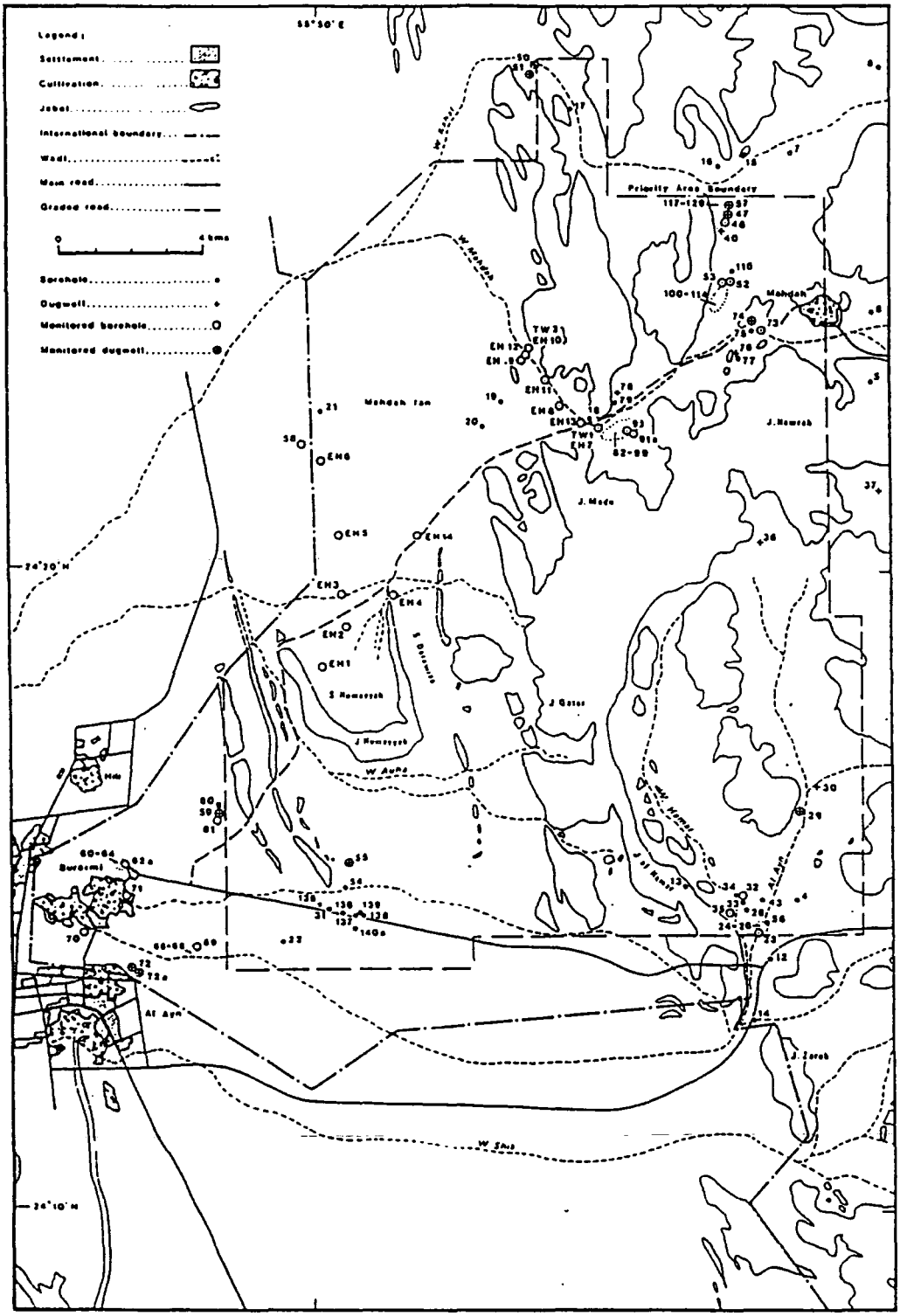
Groundwater recharge and net inflow balance remaining for the Emirates from the Omani catchments of the Buraimi region from Al Madam to Sunainah according to estimates of the Regional Development Council of Oman (1987).

This latter sequence is about 20m. thick containing marls and a substantial proportion of gypsum with yields from its saturated layer of about $6m^3/h$.

The alluvial aquifer (mostly made up of gravels of all sizes, sand and silt) is the potentially important water-bearing stratum between the Emirates and Oman. Studies in Oman by the then Public Authority for Water Resources (PAWR), the Regional Development Committee (RDC) and the Ministry of Agriculture and Fisheries (1982) have found that the gravelly alluvial mantle locally exceeds 60m. in thickness but is of a general average thickness of 30-35m. The saturated thickness averages 9m. The deposits become thicker in the outer parts of the outwash fans with an increase in the finer material away from the active wadi channel beds, which are surface and subsurface arteries of high permeability. This was evident from drillings and well pump tests of Well BH-21 in the northern part of the Mahdhah fan (Fig. 9.4), where the gravels are loose having a reasonable content of coarse sand and are therefore highly permeable. In Well BU-EH6 in the centre of the fan (Fig. 9.4), just a short distance upstream from the Al Awha wheat farm in the Emirates, the maximum thickness of the alluvium is 50m., and the saturated layer is 19m. but the permeability is very low owing to the presence of clays, marls and silts interbedded with the alluvium (Groundwater Development Consultants (GDC), Soil and Groundwater Survey for Buraimi Area, 1982).

The low permeability of the alluvium is even more pronounced in the southern part of the outwash fan within the horse-shoe shaped ridge (enclosure) of Jabal Huwaiyyah (Fig. 9.4), in Well BU-EH1 where the enclosed basin helps to trap fines sorted out by successive flash floods and also by the presence of high silt and marl content cementing the alluvium. The deposits here consist of 36m. of fine-grained alluvium of which 23m. are saturated. Transmissivity is very low being below $1m^2/d$. (see Fig. 9.4 for location of GDC wells).

The hydrogeology of the higher section of the Mahdhah outwash fan, and in locations within the gaps, whether in the Mahdhah, Zarub or 'Ajran Gaps proper, is not different. BU-EH14 (Fig. 9.4), in the upper part of the Mahdhah fan, penetrated 34m. of alluvium and the low-yielding saturated layer was made up of marls. The low-yielding, well-cemented silty or marly gravels seem to recur nearly in every borehole drilled



Source: Groundwater Resources and Development of Buraimi Area, GDC-Oman Ministry of Agriculture and Fisheries, 1982.

Figure: 9.4.

Location map of the wells of the Buraimi region of Oman (Soil and Groundwater Survey for Buraimi Area, Vol. 3, Groundwater Resources and Development, Final Report, Groundwater Resources Consultants (GDC) Ministry of Agriculture and Fisheries, Oman, 1982).

within the outwash fan, whether in the active wadi channels or away from them, in the lower or upper sections of the fan, and even within the Mahdhah Gap itself, or a little distance downstream from it, as was revealed by the drill cuttings of PAWR Wells BU19, BU20 and EH-8 (Fig. 9.4), which are all located off the active wadi channel below the Mahdhah Gap. These boreholes penetrated between 30m. and 48m. of gravelly alluvium that were partially cemented with marls, and all boreholes had discharge rates of less than $8m^3/h$. EH11, located within the active wadi channel of Wadi Mahdhah, downstream of the gap (Fig. 9.4), also encountered the same subsurface conditions within the 34m. of alluvium, and the 6m. saturated layer was also in marly gravel horizons. In well EH-9, further downstream in the Mahdhah fan (Fig. 9.4), the whole 30m. of alluvium were of well-cemented silty gravel underlain by Tertiary limestone.

Wells EH-7, TW-1 and EH-13 (Fig. 9.4), all located within the 400-m. wide Mahdhah Gap, penetrated more than 40m. of well-cemented silty alluvium within the active channel of Wadi Mahdhah. Outside the active wadi channel Well BU-18 (Fig. 9.4) also penetrated more than 40m. of well-cemented gravels. Well EH-13 (Fig. 9.4) drilled further downstream in the outwash fan, on the other hand, met a massive unfractured bedrock at 26m., while all the overlying 26m. of alluvium were well-cemented and unsaturated. This massive unsaturated elevated bedrock acts as a subsurface barrier to groundwater flow. The fractured Hawasina metasediments reached by borehole EH-13 in the Mahdhah Gap (Fig. 9.4) gave poor well yields, thus reflecting the limited groundwater potential of the Hawasina metasediments. (GDC = Groundwater Resources and Development, Soil and Groundwater Survey for Buraimi Area, Vol. 3, 1982).

All the studies and borehole drillings by the various government and private institutions in Oman over the past eight years have attested to the limited groundwater potential of the alluvial aquifer of the Mahdhah outwash fan below the mountain gap owing to the limited thickness of the saturated layer and also its high content of fines responsible for the limited storage capacity. GDC (The Soil and Groundwater Survey for the Buraimi Area, Final Report Vol. 3, 1982), concluded that "only the alluvial aquifer immediately upstream from the Mahdhah Gap has potential

for development with respect to aquifer transmissivity, as a result of the coarse and relatively thickly developed gravels".

Again, wells drilled in the 'Ajran Gap, in the extreme southeastern corner of the Al Jaww Plain, also attested to the occurrence of the same cemented alluvium, but also showed highly variable yields within short distances because of lateral variation in lithology. All the wells were in the same locality within a few metres of each other (Water Resources of Abu Dhabi, A. Gibb, 1970). The variation in lithology in the Gibb (1979) wells is shown in the Table 9.3.

Well No.	Thickness of Saturated Layer	Discharge Rate
1877A	4.7m	$15.5m^3/h.$
1877B	5.3m	$41.7m^3/h.$
7836A	11.3m	$32.7m^3/h.$
7836C	11.3m	$61.4m^3/h.$

Source: Water Resources of Abu Dhabi, A. Gibb, 1970.

Table 9.3.

Variation in the saturated thickness and well discharge rates in the cemented alluvium of the 'Ajran Gap.

This anomalous lithological situation repeats itself further west in the Um Ghafah area in the Al Jaww Plain as will be discussed later.

The Zarub Gap is made up of a series of three small gaps or bedrock constrictions through which flow Wadi Al Ain (known in Oman as Wadi Al Wadiyyain), Wadi Um Baq and Wadi Shik. All the three wadis discharge their waters westwards into the Al Jaww Plain towards Al Ain and Jabal Hafeet, flowing as Wadis (from north to south): Al Ain, Shik and 'Idhan.

The alluvial aquifer upstream of the Zarub Gap in Omani territory covers an area of 29km^2 and becomes relatively thinner upstream. The average thickness of the saturated layer in the alluvium, and the hydraulically connected underlying fractured Tertiary Maastrichtian carbonates, the Permian to Cretaceous Ophiolites, and Permian to Jurassic Hawasina Metasediments, together with the average hourly well discharge rates, are given in Table 9.4. More detailed information for specific wells in the Zarub Gap area is also given in Table 9.5.

The alluvial mantle upstream of the southern gaps at Zarub, through which runs the international boundary with Oman, puts the whole downstream section of the piedmont plains below the gaps within the Al Jaww Plain of the Emirates. The alluvial mantle is thicker than that seen for the zone north of Mahdhah. Although in most cases the saturated layer extends into the fractured zone of the parent rock below, the overlying alluvium averages 25m. in thickness. The effective saturated thickness averages 38m. in Wadi Al Ain in the north and Wadi Shik in the south, and 40m. in central Wadi Um Baq. The overall effective thickness of the saturated layer averages 35m.

The important deductions from Table 9.5 are that the discharge rates from the saturated zones in the alluvium and the underlying fractured ophiolite bedrock, from depths ranging from 50m. to 100m., were 98m^3/h. at 53m. depth (Well ZG-1); and 126m^3/h. at 100m. depth (Well ZG-3), with a general average rate of 120m^3/h. The discharge rates from the alluvium and Hawasina aquifer were varied. Whereas in Well ZG-6 at 92m. depth the discharge rate was 69m^3/h., and in Well ZG-8 (at 31m. depth), it was 16m^3/h., (which was the lowest rate obtained during the well tests in the Zarub Gap by the RDC in 1985), in the same well (ZG-8) at a depth of 85m., the well yield varied from 106m^3 to 118m^3/h. (a discharge rate that may have even been influenced by a deep-seated thrust plane)(1985). In the alluvium and Tertiary limestones and clastics saturated zone, higher discharge rates were obtained from deeper points such as at Well ZG-9 at 100m., where they averaged 119m^3/h., and in the medium depth of 39m. and 70m. in Well ZG-10 where they were 74m^3/h. and 50m^3/h. respectively (M. Saines and S. Ansari, Results of Appraisal Drilling in Zarub Gap, Buraimi Region, RDC, Oman, 1985).

Hydrogeologic Unit	Av. Saturated Thickness - m	Lithology	Yield m^3/h	EC (mmhos/cm)
- Alluvium	21	Gravel, sand and silt (loose to cemented)	43	380
- Alluvium and Tertiary	68	Alluvium and carbonates, limestone and mudstone	94	1230
- Alluvium and Ophiolites	59	Alluvium and fractured basic igneous rocks	106.5	410
- Alluvium and Hawasina Formation	69	Alluvium and shales Limestone and chert	147.3	425
- Hawasina Metasediments	65	Shales, limestone and chert	27	1650
Source: Results of Appraisal Drilling in Zarub Gap, Buraimi Region, Oman. 1985 Page 43 Authors M.Saines and S.Ansari.				

Table: 9.4.

Water-bearing units and their hydrogeological properties in the Zarub Basin and Gap area.

The fractured ophiolite bedrock and the overlying Quaternary alluvium offer the best fresh groundwater aquifer properties where also the quality of the water is potable with ECs ranging between 380 and 425mmhos/cm.

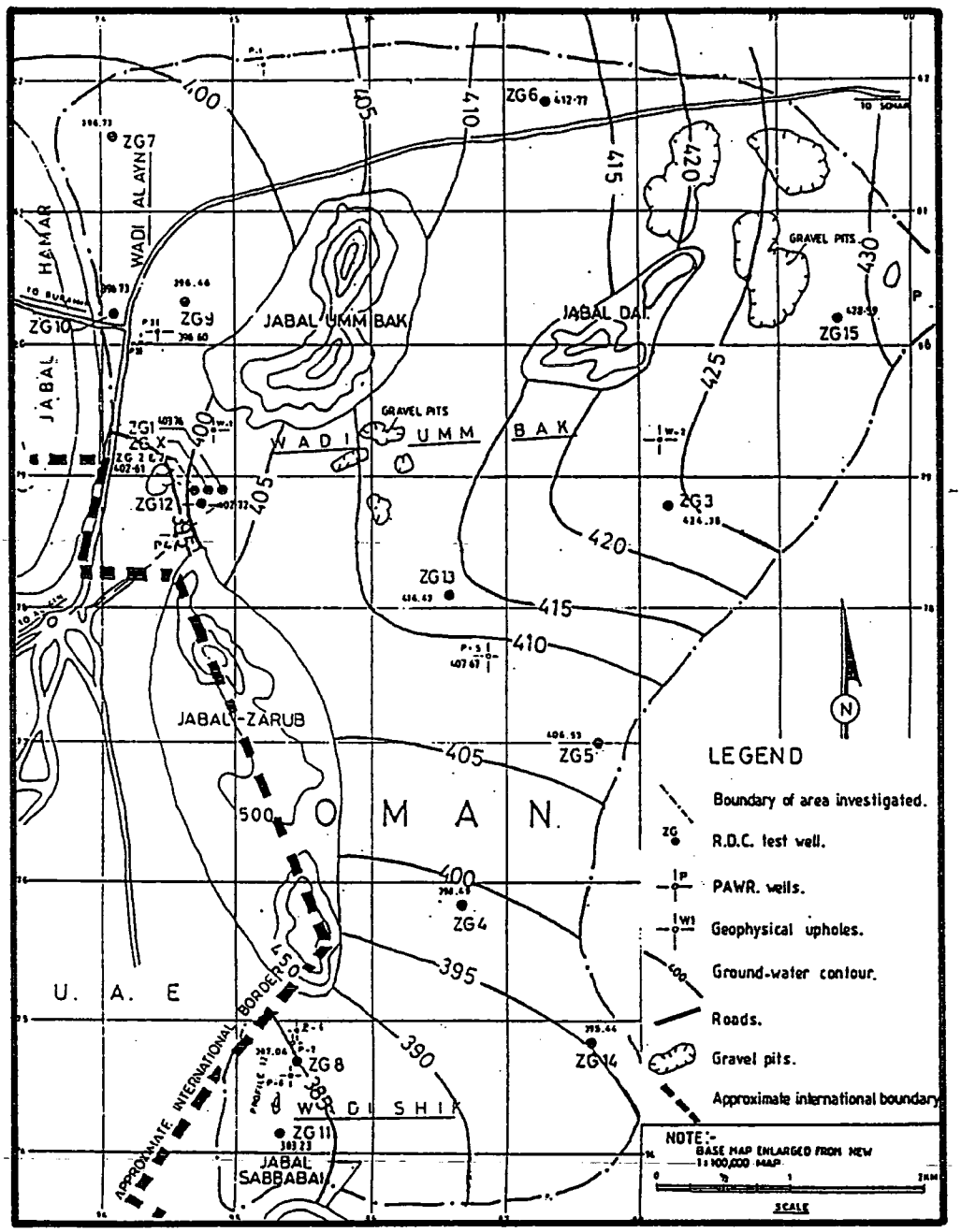
Well No	Depth Tested(m)	Aquifer Tested	Saturated Thickness(m)	SWL below casing top(m)	Discharge Rate- m^3/h	Transmissivity m^2/day
ZG-1	53	All. + Oph.	36	16.5	98	-
ZG-2A	65	All. + Oph.	48	17.0	121	-
ZG-3	58	All. + Oph.	38	20.0	122	2936-6854
ZG-3	100	All. + Oph.	80	20.0	126	4590
ZG-4	92	All. + Oph.	77	15.0	120	131
ZG-6	92	All. +Hawasina	64	28.0	69	166
ZG-7	54	All. +Tertiary	30	24.0	119	398
ZG-7	100	All. +Tertiary	76	24.0	117	1410
ZG-8	31	All. +Hawasina	13	18.0	16	-
ZG-8	85	All. +Hawasina	67	18.0	118	765
ZG-9	52	Alluvium	33	19.0	115	-
ZG-9	100	All. +Tertiary	80	20.0	119	-
ZG-10	39	All. +Tertiary	22	17.0	47	31
ZG-10	70	All. +Tertiary	54	16.4	50	125
ZG-11	84	Hawasina	64	20.0	15	9
ZG-12	47	All. +Hawasina	31	17.0	109	-
ZG-12	92	All. +Hawasina	75	17.0	124	3616
ZG-13	47	All. + Oph.	29	18.0	126	-
ZG-13	84	All. + Oph.	66	18.0	128	-
ZG-14	54	All. + Oph.	33	21.0	107	701
ZG-15	68	All. + Oph.	42	26.0	119	1813
ZG-X	69	All. +Hawasina	42	17.0	327	3800

Source: Results of Appraisal Drilling in the Zarub Gap, Buraimi Region, Oman. (1985) Regional Development Council (M. Saines and S. Ansari)

Table: 9.5.

Results of the pumping tests from the different water-bearing strata in the inland basin of Zarub (Mussaileq) and the Zarub Gap areas in Oman adjoining the Al Ain region of the Emirates (1985).

The highest well discharge rates were for wells in the Quaternary alluvium and the underlying fractured ophiolite bedrock and the lower discharge rates were for wells in the alluvium and Hawasina. The lowest well discharge rate was in Well ZG-11 in the Hawasina metasediments.



Source: Report on Results of appraisal drilling in Zarub Gap, Buraimi region, Oman, Saines, M. and Ansari, S.U. (1985).

Figure: 9.5.

Location map of the ZG series of wells in the Zarub Basin and Gap area (The Regional Development Council, Oman, 1985)

The well discharge rate obtained from saturated layers contained totally in the Quaternary alluvium, as at Well ZG-9, was similar to that in the alluvium and the ophiolite together (around 115m^3/h.). The lowest groundwater well discharge rate was obtained from the saturated zone totally contained in the fractured Hawasina bedrock in ZG-11 at a depth of 84m.(15m^3/h) (Table 9.5).

The exceptionally high rate of 327m^3/h. of Well ZG-X, at a depth of 69m. in an aquifer in the alluvium and Hawasina metasediments in the centre of the Zarub Gap, was due to the powerful pump installed on the 17.5 inch borehole of ZG-X, and also to the penetration of the borehole into a major thrust zone.

(All the ZG-Wells of the Zarub area are shown in Fig. 9.5)

The whole area, upstream of the Zarub-'Ajran Gaps is a series of internal alluvium-filled basins that would have been of an internal drainage character had it not been for the gaps through which excess water in storage is released by overspilling the ground reservoir into Emirates territory as underflow. It therefore acts as a balancing underground water reservoir, the total volume of groundwater in storage of which was calculated by Saines and Ansari (1985) to be 61.15MCM, under the previously noted surface area of 29km^2. Assuming that 70% of this volume is recoverable, then 42.8MCM may be pumped out in about 4 consecutive years of drought. The net surface flow amounts to nearly 11.0 MCM/a from the main Zarub Gap, flowing across Al Jaww in Wadis Al Ain and Shik; and 0.78 MCM/a from the southermost sub-gap of Zarub (through Khuraijah), flowing as Wadi Hamad. Finally 3.78 MCM/a underflows Wadi 'Ajran across the 'Ajran Gap, most of which turns southwestwards and flows back into Omani territory.

The estimated groundwater flow through the Zarub Gap is 9.3 MCM/a (Saines and Ansari, 1985). In the whole area upstream of the gaps groundwater occurs under water-table conditions (unconfined/phreatic), though there may be places where groundwater occurs in a semi-confined state, such as in the vicinity of the new Buraimi wellfield.

9.3.4.2. The hydrogeology on the Emirates side of the border

Whereas studies on the Oman side of the border have been systematic and well-coordinated between the various official users of groundwater, groundwater studies in the Emirates side have been limited, some having being carried out in the late 1970s and early 1980s in relation to the public water supply wellfields of the northern dune areas and Um Ghafah. All drilling for agricultural use and forestry has always been done haphazardly with little hydrogeological investigation.

As noted earlier, the alluvial areas north of Al Ain are of limited areal extent occurring between Al Hili in the northern outskirts of Al Ain town up to three kilometres beyond the northern boundary of the Al Awha government wheat farm in Qarn 'Uyain and Qarn Salabeekh, marking the distal parts of the Mahdhah outwash fan. Any other limited area of alluvium along the border to the north is in the form of protrusions of wadi courses into the sands of the desert foreland (Fig. 9.6).

The extensive stretch of land formed by the braided wadi courses of Wadi Sumaini in Seih Sulailiyyah and Seih Sumaini falls within Omani territory before narrowing down as it reaches Al Shuwaib in the Emirates. The largest single area of alluvium within Emirates territory is therefore that of Al Jaww Plain with a total surface area of 418km^2 (Fig. 9.6).

Geologically, the Al Jaww Plain is a geosyncline formed between the outlying Jabal Hafeet anticlinal ridge trending NNW to SSE and the series of Jabals Hamar, Zarub, Malaqet, Sababah, Mundassah, Sa'ah and Khatmah to the east (Fig. 9.6). This is similar to the physical setting further north between Al Madam and Al Dhaid where a similar geosyncline occurs between the anticline formed by Jabals Mileiha and Fayah to the west and the main ophiolite mountain block to the east, with almost the same extent of 20kms. between both highland boundaries.

The bedrock of Al Jaww Plain is made up largely of the Semail ophiolite suite of impervious gabbros and serpentinites forming the baserock below 985m. from the surface in the centre of the plain, where it is overlain by massive fossiliferous limestone (Tertiary to Lower Eocene) of nearly

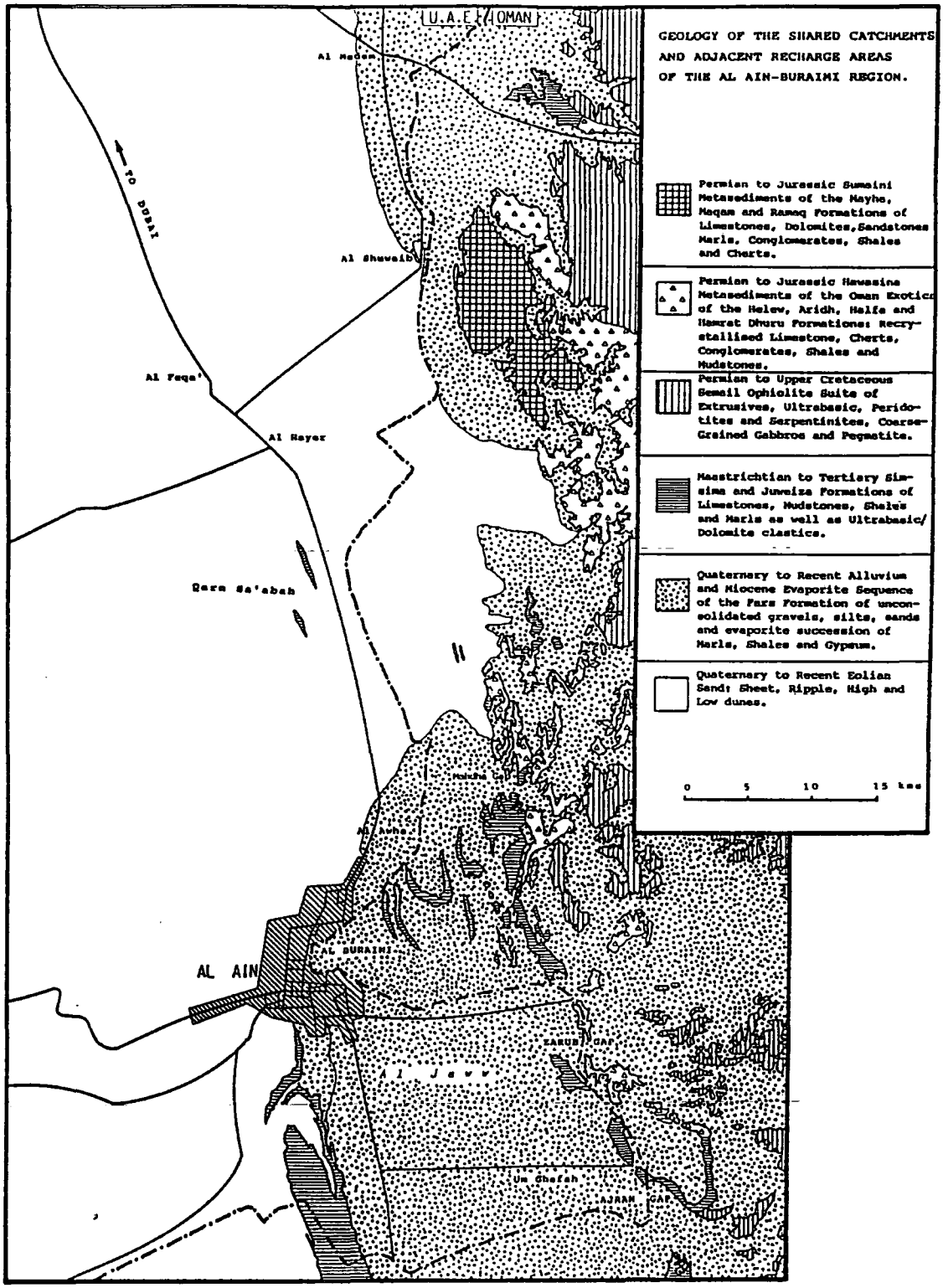


Figure: 9.6.

The geology of the shared catchments and adjacent areas of the Al Ain-Al Buraimi region.

330m. thickness appearing in the west as the heavily eroded anticline of Jabal Hafeet. The Jabal Hafeet anticline has on its eastern and western flanks remnants of the overlying Miocene Fars Formation consisting of limestones, marls, gypsum and gypsiferous marls and clays with conglomerates reaching thicknesses of well over 650m., of which the upper half of the strata (over 300m.) is of the evaporite sequence of the Oligo-Miocene (composed of rubbly dolomite limestones, sandstones, sandy limestones, marl, gypsum, mudstones and conglomerates). In turn, in its uppermost section, this sequence is dominated by silts, clays and gypsum forming the immediate base or aquiclude of the overlying fresh water-bearing Quaternary alluvium. This Fars evaporite sequence is thickest in the centre of Al Jaww but, owing to minor folds in the underlying hardrock Tertiary strata, it is thinnest in places where it is underlain by upfolds that have pushed the baserock nearer to the surface. The evaporite formation, as discussed in Chapter 6, has a great negative impact on the quality of groundwater in this region, and any deeper drilling in Al Jaww Plain itself is likely to draw up brackish to saline water.

The deposition of the Quaternary to Recent fluvial mantle has largely been influenced by the mountain gaps to the east through which flows surface runoff and all the loose alluvial material (varying in size from boulders to fine sand and silt), have been deposited along the active wadi channels. Consequently, the gravels and sands are less compact and more transmissive than further away from the channels on either side of wadis where clays and silts have compacted the alluvial deposits.

The alluvial deposits may reach a thickness of between 35m. and 40m. under the active wadi channels of Wadis Shik and Al Ain in the centre of Al Jaww Plain, but are relatively thinner near the mountain subgaps of Zarub, where they are about 20-25m. in thickness (as in the Omani Wells ZG-1 and ZG-X in the middle of the Zarub Gap (Fig. 9.5))), and can be as thin as 10m. or even less in the fringes of surface flow channels or in areas of subsurface highs caused by irregularities in the Tertiary limestone. In general, the deposits become thicker towards the west and recent drillings by NDC-US Geological Survey near Mazyad (March 1989) have found the Quaternary alluvium to be as thick as 152m. before the Miocene evaporites sequence is reached. The alluvium was reported by Gibb (1970) to be 100m. thick in the Mas'udi area of Al Ain.

The alluvial deposits are made up largely of subrounded, moderately well-sorted gravels (from both the Semail ophiolite and Hawasina groups), coarse to medium sand with clay and marl cement of varying degrees of compactness. The content of clay and silt fines, not only increases away from the mountain front and active wadi channels, but also with depth, where the gravels are well-cemented.

The Tertiary Lower Eocene Limestone and Miocene Fars Evaporites, have poor groundwater potential, not only due to their low permeability but also to the high salt content in the Miocene gypsum beds they contain, which assume a thickness of 5 to 15m. The gypsum basal seal of the Quaternary aquifer, formed by the Fars evaporites, is not absolutely water-tight and there are places of hydraulic connection leading to contamination of the fresh groundwater in the overlying Quaternary alluvium.

The water-bearing stratum in the Quaternary deposits is therefore the main aquifer, though it is irregular in thickness and spatial distribution. In the Quaternary mantle are active wadi channels emanating from the mountain gaps to the east. These wadi channels contain highly permeable aquiferous deposits, in two distinct wadi channels: one to the north that includes the channels of Wadis Shik and Al Ain; the other to the south of the Al Jaww Plain, embracing Wadis 'Ajran and Hamad. Areas away from the wadi channels, and in between them, are alluvial tracts of compact deposits with a high silt content and therefore with a limited water-bearing capacity.

The aquifer units are made up of gravels and conglomerates of various sizes with calcareous cementing and also in places with calcareous sandstone. The ideal water-bearing deposits are the loose gravels and sands, making the whole wadi channel courses from their source at the gaps in the east, forming elongated highly transmissive aquifers extending to Al Ain and Al Buraimi in the west.

The evaporites of the Miocene Lower Fars formation are distinguishable by their homogeneous white marly clay and chalk horizons. They underlie the Quaternary alluvium from the eastern mountain flank near the gaps, across the Al Jaww Plain, with varying degree of thickness and nearness to the surface. Their greater thickness is in the central and southern

half of Al Jaww, but they get noticeably thicker on the western side of Al Jaww near the foothills of Jabal Hafeet, where they also receive fine material deposited from the limestones of the mountains. The alluvium in general is largely made up of gravel, well-cemented by a fine carbonate matrix that forms hard compact conglomeratic zones underlain immediately by clay, marl and gypsum of the Miocene Fars formation. This last sequence is ubiquitous, recurring in lithologies pierced by the majority of the boreholes drilled in Al Jaww. Whether old borehole cuttings, such as those contained in the Water Resources Survey of Abu Dhabi (1970), or recent cuttings, obtained from records of the Groundwater Deptartment of Al Ain, the presence of gypsum is evident (Fig. 5.23 Chapter 5). Wherever this clay-marl-gypsum sequence occurs, it limits the storage capacity of the water-bearing strata, both to absorb recharge water or offer reasonable discharge.

The aquifer in the Quaternary alluvium, is neither thick nor continuous as a result of surface irregularities caused by outcropping or subcropping massive Tertiary carbonate ridges and the vertical and horizontal compactness of the alluvium itself. Sometimes even in the active wadi channels several water-bearing strata may be penetrated by boreholes. Such strata are trapped between alternating impervious horizons of clay and silt, yet the aquifers retain their longitudinal unconfined character guided by the main groundwater flow beneath the wadi channel.

When the aquifer is within the wadi alluvium, either conglomerates with fine gravel, as in the active wadi channel of Wadi Shik; or sandy limestones, ultrabasic conglomerates and sandstones, as in the active wadi channel of Wadi Sa'ah, the saturated zone is encountered between 20-30m. from the surface. It is 2-8m. thick and is unconfined containing groundwater with salinities ranging from 700-1200 mmhos/cm.

In a borehole in the main wadi channel of Wadi Al Wadiyyain (Wadi Al Ain) the Gibb report of 1970 (borehole BH/TW-14) reported the unconfined aquifer to be 17.8m. thick and the SWL as standing at 41.0m. The water-bearing material was coarse-grained crystalline limestone and the groundwater had an EC of 360 mmhos/cm., and a discharge rate of $28m^3/h$. This is the main wadi channel, which flows out of the Zarub Gap, crosses the northern part of Al Jaww Plain within Emirates territory and flows

to Al Buraimi in Oman.

Reduced falaj flow and the drying up of many wells within Al Buraimi was acute throughout 1987 and 1988, causing such critical shortages in the Al Buraimi town domestic water supplies that a new public supply wellfield had to be developed by the end of 1988 10kms. SSE of Al Buraimi town a few metres from the border with the Emirates. Water from this wellfield is transported by pipeline to Al Buraimi.

Boreholes drilled in 1988 along the Sohar road, in the northern extremity of Al Jaww Plain in the Emirates during prospecting for water for a proposed commercial water bottling firm, provided negative results. Well discharge rates were so poor as to be regarded as practically unimportant (BRGM, in a feasibility study for a private bottling company, 1988; personal discussion with Mr. Torent, chief hydrogeologist for the study).

9.4. The groundwater balance in the Al Ain region (Table: 9.6)

With the hydrogeology of the Al Ain region and adjacent groundwater recharge areas in Oman described in detail, and the quantities of groundwater shared between the Al Ain and Al Buraimi areas identified in the foregoing synthesis, it is appropriately within context to conclude with a summary of the groundwater recharge-discharge balance of the Al Ain region to highlight the critical imbalance of the water resources in this shared groundwater front. The salient physical and economic factors governing this state of groundwater imbalance in the Al Ain region are:

(i) The unfavourable hydrogeological setting characterized by the preponderance of the evaporite-clay-gypsum lithologies beneath the aeolian and alluvial deposits. Even the limited alluvial tracts are calcrete-cemented, as in Al Jaww Plain, reducing their storage and transmissive capabilities. Added to this, is the limited surface and subsurface inputs into the region from the catchments in the Oman Mountains to the east.

(ii) The overabstraction of the groundwater resources exceeding natural and artificial recharge several times.

	Region	Area Km^2	Recharge from direct rainfall	Recharge from surface flow	Recharge from subsurface flow
FRESH WATER	Northern Dune Area	865	14.55	4.85	17.91
	Al Jaww Plain	418	7.11	0.50	10.22
RECHARGE	Sub-total	1274	21.66	5.35	28.13
	Recharge to fresh water areas including 30.25 MCM from irrig. return			79.60 MCM/a	
BRACKISH WATER	The region to the west and south of the Northern Dune Area and Al Jaww Plain	6202	105.43	-	125.30
	Recharge to brackish water areas including 26.53 MCM from irrigation return			257.26 MCM/a	

	Consumer	Number of operating wells	Volumes extracted
FRESH WATER	Agriculture	3361	445.33
	Public supply (WED)	447	50.95
	Municipality	300	10.10
EXTRACTION	Forestry	259	21.00
	Total fresh extraction		527.28 MCM/a Deficit 447.68 MCM/a
			Recharge to extraction ratio 1 : 7
BRACKISH WATER	Agriculture	2535	335.89
	Public supply(WED)	22	6.50
	Municipality	-	6.70
	Forestry	606	91.10
	Total brackish water extraction		440.19 MCM/a Deficit 182.93 MCM/a
			Recharge to extraction ratio 1 : 2

* All water volume units are in million cubic metres per annum (MCM/a)

Table: 9.6.

The groundwater recharge/discharge balance of the Al Ain region (1988).

The largest contribution to groundwater recharge is from direct rainfall (127.09 MCM/a), followed by that from subsurface flow (28.13 MCM/a) and that from surface flow (5.35 MCM/a). The total volume of groundwater recharge is 336.86 MCM/a of which 77% recharges brackish, and 23% fresh, water areas. Against this input is the total output of 527.28 MCM/a in the fresh water areas, giving an imbalance ratio of 1:7, and an output of 440.19 MCM/a in the brackish water areas, giving an imbalance ratio of 1:2. The ratio of the overall recharge (336.86 MCM/a) to discharge (967.47 MCM/a) is 1:3.

Table 9.6 presents the various recharge and discharge components of the groundwater balance of the Al Ain region for 1988. As seen in the table, the largest contributor to recharge is direct rainfall (127.09 MCM/a). Such a contribution is minimized by the widespread occurrence of the Oligo-Miocene clay-gypsum-anhydrite Lower Fars formation, which holds brackish to saline water that contaminates the infiltrating rain water. The contribution from subsurface flow is 28.13 MCM/a, and that from surface flow only 5.35 MCM/a. The total recharge to both the fresh and brackish groundwater areas in the Al Ain region amounts to 336.86 MCM/a., of which nearly 77% recharges brackish and 23% fresh, groundwater areas. Against this input is the output of 527.28 MCM/a of groundwater abstracted in the fresh water areas (leaving a water deficit of 447.68 MCM/a) giving a recharge-discharge ratio of 1:7; and an abstracted volume in the brackish groundwater areas of 440.19 MCM/a (with a water deficit of 182.93 MCM/a) giving a recharge-discharge ratio of 1:2. The relatively favourable imbalance ratio in the brackish groundwater areas is caused by the unfavourable quality of the water that limits its intensive use. The striking state of groundwater imbalance is in the fresh water areas accentuated by the limited favourable lithologies and the meagre recharge inputs.

As agricultural development in the Al Ain region escalates unabated, coupled with continued overdevelopment of the groundwater resources in the nearly depleted Quaternary deposits, and with the planned agricultural and water resource development on the Omani side of the border, this state of imbalance in the shared groundwater resources of the Al Ain-Al Buraimi front could aggravate the delicate status of the water resources in the Al Ain region of the Emirates.

9.5. Synopsis

An important political component has been introduced into the overall water resource assessment by this chapter. After a brief discussion on the shared resources at the regional level, the more important cases, which occur at the local level, have been considered. By far the most significant example politically, that of Al Ain-Al Buraimi, has been accorded a detailed treatment that is concluded by the groundwater recharge-discharge balance of the Al Ain region of the Emirates.

CHAPTER TEN

RECHARGE POTENTIAL, GROUNDWATER RESERVES AND THE GROUNDWATER BALANCE

10. RECHARGE POTENTIAL, GROUNDWATER RESERVES AND THE GROUNDWATER BALANCE

10.1. Introduction

The main areas of recharge in the Emirates are the piedmont plains on either side of the central mountains fed by alluvial-filled mountain wadis. Recharge starts within the mountain zone with the infiltration of flood water in the wadi alluvium, and then spreads out on the coalesced outwash fans that form the plains. The floods may even overflow the plains into the desert foreland sands through gravel-filled courses as is the case with Wadi Lamhah. Further away from the plains these highly permeable wadi courses are covered with medium- to coarse-grained sand. The percentage of gravels of all sizes to sand and finer material decreases away from the mountains. As the fine deposits become dominant in the outer western parts of the central plains, permeability is greatly reduced.

The well-sorted medium to coarse sands of the desert foreland are highly permeable. Dincer et al (1974), experimenting on the dune sands of the Dahna region of eastern Saudi Arabia, proved, through observation, that:

> "temperature gradients, moisture content, size distribution of the sand, and tritium, deuterium and oxygen-18 content of the moisture in the sand dunes in a very arid region show that a significant portion of an annual rainfall of about 80mm. infiltrates through the sand dunes and can be a source of major recharge to the aquifer formation (outcrop) covered by the sand dunes "
>
> (Dincer, T.A, Al Mughrin and Zimmermann, U; Journal of Hydrology 23, 1974)

They found that of the mean annual rainfall of the 80mm. for the Dahna area, 20mm. infiltrated into the well-sorted sands. This amounted to 25% of the mean annual rainfall.

Infiltration rates in the mountain wadi alluvium and, to a lesser degree, in the piedmont plains, are high. Infiltration tests for Wadis Al Beeh and Ham, carried out by the US Bureau of Reclamation (Water Supply Augmentation for the UAE, US Department of the Interior, 1979), resulted in infiltration rates ranging from 0.6 to 5.0 $m^3/m^2/d$ for Wadi Al Beeh and 0.6 to 7.0 $m^3/m^2/d$ for Wadi Ham, the higher rates being in the active wadi channels containing a high proportion of loose boulders and gravels. An average value of $2m^3/m^2/d$ was assumed as a reasonable infiltration rate for the alluvium of Wadi Al Beeh and the same was also adopted by Halcrow-MAF (Dams and Recharge Facilities in the UAE, Halcrow-MAF, 1982) for mountain and piedmont plains wadis, for design purposes. This amounted to 2MCM of water infiltrating in $1km^2$. Such a rate of infiltration would decline to about $1m^3/m^2/d$ lower down the soil horizon.

The Halcrow study, Water Resources of the Trucial States (1969), described how a volume of 5.24 MCM of flood flow during the flood event of 2-02-1968 infiltrated the Wadi Lamhah flood plain in a distance of 22kms. during 22 hours of flooding (average channel width 30m.), between Falaj Al Mualla (upstream) and Tawi Qarn (downstream). This volume was assumed to have infiltrated in this stretch of Wadi Lamhah which crossed the desert foreland but still maintained a coarse-to-fine sand and gravel wadi bed. The infiltration rate was 0.1 mm/s., equivalent to $9.0m^3/m^2/d$.

Similarly, rates of infiltration have been tentatively worked out for this study for Wadi Al Beeh and Wadi Sfini using available MAF daily flood discharge data for the flood event of 14-2-1982. In Wadi Al Beeh, the runoff volume recorded in the upstream flood-recorder at Al Burairat was 1.65 MCM and at the downstream flood-recorder on the Digdaga road (a distance of 7.5kms.) 0.45 MCM. The difference of 1.61 MCM infiltrated the loose piedmont boulders and sands of a channel averaging 1km. in width in a flood flow time of 10 hours. This amounted to an infiltration rate of 0.0055mm/s. or $0.25m^3/m^2/d$.. The volume of flood water that infiltrated made up 70% of the 1.65 MCM recorded upstream (or a runoff ratio of 0.7). The generally low infiltration rate reflects the larger surface area of flood flow, typical of wadis in the northern limestone country of Ru'us Al Jibal.

On the same day (14-2-1982), in Wadis Sfini and Ashwani, the flood volume gauged in the Wadi Ashwani flood-gauging station (upstream of its confluence with Wadi Sfini) was 1,634,580m^3; the flood volume for Wadi Sfini at its flood-gauging station (upstream of its confluence with Wadi Ashwani) was 1,891,152m^3. The total volume at a third gauging station located downstream of the confluence of the two wadis (where both wadi flows pass by the flood gauging station), was 2,491,537m^3 in a flood duration of 8.5 hours. The difference of 1,034,195m^3 infiltrated the two wadi floors of Ashwani (2.5kms. long and 30m.wide) and Sfini (5.5kms. long by 60m.wide), in a total surface area for both wadi floors of 390,000m^2. This gave an infiltration rate of 0.312$m^3/m^2/h$ or 7.5$m^3/m^2/d$.

The rainfall was localized and concentrated in the northern part of the joint basin for the two wadis though it totalled only 14.0mm. The rainfall total for Wadi Siji (to the north) for the two days (13/14-2-1982) was 141.6mm., which gave rise to a flood volume of 30.44 MCM. The total gauged flood volume for both Wadis Sfini and Ashwani was 3.53 MCM, which was 11.6% of the runoff volume for Wadi Siji. Of this runoff volume, 1,034 MCM infiltrated, 30% of the total runoff volume.

10.2. Groundwater Reserves

Estimates of groundwater in storage in the western (central) piedmont plains and a part of the desert foreland in the Northern Emirates were first made by Halcrow (1969). Both the piedmont plains and the desert foreland of Halcrow's calculations had a combined area of 1,600km^2. The average saturated thickness was 22m., and the effective porosity was estimated as 0.15, which gave the volume of groundwater in storage as 5,280 MCM. Halcrow ignored the eastern coastal piedmont plain from Dibba to Kalba; and the whole of the Halcrow survey was limited to the Northern Emirates. Mar'ee (1978) gave the storage, under an area of 1250km^2 of piedmont plains and dune sands with an average saturated thickness of 20-30m. and specific yield that varied between 0.05 and 0.10, as 3,000 MCM. Iwaco (1986) derived a figure nearer to that estimated by Halcrow for the Quaternary aquifer for an area in the Northern Emirates of 1,260km^2 and for the Al Ain area of 570km^2 of the plains (total area 1,780km^2). Using the same effective

porosity value as that used by Halcrow (15% or 0.15) and a 20m. saturated thickness, again nearly the same as that of Halcrow, the estimated groundwater in storage was given by Iwaco as 5,340 MCM. This figure was similar to that given by Halcrow (1969), despite the difference of twenty years of heavy groundwater abstraction from storage.

Between 1966 and 1986 the saturated thickness had shrunk by several metre. Even before the Iwaco report was prepared (1986) parts of the Quaternary aquifer at Al Dhaid had already been exhausted. At the time of the Halcrow study water levels were higher than they are now and were within the Quaternary alluvium. At present (1990) abstraction is from the Juweiza carbonate clastics-in-shale underlying the Quaternary alluvium, with the upper part of this formation starting at levels varying from 6m. to 88 m. below the surface but occurring in most parts of the western piedmont plains at levels of 15m. below the surface, as in Wells GPs-1, 15, 16 and 17 (see Chapter 5, Section 5.5.1). The saturated layer under the piedmont plains is far from being homogeneous. This is clear from the occurrence of the water-table at varying levels which seem also to include those levels of limited perched groundwater bodies. The common groundwater development feature in large parts of the piedmont plains at present (1990) is the pumping of water from deeper water levels in the Juweiza below 100m. and even from levels as deep as 250-400m.

The saturated thickness in the piedmont plains and the desert foreland has shrunk by 12-15m. from the original 25m. reported by the Parsons Report (1963); by 10-12m. at Al Hibab and 5m. at Al Wuhoosh (from an original 20m. in the latter wellfield in 1971). Thus, the saturated thickness at Al Aweer and Al Hibab has been reduced by half, so must have been the storage capacity in the area of the three Dubai wellfields.

The 45m. thick saturated zone at Sirrah (brackish water) aquifer in the desert foreland, which was reported by Halcrow (1969) to have its upper level (SWL) at 12-13m. below ground level, at present (1989) stands at 32-34m. below the surface and the saturated thickness has been reduced to 20-24m. In 1966 levels in Al Dhaid were reported by Halcrow to be 11-13m. below the surface in the Quaternary deposits;

now, wherever there is water in the wadi gravels, the water level is at 33-35m. below the surface. The average saturated thickness in this area was given by Halcrow (1966-69) as 22m., by Mar'ee ten years later (1978) as 22.5m. and finally by Geoconsult-Iwaco, yet another ten years later (1986), as 20m. In 1988 the average saturated thickness was 0-5m. This confirms the total exhaustion of parts of the aquifer in the Quaternary in several areas of Al Dhaid since 1984.

The progressive decline in groundwater levels, in the last two decades all over the Emirates, has already been discussed (Chapter 5, Sections 5.5.1 and 5.5.2). The average annual rate of decline of groundwater levels for the whole Emirates has been 1.2m. Well GWR-3 in Al Hamraniyyah had run dry by 1985 (Fig. 5.49A, Chapter 5). In southern Al Dhaid the annual rate of decline in the groundwater levels has been much more (about 3.0m/a). The annual groundwater drop at Idhn has been 3.3m/a; at Al Madam in the central parts of the piedmont plains the decline rate has been 0.9m/a; at Ghashabah it has been 1.3m/a, and at Um Ghafah the average decline has been 3.7m/a, although in some wells the annual drop has been as much as 4.4m/a. The saturated thickness in Um Ghafah is at present (1989) less than 20m. and groundwater levels that stood in 1966 at 18m. below the surface, stand today at an average depth of 26m. (1989). In Um Ghafah Wells-401 and 402 (Fig. 5.47 B and D) groundwater levels are even below 40m. (1990). Substantial areas in Um Ghafah have dried up. Examples are the wells of the citizens' gardens at Um Ghafah (1988). Production from the official public supply wellfield of Um Ghafah is maintained at 0.9-1.4mgd (1988-1990). The saturated zone, has been drastically reduced to about 10m. or even less, and in many places it is hardly 2m. thick (1990).

The deeper Tertiary water-bearing strata of the Juweiza formation, which underlie the Quaternary alluvium in large parts of the western piedmont plains and the desert foreland, are poor in both well discharge rates and water quality of groundwater. All the old-established wellfields of the desert foreland, that have supplied water to the major coastal towns for three decades, contain waters that have deteriorated in quality since the early 1960s. The waters of Aweer-Hibab-Wuhoosh range in TDS from 1300-2200ppm. (EC 1800-3000mmhos/cm.), and in the Al Badea' wellfield of Sharjah the ECs

are worse. Elsewhere in the desert foreland, as at Suwaihan, groundwater quality is even poorer. In Suwaihan, levels in hand-dug 'tawis' (wells) were around 4m. below surface in 1966, whereas in 1988 the groundwater levels were standing at between 29-35m.

These recessions in groundwater levels have also meant reductions in the storage area and volume of aquifers. Therefore, the estimated reserves in storage cannot be of the same order in 1986, as presented by Iwaco, as those given by Halcrow in 1966-69. If present-day estimates of fresh groundwater in storage are to be attempted, then these are going to be for much reduced saturation thicknesses in the Quaternary aquifer system. Such estimates of the reserves do not seem to offer a promising picture in view of the progressive shrinkage of the storage capacity of aquifers of potable groundwater.

The piedmont plains from Ras Al Khaimah to Um Ghafah (in Al Ain) have an area of about 1981km^2. Effective storage has a value of 0.10 (or 10%) and the saturated thickness averages 5m. The fresh groundwater volume in storage is in the order of 991MCM (1988). In the area of fairly marginal water of the Aweer-Hibab-Wuhoosh-Badea' wellfields in the desert foreland, with a total surface area of 120km^2, an effective storage value of 0.20 (or 20%) and a saturated thickness of 15m., the water in storage is 360MCM (1988).

In the public supply wellfields of the northern dunes in Al Ain, the area is 150km^2, effective storage is 0.05 (or 5%) (Gibb, 1974) and the saturated thickness is about 15m. (1988) (it was 21m. in 1976; there has been a fall in the water-table of 6.0m. since), giving a volume of groundwater in storage of 112.5MCM (1988).

The eastern piedmont plains of the alluvial embayments of the east coast, have an area of 250km^2, with a much depleted Quaternary aquifer mostly in wadi terraces and outwash fans, swelling its groundwater in storage soon after the winter rains but shrinking equally fast soon after, have an average saturated thickness of 10m. and an effective storage of 0.03 (JICA, Wadi Al Baseerah Basin Water Resources Project, Vol. 3 Appendix. p. 3.6-105 (1980)) giving a volume in storage of 75.00MCM (1988).

In central Abu Dhabi the immediate area of the wellfields of Al Helew, Bida' Khalfan and Bujair has an area of 25km^2, a saturated thickness of around 15m., effective storage of 0.10 and fresh groundwater reserves of 38.00MCM (1988).

Finally, the northern Hajar limestone aquifer is thought to offer good potential, although the estimated thickness of the fresh groundwater zone of 300m., as suggested by Iwaco (Deep Wells Project, Final Report, Vols. 1 and 7, 1986), appears to be doubtful in view of the limited data on this aquifer system. As fresh water in boreholes that struck vertical planes in the Hajar carbonate massif was plentiful, and recovery after the sharp drawdown was within minutes (Well RK-16 displayed recovery within 7 minutes after a drawdown of 7m.), it can be proved that groundwater occurs in limited space and is not necessarily at a uniform level within the whole Ru'us Al Jibal limestone massif. On the western side of the Hajar block there is acute sea-water intrusion at Sahwat, Sha'am and even as far inland as Wadi Al Beeh. This points to the delicate balance between the sea and fresh water bodies (in both the Quaternary and the limestone strata underneath it), with the fresh groundwater floating on the denser saline seawater.

The estimated freshwater in storage in the Hajar aquifer, presented by Iwaco (1986) on the assumption of a 300m. thick zone in the southern part (area 270km^2), and a 150m. thick zone in the northern part (area 370km^2), with a general porosity value of 0.10, which gave volumes of 8,100 and 5,550 MCM, respectively, appears much exaggerated. In view of this exaggerated fresh groundwater saturated zone, as suggested by Iwaco, and the unavailability of related more reliable hydrogeological data, quantifying the volume of fresh groundwater in storage in the Hajar massif of Ru'us Al Jibal is impossible at present.

With the foregoing explanatory review of the dwindling fresh groundwater potential by the continuous overabstraction and lowering of water-tables, the exhaustion of aquifers or parts of them, as is already happening in some localities, and the increasing problem of sea-water intrusion in coastal wellfields or contamination from deeper saline waters in inland wellfields, development cannot be outlined within the present inescapable option of 'mining' of groundwater

resources. In such an advanced stage of groundwater overdevelopment as exists at present in the Emirates, the courses to be followed should be those of a moratorium of further overdevelopment of groundwater resources, conservation in the strictest and harshest meaning of the word and encouragement of alternative resources. The use of water from any alternative non-conventional water resource should be strictly on the basis of both application according to water quality and also the economic viability of such an application.

The present depressing state of groundwater resources is the outcome of chronic indifference over the continuity and inexhaustibility of groundwater. The current dominating basic philosophy is that, with ready capital, groundwater can be extracted in any volume at any place and time. Turning the desert green at all cost seems to be the driving force in this groundwater resource overdevelopment. The existing uncontrollable trends in abstraction and use have already developed into a tradition that will be hard, if not impossible, to overcome, let alone reverse.

10.3. Previous groundwater recharge and balance estimates

10.3.1. General

Surface runoff is the primary source of recharge to the main aquifer system in and underlying the alluvial deposits, on either side of the mountain divide, and their wedge-like extensions beyond the piedmont plains to the west, as far as the sandy desert foreland. The various catchments, which raise all the surface runoff, are limited to only a small part of the Northern Emirates as has been discussed in Chapter 4.

Direct rainfall over the whole surface in the various regions of the Emirates, outside the mountains, is the secondary source of recharge. The topography of the land is dominated by the narrow mountain divide, and deep wadis, which in the northern limestone part, are canyon-like. There are low hills at the forefront of the main mountain block, with narrow outlets through which surface flow is disgorged to the piedmont plains. The wadi waters fan out and percolate into the alluvium at the foothills and the piedmont plains.

If rain persists and overland flow continues, the wadi courses are deflected to run semi-parallel to the mountain front to either lose their way in the desert flats (sabkhas) or, as is the case with Wadi Lamhah, reach the sea in the only wadi in the Emirates that does so to the west of the Oman Mountains. There is no wadi with overland flow that runs at right angle, across the western lowlands, as far as the coast. Recharge from overland flow, therefore, takes place mostly in the 15 to 20km-wide western piedmont plains from where it moves underground northwards, northwestwards and westwards, aided by permeable wedge-like buried alluvial wadi channels.

10.3.2. Recharge and balance estimates of the 'Water Resources of the Trucial States' study, (William Halcrow), 1966-69

As noted earlier in this chapter, the earliest recharge estimates, though only for the piedmont plains to the west of the mountains, were those presented in the Water Resources of the Trucial States study (the Halcrow Report, 1966-69). They were based on both a median annual runoff estimate and a flow-net analysis of the shallow aquifer in the central piedmont plains. The estimated volume of recharge derived for the part of the piedmont plains from Mileiha to Ras Al Khaimah was 105 MCM/a. For the whole of the western piedmont plains from Al Ain to Ras Al Khaimah, this figure was extrapolated, based on the flow-net devised by the survey, by adding 50% for the rest of the area from Mileiha to Al Ain, arriving at a total outflow for the whole land front of 157MCM. The total net abstraction from the western piedmont (gravel) plains, for the two years 1966-68, was estimated by Halcrow as being 140.44 MCM., or an annual rate of nearly 70 MCM.

With the assumption that the whole system is in a state of equilibrium, the corresponding long term mean recharge volume was given by Halcrow as 227 MCM. This volume amounted to 31% of the total volume of 737 MCM of precipitation over the mountain catchments draining westwards to the piedmont plains. The Halcrow report took no account of the considerable contribution to recharge into the aquifer of the piedmont plains from direct rainfall. Of the estimated volume of precipitation produced for the years 1966-68 on the western mountain catchments of 664 MCM, wadi runoff was estimated as 91.0 MCM.

The runoff factor was given as 14%, which, though Halcrow recognized as being high for an arid country, was found by the FAO consultants Carr and Barber as having a certain credibility (Preliminary appraisal of water resources of the UAE, Phase 1, UN-FAO, 1976). The estimated mean annual input of 227MCM was based on an annual catchment yield of 58mm., which was more than twice the value of similar catchments of well-studied wadis in southwestern Arabia.

Using three groups of exploratory boreholes around Aweer-Muwaileh, Lamha-Sirrah and Hamraniyah-Burairat, which covered an 88-kilometre land front, the mean rate of groundwater flow was calculated by Halcrow and found to be 105MCM/year along that front, on the basis shown in Table 10.1.

Front	Width in Kms	Mean Flow $m^3/d/m$	Total Flow m^3/d
Badea'/Aweer	16	3.2	51,200
Bahayes/Mileiha	20	3.4	68,000
Sirrah/F. Mualla	11	4.8	52,800
Lamhah/Manama	12	0.4	4,800
Hamraniyyah/Burairat	29	3.8	110,200
	88		287,000 m^3/d. **(105MCM/a)**

Source: Trucial States Water Resources Report, 1966-69.

Table : 10.1.

Halcrow's groundwater flow estimates in an 88km-front between Al Aweer and Al Burairat (1969).

The total volume produced by precipitation during the 1966-68 rains in the catchments, with an area of 4000km^2, was given as 664MCM. As the mountain front described above received flow from about 77% of the western catchments, it was then estimated that the volume that was available as runoff amounted to 572MCM. Correspondingly, the105MCM/a

of annual groundwater flow, derived above, made up 18% of the 572MCM estimated volume produced from the rainfall in all the catchments. Halcrow's arbitrary front was said to mark the western limit of the piedmont plains coinciding with that for potable groundwater, to the west of which the groundwater quality deteriorated. The estimated 105MCM was regarded as the theoretical water potential available for exploitation annually east of the front (i.e. the land upstream of it, which included the piedmont plains). Any groundwater extraction in excess of this amount, or even 75% of it, would inevitably draw in seawater.

In quantifying the storage potential it was found that the saturated layer varied from a mere 2m. at the foothills in the extreme east of the piedmont plains (at Manama) to more than 45m. at Tawi Sirrah in the dune sands beyond the western fringe of the plains (1966-69). The average thickness taken for the whole saturated zone in the piedmont plains was 22m. The total surface area of the plains to the east of the arbitrary front was given as 1600km^2. As the specific yield values ranged from 0.05 to 0.30, corresponding to the varying water-bearing lithologies (from coarse gravel to very fine sand) a notional storage value of 0.15 was generally adopted.

The 'effective storage' of 'tolerable water' (of up to EC 2000mmhos/cm.), the so-called permanent reserve, was estimated by Halcrow as being 5,280MCM according to the following calculation:

$$22 \times \frac{0.15}{100} \times 1600 \times 10^6 = 5{,}280 \times 10^6 m^3 = \textbf{(5,280MCM)}$$

10.3.3. Recharge and balance estimates of the 'Water Resources Survey of Abu Dhabi' study, (Alexander Gibb), 1969-70.

The Water Resources Survey of Abu Dhabi (Gibb, 1970), which coincided with Halcrow's survey in the Northern Emirates, estimated recharge in a 40-km. front of the Oman Mountains to the east of Al Ain with an area of 300km^2, on the basis of a catchment yield of 75mm. This was

three times higher than precipitation values in comparable catchments elsewhere in the Arabian peninsula. It was assumed that 50% of the rainfall would flow as surface runoff, thus deriving the estimated annual recharge volume for the area of 25 MCM. To this was added 1 MCM of imported water from the Mahdhah outwash fan through Falaj Hilli. Furthermore, the Gibb Survey estimated the volume of surface flow continuing west of Al Ain as 8.0 MCM. Against this stood a crude estimate of the net consumption of the Al Ain region of 15.7 MCM/a (for 1970). This gave a favourable groundwater balance of +10.3 MCM/a, which was made even more favourable when the estimated outflow to the west of Al Ain was taken into account (8MCM). This presented a false picture of the situation in a region where there was, and has always been, excessive groundwater extraction.

The environment here, though similar to that in the Northern Emirates in that it also includes alluvial piedmont plains, does not receive its recharge directly from the mountains, but through the intermediate Oman Plains that lie between the main mountain block and the limestone hills further west. The interior plains act as a balancing reservoir regulating groundwater flow, through the three mountain gaps of Mahdhah, Zarub and Ajran, into the Al Jaww Plain and northern dune areas of the Emirates. The recharge front extends southwards from Wadi Sharm, north of Mahdhah in the north, to Ajran in the south.

Disregarding any contribution to recharge either from direct rainfall over the whole area or from irrigation returns as being indeterminate, the Gibb Survey regarded the ability of the first to penetrate down more than 15m. to the aquifer to be doubtful; the second, to be of localized extent. Thus the minimal estimates were limited to quantifying recharge through the three main mountain gaps.

Recharge through the Zarub Gap, in the northern parts of Al Jaww Plain, takes place by way of a wadi channel filled with highly permeable gravels underlain by a 15-m. thick aquifer of the same material. Evidence of the concentration of infiltration within the wadi channel is in the sudden high rise in the water levels in the boreholes located within the channel or just on its sides, immediately after the rains and the resulting floods. Movement of groundwater is also fast under the main wadi channels aided by the

steep inclination of the strata. The Gibb Report mentioned a groundwater flow rate beneath the channels (Wadi Al Ain, Wadi Shik and Wadi Idan) of 60m/d, equal to travelling from the Zarub Gap to Al Ain, a distance of 20kms., in one year.

With data on permeability and hydraulic gradient obtained from actual well pumping tests and the cross-sectional area of the aquifer from geophysical surveys, the water available as recharge was calculated by Gibb according to the following formula,

$$Q = K.i.A.$$

Where, Q = Groundwater flow expressed in m^3/d.
K = Permeability of the aquifer in m/d.
i = Hydraulic gradient (dimensionless).
A = Cross-sectional area of the aquifer in m^2.

The recharge volume from the Zarub Gap accordingly was,

$$Q = 200 \times 0.011 \times 18{,}000 = 39{,}400\ m^3/d$$
$$\text{or} = \mathbf{14.5MCM/a.}$$

The volume of recharge through the Ajran Gap was estimated using the same values of permeability and hydraulic gradient as for Zarub. Most of the course of the wadi (W. Muraikhat) is in Omani territory where no drilling of test boreholes was allowed by the authorities. As only a small part of surface runoff was expected to flow into UAE territory, an estimate was put at 5% of the total volume passing through the 'Ajran Gap. The thickness of the aquifer in the channel of the wadi was given as 25m. This aquifer was made up of marls and clays, in addition to gravels and conglomerates. The permeability was taken as 7m/d. in a general aquifer thickness of 20m. in this southern part of Al Jaww.

Using the same equation as before (Q = K.i.A.):

$$K = 7m/d,\quad i = 0.005,\quad A = 20 \times 6{,}000m^2 \quad \text{then,}$$
$$Q = 7 \times 0.005 \times 20 \times 6{,}000 = 4{,}200m^3/d$$
$$\text{or} = \mathbf{1.54MCM/a.}$$

Finally, surface flow through the Mahdhah Gap was to the northwest in a definite wadi channel rather than fanning out all over the outash fan and be widely absorbed in it. The Gibb Report assumed the wadi flow channels to swing south-westwards, bypassing Jabal Awha in the direction of Al Hamam in Bid'a Bint Saud public supply wellfield and extending further southwest towards Bu Samrah and Al Sad. The same lithological characteristics pertain here as in Zarub and the recharge volume was calculated as follows:

$K = 200m/d$, $i = 0.01$, $A = 26,200m^2$ and therefore,

$Q = 200 \times 0.01 \times 26,200 = 52,400m^3/d$

or = **19.2 MCM/a.**

The total volume of recharge water replenishing the aquifers in the whole front from Wadi Sharm to Ajran Gap added as follows:

$14.5 + 1.54 + 19.20 =$ **35.24 MCM/a.**

10.3.4. Recharge and balance estimates of the 'Development of Water Resources in the Emirate of Dubai' study by Wellfield Services Ltd. (1976)

The Parsons Report (Dubai Groundwater Investigation, 1963) limited to Al Aweer wellfield of Dubai, did not attempt any recharge estimate, while the Wellfield Sercices Study (Development of Water Resources in the Emirate of Dubai, 1976) resurveyed the area, and by then, the wellfield of Wuhoosh had already been commissioned and was providing water alongside Al Aweer. Recharge was estimated on the basis of runoff. The study took into account the whole catchment area of Wadi Sumaini, which also included the basins of the smaller wadis of Khudhairah, Mayhah and Muzeirea' as well as 20% of the Wadi Sharm catchment further south, which all had a total area of $388km^2$. Using a mean annual rainfall depth of 150mm. and an annual runoff coefficient of 29%, and assuming that all catchment runoff yield infiltrated, a total volume of 18 MCM/a. was derived as the recharge volume into the vicinity of the Dubai Aweer-Wuhoosh-Hibab wellfields. This was equivalent to 0.44 MCM/a. per kilometre width of through-flow.

10.3.5. Recharge and balance estimates of the 'Preliminary Appraisal of Water Resources Report' (Carr and Barber) of the FAO, 1976.

Estimates by the FAO consultants Carr and Barber (Preliminary Appraisal of Water Resources in the UAE, Phase I, 1976) involved the gross balance of the aquifer system between Al Ain and Ras Al Khaimah with a total area of 4,000km^2 and a land front 170km. long. A 25mm. catchment yield was used, based on similar yields of wadis in Saudi Arabia and Yemen, and also from the UN's worldwide experience, resulted in a mean annual runoff estimate of 100 MCM/a, equivalent to an annual recharge input of 0.6 MCM per line kilometre.

Strictly limited to the piedmont plains on a 170-km. recharge front, from Al Ain in the south to Ras Al Khaimah in the north, the Carr and Barber report presented a crude groundwater balance with reference to the entire aquifer system based on an average saturated thickness of 10m. in the central (western) piedmont plains. This thickness increased northwards under the Jiri Plain, and westwards under the sand dunes of the desert foreland where the aquifer of the plains is in hydraulic contact with the aquifer of the sand dunes. The same coarse alluvium saturated zone of the piedmont plains was in hydraulic contact with the underlying mudstone evaporite sequence (the shale and clastics of the Juweiza Formation), which had low permeability and transmissivity and contained marginal quality water.

Referring specifically to the coarse alluvial aquifer, Carr and Barber pointed out the slim possibility, in areas of concentrated agricultural and domestic groundwater abstraction, of developing depression cones of great areal extent to intercept the east-west groundwater flow. Furthermore, the then (1976) rate of groundwater abstraction, in such areas, did not warrant the capture of the entire underflow. Therefore, Carr and Barber concluded that the deficits in the whole groundwater system were concentrated within the immediate vicinities of these extraction areas.

At the time of the Carr and Barber study (1976), the expansion in agriculture, and the enhanced groundwater abstraction rates that followed, had not yet taken the dimensions of the early 1980s and the Report pointed out that subsurface flow from the groundwater system

towards the sabkhas and the sea, could not have changed materially considering the short time since the development in agriculture had started (prior to 1976), given also the steep hydraulic gradient of the system. Carr and Barber estimated losses to sabkhas and the sea in the order of 60MCM/a, and, pointing to the lack of quantification of consumption by natural vegetation or evapotranspiration, Carr and Barber presented the following tentative estimate of a groundwater balance:

Mean annual recharge	about + 100MCM/a
Net consumption by agriculture	about - 140MCM/a
Extraction/Municipality water supply	about - 24MCM/a
Consumption by natural vegetation	Not quantified
Evaporation on sabkha and losses to the sea	say - 60MCM/a

Source: Preliminary Appraisal of Water Resources (1979)

Table: 10.2.

The groundwater balance of the Emirates by Carr and Barber (1976)

The deficit in this groundwater balance was, therefore, 124MCM/a., which was pumped from storage.

10.3.6. Recharge estimates of the 'Water Resources and Rural Development in the UAE' study by the International Development Centre of Japan (IDCJ), 1978.

Of the 100 MCM recharge estimated by Halcrow (1969) for the whole length of the piedmont plains from Ras Al Khaimah to Al Ain, 46MCM were thought to be the recharge of the part of the plains north of Mileiha, a volume that nearly conformed with the upper limit of 59.4 MCM/a. annual recharge volume from 9 catchments north of Mileiha,

estimated by the International Development Centre of Japan (IDCJ) (Water Resources and Rural Development in the UAE, 1978) (Table 10.3). This upper limit of IDCJ's estimate was based on a runoff coefficient of 25-40% of the total basin precipitation. There was also a lower limit of 10-20%, with the higher coefficients being for catchments within the ophiolite mountain zone south of the Dibba line.

Unlike previous recharge estimate attempts which concentrated only on the western piedmont plains, the IDCJ included estimates for 6 east-flowing catchments making up nearly the whole east coast drainage system, as shown in the summary of IDCJ calculation in Table 10.3.

Neither the IDCJ (1978) nor Carr and Barber (1976) considered any contribution to recharge from direct rainfall over the plains. Whereas IDCJ made its study for the purpose of artificial recharge augmentation design requirements (dams), Carr and Barber appraised the water resources of the country with the potential for irrigation. While Halcrow regarded the whole contribution of 17.82 MCM/a to groundwater recharge from rainfall on the east coast wadi basins as totally lost by out- or under-flow to the sea, Carr and Barber did not take into account any contribution to groundwater recharge from direct rainfall on the east coast.

10.3.7. Recharge and balance estimates of the 'Reconnaissance Report on the Eastern Region of Abu Dhabi (Al Ain) by Hydroconsult (1978).

Besides adopting the Gibb (1970) recharge potential values for the three Oman Mountain Gaps, Hydroconsult attempted recharge estimates for each wadi flowing from the Mahdhah fan area, added an estimate for Wadi Hamad in southern Al Jaww, estimated the recharge to the vast southern (brackish water) dune area in a front between Ain Busakhinah and Al Qoa', and emphasized the contribution to recharge from direct rainfall, surface flow and irrigation returns. The first of these four recharge elements was not attempted, and the last two were considered insignificant, by the Gibb Report, ten years earlier (1969-70).

In presenting the volume of recharge into the aquifer of Al Jaww, Hydroconsult used Gibb's estimates with the additional breakdown of

Area	No.	Dam Site	Geological Features*	Catchment Area A (Km^2)	Annual Rainfall R (mm)	Precipitation A.R ($10^6 m^3$)	Annual Volume of Water Developed f.A.R. ($10^6 m^3$)			
							f	Upper limit	f	Lower total
WESTERN	(1)	SHAAM	L	37	155	5.74	0.25	1.43	0.10	0.57
	(2)	GHALILAH	L	72	155	11.16	"	2.79	"	1.12
	(3)	BIH	L	480	155	74.40	"	18.60	"	7.44
	(4)	NAQAB	L	92	144	13.25	"	3.31	"	1.33
	(5)	TAWIYAYN	L	198	115	22.77	"	5.69	"	2.28
	(6)	MUTARIDAH	L	52	87	4.52	"	1.13	"	0.45
	(7)	MAWRID	S	63	162	10.21	0.40	4.08	0.20	2.04
	(8)	SIJI	S	118	185	21.83	"	8.73	"	4.37
	(9)	SIFUNI	S	218	156	34.01	"	13.60	"	6.80
TOTAL				1,330		197.89		59.36		26.40
EASTERN	(10)	SHINAL	S	120	157	18.84	0.40	7.54	0.20	3.77
	(11)	ZIKT	S	73	141	10.29	"	4.12	"	2.06
	(12)	SHAMAH	S	114	185	21.09	"	8.44	"	4.22
	(13)	MADHA	S	94	169	15.89	"	6.36	"	3.18
	(14)	HAM	S	280	134	37.52	"	15.01	"	7.50
	(15)	RUMTH	S	28	126	3.53	"	1.41	"	0.71
TOTAL				709		107.16		42.88		21.44
GRAND TOTAL				2,039		305.05		102.24		47.84

* L : limestone S : mainly serpentinite

Table: 10.3.

Annual runoff volumes of catchments in the limestone and ophiolite parts of the central mountains, by the International Development Centre of Japan (IDCJ), 1978.

The upper limit of recharge volume from runoff of 59.4 MCM/a estimated by IDCJ was on the basis of a runoff coefficient of 10-20% for west-flowing wadis. This upper limit recharge volume appears to coincide with that of 46.0 MCM/a put forward by Carr and Barber as the volume recharging the fresh groundwater system in the piedmont plains to the north of Mileiha. Both IDCJ's and Carr and Barber's recharge estimates are higher than the actual volume recharging the aquifers in both the eastern and western piedmont plains from all the gauged and ungauged catchments derived by the present study for the part of the Emirates north of Al Madam (28.97 MCM/a).

the recharge elements for Wadi Hamad. Applying Darcy's equation as did Gibb (Q = K.i.A.), the estimated volume of recharge through the Zarub Gap was given as 13.1MCM/a, the recharge through the Ajran Gap (the part that flows into the Emirates) as 1.545MCM/a, and that for Wadi Hamad, waters of which emenate from a secondary gap between Jabals Mundassah and Al Oad between Zarub in the north and Ajran in the south, as 0.36MCM/a. This gave a total recharge value for the whole groundwater flow in Al Jaww of 15MCM/a.

The other three elements of recharge: direct rainfall, surface flow within Al Jaww and irrigation returns, have been presented by Hydroconsult as follows:

10.3.7.1. **Recharge from local rainfall**:

With the long-term mean annual rainfall then (1978) determined as 100mm. and considering the extremely high evaporation in Al Jaww Plain (more than 30 times the mean annual rainfall), 5% of annual rainfall was assumed to percolate through the permeable gravels. The surface area of Al Jaww (400km^2) would receive a total recharge volume of 2MCM/a. from direct rainfall.

The Hydroconsult recharge estimates for the Al Ain region, considered by Groundwater Development Consultants (GDC, 1982) as high despite the fact that the estimates were based on available long-term rainfall means, included larger areas than those treated by GDC and added estimates of runoff from piedmont alluvial areas. Different mean annual rainfall values were assigned to 4 sections in each catchment subdivided according to topographic characteristics (mountains, high alluvial plains, piedmont plains and sand dune areas). These rainfall means ranged from 50mm/a for the interior plains of the southern brackish water desert (Addhahirah), 120mm/a for the desert foreland of the northern dune area (Al Hayer), 150mm/a for the piedmont plains (the Mahdhah and Al Jaww plains) and 200mm/a in the higher mountains in Oman to the east. The total runoff for each section of the wadi catchment and its different components is summarized for each hydrological unit in Table 10.4.

10.3.7.2. **Recharge from surface flow:**

Surface flow across a 70-km. front, which included the catchment of Wadis Sumaini, Khabb, Ma'aisheq, Mahdhah, Al Ain, Shik, Hamad and 'Ajran, forming the fresh-water recharge zone, was considered by Hydroconsult in its recharge estimates. In another 100-km. front in the southern brackish groundwater area (the southern desert), where surface flow hardly reaches the common border with Oman, flow was wholly subsurface. Hydroconsult took into account all the parameters of input including that of recharge from direct rainfall in the three areas of the 'Northern Dunes', the 'Al Jaww Plain' and the 'Brackish Water Sand Dune' areas. Hydroconsult also estimated the contribution from irrigation return and falaj flow. The estimated crop from the various recharge items for the three areas is given in Table 10.5.

The volume of flood water in the wadis crossing Al Jaww was estimated by Hydroconsult as 10.25MCM/a for Wadis Shik and Al Ain; 0.78MCM/a, for Wadi Hamad and 3.78MCM/a for Wadi Ajran (i.e. Wadi Muraikhat), which is not taken into consideration as most of its runoff flows back southwestwards into Omani territory. A 20% value was assumed to percolate to the aquifer out of these surface flow totals. This gave an expected recharge volume into the aquifer in Al Jaww of 2.2MCM/a (Table 10.5.).

10.3.7.3. **Recharge from irrigation return:**

In areas where there was concentrated agricultural activity in localities of shallow unconfined aquifers, where excessive irrigation water was applied with the basin inundation method (widespread at the time of the Hydroconsult survey in the Al Ain area), part of the irrigation water was likely to percolate to the aquifer. Hydroconsult made use of the estimates of well-pumping rates, and falaj discharge flows quoted by Gibb ten years earlier (1969) for which the volumes were given as 11MCM. and 16.6MCM. per year. Thus, the total volume of 27.6MCM was withdrawn from the aquifer annually. In 1978 field irrigation efficiency was put at 40%, or even less, as a result of which an estimated 12.5MCM/a. of groundwater were wasted. Considering similar soil and irrigation conditions in identical environment in Saudi Arabia, Hydroconsult estimated that 60% of the wasted water

	Ophiolites and higher limestone outcrops	Piedmont and upper wadi alluvium	Lower mountain outcrops	Interior alluvial plains
Rainfall in mm	200	150	150	120
Total Runoff (%)	25	10	10	8
Total Runoff in mm	50	15	22.5	9.6
Allocation of Total Runoff				
a) Baseflow in mm	10 (5%)	0	0	0
b) Riverbed Infiltration in mm	16 (8%)	9 (6%)	9 (6%)	6 (5%)
c) Flood Flow in mm	24 (12%)	6 (4%)	13.5(9%)	3.6(3%)

% in brackets refers to ratio to total rainfall.
Modified from Hydroconsult,"Eastern Region of Abu Dhabi Water Resources", 1978

Table: 10.4.

Allocation of annual rainfall and runoff totals to each hydrological (topographical) zone in the Al Ain region by Hydroconsult (1978).

Due to inavailability of long rainfall records for the Al Ain region then (1978), the mean annual rainfall totals used by Hydroconsult were basically high. The runoff ratio used by Hydroconsult for catchments in the Oman Mountains to the east of Al Ain varied from 8% for the interior alluvial plains to 20% for the high ophiolite and limestone mountains of the upper reaches of wadi catchments in Oman.

	Northern Dunes	Al Jaww Plain	Brackish Water Dune Area
REPLENISHMENT			
Subsurface Inflow	13.7	15.0	73.0
Infiltration from direct rainfall	20.0	2.0	110.0
Infiltration from surface flow	8.0	2.2	-
Irrigation return and falaj flow	+41.7	9.3 (8.3+1.0) +28.5	+183.0
ABSTRACTION	-5.5	-29.0	-32.0
Balance	+36.2	- 0.5	+151.0

All volume units in million cubic metres
Modified from Hydroconsult:"Eastern Region of Abu Dhabi Water Resources", 1978

Table: 10.5.

The groundwater balance of the Al Ain region by Hydroconsult (1978).

Like the Gibb groundwater balance before it (1969-70), the Hydroconsult balance estimates for the Al Ain region resulted in a false favourable water balance in a region that has been known since the Gibb study to be an area of heavy groundwater abstraction that exceeded replenishment. This is particularly so in the northern dune area where most of the public supply wellfields are concentrated.

would return into the groundwater system. This recirculating irrigation water made up a volume of 8.3MCM/a (Table 10.5).

Another possibility of water returns to the groundwater system was that from domestic consumption through septic tanks or home gardens. The amount produced from the wellfields of the northern dune areas in 1978 was given as 4MCM/a of which 25% was postulated by Hydroconsult as returning to the aquifer system, the volume for which was given as 1MCM/a.

10.3.7.4. Recharge in the Northern Dune Area

Hydroconsult (1978) calculated groundwater inflow here along a 15-km. front stretching across the main wadis of Khabb, Safwan and Ma'aisheq from the Kara'a wellfield in the south to about 4kms. north of the Al Hayer-Suwaihan Road junction on the Al Ain-Dubai highway, a total area of 150km^2. The average aquifer thickness was put at 22.5m., the hydraulic gradient in the vicinity of Bid'a Bint Ahmad and Mohayyer as 0.005, and the permeability varying from 10m/d. to 55m/d.. However, 25m/d. was taken as the average permeability value for calculations of the groundwater in storage, which was given as follows:

$$Q = 25 \times 0.005 \times 15000 \times 22.5 = 42{,}187 m^3/d.$$
$$\text{or} = \mathbf{15.8\ MCM/a.}$$

Recharge from surface flow in Wadis Khabb, Ma'aisheq and part of Wadi Mahdhah that flowed towards the wellfields of the northern dunes area was estimated as 6MCM/a (from a total of 7.5MCM/a, 20% was lost to evaporation). Added to this was the surface flow of the same wadis before reaching the wellfields area, up to the mountain front, estimated as 7.7MCM/a. This gave a total recharge volume from this source of, 13.7MCM/a, which was not far from the 15.8MCM/a obtained by using Darcy's equation described above.

The interesting quantification of recharge presented by Hydroconsult was that derived from direct rainfall over the sand dunes. Based on the findings of a research by Dincer et al (1974), who used stable

isotopes and tritium in the experiments of infiltration in the dune sands of Al Dahna region (100kms. east of Riyadh) in Saudi Arabia. With a mean annual rainfall of 80mm. and a sandy environment similar to that in most of the sands of the Desert Foreland of the Emirates it was found that 20mm. out of the annual 80mm. infiltrated through the sands, amounting to 25% of this annual rainfall total. Accordingly, with 100mm. annual mean for the northern dunes of the Al Ain region, as given by Hydroconsult, in the area of the wellfields of 150km^2, and taking 20% as infiltrating (20mm.), the volume available for recharge from local rainfall was estimated as 3MCM/a.

The total recharge volume, from all these recharge components into the vicinity of the wellfields area, was put at 18.8MCM/a (for an area of 150km^2).

For the whole northern dune region, with an area of 1000km^2, the total volume available for groundwater replenishment was worked out by Hydroconsult as follows:

Net Surface Flow	10.08MCM X 80% (infiltrating)	= 8MCM/a
Subsurface Flow		= 14MCM/a
Direct Rainfall	1000km^2 X 100mm X 0.2	= 20MCM/a
Total recharge into the northern dune area		= **42MCM/a.**

(Table 10.5.)

Storage potential within the wellfields area (150km^2) and the whole northern dune area (1000km^2), was calculated according to the equation: Q = A.s.h., where,

Q = Water in storage
A = Aquifer area
s = Specific yield
h = Saturated thickness

Three varying thicknesses of the saturated layer under different surface areas were :

Q = 17.5m (thickness) for an area 56km^2

Q = 22.5m (thickness) for an area 72km^2

Q = 27.5m (thickness) for an area 22km^2

and 's' is common to all (0.10).

The storage for each thickness and area was calculated as follows:

Q 17.5m = 56km^2 X 0.10 X 17.5m = 98MCM

Q 22.5m = 72km^2 X 0.10 X 22.5m = 162MCM

Q 27.5m = 22km^2 X 0.10 X 27.5m = 60.5MCM

Total = **320.5MCM.**

The storage potential in the whole northern dune area of 1000km^2, with the specific yield (s) as 8.0 and the average saturated aquifer thickness as 15m., and using the equation:

Q = A s h, used above, then the total storage was (1978):

Q = 1000km^2 X 8.0 X 15 = **1200MCM.**

With the annual total recharge into the northern dune area, already determined as 42MCM, Hydroconsult estimated this to effect a rise of 4m. in the water-table in the region. The aquifer then (1978) was said to be in a state of equilibrium as no noticeable water level changes were observed during the time of the Hydroconsult study in this northern sand dune area. This ideal state of 'equilibrium' no longer exists and the groundwater levels in nearly all the wellfields are in systematic decline (Chapter 5, Section 5.5.2). All recharge and balance estimates by Hydroconsult for the Al Ain region are given in Table 10.5.

10.3.8. Omani recharge and balance estimates related to the Al Ain region, 1982-87

There were other recharge estimates for the catchments within Oman that are responsible for the surface and subsurface flow into the Al Ain region. The consultants and the wadi catchments they studied are given in Table 10.6, while Table 10.7. summarizes the groundwater balance estimates derived by these consultants in the catchments in Oman.

10.3.8.1. Estimates of groundwater recharge and balance of the 'Soil and Groundwater Survey for Buraimi Area- Groundwater Resources and Development' by Groundwater Development Consultants (GDC), 1982.

Of the consultants that presented groundwater recharge and balance estimates (Table 10.7.), the GDC (1982), Horn (1979) and MacDonald (1982) estimates compared favourably, whereas those for Ilaco (1975) and Hydroconsult (1978) were higher, particularly in comparison with those for the GDC estimates (Table 10.7.). As noted earlier, the Hydroconsult estimates were for larger areas and included runoff from the piedmont plains and therefore had a high degree of credibility. Although the MacDonald estimates were based on a complicated analysis of long-term rainfall values, adjusted to Wadi Sumayel long-term flood records, they were the most conservative of the set of estimates in Table 10.7. Equally so were the GDC estimates based on a rigorous analysis of the recent but scattered rainfall data.

The GDC groundwater recharge and balance calculations were based on 30.1mm. effective rainfall. Their net attenuated flows meant all active wadi flows that could be controlled and used for irrigation, as well as recoverable recharge water in the aquifer system. The ratio of this effective rainfall to the total basin rainfall was 20-22% for all the catchments, which, when taking the 8-year short-term rainfall mean for Mahdhah of 113mm., or the higher long-term rainfall mean of 140mm., gave an effective catchment yield of 23-25mm. and 28-31mm. respectively. The latter effective rainfall value was adopted by GDC as the basis for their estimates.

Consultant	Catchments	Year
Ilaco	Wadis: Sumaini, Sharm, Mahdhah-Kahal Zarub, Shik and Lihasi	1975
Horn	Minor catchments in the north, Sumaini Sharm, Mahdha-Kahal and Zarub.	1979
MacDonald	Wadis: Mahdhah and Dhahir (above Zarub)	1982
Groundwater Development Consultants (GDC)	Wadis: Scharab, Khudhairah, Mayhah Sumaini, Sharm, Safwan, Kahal Mahdhah and Musailiq.	1982
Regional Development Council (RDC)	Wadis: Sumaini, Sharm, Kahal, Mahdhah, Buraimi, Lihasi, Hafeet Basin, Milhah, Sunainah and Madam Plain.	1987

Table: 10.6.

Consultants and the wadi basins for which they prepared groundwater recharge estimates in Oman (to the east of the common border with the Emirates) responsible for replenishing the aquifers in the Al Ain region of the Emirates.

Even the GDC estimates appeared conservative by comparison with those of the Regional Development Council (RDC) estimates of 1987 which will be discussed later. The two cases of falaj flow of Falaj Hilli (in the UAE) and Falaj Mahdhah (in Oman), cited by GDC in defence of their low annual total catchment yield for the Wadi Mahdhah basin, were based on inaccurate or insufficient falaj flow measurement. The flow of 5-10 l/s (2.2 MCM/a) for Falaj Hilli, as given by the GDC, must have been based on a spot measurement in the drier part of the year. Falaj flows are best taken as averages over the whole year based

	Total Area considered	Total volume of runoff	Total volume of recharge	
ILACO	1434	31.60	22.50 9.10	1975
HYDROCONSULT	1683	52.66	27.22	1978
HORN	1663	42.30	37.30	1979
Groundwater Development Consultants	1288	32.11	21.59 19.54*	1982
Regional Development Council	1488	-	41.22 28.13*	1987
Edworthy-Brandt	1460	-	28.50	1985
All volume units in million cubic metres per annum * Actually remaining for the UAE crossing the border as underflow.				

Table: 10.7.

Previous groundwater recharge estimates for the Sumaini-'Ajran land front of the Al Ain region in the Emirates.

Of these previous groundwater balance estimates, those of GDC, Horn and MacDonald compared favourably, whereas those for Ilaco and Hydroconsult were higher, particularly in comparison with the estimates of GDC. Although the MacDonald estimates were based on a complicated analysis of rainfall, they are the most conservative of the set of estimates presented in the Table. Similarly, the GDC estimates appear conservative by comparison with those of the Regional Development Council.

on several measurements as can be seen in the average flow for Falaj Hilli for the years 1981, 1982 and 1983, which were 0.82, 0.67 and 0.44 MCM/a based on falaj flow records of the MAF of the Emirates.

These low falaj flow values for Falaj Hilli were affected by excessive pumping from both the Ghashabah public supply wellfield (maintained at 1.0 MGD or 1.7 MCM/a.) and the Al Awha government wheat farm (about 2.9 MGD or 4.8 MCM for 7 months in 1982) irrigating 1,225 hectares of wheatland (Al Ain Agriculture Department Statistics 1982-83). Even in 1982, during the time of the GDC study, the low Falaj Hilli flow was being augmented from the Al Ain public supply network. On the other hand, the high flow for Falaj Mahdhah, which GDC conceded as contradicting their recharge estimates, had the following average flow (based on 7-15 measurements in a year) as measured by the RDC staff of Oman:

1982	1983	1984	1985	1986	1987	1988	7-year Av.	
128	120	66	31	21	65	104	91	l/s
4.0	3.8	2.1	1.0	0.7	2.1	6.4	2.9	MCM/a

(Source: Regional Development Council, Oman, 1988).

Table: 10.8.

Flow measurement of Falaj Mahdhah in Oman.

The yearly falaj flow, based on average of several readings during the year, is more representative than spot readings that may only represent flow for the drier or wetter part of the year. Here, the high flow value for 1988 was due to fewer falaj flow measurements taken and also that the measurements were taken after the exceptionally high rainfall of February (1988).

As falaj flow in this area shows considerable fluctuation in response to groundwater recharge and abstraction near a falaj channelling section, and being within piedmont alluvial deposits so close to the foothills, that are known to have low storage capacity, it is the yearly falaj flow average that is representative. The low values for

1984 and 1985 were due to very low rainfall in both winters, and the high value for 1988 was due to fewer measurements taken and also that the measurements were taken after the exceptionally high rainfall of February (Table 10.8). The average falaj flow for 7 years was 91.0 l/s. or 2.9 MCM/a, and only if 1988 is excluded from this average that the mean flow for 1982-87 would become 2.3 MCM/a, which was not much out of line from the 2.14 MCM/a estimated for the Mahdhah basin by GDC.

The estimate of the median year annual flood and attenuated flow by GDC of 9.73 MCM/a for the Musailiq (Zarub) basin conforms with that by Saines and Ansari (Results of Appraisal Drilling in Zarub Gap, Buraimi Region, Oman, 1985), who estimated the flow through the Zarub Gap as 259 l/s. (8.2 MCM/a), which did not include the 130 l/s (4.9 MCM/a) of groundwater consumption by upstream users in the basin. Should the latter be taken into account, then the discharge of the basin becomes 12.3 MCM/a, which is 26% more than that estimated by GDC. As the 9.73 MCM/a volume was what was left for use for the downstream section of the basin (i.e., within the Emirates), close to the 8.2 MCM/a that underflowed the Zarub Gap into the Al Jaww Plain of the Emirates for its downstream users (1982-85), then the estimate appears credible.

10.3.8.2. Estimates of groundwater recharge and balance by the Oman Regional Development Council (RDC), 1987.

The Oman Regional Development Council (RDC) estimates (Regional Water Management Plan, 1987), which were the result of several surveys (which included also those of GDC and Saines-Ansari, discussed in Section 10.3.8.1) as well as from their practical experience as managers of the water resources in Al Buraimi region and elsewhere in Oman, are shown in Table 9.1 and 9.2, (Chapter 9). The total recharge volume was given as 95.10 MCM/a for the whole 160-km. land front from Al Madam to Sunainah (Table 9.2, Chapter 9), or 79.17 MCM/a if the Al Madam stretch was excluded, as most of its underflow did not reach the Al Ain region. For a 120 km. front from Al Madam to 'Ajran, the recharge volume was given as 57.13 MCM/a, while the front from Sumaini to 'Ajran (in line with most catchment area estimates of other studies) the total recharge volume was 41.22 MCM/a.

Taking the whole length of the land front (160km.), the total amount left as underflow crossing the UAE border was 28.13 MCM/a whereas in the part of the front north of 'Ajran it was 17.91 MCM/a. This left 10.22 MCM/a for the part of the front south of Jabal Hafeet flowing towards Al 'Ajeer and Al Zu'bah in the Emirates (Tables 9.1 and 9.2, Chapter 9). The remaining volume from each catchment, grouped as four main sectors, that underflowed the international boundary into the Emirates, is diagramatically shown in Fig. 9.2.

Table 9.2 (Chapter 9) presents the total estimated recharge derived by the various studies that were carried out in the region embracing the catchments from Al Madam to Sunainah. In Table 10.7, as noted earlier, the GDC (1982) estimated total recharge of 21.23 MCM/a was the most conservative of the set of estimates in the table, while that of the RDC (1987) was the highest (41.22 MCM/a) and was almost double the volume of the former. The estimated recharge values of Hydroconsult (1978), of 27.22 MCM/a and that of Edworthy-Brandt of the Al Ain-2000 Master Plan study (1985) of 28.50 MCM/a, agreed. The last two studies were carried out for projects in the UAE. Their estimates are regarded by the present study as reasonable in addition to the detailed estimates of upstream and downstream water consumption by the Oman Regional Development Council ((RDC)(1987)) leading to the remaining underflow crossing into the Emirates (Table 9.2 and Fig. 9.2, Chapter 9). With the proposed agricultural development in Oman in Wadis Ma'aisheq and Safwan, both of which are fed by the Wadi Sharm catchment, the existing remaining groundwater below the gaps, which underflows to the Emirates, will be expected to supply 4.95 MCM/a for the proposed additional Omani agricultural consumption below the gaps. Only 1.0 MCM/a will remain and this will have to provide nearly 17% of the irrigation requirements for the proposed 231 hectares of additional agricultural expansion in Oman which, as indications testify, is likely to take place. The annual demand for irrigation water per hectare of agricultural land in Oman was 25,477 m^3 (in 1989), and the needs of the 231 hectares will be 5.9 MCM/a. This will make the Sharm basin short of irrigation water by 4.9 MCM/a. In practice, this source of subsurface flow from Oman to Al Ain will cease.

Further south in Al Buraimi, the drying up of fresh water sources

owing to interception of groundwater flow by overabstraction in its upgradient part in northern Al Jaww in the Emirates, has warranted taking up measures by Omani water authorities to transport water by pipeline from the Zarub Gap. The two aflaj of Buraimi and Sa'arah will have their existing rate of flow of 90 l/s maintained by augmentation from the same pipeline and "the mother well sources may be cut off by the proposed wellfield in the Zarub Gap"(RDC, Regional Water Management Plan, 1987). Similarly, groundwater flow from the Zarub Gap into Wadis Al Ain and Shik of the Emirates will eventually be cut off, as this is the ground intermediate between the Zarub Gap and Al Buraimi, that is totally within the Emirates.

Another proposed site for a wellfield for Al Buraimi was suggested at Seih 'Aqdah (4 kilometres south of Tawi 'Aqdah) and the construction of the pipeline was underway (1989). The pipeline water requirement would be in the order of 8.13 MCM/a, which would intercept all the 8.2 MCM/a inflow through the Zarub Gap that has been feeding the Al Jaww aquifer in the Emirates. This pipeline may even be expected to transport more water and the anticipated shortfall may be of the order of 3.6 MCM/a (RDC, Regional Water Management Plan, 1987). Thus, another vital source of recharge to an already almost depleted aquifer system in Al Jaww, is also going to cease.

10.3.9. Recharge and balance estimates of the 'Wadi Al Baseerah Basin Water Resources Development Project' by the Japan International Cooperation Agency (JICA), 1981.

A localized recharge and balance estimate, for a 21-year rainfall mean, was made for Wadi Al Baseerah (Al Shimal) by JICA in their Wadi Al Baseerah Water Resources Development Project study (1981). The rainfall was for Dibba from 1967 to 1980, with the missing rainfall data having been filled from the long-term Sharjah rainfall record. For the year 1980-81 rainfall data for Masafi was used. A 15% runoff coefficient was adopted of which 59% was assumed as infiltrating to the aquifer system and 41% continuing as overland flow with a good deal of it being lost to the sea. The remaining 85% was designated as a loss to evapotranspiration. The effective recharge was 8.8% of the 33.3 MCM/a of total basin rainfall volume, which amounted to 2.9 MCM/a. JICA's water balance is given in Table 10.9.

Rainfall	Depth mm	Volume MCM	Percentage
Rainfall	128	33.3	100.0
Evapotranspiration	109	28.3	85.0
Surface Runoff	8	2.1	6.2
Groundwater Recharge	11	2.9	8.8
Groundwater Runoff	11	2.9	8.8

Source: Wadi Al Baseerah Basin Water Resources Development Project, Final Report, Vol. III, MAF-JICA, 1981.

Table 10.9:

Recharge and balance estimates of Wadi Al Baseerah Basin by JICA, 1980.

10.3.10. Recharge and balance estimates of the Ministry of Agriculture and Fisheries (MAF), 1982.

It was JICA's 15% runoff coefficient and the 8.8% effective recharge ratio out of the total basin precipitation, both as percentages of the total catchment rainfall, that the MAF adopted in its official estimated water balance for the whole Emirates in 1982 (Table 10.10). The estimate applied the 15% runoff factor to the rainfall of both the mountain and piedmont plain regions as a single area with a total surface area of 9,500km^2 (6,500km^2 + 3,200km^2, respectively). The rainfall mean value was 136mm. that collected a total catchment rainfall of 1292 MCM/a. Of this 76.2% was allocated to evapotranspiration losses (984 MCM), 15% for runoff (194 MCM) and 8.8% as groundwater recharge (114 MCM). The overall withdrawal of groundwater by the various sectors was estimated as 1060 MCM/a, leaving a deficit of 944 MCM/a and the groundwater recharge-abstraction ratio as 1:9 (1982).

This MAF "estimated UAE water balance", which was included in its first and only groundwater balance (1982) to date (1990), contained no explanatory notes on the method or means of deriving the data used in the calculation and the breakdown of the elements of the balance, which is merely estimated and not based on actual statistics (Table 10.10).

Only the mountain and the piedmont plains were taken into consideration as the main recharge areas. This may have been due to the main interest in the agricultural aspects by the MAF and the fact that most agricultural land is concentrated in the piedmont plains. Although the recharge calculations concentrated on these two zones, the general water balance contained groundwater abstraction (or consumption) estimates for all the zones in the Emirates, including forestry and industrial use (Table 10.10).

Total Mountain Area		6,500 Km^2
Total Piedmont Plains Area		3,200 Km^2
Total Area contributing to recharge		9,500 Km^2
Average rainfall		136 mm
Total volume of rainfall		1,292 MCM
Evapotranspiration losses	(76.2%)	984 MCM
Surface run-off including base flow	(15%)	194 MCM
Groundwater Recharge	(8.8%)	114 MCM

Source: MAF unpublished pamphlet, 1982.

Table : 10.10.

The groundwater balance estimates of the MAF, 1982.

10.3.11. **Recharge and balance estimates of the 'Master Plan for the Al Ain Region (Public Utilities part)'by Edworthy and Brandt, 1983-85 (the so-called Al Ain 2000 Master Plan).**

The Al Ain 2000 Master Plan (Edworthy-Brandt, 1983-85) assumed that no direct recharge took place in the desert area and that all the rainfall in the desert was lost to evaporation. This was the same view held in the Gibb Report (Water Resources Survey of Abu Dhabi (1970)), as one of the main participants of the 'Water Utilities Section' of the Al Ain 2000 Master Plan had also worked for the Gibb Study.

Although to the south of Jabal Hafeet, recharge was acknowledged by Edworthy-Brandt to be taking place from the east, this was not apparent due to the high groundwater salinities in the area to the west of the Emirates-Oman border. The mean annual rainfall for all the Al Ain area, used by the Al Ain 2000 Master Plan, did not differ much from that used by Hydroconsult (both were given as 100mm.). For the Al Ain catchment to the east, the mean annual rainfall value used was 153mm., which was slightly lower than the mean annual rainfall value used by previous studies. However, it must be noted that both, the Al Ain 2000 Master Plan and Hydroconsult's water balance estimates, relied greatly on the Gibb groundwater balance estimates of 1970.

Annual recharge to the aquifers in the Al Ain region, from the southern part of Al Jaww, as far as the border with Dubai/Sharjah emirates and Oman, was estimated as 23-34MCM/a (or 14-20mgd.) assuming that 10-15% of the mean annual rainfall became effective fresh groundwater recharge. This amount was apportioned to the various areas within the Al Ain catchments, from southern Al Jaww in the south to the interemirate border with Dubai and Sharjah in the north, as follows:

Catchment	Yield (MCM/a)
Sumaini	**5.6- 8.4**
Kahal, Sharm and Mahdhah	**8.0-11.7**
Musaileq	**9.4-13.9**

	Al Ain Catchment		Southern Catchment	Total
	Fresh	Brackish		
Demands				
Domestic and trade, public supply	16.0	0	0.1	16.1
Large consumers, public supply	10.5	0	0	10.5
Municipal landscaping (1)	24.1	2.4	0.2	26.7
Agriculture (1)	51.0	164.0	39.0	254.0
Forestry (1)	1.0	20.0	9.0	30.0
Export to Abu Dhabi, public supply	5.9	0	0	5.9
	108.5	186.4		
TOTAL DEMAND	294.9		48.3	343.2
Resources				
Groundwater recharge (2)	15.0		14.0	29.0
Effluent re-use (3)	11.2		0	11.2
TOTAL RESOURCES	26.2		14.0	40.2
DEFICIT	268.7		34.3	303.0

Notes: (1) Irrigation demands are net i.e. gross application less percolation back to the aquifer.
(2) Groundwater recharge in the Al Ain catchment is assumed to be the natural recharge reduced by 50 per cent to allow for abstraction in Oman and outflow across the western boundary.
(3) Resource gain from effluent re-use is assumed to be 70 per cent of the domestic and trade demand.

Table: 10.11.

The water balance of the Al Ain-2000 Master Plan (Edworthy-Brandt), 1983.

Annual recharge to the aquifers of Al Ain region, from a land front extending from southern Al Jaww to the interemirate border with Dubai, was estimated by the Master Plan as being 23-34 MCM/a. The total annual inflow from Oman into the area south of Jabal Hafeet was estimated as 14 MCM/a, which is mostly brackish. The total natural recharge was given as 58 MCM/a and the total demand as 686.4 MCM/a, which gave a recharge-discharge ratio of 1:12. However, the overall recharge discharge ratio, including recharge from effluent reuse, was 1:8.

Groundwater flow from these catchments ultimately recharged the northern wellfields, with Wadis Kahal, Sharm and Mahdhah recharging the groundwater reservoir at Al Hilli and Al Mas'udi, while Wadis Musaileq (Zarub) and Lihasi recharged the reservoir in the Al Jaww-Al Ain area.

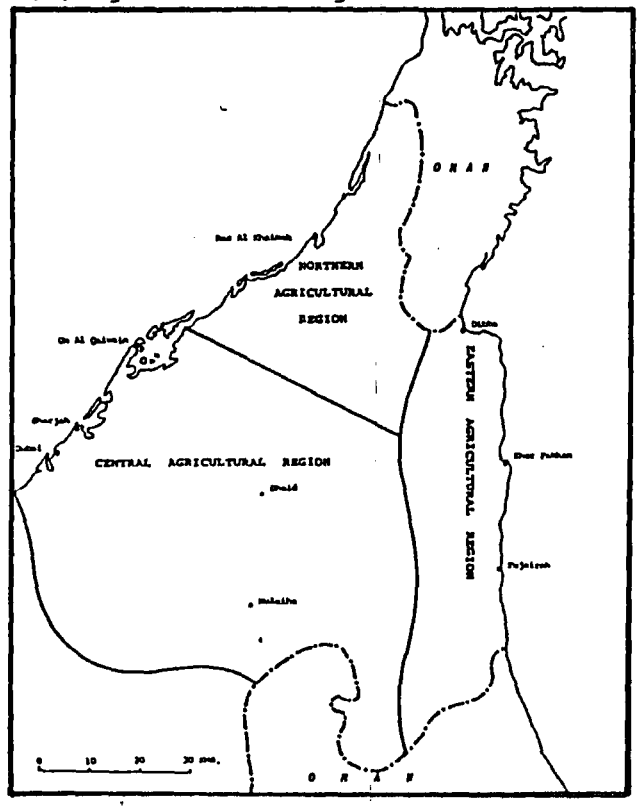
Recharge into the area to the south of Jabal Hafeet depended largely on groundwater gradient and transmissivity. With the gradient, estimated by Edworthy-Brandt from topography as 0.002, and transmissivity as $200m^2/d$ crossing a groundwater flow-section of 95kms. long, it was estimated that the total annual inflow to the area south of Jabal Hafeet was 14MCM/a (or 8.4mgd.). Groundwater in this region varies in quality from brackish to very saline. There is brackish-saline groundwater interface, which is a notional line crossing Jabal Hafeet east-west, with marginally fresh to brackish water to the north, and brackish to very saline water, to the south, of it (the Gibb Report (1970) and the Hydroconsult Report (1978)). Areas of heavy groundwater abstraction are on either side of the interface, especially along the whole length of the Al Ain-Abu Dhabi road.

The summary of the recharge contributions and the total balance for Al Ain region, presented by the Al Ain 2000 Master Plan, is given in Table 10.11.

10.3.12. Recharge and balance estimates of the Deep Wells Project (MAF-GEOCONSULT-IWACO), 1982-86

An attempt to estimate recharge and the whole groundwater balance of the Northern Emirates, based on agricultural regions, was presented by the Deep Wells Project, (1982-86) by Geoconsult-Iwaco, in its final report (Iwaco, 1986). The so-called water 'balance regions' (Fig. 10.1) were vaguely delineated by 'hydrogeological boundaries', of which only the watershed of the mountain divide (called by the report the 'Structural Ridge') was mentioned. The boundaries of the 'balance regions' did not differ much from those for the agricultural regions. For east-west boundaries of the 'balance regions', the basis used by Iwaco was 'surface water divides or groundwater flow lines' (Vol. 1, p. 112, of the Deep Wells Project Final Report 1986). Within

(A) Agricultural Regions



(B) Water Balance Regions

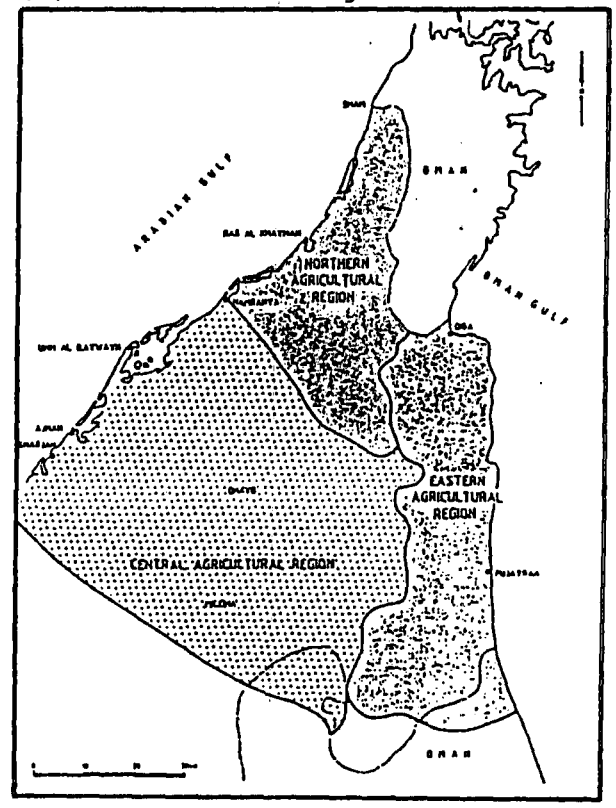


Figure: 10.1.

The water balance regions of Iwaco, 1986.

Iwaco's water balance areas were vaguely delineated by 'hydrogeological boundaries', of which only the watershed of the mountain divide was mentioned. The boundaries of the 'balance regions' did not differ from those of the agricultural regions. (refer to the water balance Tables 10.12 to 10.15).

each balance region the geomorphic divisions of mountain, piedmont plains (called by Iwaco 'Bajada') and the sandy desert foreland (called the 'Structural Plain') were repeated. In these divisions the parameters of precipitation and recharge were assumed to be equal. The total area of the three agricultural balance regions of the Northern Emirates was given as 7,800km^2, while that for the western agricultural region (Al Ain) was 9,320km^2, for which the groundwater balance presented was that prepared by Edworthy and Brandt in the study on public utilities, as part of the Al Ain 2000 Master Plan (1985) (Section 10.3.11).

According to the Deep Wells Project estimate (Iwaco,1986), mountain runoff flowing into the plains was taken as 10% of the total precipitation values for which were given as 150mm. for the mountains, 115mm. for the piedmont plains and 100mm. for the desert foreland. Of this amount of runoff to the plains 20% was thought to evaporate and 80% to percolate into the groundwater system. Recharge from direct rainfall was considered to be 5% of the total annual precipitation falling over the plains and 3% of the total annual precipitation of the desert foreland. A very small percentage of the mountain runoff was considered to reach the desert foreland and this was therefore neglected by the study. Finally, 4% of the mountain runoff from east-flowing wadis along the east coast from Dibba to Kalba, and also the west-flowing wadis of the northern limestone mountains of Ru'us Al Jibal in Ras Al Khaimah, was assumed to be lost to the sea. The breakdown of the Iwaco groundwater balance is given in Tables 10.12 to 10.15.

Although referred to according to the agricultural region, the water balance was dealt with by the 'balance areas' noted earlier in this section. The boundaries of these nearly overlapped with those of the agricultural regions. Four areas were treated and these are shown in Fig. 10.1, three were in the Northern Emirates and the fourth, the western region, was the Al Ain region but excluding the whole part of Abu Dhabi emirate to the west and south of Al Khaznah. The Iwaco four balance areas were:

1) The Western Agricultural Region	9,320 km^2	(area)
2) The Central Agricultural Region	4,290 km^2	"
3) The Northern Agricultural Region	1,510 km^2	"
4) The Eastern Agricultural Region	2,000 km^2	"
Total	17,120 km^2	(area)

The groundwater balance was calculated for each region as presented in Tables 10.12 to 10.15:

	In	Out	(in MCM/a)
Recharge of Groundwater:			
- Direct Precipitation	2.4		
- From Surface Runoff	9.7		
Abstraction of Groundwater			
Net Agricultural Requirement		71.1	
Public Water Supply		10.0	
Natural Vegetation		0.2	
Groundwater Inflow	7.0		
Total	19.1	81.3	
From Storage	62.2		Deficit

Table: 10.12

Groundwater balance of the Eastern Agricultural Region

(in MCM/a)	Piedmont Plains In	Piedmont Plains Out	Desert Foreland In	Desert Foreland Out
Recharge of Groundwater:				
- Direct Precipitation	5.4		7.7	
- From Surface Runoff	9.6		0.0	
Abstraction of Groundwater:				
- Public Supply		13.0		41.0
- Net Agricultural				
- Requirement		131.9		48.4
- Natural Vegetation		2.2		2.2
Groundwater inflow/outflow:				
- Inflow	4.2		3.0	
- Outflow		3.0		0.0
	21.2	150.1	10.7	91.6
From Storage	130.9		80.9	Deficit

Table : 10.13.

Groundwater balance of the Central Agricultural Region

(in MCM/a)	Piedmont Plains	Foreland/Coastal

			Zones	
	In	Out	In	Out
Recharge of Groundwater:				
- Direct Infiltration	2.2		1.5	
- From Runoff	7.7		2.5	
Public Water		4.0		1.0
Net Agricultural Requirement		123.7		1.5
Natural Vegetation		1.1		1.1
Groundwater Inflow	5.1		2.6	
Outflow		1.0		3.0
	15.0	125.8	6.6	6.6
From Storage		114.8	Deficit	

Table : 10.14.

Groundwater balance of the Northern Agricultural Region

	IN	OUT
Recharge of groundwater:		
Direct precipitation	19.2	
Surface runoff	29.5	
Abstraction of groundwater:		
Public water supply		90.3
Net agricultural requirements		630.6
Others		63.5
Groundwater in- and out-flow		
Inflow	46.9	
Outflow		3.0
From storage	> 691.8	
Total	> 787.4	787.4

Table: 10.15.

The combined groundwater balance of the main agricultural areas by Iwaco, 1986.

The ratio of recharge to abstraction is 1:8.

(Source of the four tables: The Deep Wells Project, Final Report, Vol. I, Iwaco, 1986. / All units in MCM/a)

10.4. Recharge and balance estimates of the present study

10.4.1. General

Comparative summaries of groundwater balance estimates for previous studies in the Emirates, and the areas covered by each study, are given in Table 10.16. Out of the 95.60 MCM/a groundwater recharge volume put forward by Iwaco, 29.50 MCM/a were derived from surface runoff. Recharge from direct rainfall, which was given as 19.2 MCM/a, was based on a 5% ratio of mountain precipitation. Iwaco did not make use of the data for the gauged catchments available from the MAF.

In a groundwater balance, the input components into the groundwater system are from surface runoff, direct rainfall, subsurface flow and recirculating irrigation water. The last item was considered by Hydroconsult (1978) and Edworthy-Brandt (1983) in their balance estimates. The contribution from surface flow was exaggerated by many previous studies due to its being crudely estimated, largely on the assumption that all surface flow was recharge. This resulted in estimates by Halcrow and Carr and Barber nearly three times higher than the most likely volumes based on gauged flows and the effective rainfall calculated from them. Recharge from direct rainfall was ruled out by Halcrow (1969) and others but overrated by Hydroconsult (1978) based on higher rainfall totals; it was grossly underrated by Iwaco, who gave it only 5% of the annual rainfall in the eastern, central and northern agricultural regions.

10.4.2. Recharge from surface runoff

The Halcrow estimates (1969) were based on a 12.5% runoff ratio to the total basin rainfall (of an average rainfall of 159.0 mm), which gave an effective rainfall value of 20mm. 46% of which was recharge (9.0mm). The IDCJ (1978) runoff ratios averaged 17.5% for the limestone and 30% for the ophiolite catchments, from an average rainfall of 135.0mm. for the former and 157.0mm. for the latter. The effective rainfall was 23mm. and 47mm. respectively, and recharge was 20% of the former (4.7mm.) and 30% of the latter (14.4mm.) or 3.5% and 9% of the total basin precipitation, respectively.

Worker/Study	IN MCM	OUT	Balance/Imbalance + MCM -	Recharge/Abstraction Ratio	Area of Water Balance
Halcrow (1969)	157	353.10	- 196.10	1 : 3	Western Gravel Plains to Al Ain Desert Foreland of N.Emirates with tolerable water.
Gibb (1970)	26	15.70	+ 10.3	2 : 1	300 km^2 area adjacent to mountain front west of Buraimi/north of Al Ain
Wellfield(1976) Services	18	21.90	- 3.9	1 : 1	388 km^2 of desertforeland/catchment of Aweer-Wuhoosh-Hibab Wellfields,Dubai.
Carr and Barber (1976)	100.00	224.00	-124.00	1 : 3	All the gravel plains as the recharge areas of the whole UAE.
Hydroconsult (1978)	253.20	66.50	+187.70	4 : 1	The Eastern Region of Abu Dhabi(Al Ain) from Al Hayer to Um Ez Zemool.
Al Ain 2000-Master Plan, Edworthy/Brandt (1983)	40.20	343.20	-303.00	1 : 9	From Shuwaib to Al Sad to Al Wagon.
Deep Wells Proj. IWACO	95.60	787.40	-691.80	1 : 8	The whole of the UAE.

Table: 10.16.

Comparison of summaries of groundwater balance of the Emirates by previous studies and the areas covered by the balance calculations (1969 to 1986).

Out of the 96.50 MCM/a groundwater recharge put forward by Iwaco, 29.50 MCM/a were derived from surface runoff. Recharge from direct rainfall, which was given as 19.2 MCM/a, was based on a 5% ratio of the total precipitation for the mountains. The 29.5 MCM/a is only more by 9% than that derived by the present study. Iwaco did not explain the way it obtained it save for the statement that it was from a runoff coefficient of 10% of the mountain precipitation, of which 20% evaporated and 80% infiltrated as recharge. In other words recharge formed 8% of the total mountain precipitation. Iwaco did not make use of the data for the gauged catchments available from the MAF.

Input components into the groundwater system are from surface runoff, direct rainfall, subsurface inflow and irrigation return. The last item was considered by Hydroconsult (1978) and Edworthy-Brandt (1983) in their balance estimates. The contribution from surface flow was exaggerated by many previous studies due to its being crudely estimated, largely on the assumption that all surface flow was recharge. This resulted in estimates by Halcrow and Carr and Barber nearly three times higher than the most likely volumes based on gauged flows and the effective rainfall calculated from them. Recharge from direct rainfall was ruled out by Halcrow (1969) and others but overrated by Hydroconsult (1978) based on results of experiments on the Dahna sands in eastern Saudi Arabia by Dincer et al (1974) of 20mm/a recharge rate or 25% of the annual rainfall for that area of 80mm.; and was grossly underrated by Iwaco, who gave it only 5% of the annual rainfall in the eastern, central and northern agricultural regions, with a total of only 19.2 MCM/a. for the whole Emirates.

The average rainfall used by JICA (1978) for Wadi Al Baseerah basin was 128.0mm., the runoff coefficient was given as 15% of this basin precipitation, which gave an effective rainfall of 19.2mm. of which 59% was suggested as recharge (11.2mm.), which made up 11.2mm., or 9% of the total basin precipitation. Hydroconsult (1978) presented its calculations based on a 25% runoff ratio, out of a 200mm. average rainfall, which raised an effective rainfall value of 50mm. of which 52% was recharge, that is 26mm. or 13% of the total precipitation. GDC, working in Oman (1982), suggested a runoff ratio of 21% out of a basin precipitation of 143mm. making its runoff calculations based on an effective rainfall of 30.1mm. for most of the basins. 70% of this effective rainfall (21.1mm.) was recharge, which made up 15% of the total basin precipitation. Finally, Iwaco (1986), worked on a 150mm. basin rainfall and a 10% runoff coefficient, giving an effective rainfall of 15mm. of which 80% was recharge, that is 12mm. or 8% of the total basin precipitation.

The 25mm. effective rainfall suggested by Carr and Barber (1976) as a reasonable basis for recharge calculations, having been used for other studies in the wadis of southern Yemen and those of the Tihama of northern Yemen, was for catchments much larger than those of the Emirates. Wadi Baihan and Wadi Hadhramaut in southern Yemen have total surface areas of their basins of 3,300km^2 and 37,500km^2 respectively. The former wadi alone is larger than the whole mountain zone of the Emirates containing all the catchments. The volume of runoff infiltrating as recharge in Wadi Hadhramaut, which is only 2.9% of the total basin precipitation, amounts to a volume of 108 MCM/a, which is nearly equal to the most generous runoff estimates for the whole piedmont plains of the Emirates from Ras Al Khaimah to Al Ain as suggested by Halcrow and Carr and Barber (157 MCM/a. and 100 MCM/a., respectively).

Annual rainfall averages for parts of the wadi catchments of southern Yemen situated above the 1000m height are about 315 mm, which is twice the value for the period mean for the mountain zone in the Emirates (154.61 mm), making the 25 mm. about 8% of the basin precipitation. Thus, this precipitation yield yardstick is proportional to basin rainfall in the catchments of the Yemen. When the 25mm. effective rainfall was applied to the catchments of the Emirates, the runoff

volume produced was found to be 46% more than the long-term average of the gauged catchments. If the 25 mm. effective rainfall raises great volumes in the secondary wadis of southern and southwestern Arabia, let alone the major wadis, the mean runoff volumes obtained for the gauged catchments in the Emirates compare unfavourably. The 8% ratio of runoff in these wadis (which is the effective rainfall) gives a 12.3 mm. effective rainfall for the Emirates out of a period annual rainfall for the mountains of 154.61 mm.

When calculating the effective rainfall responsible for flood flows in the gauged catchments of the Emirates by tracing the daily rainfall that occurred a day before (the actual lag period of between 6 and 18 hours before runoff takes place) and the day of the actual flood, the percentage of the actual runoff to the total basin rainfall (which was averaged from several daily point measurements within and around a catchment) ranged from 8% (for Wadi Al Naqab in limestone highland), with the effective rainfall being 7mm, to 38% (for Wadi Siji in ophiolite highland), with the effective rainfall being 87mm. This does not imply that the higher the runoff ratio, the higher the effective rainfall, as can be seen for Wadi Sfini (upstream of the confluence with Wadi Ashwani) with figures of 19% and 43 mm. and Wadi Al Wurai'ah, with 14% and 42 mm. Both these wadis are in the ophiolite mountain zone (Table 4.11, Chapter 4). Table 4.11 presents annual values for the exceptional flood events for the exceptionally high rainfall year of 1987-88 (for 17-18-19 February 1988) and also values for the moderate rainfall/flood year of 1986-87, as well as the median values for the length of flood records (6-13 years).

A more acceptable value for effective rainfall for the catchments of the Emirates has been obtained from the period mean runoff volumes for the gauged catchments with surface flow measurements ranging from 6 to 13 years. The ratio of these mean runoff values to the total basin precipitation for each catchment averages 12% for catchments in the ophiolite part of the mountains and 6% for those catchments in the limestone part. This gives an effective rainfall of 19 mm. for the former group and 8 mm. for the latter group of catchments. The runoff ratio or coefficient obtained from the gauged catchments has been applied to the ungauged catchments. The effective rainfall value for

catchments in the ophiolite mountain block is 17 mm., and that for the catchments in the limestone mountain block is 13 mm. The overall average runoff ratio for both the gauged and ungauged catchments remains the same (12% for the ophiolite and 6% for the limestone, catchments) but that of the effective rainfall is 18 mm. for the ophiolite and 11 mm. for the limestone catchments; while the overall average effective rainfall value for all the catchments of the Emirates is 15 mm.(Table 4.14, Chapter 4). This is 60% of the 25 mm. effective rainfall value for the catchments of the wadis of southern and southwestern Arabia.

The total annual runoff volume from the period mean of the gauged catchments (23.67 MCM/a) and that calculated for the ungauged catchments (14.69 MCM/a) is **38.62 MCM/a** (Table 4.14, Chapter 4). It is not feasible that all runoff becomes recharge as suggested by several previous studies. Despite the fact that infiltration can be very high in the active wadi channels and the sky is usually cloudy during, and the few days after, the rains, together with cooler atmospheric and soil temperatures, and evaporation is kept at a relatively modest level by comparison with other times of the year, yet a great deal of the infiltrated runoff is lost to evaporation. GDC gave a recharge factor, out of the net runoff, of 0.75 for catchments in Oman with an area for each catchment of less than 150 km^2; and 0.65 for catchments with an area each of more than 150 km^2. As 19 out of the 27 catchments (Table 4.2, Chapter 4) in the whole Emirates are less than 100 km^2 in area each, the 0.75 or 75% recharge factor, is considered a reasonable factor for UAE catchments in general, and has been applied here to derive an estimated volume of recharge out of the 38.62 MCM/a net runoff volume north of Al Madam on both sides of the mountain divide. This gives a volume of **28.97 MCM/a** as the average annual replenishment from surface runoff to the groundwater system in the part of the country within the Northern Emirates.

With regard to the catchments within Omani territory south of Al Madam, the surface and subsurface flows of which contribute to groundwater recharge of the Al Ain region, the net runoff estimated by GDC (Soil and Groundwater Survey for Buraimi Area, 1982), for the wadis flowing west in a front from Al Madam to 'Ajran, has been used in the present study due to the absence of flood-gauging stations on

the Emirates side of the border with Oman. The estimated net runoff volume for the whole front was given by GDC as 23.77 MCM/a. As only a small proportion of this ultimately crosses the international border into the Emirates, due to the high infiltration rates upgradient at the foothills and the upper parts of the outwash fans, about 30% of this volume continues as surface flow as far west as Al Jabeeb, Al Awha and Al Ain in Wadis Ma'aisheq, Mahdhah and Al Ain-Shik, respectively. The Emirates share of the net runoff is 7.131 MCM/a, of which 75% may infiltrate the wadi beds (**5.35 MCM/a**). Most of this runoff is contributed by the Sumaini-Scharab-Mayhah group of catchments in Oman, some of whose water eventually underflows the Madam Plain into Sharjah and Dubai in the Emirates. This gives a total annual mean recharge volume from runoff for the whole Emirates of only **34.32 MCM/a** (28.97 + 5.35 MCM/a).

For the area south of 'Ajran, the so-called brackish water area, hardly any flood-flows cross the border, and nearly the whole contribution is in the form of subsurface flow, which is discussed next.

10.4.3. Recharge from subsurface flow

The recharge from surface runoff developed in the 27 catchments within the Emirates north of Al Madam has already been discussed. The infiltrated waters form the inflow westwards into the desert foreland in the Northern Emirates. As recharge and balance estimates are treated for the whole of the Emirates, and not for one part or region, the only outflow from such inflow is what seeps out to the sea as natural outflow on either coastline. Lavalin (1980) presented the estimates of natural groundwater outflow given in Table 10.17.

Khawr Khuwair	(west coast)	3,400 m^3/d
Al Badyah	(east coast)	10,400 m^3/d
Zubarah	(east coast)	8,340 m^3/d
Dhadhnah	(east coast)	3,670 m^3/d
	Total	25,810 m^3/d
	or	(9.4 MCM/a)

Table: 10.17.

Estimates of natural outflow to the sea through submarine springs in both the west and east coasts of the Emirates (Lavalin, 1980)

Groundwater abstraction has increased phenomenonally since 1980 and it is unlikely that such an annual volume of natural groundwater outflow is still maintained because of effective interception of through-flow by heavy abstraction and the resulting reversal action of seawater incursion. It is thus suggested here that 50% of the volume, quoted by Lavalin in 1980, may still escape to the sea during the rainy season, particularly on the east coast. This amounts to **4.7 MCM/a** of outflow (in the form of subsurface inflow) to the sea.

The major contribution by subsurface flow to the aquifer system of the Emirates is that which underflows the Emirates-Oman border south of Al Madam, along a 160-km. long front from Al Madam to Sunainah. This inflow amounts to **28.13 MCM/a**, of which 17.91 MCM/a is for the part of the land front from Al Madam to 'Ajran (fresh water), 86% of which is for the part of the land front from Sumaini to Al Madam (15.40MCM/a); and 10.22 MCM/a is for the part from 'Ajran to Sunainah (brackish water) as estimated by the Regional Development Council of Oman (1987). This is the net underflow left for the Emirates after all kinds of uses upgradient in Omani territory (upstream and downstream of the mountain gaps), and it forms what is left of recharge from infiltration of surface runoff in the upper and middle courses of wadis across the border in Oman.

10.4.4. Recharge from direct rainfall

10.4.4.1. Recharge from direct rainfall in the piedmont plains

If 12% is the runoff coefficient out of the total catchment precipitation, and rain usually falls before, during and continues after runoff, its infiltration velocity is enhanced by that of surface water and is slowed when the rain is falling before or after a flood event. Of this rainfall 12% forms the runoff that fans out on the piedmont alluvium after leaving the mountain front, 75% infiltrates as recharge as was shown earlier (Section 10.4.2). To allow for both the slow and enhanced infiltration rates of direct rainfall, an 80% rate of the 75% of runoff recharge can be used, which amounts to 6% of the total period mean annual rainfall for the plains of 127.41mm. This gives 8mm. as effective recharge from direct rainfall.

For the total area of the piedmont plains of 2,030km^2, on both sides of the mountains, including the Al Jaww Plain in Al Ain in the south, the total volume of actual groundwater recharge from direct rainfall is in the order of **16.24 MCM/a.**

10.4.4.2. **Recharge from direct rainfall in the desert foreland**

With the exception of the Hydroconsult study (1978), all previous studies disregarded recharge from direct rainfall through the dune sands of the desert foreland. Mar'ee (University College (London), thesis, 1978) discussed the possibilities in its favour but did not attempt to quantify it. Prior to that, Halcrow (1969) had not recognized any infiltration from direct rainfall occurring in the piedmont plains and the desert foreland, and concluded that there was total loss of precipitation to evaporation estimated at 26,290 m^3 (piedmont plains) and 1400 MCM/a (desert foreland). Gibb, in the 'Water Resources Survey of Abu Dhabi' (1970), excluded the possibility of recharge from this source. So did the two Japanese consultants IDCJ (1978) and JICA (1980). Hydroconsult (1978) was the only consultant to consider such a contribution based on a 20% value of the annual precipitation.

Recharge from direct rainfall is taking place through the well-sorted quartzitic sands of the desert foreland grain size of which was measured in the Emirates by Glennie (1970) and found to be between 0.15 mm. 0.26mm., (the sand deposits becoming better sorted upwards in the profile). The results of the Dincer et al experiments (1974), noted earlier, resulted in a 25% out of the 80 mm. annual mean precipitation infiltrating the dune sands of Al Dahna area in eastern Saudi Arabia (20 mm.). The dunes of Al Dahna desert, lying 100 km. east of Al Riyadh, are of the 'uruq' longitudinal type, parallel and sharp-crested dunes separated by broad wadis. Water-table levels during the time of Dincer's experiments were between 400-450 m. below the surface and the dunes were 50-150 m. high (The Shared Water Resources of the Gulf States and the Arabian Peninsula, FAO, 1979).

Groundwater levels in typically similar sand dune areas in the Emirates are 44-49 m. in Al Aweer, 38-54 m. in Al Wuhoosh, 20-36 m. in Al Hayer North, 38-41 m. at Al Kara', 32-34m. in Bida' Bint Ahmad,

34m. in Suwaihan Road, 26-34 m. in Mohayyer East, 20-33 m. in Jubaita and 18-22 m. in Bida' Bint Saud. The period mean annual rainfall for the desert foreland is 91.71 mm., though in central Abu Dhabi it is about 80 mm. In central Abu Dhabi also groundwater level depths are 34-67m. (Bujair), 67-70 m. (Al Hilew and Bida' Khalfan), 52 m. (Bida' Rashed), 40 m. (Jaww Al Oad) and 100 m. (Al Khadher Nassas).

With the foregoing comparison of groundwater level depths from the dune surface in both the Dahna sands of eastern Saudi Arabia and those of the Emirates, the water-bearing zone in the Emirates stands a better chance of being recharged from direct rainfall. However, in both cases the levels are deep enough to be affected by isolated short-lived inputs of rainfall. Although no infiltration can take place in sands with a mean annual rainfall of less than 50mm., as suggested by Dincer et al (1974), this is relative and is governed by the grain size and sorting of the sand particles. In the rainstorm of the 17th., February 1988 (19th. February in central Abu Dhabi), there was a total fall of 171.1mm. in 23 hours in Minhad in Dubai, 160.8 mm. in Al Hibab and 141.0mm. in Al Aweer. Such consistent rainfall over a long period, which was also characterized by outbursts of heavy showers, may have qualified for the recharge process. The medium through which infiltration usually takes place in the desert foreland of the Emirates is favourable, but distance to the water-table and the differential vertical movement of water are important constraints.

Furthermore, the low tritium values of Al Khadher Nassas (0.5 TU), Suwaihan (0.0 TU), Bujair (0.0-0.3 TU), Bida' Rashed (0.0 TU), Jaww Al Oad (0.0 TU), Bida' Khalfan (0.0-0.2 TU) and Attarq and Huwailah in Liwa(0.0 TU) do not appear to favour the recharge process from direct rainfall. However, it must be pointed out that these tritium values are all for samples taken from boreholes at depths between 34-100 m. below ground level (Chapter 7).

The conclusion by the IAEA Isotopes Report (1988) that these wells contained pre-1954 water (thermonuclear year) may be true if the universally acknowledged slow vertical movement of water in the lithosphere, of about 1 m. a year, is taken into account, which would mean that post-1954 waters have not yet reached the intake levels of the existing wells (34-100m.). That the arrival of such waters to the

level of the existing water-table might not happen at all can be equally true due to the fact that possible recharge waters higher up in the giant dune mass are widely intercepted by pumping from shallow boreholes, or boreholes that are deep enough, with the facility of raising and lowering the pump to tap groundwater from all levels. Samples for tritium detection should be taken from shallow wells to determine the recharge process accurately, as Dincer et al have done in Saudi Arabia. Evidence that infiltration of rain water into the sands is taking place was offered by the presence of the saturated zone several metres thick, on the leeward side of the dunes at Al Jabeeb and Al Hayer North after the heavy rains of February 1988, where also seasonal vegetation clustered on the side of the dune indicating the presence of recently infiltrating rain water. Evaporation, however, continues to take place from the lower part of the dune after the saturated zone sinks far from the top of the dune, which is also another constraint. There are wells that were observed at the foot of sand dunes which were drilled to shallow depths to tap this water.

Recharge through the dune sands from direct rainfall is taking place in areas of both fresh and brackish to saline water, and in many places fresh water is abstracted from shallow wells higher up the dune and brackish water from wells drilled at the dune's base or in the deflation basins (troughs or sabkhas between these dunes), as is widespread in Liwa. The shallow agriculture and forestry wells along the Abu Dhabi-Al Ain highway, and those dotted all over central Abu Dhabi, derive their water from infiltrating direct rainfall, which becomes directly contaminated by contact with the anhydrites and gypsum occurring close to the surface in these areas.

20% of the period mean rainfall is taken by this study as infiltrating through the dunes to recharge the shallow aquifers whose deposits contain thin beds of silt, even in the giant dunes, that may hamper or prevent the continuous downward journey of water to the actual (saline) water-table in the underlying sabkha all over the desert foreland. The period mean rainfall for the desert foreland is 91.71 mm. for stations not deep inland as those in central Abu Dhabi for which the mean rainfall is estimated to be about 80 mm. as noted earlier. Thus, the period mean used here is 86.0 mm., and the 20% of

this amount that is expected to infiltrate the sands, is 17 mm. The areas for which such infiltration has been calculated are sand dune areas lying in the sphere of influence of groundwater abstraction points, which occur in the vicinities of both fresh and brackish groundwater. Such places and their surface areas are listed and broadly grouped in Table 10.18, and also generally given in Table 10.19, which presents the groundwater balance for the whole Emirates.

Taken as a whole, the total dune surface area considered in this estimate of recharge from direct rainfall in the dune sands adds up to 19,618 km^2. With the 17 mm. rainfall depth, the total volume of recharge from direct rainfall in the sands is 333.51 MCM/a, of which 25% is in fresh (83.38 MCM/a) and the rest is in brackish (250.13 MCM/a) water areas. It may be assumed that in both cases less than 50% of this recharged groundwater volume is recoverable.

10.5. The general groundwater recharge/discharge balance of the Emirates (1988). (Table 10.19)

Table 10.19 presents the input and output components of the groundwater balance of the Emirates, envisaged by the present study, and described in the preceding sections of this chapter. The contribution to recharge from surface runoff for the whole land front from Ras Al Khaimah to Al Ain (34.32 MCM/a) is less than was estimated by previous studies (105-170 MCM/a). The inflow into the Al Ain region from the catchments in Oman stretching from Sumaini to Sunainah is given as 28.13 MCM/a (1987), though the actual volume of inflow remainig for the Emirates is reduced by consumption above and below the gaps in Oman; and, in view of the planned agricultural development there, would be eliminated.

The Al Ain region draws groundwater heavily from old unreplenishable reserves. The calculation of an 8mm. and a 17mm. effective recharge from direct rainfall in the piedmont plains and the desert foreland is governed by the degree of finer sediments present in the soil to enhance or hamper infiltration, the rate of which is higher in the sands of the desert foreland than the gravels, sands and silts of the piedmont plains.

Desert foreland sand areas	Surface area in km^2
Dune sands in the emirates of Sharjah, UAQ, Ajman and Ras Al Khaimah	2,488
Northern dune area of Al Ain	856
Brackish water dune area of NE., E. and SE. Abu Dhabi emirate	6,200
Giant dune areas of Liwa and central Abu Dhabi in the vicinities of the wellfields of Bujair, Bida' Khalfan, Bida' Rashed, Al Helew and Bida' Mubarak.	1,689
All other dune sand forestry, municipal and agricultural areas.	7,500
Total	19,618 of which:
	25% fresh water areas
	75% brackish water areas

Table: 10.18.

Breakdown of the localities in the desert foreland and their total area for which recharge from direct rainfall has been calculated for the present study.

Based on a 17mm. rainfall depth, the total volume of recharge accrued from direct infiltration of rainfall amounts to 333.51 MCM/a, of which 25% is in fresh water areas (83.38 MCM/a) and 75% is in brackish water areas (250.13 MCM/a). It may be assumed that 50% of the total volume is recoverable.

With regard to the output components (abstraction), groundwater abstraction by the largest water user, agriculture, quantified by actual well-discharge tests for this study ((2556.16 MCM/a), Chapter 8, Section 8.4.3) was used for agricultural abstraction and the volumes for all the other output components were carefully derived by investigation carried out for this study. The total volume abstracted by agriculture and forestry includes both fresh and brackish water as

	IN	OUT
RECHARGE		
From surface runoff:		
- Northern Emirates	28.97	
- Al Ain region	5.36	
From subsurface flow:		
- Al Ain region	28.13	
From direct rainfall:		
- Piedmont plains (area 2030 km^2) (on basis of 6% of annual rainfall (8mm.))	16.24	
- Desert foreland (area 19618 km^2) (20% of annual rainfall (17mm.))		
- Fresh water	83.38	
- Brackish water	250.13	
From irrigation return:		
- 8% of agricultural water use	255.10	
Total recharge volume	667.30 MCM/a	
ABSTRACTION		
- Domestic supply		166.00
- Agricultural use		2556.16
- Forestry:		
Abu Dhabi		432.74
Al Ain		112.00
- Municipal town reserves/falaj augmentation		26.80
- Agricultural abstraction in southern desert of Al Ain		48.00
- Natural falaj flow		13.01
- Natural outflow to sea		4.70
Total discharge volume		3359.41 MCM/a
Ratio of overall recharge to discharge		1:5
Volume of groundwater mined from replenishable and non-replenishable storage		2692.11 MCM/a
Ratio of natural recharge to abstraction		1:8
Percentage from total groundwater volume abstracted:		
- by agriculture		95 %
- by domestic supply		5 %

All units are in million cubic metres/annum (MCM/a)

Table: 10.19.

The general groundwater recharge/discharge balance of the Emirates (1989).

Groundwater abstraction by the largest water user, agriculture, was quantified for this study by actual well-discharge tests. The estimates of recharge from runoff was calculated for both the gauged and ungauged catchments, the effective recharge from direct rainfall was based on 8mm. for the piedmont plains and 17mm. for the desert foreland and returns from irrigation water was taken as 8% of the total water used by agriculture, forestry and falaj flow. The quotas of agricultural and domestic abstraction have remained 95% and 5%, respectively, since the 1960s. The total volume abstracted by agriculture and forestry includes both fresh and brackish water as long as (in both cases) the water is used for irrigation. The ratio of natural groundwater recharge (412.20 MCM/a) to discharge (3359.41 MCM/a) is 1:8, and the ratio of the overall recharge (667.30 MCM/a) to discharge (3359.41 MCM/a) is 1:5. Of the total groundwater abstracted (3359.41 MCM/a, including falaj flow and outflow to sea), about 30% (1107.80 MCM/a) is from fresh and the remaining from brackish sources (2351.59 MCM/a). The groundwater mined from replenishable and non-replenishable storage is 2692 MCM/a (80% of the total volume of groundwater abstracted).

long as (in both cases) the water is used for irrigation. The ratio of natural groundwater recharge (412.20 MCM/a) to discharge (3359.41 MCM/a) is 1:8, and the ratio of the overall recharge (667.30 MCM/a) to discharge (3359.41 MCM/a) is 1:5. Of the total groundwater abstracted (3359.41 MCM/a, including natural falaj flow and groundwater outflow to sea), about 30% (1107.8 MCM/a) is from fresh, and the remaining from brackish, sources (2351.59 MCM/a). The groundwater mined from replenishable and non-replenishable storage is 2692.11 MCM/a (80% of the total volume of groundwater abstracted). The interesting observation is that quotas for agricultural and domestic groundwater abstraction have remained as 95% and 5%, respectively, out of the total groundwater abstracted, since the Trucial States (Halcrow) Water Resources Survey of 1966-69.

10.6. Synopsis

Introductory sections on infiltration rates and groundwater reserves throughout the country have provided the background to a comprehensive catalogue of all the recharge and balance estimates included in existing reports. Results from 11 previous reports have been discussed in detail, together with summaries of Omani recharge and balance estimates related to the Al Ain region (1982-87). A review of the groundwater recharge and balance estimates of all the previous studies, carried out in the Emirates and adjoining parts in Oman, is provided for comparison with the recharge and the groundwater balance estimates specifically made for this study. Finally, all the input and output components of the groundwater balance of the Emirates derived by the present study have been explained and comprehensively presented.

CHAPTER ELEVEN

WATER RESOURCE MANAGEMENT

11. WATER RESOURCE MANAGEMENT

11.1 Introduction

Basic to economic development in general, and the realization of the goal of food security in particular, is an assured water supply. This can only be achieved through a well-informed and well-concerted water resource management. In view of the depleting groundwater resources, the well-intentioned but misguided agricultural development with its confused water use trends and the ever-escalating development of non-conventional water sources (desalinated water), the water management needed to come to grips with the rampant water resource problems, would have to be of high calibre.

In the preceding chapters of this study a detailed assessment of the conventional (surface and ground water) and non-conventional (desalinated and recycled waste water) water resources of the Emirates has been presented and the existing state of these resources has been identified. At the beginning of each chapter, management aspects relating to the different fields of water resources, such as the meteorological, surface runoff and groundwater recording networks, have been discussed within the context of each aspect of the water resources discussed in the respective chapter. In this chapter, the elements of the water management process, from the planning stage to that of augmenting water resources, are discussed with reference to related water resource management problems in the Emirates. The thoughts presented in this chapter are intended to link the elements of this study and put all its sections in perspective. It thus summarizes the different factors of the water resource situation discussed in the preceding chapters, assesses the existing water resource management and looks into the future trends of the resources.

Water resource management, as discussed in this chapter, is broadly defined to include the developing of both the conventional and non-

conventional water resources and 'managing' both the newly developed and the already existing water resources. The whole management process involves the planning for new sources of water, monitoring the quantity and quality of the existing sources to ensure quantitatively adequate and qualitatively acceptable water supplies, distributing these supplies to the different users and also augmenting (or conserving) water resources in general.

The main water management issues are of both natural and institutional dimensions. The natural issues relate to water availability in quantity (which in an arid region like the Emirates assumes great importance) and in quality (which in a water-deficient country like the Emirates also becomes determinant to potable and agricultural uses alike); and the institutional issues relate to the water-administering organizations that handle the day-to-day provision of adequate water supplies for the different applications. Institutionally, responsibility for water management in the Emirates is fragmented in many organizations supplying water to competing users. Apart from the constraint of local emirate-centred politics that dictate water resource management within an emirate (at least for the three emirates of Abu Dhabi, Dubai and Sharjah), with no interemirate water resource sharing, there are no social, legal or even environmental limitations to water resource development in the Emirates. Such development is largely state- or local government-motivated.

The options that have been implemented so far to try and solve the water shortage problems in the Emirates are limited to augmentation by the construction of earth flood-retention dams across some of the major wadis (such as Wadi Ham and Wadi Al Beeh), which help dam flood waters during the winter rainy season for up to three weeks in exceptionally rainy years (1982 and 1988), but with the benefits to recharge minimized by the high evaporation and the silting of the wadi-bed beneath the dammed waters hindering infiltration. Other options of augmenting water supplies have been in the sectors of desalinated seawater and recycled wastewater production. The former has already reached great proportions in its development, the second is also fast increasing; the use of the product water of both is limited to the main towns.

With regard to groundwater resources, it has been shown in Chapters 5 to 8 that there is limited scope for their development and the only option available to protect reserves is in conservation. Even then, conservation cannot be relied upon as the sole redresser of water shortage due to the voluntary implementation of conservation measures, but also due to the inevitability that what groundwater that might be saved may eventually be absorbed by additional economic growth that would make its demands on water supplies.

Conserving groundwater by means of the expensive modern irrigation methods (the sprinkler, drip and bubbler) is theoretically believed to be between 10-25% of what would be applied by the traditional furrow-and basin flooding method. The cost of converting to modern irrigation systems has never been an issue in the Emirates but overirrigation with these modern methods negates the water conservation benefits expected from them. Another water conservation avenue is in developing agriculture based on salt-tolerant plants and those with lower transpiration rates. An example occurred with leguminous fodder grass species grown with seawater on an experimental farm in Kalba on the east coast (a worthwhile activity that ceased after two years due to the lack of local involvement). Such specialized water conserving options would require highly improved management that is backed by technological skills to enable it to handle all water resource development-within-conservation aspects.

11.2 Management considerations of the hydrometeorological networks

Hydrometeorological data are the basis for both surface and groundwater resource management. The existing state of the meteorological, flood-gauging and groundwater level recording networks has already been portrayed in detail, based on field observation, in the relevant chapters (Chapters 3, 4 and 5). Therefore, proper groundwater resource management requires comprehensive rainfall, surface runoff and groundwater level measurement data that should be detailed, accurate and up-to-date. In their present state, the hydrometeorological networks are not adequately distributed. Groundwater level recorders are concentrated in the western piedmont plains with very few present in the greater part of the desert foreland (Fig. 5.42, Chapter 5). With the

proposed installation of 30 telemetric groundwater level recorders in both the Al Ain region and Liwa, by the current water resources survey of the NDC-US Geological Survey (1988-), these parts of the Emirates, lying within the emirate of Abu Dhabi, would at least have some coverage of groundwater level measurement.

Despite this, groundwater levels over extensive tracts in Al Khatm, Al Dhafrah, Al Hamrah, Al Qafa, Baynoonah and Al Maghreb would still remain unmonitored. This also applies to the part of the desert foreland which lies in the Northern Emirates.

It has been shown (Chapters 3 and 4) how the surface runoff gauging stations cover only parts of the catchments. Every catchment however small, should be covered by a well-distributed network so as to evaluate all contributions to groundwater recharge from surface flow. In its present state, the meteorological network is not satisfactorily spread over the country. Rainfall recorders are widely spaced and are generally located, for convenience of accessibility, on higher points in wadi basins and near the sources of wadis.

It has also been shown (Chapters 2 and 4) how most of the rainstorms are highly localized, causing floods in some wadis and not others, or in one tributary of a main wadi, and not in neighbouring tributaries. Although rainfall occurs widely in winter, the rainiest conditions are those associated with the cool moist Mediterranean fronts reaching the Emirates from the west and northwest. Summer monsoonal and convectional rainstorms, though are less widespread in occurrence than the winter storms, are even more localized and are concentrated in the mountain zone, in intermontane basins like those of Masfut and Masafi and in the hilly 'corridors' such as the Dibba-Idhn, Wadi Ham and Wadis Al Qawr (east and west). Aspect is a key variable affecting rainfall totals and therefore some recorders should be sited on wadi sides. However, for reasons of accessibility, they are usually located at upstream points or along wadi courses. As a result, most of the monsoon and convectional storms, and the runoff, which has accrued from them, remain difficult to explain with the existing inadequate distribution of rain recorders.

The general lack and unrepresentative siting of rain recorders can be demonstrated by actual rainfall and flood intensity events. The flood

event of 14 February 1982, in the small catchment of Wadi Ashwani (46km^2 in area) gave a volume of 1.63 MCM at a peak flow rate of 155.1 m^3/s, and that for the much larger Wadi Sfini (138km^2), a volume of 1.89 MCM at a peak flow rate of 199.3 m^3/s. Wadi Ashwani thus had the higher flood volume relative to the size of the catchment, which is only 1/3 of the area of Wadi Sfini. The localized nature of the rainfall was shown on the previous day on the mountain slopes between Wadi Ashwani and Wadi Siji catchments in that only 11.0mm. fell that day at Sfini (where there is a rain recorder), while 104.4mm. fell at Siji (less than 10km. to the north) over the same 23-hour period. There is no rain recorder on the south-facing slopes of Wadi Ashwani and the concentration of rainfall on that slope indicates the southerly monsoon air flow as its source (Chapters 3 and 4).

Another example is that of Wadi Al Wurai'ah on the east coast, where there is no rain gauge/recorder at any point along its 12km. course or on the surrounding slopes. Rainfall totals for either Khorfakkan (12 km. to the east, on the coast) or Dibba (30km. to the north, also on the coast), or even stations further inland, such as 'Asimah or Masafi (15km. beyond the sources of Wadi Al Wurai'ah in the heart of the central mountains to the west), are used as references for the rainfall for the Wadi Al Wurai'ah catchment. However, none of the totals measured by the rain recorders in these stations matched the flood volume of the wadi of 5.4 MCM on 11-2-1983 (Table 4.10 B, Chapter 4). This flood volume could be related more to the 24-hour rainfall total of 138.0mm. for Khorfakkan than the 16-hour 52.0mm. total for Dibba or even the 24-hour rainfall total of 28.6mm. for Masafi. A rain recorder located on the south-facing (that is the northern slopes of Wadi Al Wurai'ah) would have been appropriate for gauging the actual amount of rainfall responsible for that large flood volume, as rainfall must have fallen with greater intensity in the hills inland than at Khorfakkan.

The same dilemma arose when trying to explain the flood volume of 0.055 MCM that occurred in Wadi Al Baseerah on 20 July 1988. When the rainfall totals of the surrounding rainfall stations for July 19-20 1988, were reviewed, they gave the following totals: Dibba 42.2mm.; Sinnah (in upstream Wadi Al Baseerah), 29.9mm.; Masafi (near the source of Wadi Al Baseerah), 14.0mm.; Al Burairat (on the rain-shadow on the other side of Ru'us Al Jibal), 16.6mm.; Khorfakkan (30km. to the south

on the same east coast), 168mm. and Fujairah (45km. further south on the east coast), 6.0mm.

The rainstorm that caused the Wadi Al Baseerah floods, at the height of the dry summer months (19/20-07-1988), was an extreme northern swirl of a monsoon source that was concentrated in a narrow zone on the east-facing slopes of Jabal Waam between the villages of Waam and Dhanhah where no rain gauge/recorder exists. Such storm incidence is common in the summer months of July and August. Wadi Al Baseerah catchment is one of many areas in need of more well-distributed rain recorders.

Other localities without rain recorders include the catchment of Wadi Al Qawr (west), a number of locations in the desert foreland in the Northern Emirates as well as in central Abu Dhabi in the wellfields areas of Bu Hasa-Shah and Liwa.

For meteorological observations there are no areas that are important or others that are less so. A well-distributed and regularly observed meteorological network is vital for the analysis of rainfall trends and their contribution to surface runoff and ultimate recharge to groundwater. This leads to the question concerning the ability of the meteorological observation institutions to run this important field of activity efficiently. In their present state the MAF, the MEW, and the Agriculture Department of Al Ain, the airports and the oil companies (in central Abu Dhabi) and also the port authorities, do not seem to be carrying out meteorological observation comprehensively. The airports only recently showed interest in rainfall measurement, which was intentionally neglected in the past with the excuse that these authorities were exclusively concerned with aviation. The seaports measure air temperature and most of them do not measure sea temperature. The oil companies in central Abu Dhabi report rainfall as "rain" with no totals, therefore leaving gaps in the rainfall data for that part of the Emirates, save for the readings of the military outpost at Al Rudoom in Liwa.

There are only two persons in charge of meteorological observations in the MAF, and the quality of observing is deteriorating due to this understaffing. The suggestion that the Ministry of Communications (the

Civil Aviation Department) should absorb all meteorological activities in the Emirates, is not feasible as this authority itself stems from the aviation base. Responsibility for the meteorological sector should be entrusted to a national body, similar to the British or Indian Meteorological Office, totally dedicated to this specialized task, enriching it with research into and analyses of the various aspects of this science directly related to water resources, and disseminating meteorological data.

11.3. Water resources development and related problems

11.3.1. Trends in water resource development in the Emirates

The substantial positive achievement in the development of the water resources of the Emirates in the first 15 years after the formation of the federal state (1971-1986), was the provision of clean potable water to nearly all the inhabitants of the seven federated emirates. This was possible before the slump in oil prices in the mid-1980s through the heavy funding of water projects largely contributed by the emirate of Abu Dhabi. Extensive water resource development happened so fast that the negative technical and administrative aspects were compounded, responsibility for water management became fragmented and the number of authorities responsible for water multiplied, leaving the main water-governing institutions burdened with the day-to-day problems of water supply. There was also an apparent absence of planning or rational development of the resources both in concept and practice.

The reason for concentrating activities in the field of water resources in the Emirates in the past two decades on the development of new water sources alone, is clear. After the discovery of oil in Abu Dhabi in the mid-1960s, and the formation of the federal state in 1971, the emerging united emirates embarked on an ambitious overall development in all economic and social fields. The result of this has been a leap from the falaj and hand-dug wells water supply system (which existed within the limits of towns such as Dubai and Sharjah up to the mid-1960s) to the large-scale groundwater abstraction with the high-speed motor pump. The effect of this extensive groundwater development has been the depletion of the Quaternary aquifer system in most of the potentially important

regions (such as the piedmont plains) too fast to allow any scope for an interregional or interemirate transfer of groundwater to supplement supplies in areas with acute water shortages.

From the earliest historical times, the falaj was the only water supply system for both domestic and agricultural use. It was a communal water system, shared by all concerned, bound local societies and guided economic development. It was a public utility system that provided water for the ruler and the ruled and was managed by a traditional voluntary method of apportionment of water supply. This had remained as the water supply system until the advent of the motor-pump in the early 1960s, although some important aflaj, such as Falaj Filli and Falaj Al Madam, remained supplying agricultural areas at their outfalls until the late 1970s, when falling groundwater levels drastically reduced their flows.

The motor-pump dominated groundwater abstraction from the mid-1960s onwards, but especially since 1972, when its widespread application was aided by the influx of federal capital into the poorer emirates. The motor-pump transformed groundwater resource development from the communal to the individual basis, whereby users draw water uncontrollably from the same aquifer, with no feeling of responsibility for nearby users or the community as a whole. The cooperation was absent which would have created an urge to regularize abstraction and minimize the proliferation of cones of depression that would result in the dewatering of those parts of the aquifer most overdeveloped. With the motor-pump, cultivation has also extended to sandy tracts of the desert foreland that it would have not been thought possible to cultivate a few years earlier.

As the groundwater resources began to deteriorate in quantity and quality by the late 1970s, after only a decade of intensive development, the alternative non-conventional desalinated and recycled wastewater sources started to be developed to supplement the demand in the large towns. By 1990 the daily desalinated water production had reached 180 mgd. (300 MCM/a) of which 88% was produced in the three coastal towns of Abu Dhabi, Dubai and Sharjah (Chapter 8, section 8.5.). By the same year also, recycled wastewater production had reached an output of more than 48 mgd. (nearly 80 MCM/a).

Overdevelopment of the groundwater resources for agriculture continues all over the Emirates despite the increasing trend in adopting modern irrigation methods. Groundwater levels are consistently and sharply declining (Chapter 5, Section 5.5.) and in nearly all the regions groundwater is being abstracted from the less transmissive and salty Tertiary shale and evaporites sequences.

11.3.2. Management problems related to the development of the conventional and non-conventional water resources

11.3.2.1. General

As discussed in chapters 4, 8 and 10, groundwater abstraction far exceeds replenishment, and in nearly all areas groundwater is pumped out of non-replenishable storage. The development of desalinated water is increasing rapidly in Abu Dhabi and Dubai and there does not seem to be a ceiling to production for this water source. Recycled wastewater, limited only to the four towns of Abu Dhabi, Dubai, Sharjah and Al Ain, is the least developed of the three water resources and the use of treated wastewater is limited only to irrigating municipal horticultural schemes. In all the three sectors of water resources, the dominating feature in their technical and administrative management is the lack of institutional coordination and the total absence of a national plan outlining targets in their production, use and future development in general.

The underlying trend in water resource development is not that of conservation or rational use of water but that of relentless prospecting for new sources to be 'mined' out of storage. Whatever water bulk the various water sectors are capable of producing, there is always use for it, even though this may be by exaggerating existing water applications. The natural conditions of surface and groundwater, and the existing state of all the water resources in general, have been portrayed in the main part of the present study (Chapters 4 to 10). In this section, some technical and administrative aspects of water resource management are addressed and the comments are based largely on observation and discussions with people in charge of the day-to-day running of the water supply services in the field. The purpose of the ensuing discussion of

examples of inadequate technical and administrative aspects of water resource management in the Emirates, is to reveal the level of efficiency of this management and the state of the water resources. These examples are discussed for the conventional and non-conventional water resources separately.

11.3.2.2. Management problems of the conventional water resources: Groundwater

11.3.2.2.1. The siting of water wells

The following three common features characterize the siting of water production wells in the Emirates:

(i) The development of wells close to one another with the spacing between them as close as a mere 60m., as at the new MEW Sha'arah wellfield in Wadi Ham in Fujairah.

(ii) The development of wells or complete wellfields along the whole groundwater flow profile as far as the farthest point groundwater of acceptable potable quality can be tapped. Such a development leads to interception of groundwater flow, eliminates the positive effects of recharge and deprives downgradient points of much of the additional inflow.

(iii) The development of wells or complete wellfields belonging to different competing users in the same locality, such as the agricultural wells that are sited side by side with the public supply wells in the northern dune area of Al Ain all along the Al Ain-Dubai highway as far as Al Faqa'.

The most ill-advised siting of production wells is that within mountain wadis, which are recharge arteries or conduits of flood waters from the catchments to the plains; or at the foothills of the catchments on the piedmont plains where recharge waters are in transit in their journey to the piedmont plains and the desert foreland. As such, areas within or close to the mountains show low storage capacity, which is evident in

the rapid fluctuation of groundwater levels reflecting changes in storage (Chapter 5, Section 5.5.2). The siting of wells and concentrating groundwater abstraction in such areas is therefore questionable. The development of the Kashoonah-Al Shuwaib wellfield in Al Ain repeated the same mistake of the Hamdah wellfield (in Sharjah) to the north, and that of the Ghashabah and Um Ghafah wellfields (in Al Ain) to the south. Groundwater reserves at the Hamdah wellfield have been almost depleted and those at Ghashabah and Um Ghafah are rapidly following suit. Selected examples of ill-advised mountain wadi and foothill recharge-zone well-siting are discussed in the ensuing subsections.

11.3.2.2.1.1. The Sha'arah and Kidnah wellfields of Wadi Ham and Wadi Kidnah on the east (Batinah) coast

The new MEW Sha'arah public supply wellfield (1988-89) was developed on the flood plain of Wadi Ham, immediately below the Wadi Ham dam (off the Fujairah highway). 16 boreholes were drilled down to 91m., of which 40m. were made up of Tertiary and Quaternary wadi alluvium (gravel, clay, silt and sand) below which lay the gabbro bedrock, of which the uppermost 3m. were a fractured zone that contained most of the available groundwater. Pumping of groundwater cannot be sustained for long from a fractured bedrock zone, and pumping during the rainy season would interrupt inflow to other abstraction points downstream. As the new Sha'arah wellfield is located 3km. upstream of the Fujairah wellfield, abstraction of groundwater in Sha'arah would intercept any meagre inflow, remaining in the lower levels of the alluvium and the fractured zone, from recharging the middle and lower sections of the aquifer of the Wadi Ham alluvial outwash fan. (Fig. 11.1.).

In the wellfield at Kidnah, which is located in the flood plain of Wadi Kidnah, a tributary of Wadi Ham, groundwater storage is known to fluctuate drastically as is evident in changes in groundwater levels (for example: May 1987, 11.22 m; December 1987, 16.13m.; February 1988, 10.44m. and December 1988, 18.10m.) (also refer to Chapter 5, Section 5.5.2). Groundwater production in the Kidnah wellfield dropped from about 0.18 mgd. at the start of wellfield operation in 1984 to a mere 0.03 mgd. in 1988-89 (source: MEW). Discharge naturally increases during and just after the winter rains but any groundwater abstraction

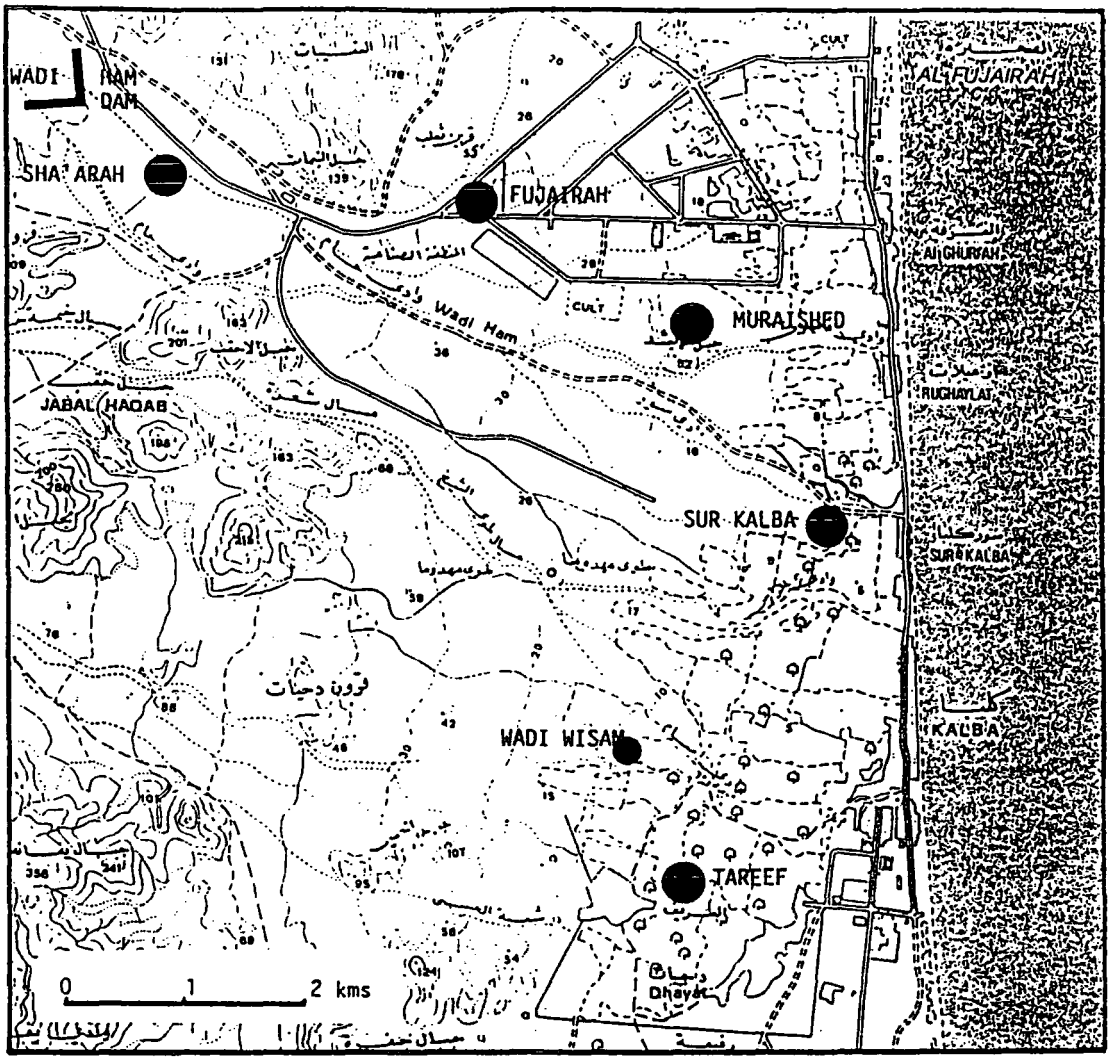


Figure: 11.1.

The ill-advised siting of wells (or wellfields) along the whole groundwater flow profile in the lower Wadi Ham and its outwash fan.

Sha'arah wellfield (MEW), located immediately below the Wadi Ham earth flood retention dam, is tapping groundwater mostly from the ophiolite fractured zone in a part of Wadi Ham just a short distance upstream of a point where inflow in the alluvial deposits (and the 2-4m. fractured bedrock) disgorges into the outwash fan. Such a development of abstraction points upgradient of existing ones downgradient would lead to interception of groundwater flow and eliminate recharge and deprive the downgradient wellfields of much of additional inflow. The distance between the Sha'arah boreholes is hardly 60m. and as this new wellfield is located less than 3km. upstream of the Fujairah wellfield (which is already sited off the main groundwater flow head), groundwater flow into the sphere of influence of the Fujairah wellfield would be minimized (refer to Figure 5.39 in Chapter 5). Consequently, salinities are rising rapidly in the Fujairah wellfield as a result of the extension of the seawater front due to the weakening of the fresh groundwater head, and the wellfield is going to be on a stand-by supply basis or its waters are going to be mixed with desalinated water from the two Qidfa' desalination plants (1991).

from such locations is at the expense of the wellfields in downstream parts of the outwash fan.

Water in the alluvium of mountain wadis is drained off rapidly after the rains, dwindling first into base-flow and finally remaining as a saturated zone in the lower part of the wadi alluvial mantle and a 2-4m. fractured bedrock. Despite the experience gained from the failing supplies at Kidnah, the Sha'arah wellfield was developed in identical physical conditions by the same official groundwater developer, the MEW.

11.3.2.2.1.2. **The Kashoonah-Al Shuwaib wellfield north of Al Ain**

The Kashoonah-Al Shuwaib wellfield is situated to the west of the main flow channel of Wadi Sumaini, which marks the international border with Oman. The wellfield is intensively developed (204 wells in an area of 86km^2) (Fig. 11.2), and the eastern part of the Al Shuwaib section of this wellfield is actually on the flood plain of the left bank of the active channel of Wadi Sumaini. The Wadi Sumaini channel is the main recharge channel into which collect all surface runoff from the catchments of Jabal Sumaini to the east. The 80 wells in the Shuwaib section of the wellfield (WED Al Ain) are taxed to the limit, and even the targeted 4.0 mgd. output from them has not yet been attained after nearly two years of operation since January 1989 because of gradually reducing well discharge rates. The 30 wells in operation in the Kashoonah section of the wellfield (WED Abu Dhabi) produce 3.0-4.0 mgd. Groundwater quality has deteriorated from about EC 700 mmhos/cm. at the beginning of development (1987) to EC 1200 mmhos/cm. in 1989. This rising salinity is not only because the Quaternary alluvium in this foothill location is dewatered by the intensive groundwater abstraction, but also due to the fact that, unlike such locations close to the mountain front in the Northern Emirates, clays, marls and anhydrites intercalate in the water-bearing strata and occur close to the surface in these foothill locations, such as at Al Shuwaib in Al Ain (Fig. 11.2).

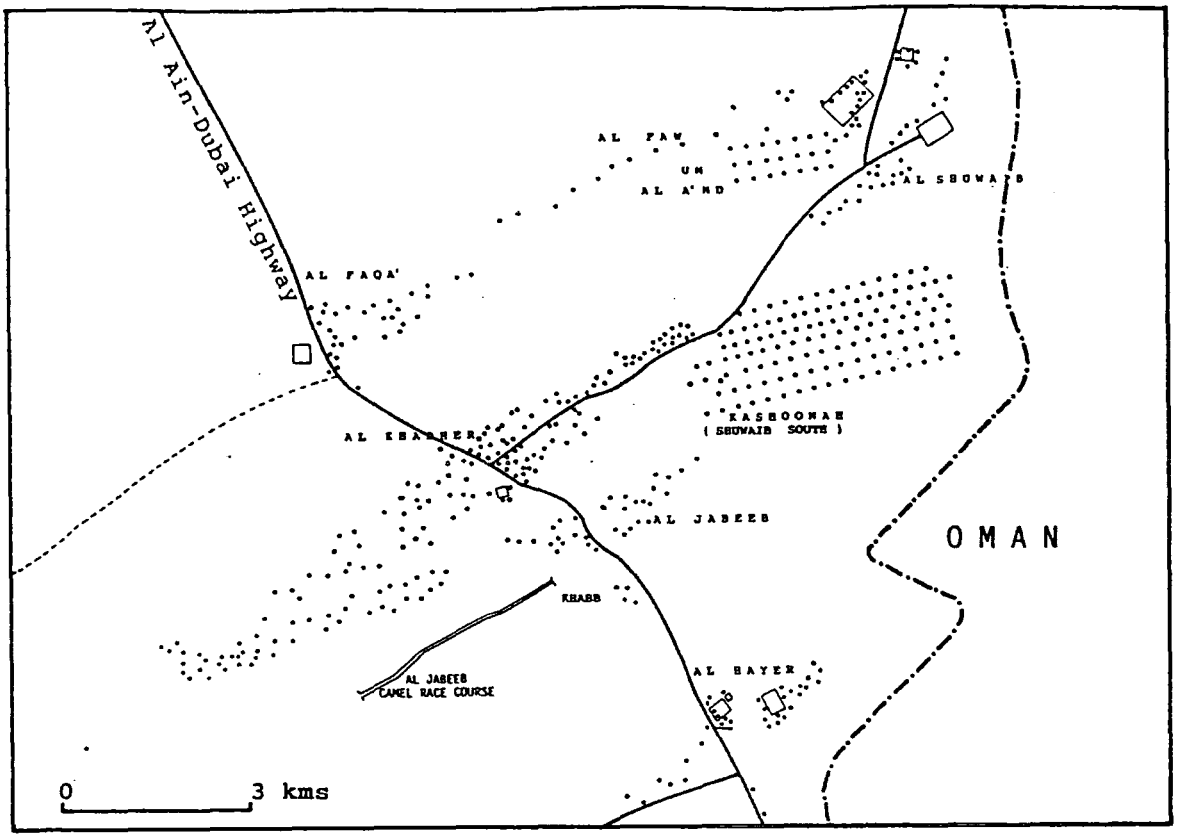
Like other foothill recharge sites, discharge from the wells at Kashoonah-Al Shuwaib surges immediately after the rains but drops rapidly shortly afterwards, and continuous pumping from such a concentration of wells will be at the expense of extraction points

further to the west and southwest (Al Sad and the northern dune areas) that will suffer irreparably in the long run from dwindling inflow.

Assuming that the siting of the Shuwaib wellfield near the recharge zone was intended to enhance the inflow of fresh water by dewatering that part of the shallow aquifer, an intention that was never contemplated by the developers of the wellfield, then the mean annual runoff expected to recharge this part of the aquifer should have been carefully considered. In this particular area, most of the 10.13 MCM/a volume of runoff (Chapters 9 and 10) flows towards Al Madam and finally flows into the desert foreland areas of Dubai and Sharjah. Assuming that 25% of this volume (2.53 MCM/a) flows westwards or southwestwards into the northern dune area of Al Ain, then the total annual groundwater abstraction in both the Shuwaib and Kashoonah parts of the aquifer of 10.78 MCM/a exceeds this assumed inflow by more than four times. Inflow from Wadis Kahal and Mahdhah is too far to the south to be considered with this. A mere 0.35 MCM/a is calculated for possible recharge from direct rainfall, but the water-table is too deep to allow this contribution to show any immediate effect.

As noted earlier, underlying the Shuwaib alluvium are marly-clayey-anhydrite interbeds, and the continuous pumping from a vast wellfield of 220 wells (Kashoonah, Shuwaib, Al Fao and Um Al 'Amd) (Fig. 11.2) is already causing increasing salinities as the alluvial aquifer is being depleted of its fresh water, and mineralized water is being stirred up from these underlying saline formations.

The ill-advised siting of wells, that leads to interception of groundwater flow, can further be realized by considering the very slow movement of groundwater from the point of recharge to the points of abstraction. Such slow groundwater movement was estimated by Gibb-Hunting for the Dhaid area (1975) as taking 70 years to cross a 25km. journey from the mountain front as inflow, with velocities varying from 0.02 to 0.6m/d; and by Lahmayer (1977), for Al Khadher wellfield in Al Ain, as taking an inflow travel period of 2.85 years for a similar distance between the Sumaini mountain block to the east and the wellfield. This, assuming an uninterrupted inflow by interception of areas of heavy groundwater abstraction as described earlier.



Source of data: Groundwater Department, Al Ain.

Figure: 11.2.

The intensively developed wellfields of Al Shuwaib-Kashoonah-Al Khadher of the recharge zone in the northern alluvial-aeolian area of Al Ain.

Like other foothill recharge sites, discharge from the wells at Kashoonah-Al Shuwaib surges immediately after the rains but drops rapidly shortly afterwards, and continuous pumping from such a concentration of wells will be at the expense of extraction points further to the west and southwest (Al Sad and the northern dune areas) that will suffer irreparably in the long run from dwindling inflow.

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With the extensive development of numerous groundwater abstraction centres of all types, from single wells to full-fledged wellfields, which tap past and present inflow along the whole length of groundwater flow gradient, not only will the through-flow be slowed to negligible amounts, but it may eventually be severed from existing downgradient points such as the wellfields of the northern dune area and Al Sad. While acknowledging the desperate search for fresh groundwater sources by a host of competing users, such an ill-informed and short-sighted haphazard locating of groundwater abstraction centres leaves very little scope for groundwater resource planning for the future.

11.3.2.2.2. Management aspects related to well development in the Emirates

The development of wells has recently been helped by the introduction of the pvc borehole casing, which is inexpensive, durable and unaffected by corrosion. Screening, and even casing, was overlooked by some official water organizations but is now widely supported. There is an unknown number of uncased wells in areas where anhydrite formations alternate or underlie fresh or brackish water formations, as in the desert foreland of Abu Dhabi (Chapter 5, Section 5.3.2.4.3.2.). Such uncased wells may form points of hydraulic connection, and therefore contamination, with extremely saline waters, as may be happening in boreholes drilled in the seihs to the west and southwest of Al Ain (Al Za'alah wellfield).

Gravel packing[1] of existing boreholes is done with angular building aggregate and not with rounded wadi gravel. Wadi gravel does not become compact, but angular building aggregate tends to settle firmly and become blocked with fine sand and silt. As a result, well-screens[2] become blocked after sometime depending on the water-bearing

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(1) Which is the artificial base necessary to hold firmly the bottom of a borehole drilled in a soft water-bearing material, as is the case with most aquifers in the Emirates.

(2) Which are perforated tubes fitted at the lower part of the borehole lying within the water-bearing material and serve both as a support of the hole in the unconsolidated aquifer material thereby preventing collapse, and also as a filtering medium keeping sediments out of the well pump intake level thus minimizing resistance to water flow.

material through which the pump suction is taking place. This may happen within a short time of the start of pumping of a new well or may start showing signs of blockage after some years. In this way, discharge from wells is reduced in the worst cases to 50% by such blockage. No blasting or shooting[1], air-shocking[2] or hydraulic flushing or jetting [3] is used to treat such a blockage.

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(1) Involving detonating explosives in a borehole where the explosive gases help to widen or clean the pores of the water-bearing material after compaction, but with the possible adverse vibratory effect as a result of the expansion and contraction process of blasting.

(2) A highly specialized and skilled technique in well development involving the use of compressed air at the start of well development by installing an air pipe inside the delivery pipe of the well. 60% of this air pipe should be below the water level in the well; the end of the air pipe should be placed below the end of the delivery pipe and compressed air is then released. This would create air bubbles that would in turn clean the pores by loosening them and result in a surge of water towards the well-pump as the air bubbles contract. The end of the air pipe is gradually raised at intervals and air-shocking is repeated until the whole length of the well screen is cleaned of particle blockage.

(3) Which involves cleaning the well tube and its screen by pressurized water. This is very effective only with well screens with perforations or slots forming a large percentage of the surface of the screen pipe (the cast iron or stainless steel types used mostly in boreholes in the Emirates) although its horizontal cleaning area from the well tube is limited.

Well caving or collapse[1] is common in Kashoonah, Al Khadher Nassas, Suwaihan, Al Badea', Al Aweer and even Al Shuwaib in wells whether cased and sealed or not. Well caving was reported by Gibb-Hunting during the test pumping of the Al Hayer North wellfield in Al Ain (Gibb and Partners and Hunting Technical Services, Report on Testing of Wells at Al Hayer, Al Ain, August, 1974).

Motor pumps corrode within short periods of the start of well operation in areas like Seih Al Miyah, Seih Bin Ammar and Al Rugai'at in the Al Ain region. Such motor-pump corrosion was also reported by Gibb-Hunting during the test pumping in the Bida' Bint Saud wellfield (Gibb and Partners and Hunting Technical Services, Test pumping at Bida' Al Saud, Final Report, April 1974).

During the investigation process in well development, after all the geological and geophysical results have been evaluated, an exploratory or small-diameter pilot borehole should be sunk in the most promising part of an aquifer. Unlike direct motorized pumping from submersibles, as is the norm in all well pump testing cases in the Emirates, the air-lift well testing should be followed in the pilot borehole as it is the ideal way of indicating the characteristics of an aquifer, particularly the flow rate of water into the borehole. The relevant data involving transmissivity and other hydrogeological characteristics would decide whether or not the well should be developed. All such data should be documented for future reference.

Air-lift pumping is carried out by the Groundwater Department of Al Ain. not for testing pilot wells, which are not normally drilled in well development schemes, but on already developed producing boreholes, and its application is not for the purpose of aquifer testing, but for cleaning the borehole tube and 'mud-cake' left behind from using the

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(1) When a cavity forms in the well pumping sphere by the denudation of the aquifer material if there is no well-casing or formation stabilizer, which is a cement-based seal of grout mixed with bentonite or aluminium powder making a white viscous clayey material which later hardens in the well-tube into a 'mud-cake'.

clayey sealant described earlier. While the air-lift well testing method is comparatively inexpensive, the usual pump testing, practised widely, is costly and not as accurate. The appropriate duration of such pump testing averages 36hrs., though a test run of up to 5 days is not uncommon. However, such well pump testing durations are rarely adhered to in the process of well development in the Emirates.

11.3.2.2.3. **Management problems related to the maintenance of water supply equipment.**

It has been shown earlier (Chapters 3 and 4) how rain recorders fail quite frequently at the critical times during rainstorms (see also Appendix 2). Thus, a number of rain records for important stations within the catchments are not available. The same is true to some degree with groundwater level recorders, the majority of which plot poor quality charts. There are even cases of flood or groundwater level recorders being stolen or washed away by floods, and rain recorders used occasionally as shooting targets.

One of the marked cases of equipment disrepair is that of the control-rooms that are meant for operating MEW wellfields in the Northern Emirates. Most of the facilities in such control-rooms have been out of order since a short time after the commencement of operation of the wellfields. In recent field visits (August 1989) to all the control-rooms, it was found that most of the equipment panels did not work save for the electric switching gear that operated the well pumps. The rest of the panels that were non-operational were supposed to monitor the TDS and temperature of groundwater. There is not, and there has never been, any technician in the MEW capable of maintaining any of the equipment in the 5 control-rooms in MEW wellfields.

Furthermore, most of the individual wells, and those in the MEW wellfields, have no flow-meters, while most of the flow-meters fitted on wells are either malfunctioning or in total disrepair. Readings from these flow-meters are 40% in error owing to back-pressure caused by air trapped in the pipes during periods of resting the motor-pumps. When checking the actual discharge rate from boreholes fitted with such flow-meters for the present study by filling a 44-gallon barrel several times and taking an average of these measurements to obtain a median

filling time, it was found that the flow-meter was giving a flow rate higher by 40%.

11.3.2.2.4. Management problems related to groundwater level monitoring

Monitoring of groundwater levels, though still limited and irregular, started in the early 1980s by which time groundwater abstraction had already considerably exceeded recharge. In nearly all regions, groundwater resources have reached a stage of overdevelopment, whereby aquifers are being dewatered by the widespread uncontrolled 'mining' of groundwater in storage. It has been shown how groundwater levels are sinking consistently (Chapter 5, Section 5.5.2), and how in the Dhaid region farmers are systematically deepening the boreholes, which, in the case of some, have been deepened to more than 500m. These boreholes were not deeper than 100m. less than 10 years ago.

Wells are drilled by multifarious organizations, varying from the governmental to the individual, and their exact number in any area of the Emirates is not known. Groundwater level monitoring in the Northern Emirates is largely carried out by the MAF, especially since the observation wells set up by the Deep Wells Project (1982-86), came into operation in 1985, and monitoring is mostly concentrated in the western piedmont plains. Few of the observation wells are near agricultural areas of heavy groundwater abstraction, such as Al Dhaid and Al Hamraniyyah. Older groundwater level recorders at Al Madam and Al Dhaid (since 1976) show slight variation in water-table levels due to their location in perched groundwater bodies detached from the main water-bearing stratum from which the surrounding agricultural or public supply wells are drawing water. The drop in groundwater levels in such old recorders has been about 1.0m. for the whole period since 1976, while the drop in groundwater levels in wells in the surrounding agricultural areas has been at an annual rate of between 0.7m. to 3.8m. (see Chapter 5, Section 5.5.2.).

In view of what has just been said, such groundwater level data should be used with care bearing in mind that it is almost inconceivable in official quarters to relocate observation wells once they have been sunk in a particular spot, however questionable this location may turn out to

be. Groundwater level data of the MAF do not contain analytical resumes or any warning that might draw the attention of the user to possible discrepancies. The MEW, on the other hand, monitors groundwater levels in some of its wellfields with the help of its increasingly troubled groundwater level recorders, some of which have been abandoned owing to disrepair and lack of maintenance facilities in the Ministry. Groundwater levels in the rest of the individual MEW wells that supply water to 95% of the villages of the Northern Emirates, is unmonitored. In addition, water supply from these MEW village wells, and also from most of MEW wellfields, is unmetered and unchlorinated.

In the continuous stretch of wellfields of the northern dune area of Al Ain, groundwater levels are monitored by 9 automatic groundwater level recorders and also by random measurement with a portable probe. Wells are too numerous in this area, with several of them being laid off for long periods to recover their previous levels. Such recovery of groundwater levels does not seem to happen fully owing to the closeness of the wells, which leads to a progressive general decline of the water-table as indicated by all the groundwater level measurements (Chapter 5, section 5.5.2.)

Similar groundwater level observations are made in the Al Aweer and Al Badea' wellfields of Dubai and Sharjah in the desert foreland. However, in both these areas, groundwater level monitoring has become meaningless because most of the pump intake levels in the boreholes of both wellfields are below MSL.

11.3.2.2.5. Water management considerations of groundwater resource development in the Northern Emirates.

11.3.2.2.5.1. Water supply shortages:

There are many areas in the Emirates where there are acute shortages of domestic water supply. The worst such case is the town of Ajman where the situation becomes critical in summer. In Al Dhaid domestic water supply shortages are largely due to competition over potable groundwater reserves by overabstraction in agricultural wells. The four wells, that once existed in a foothill area in Wadi Ashwani to supply water to the villages of Siji and Al Madam with 0.3 mgd. (1984), have run dry and

have been abandoned. In the intermontane basin of Masafi, the alluvial aquifer has almost been exhausted and supplies for the town of Masafi are brought from Marbadh 10km. away. In both North and South Mileiha (in the emirate of Sharjah) the production of a well, that once supplied the two villages, dropped from 0.12 mgd. (1986) to a mere 0.019 mgd. (1988). Water is available at Tawi Khaydher 5km. away, also within the emirate of Sharjah, from where it could be transferred to Mileiha; but this is subject to local political approval, which has not been forthcoming.

Regular fresh water supplies are still absent in a number of bedouin habitations in the heart of the mountains and water to these settlements is intermittently delivered by road-tankers. There are however some limited positive signs of change of local tribal traditions involving water sharing. This is based on voluntary gestures between tribal chiefs that are bound by family or personal ties despite the tribal or territorial (different emirates) dividing realities. The two recent examples of such positive trend are those of the villages of Tayyebah and Habhab. Tayyebah (belonging to the emirate of Fujairah) had suffered from water shortage for 15 years and had been relying on a single well situated in the middle of Wadi Tayyebah drawing saline water from a structural fissure. The nearby intermontane basin of 'Asimah (belonging to the emirate of Ras Al Khaimah), on the other hand, had copious undeveloped fresh groundwater reserves. Favourable local tribal conditions in 1987 allowed the drilling of a well within Ras Al Khaimah territory, about 1km. away from the Fujairah village of Tayyebah, from which water has since been pumped to the latter. Again, Habhab (Fujairah) has been receiving its water supply for some years from the village of Khatt (Ras Al Khaimah) on an unofficial basis, simply because of friendly neighbourly relations between the walis (tribal chiefs) of the two areas. This is the spirit that ought to be encouraged nationally elsewhere in many areas where old tribal bigotism prevails.

Other problems facing the development of public supply wells, which perpetuate water supply shortages, include the usurping of publicly-developed wells by individuals after they have been basically developed to supply water to whole communities; and acquiring land by the official water-related organization for developing such sources of public supply. An example of the former is that of the MAF observation well GP-18, southeast of Al Dhaid (a Deep Well Project well, 1986),

which was connected to a private garden (although the observation well is located outside the fence of the garden), has been fitted with a pump and its water diverted by the owner of the private farm into the garden for irrigation (observed in 1990). The second, more important, example, is that of the MEW public supply wellfield at Zikt, which was intended to supply the village of Zikt with drinking water from five wells. Once the wellfield had been developed and was ready for operation, the five wells, with all their fixtures (pumps, pump-houses), were enclosed within a large private garden and their water used for irrigation instead.

The permanent problem facing the federal MEW is that of acquiring land to develop public supply wells. In almost all cases, wherever the MEW chooses a drilling site, either the wali or another of the tribesmen, assert their private ownership of that site. There is no recognition by individuals that water sources developed for the public benefit should be publicly owned. There exists no legislation to that effect. In several cases not only do individuals or local authorities get compensation for use by the federal MEW of a small plot of land (accommodating one or a few wells), but once water of potable quality has been extracted, any of these parties could start up a garden close to this new water source and draw irrigation water from it, and so accentuating shortages of drinking water.

11.3.2.2.6. Water management problems in Al Ain

A unique water management situation exists in Al Ain whereby the development of new sources of groundwater, from the feasibility stage to the drilling and fitting of the boreheads with motor-pumps, is carried out by the Groundwater Department that comes administratively directly under the Al Ain Diwan (ruler's office). This is different from the Water and Electricity Department of Al Ain (WED Al Ain), which is financially part of the Water and Electricity Department of Abu Dhabi (WED Abu Dhabi) but from which it is practically detached. Once the water projects have been developed by the Groundwater Department, they are handed over to the departments of Agriculture, Forestry and Water and Electricity, as well as to large and small individual users. The main difficulty as far as public supply wells are concerned, is that WED Al Ain finds itself managing handed-over wellfields without having been

involved or consulted throughout their development phases. Besides this, all the departments noted earlier, for which the Groundwater Department develops wells, possess their own drilling-rigs and maintenance crews to carry out their own well development.

The multiplication of groundwater resource development duties by almost every department, however small and distantly related to water use, is a dangerous trend that calls for urgent reviewing. The reason being that it embodies fragmented management and unwanted competition between the various users over the contents of the whole, or part of, an aquifer in the same area (Al Ain) that forms a part of the same emirate (Abu Dhabi). As a result, a number of wellfields have failed. These include Al Za'alah, Ghashabah, Seih Al Miyah and Um Ghafah. Finally, the new Shuwaib cluster of wells is already showing decreasing discharge rates (Fig. 11.2).

The ideal management alternative to the institutional water management problem of Al Ain would be to amalgamate the Groundwater Department (the main groundwater resource developer in Al Ain) with WED Al Ain (the main domestic water supplier) in a single water management entity. There would be two distinct sections of groundwater development and supply. Another alternative would be to transfer the groundwater development responsibilities of domestic sources to WED Al Ain and, since the Groundwater Department has better qualified hydrogeologists, it would also retain its existing role of developing groundwater sources for the other local departments (Agriculture, Forestry and the Diwan), which should cease to have their own groundwater resource development facilities.

11.3.2.3. Management problems in the non-conventional water resources sectors: Desalinated water and recycled wastewater.

11.3.2.3.1. Desalinated sea- and ground- water

Desalinated seawater was originally intended as an alternative to the drinking water supply in the large towns when the usable groundwater supplies were becoming widely depleted and their deteriorating quality was rendering them unpotable. As this new water source has developed, it has provided a readily available water supply for all applications,

ranging from drinking to irrigating forest salt-tolerant plants. Such applications have established trends in water use that would influence future development of both the desalinated sea- and ground water resource. Unlike groundwater, which is usually developed by a water-related department, bulk desalinated seawater is linked with electricity generation. Although power generation may theoretically be part of a water and electricity department in an emirate, the desalinated seawater it develops is detached from that department or from any projections a water department may make to meet future demand for water. The result is the permanent problem of incompatibility of supply and demand in the towns.

The most serious problem in the development of the desalinated water resource is the increasing use of most of the daily production for irrigation, whether in town reserves or household gardens, either mixed with brackish groundwater or treated wastewater. It is estimated by the distribution section of WED Abu Dhabi that only 29 mgd. are actually consumed by the inhabitants of the town of Abu Dhabi as domestic use (1989), which includes drinking, washing, bathing and cooking, out of the 69 mgd. made available for the town and its satellite townships (after deducting the 14 mgd. transferred to Al Ain). This has been confirmed by a survey carried out for this study to derive the actual per capita consumption for various groups of the inhabitants and types of households according to the available amenities that use water in each type of household. For Abu dhabi, the gross daily per capita consumption in litres (lpcd.) is 780 lpcd. (69 mgd. to an estimated population of the town of Abu Dhabi for 1989 of 364,000.). On the other hand, the actual daily per capita consumption is 317 lpcd., which is 42% of the gross daily per capita consumption (Table 11.1).

This result of the per capita consumption appears to conform with the proportion of the 29 mgd. of desalinated water, that is actually consumed domestically noted earlier, to the 69 mgd. volume made available for the town of Abu Dhabi (42% against 58%). Thus, nearly 60% of the desalinated water produced by Abu Dhabi, which is its only water source, is used by other outlets, of which irrigation is the most dominant; and also the 'unaccounted for' amount lost by leakage and other means in the town's water supply system.

The outcome of the uncontrolled use of the expensively produced desalinated seawater in the towns of Abu Dhabi, Dubai and Sharjah has been a lack of water surplus in storage for more than a few hours, and a total lack of any contingency measures. Any extra volume of desalinated seawater planned from existing or future desalination plants would be absorbed as soon as it is produced. The question that forces itself is whether desalinated water is to be earmarked for domestic consumption that would also secure a surplus against any possible breakdown of production or, continuing with the existing confused uses of irrigating town reserves from this potable resource, whether most of the daily desalinated water output is to be used, saving nothing, and encouraging even more production?

11.3.2.3.2 **Development problems related to desalinated brackish water**

The main problem in brackish water desalination by reverse osmosis (RO) is the short life of the synthetic semipermeable membranes which are also very sensitive to organic residues, should these escape the pretreatment stage, and reach the membranes. Replacement of the expensive membranes is thus frequent, which in turn increases the cost of water production. The cost of electricity or fuel used for the process is also high. The brackish water RO desalination plant at Al Wagn has failed to operate on its original solar energy and is now fuel-operated. It has always failed to produce product water at 50ppm., and has continued to produce it at 700ppm. In addition, due to inadequate design specifications of its solar cells, the plant has not been able to store enough energy for its operation after sundown. The transfer of water from the RO plants in the desert of Abu Dhabi to the remote settlements is a limiting factor owing to the great distances. Despite this, desalinated brackish water is going to be transferred to Al Qoa' from the planned 1.0 mgd RO plant at Al Wagn. Input costs into the production process are not an issue in the Emirates, and the expensive water that is going to be produced, in a desert area badly in need of it for drinking, would be put to the same confused multifarious uses of which that of irrigation would be the dominant one.

11.3.2.3.3 **Development problems related to recycled wastewater**

The treatment of wastewater has not yet taken roots in the water resource management thinking in the Emirates. The main philosophy behind wastewater recycling is based on the single-purpose provision of irrigation water for municipal reserves in the large towns. The established trend is that the more any development of the wastewater recycling capacity makes available additional volumes of this resource, the more it should be be absorbed by a further extension of the town's horticultural area. Dubai is already making plans for such an extension of the green area within the town's limits to be executed when its new sewerage plant at Al Aweer makes available the 29 mgd. of treated wastewater in its first stage (1991).

Table 11.1. shows the daily volume of treated wastewater as a percentage of the actual and the gross per capita consumption in the four main towns where there are sewage treatment works. Whereas the average volume of treated wastewater is 62% of the actual per capita consumption, it is only 23% of the gross per capita consumption or the total volume of water made available in the four towns (1990). The main problem in the development of treated wastewater is the completion of the sewerage network within these four major towns, and the fact that no sewerage systems and treatment plants exist outside these main towns. The other more important problem, is that no surplus of this resource can be hoped for to be used for artificial recharge according to the existing trends in the use of the treated effluent.

The present production of treated wastewater (48 mgd. or 80.0 MCM/a (1990)) fails to meet the irrigation demands of the municipal horticultural schemes. Even with the assumption that the four towns are capable of treating all their domestic wastewater, the volume from this source could only be increased two-fold since only part of the daily water supply made available to these towns is actually used domestically and finds its way to the sewage treatment plants as shown in Table 11.1. Another problem in developing wastewater treatment is the high initial construction cost of the sewage treatment works, although the unit production cost of the treated water from this source is cheaper than that from the desalinated source, and is only about double the production cost of groundwater (Chapter 8, Section 8.7). It is therefore

	Abu Dhabi	Al Ain	Dubai	Sharjah	Average for all towns
Gross volume of water available for use..... in the towns (mgd)	69	34	69	32	-
Gross per capita consumption (lpcd).....	780	1132	920	853	883
Actual per capita water consumption: (lpcd)... (1)	317	317	317	317	317
(mgd).....	29	9.5	24	12	-
Total volume of recycled water (mgd).....	25	6	14	7	-
% of recycled water to actual per capita..... consumption	86	63	58	58	62
% of recycled water to the gross per..... capita consumption	36	18	20	22	23
% of area covered by sewage system in the..... towns	80	60	60	30	-
Total population (1989)..... (2)	354000	120000	300000	150000	-

(1) Data from a survey carried for the present study.
(2) Estimated, based on past growth trends (for lack of published official figures).
** Sources of all the other data are the respective water-related organizations.

Table: 11.1.

The total volume of water produced in the four main towns of Abu Dhabi, Dubai, Sharjah and Al Ain; the gross and actual daily per capita consumption; percentage of the recycled wastewater to the gross water produced and that actually used domestically (1989).

Whereas the average volume of treated waste water is 62% of the actual per capita consumption, it is only 23% of the gross per capita consumption of the total volume of water made available in the four main towns of the Emirates (1990). The total production of recycled water at present (1990) is 48 mgd. (or 80 MCM/a) which is totally absorped by the town horticultural schemes and even fails to meet their irrigation needs.

difficult to envisage widespread development of such sewage plants in the provincial towns and villages given the existing federal budgetary constraints.

Finally, the fact that sewerage plants are all located in coastal towns with a minimum distance of 20km. from the nearest depleted groundwater area (the piedmont plains; the traditional desert foreland wellfields of Al Aweer and Al Badea'), poses the problem of the transport of treated wastewater to the would-be points of artificial recharge. However, a possible solution to this would be to use the existing pipelines that transport water from the wellfields by reversing the flow with treated wastewater. As this reverse flow is going to be slightly upgradient, it would require boosting by pumps set up along the pipeline. For the 20-km. Dubai water pipeline from Al Aweer, two or three such booster pumps would be sufficient to handle the operation (personal communication with E. Tulloch, Chief Engineer of Dubai Water Department, July 1990).

11.3.2.3.4. <u>The problem of water losses (leakage) in the water supply systems of the towns</u>

Water losses by leakage, the so-called 'unaccounted for' water losses, that includes both leakages and clandestine connections in the water supply networks of the towns, is a management problem that needs to be seriously addressed. Water losses are acute in older supply systems, such as that of Dubai, where it is thought by official sources to amount to between 30-40% of the total daily volume of water pumped into the system. Leakage in the Sharjah water supply system has been reduced from 45% to less than 25% (based on official estimates of the Sharjah Electricity and Water Department) by substituting old tortuous household connections with direct new ones.

The leakage problem is less severe in Abu Dhabi because the larger part of the water supply network is new and means of leakage detection are better than in the other towns of the Emirates. Furthermore, the replacement of defective parts of the system is effected promptly and with the best of equipment.

By present-day water volumes, controlling the 'unaccounted for' losses, of which system leakage is the largest contributor, may save up to 40% in the worst, and 10% in the best, of cases, which may amount to between 47-63 mgd. (78-105 MCM/a).

11.4. Water legislation, policy and the water-managing organizations: the existing water management infrastructure

11.4.1. Water legislation and water policy

The absence of a well-defined water policy is not only common to countries of the Gulf region and the Arabian Peninsula, but also the majority of Third World countries. In the Emirates there exist no water policies at the local or federal levels, and the day-to-day running of water resources relates only to the supply aspects of their management to meet the daily demand. Water-governing organizations carry out water services totally separated from each other. All organizations and individuals drill for water, but largely on a trial and error basis, with no sound hydrogeological prospecting.

A national water policy, in the comprehensive sense, embracing all water-related facets in statutes, regulations or administrative measures, does not exist in the Emirates. This is a reflection of the political make-up of the federal state of 7 emirates, each with its distinct local identity. The emirates of Abu Dhabi, Dubai and Sharjah run their own water-related affairs through one or more water organization independent of the federal ministries of the MAF and MEW.

The widespread development of the motorized boreholes has wiped out the old tribal communal water sharing system that regulated water use from the falaj and hand-dug well. Present-day individual wells belong to the owner of a farm who uses its water without obligation to any official authority or even his next door neighbour. As such, it is deemed irrelevant to dwell on tribal water regulations as they have become history.

The old Islamic water legislation stipulated that water belonged to whoever developed it but secured its public use and safeguarded it

against abuse or pollution. The Ottoman water law underlined the right of all to water use but also inventorized its sources, ownership of land and irrigation rights and their sale with or without the land on which the water sources are developed, and also allowed for the maintenance of these water sources. The modern Anglo-French water law of the colonial era up to independence, stressed public ownership of water but regularized its development with licensing, taxation and localized management. All these water laws had the common denominator of public access to water use.

As more than 90% of the agricultural wells, all the public supply wellfields and also desalinated and recycled wastewater are developed by the state or the local government of an emirate, water ownership is therefore, technically, public. Legislation defining in detail all water related legalities, from the licensing of wells to regulating the use of water from them, but within the general basic concept of water as a public property, should come before drawing up a local or national water policy and plan.

11.4.1.1. Public ownership of water resources

Public ownership of water is essential for a responsible management of water resources. It is implemented in most countries with a variety of political regimes and cannot be branded communist. In the United States individuals may happen to derive their domestic needs from a well on their property (in a state like Virginia), but this is monitored by the local water authority that fits it with a flow-meter and a rate is payable towards the use of water and its post-use treatment as sewerage. In some drier states, such as Arizona and California, controls on the amounts of water extracted from individual wells are stricter. In general, water resources as a public utility are publicly-owned.

In the Kingdom of Morocco the law stipulates that any natural resources below ground surface belong to the state; foremost among these resources is water.

Thus, public ownership of water is an important basis in water management and assumes even greater importance in an arid environment such as that of the Emirates.

As such, legislation would require from the individual or institutional user of the resources a disciplined, conscious and responsible cooperation with or without overseeing by the authorities. It would also require the water resource management authorities to be properly staffed with professionals on both the planning and engineering aspects.

11.4.1.2. The General Water Resource Authority of the Emirates (1981)

Following the UN Mar del Plata Water Conference (1977), which recommended conserving and optimizing water use by means of communal sharing and efficient application, and also in view of the general deteriorating water resource situation in the Emirates, an attempt was sought in centralizing water management in the Emirates. The result was the General Water Resource Authority Law, that was passed in 1981, but has not been put into effect since. The delay in its implementation is due more to the deep-rooted local political, social and economic disparities than to budgetary constraints.

A translation of Articles 4, 5 and 6 of the Law, which concern the duties of the Authority and the measures of implementing them, is included in Appendix 7. Besides setting up the Executive Council of the Water Authority, the Law was an introduction to preparing a national water policy. It gave powers to the Water Authority to gather water resource data, to coordinate between the various users and to suggest ways of conserving water resources and solving the problems in their development. Article 4 of the Law, however, stressed the independent identity of other water-related local and ministerial authorities, which were to continue initiating their own water development projects and running them independently. As the basis of the General Water Authority was central (i.e. federal) aiming at controlling the resources nationally, Article 4 of the Law contradicted this principle. It perpetuated the prevailing fragmented water management that the very General Water Authority Law had intended to correct. It also underlined the irreconcilable local socio-political realities.

As can be seen from the translation of the three Articles of the Law (Appendix 7), the General Water Authority would be a data-collecting and well-licensing body, if it came into being. The data would be for the purpose of formulating a water policy or plan. The sources of such data would be the existing main data-collecting institutions, such as the MAF, data for which are neither adequate in quantity nor acceptable in quality; and their documentation is either archaic or non-existent. The General Water Resources Authority would be staffed with people working in the existing water-governing bodies, but mostly from the MAF, and the inadequacies that exist in these organizations would be transferred *en bloc* to the Authority.

The logical approach would be to upgrade the technical and administrative quality of the existing local water-related organizations. This could be done by enriching these authorities with the required highly-calibred local professionals. In this way, a specialized and experienced staff base could be developed that would be capable of planning and managing short- and long-term development of water resources on the local (emirate) level. Such an achievement in the management of the water resources on the emirate level could provide a sound basis for a future merger of local water organizations into a national water resource authority, should circumstances become more favourable for this to take place.

11.4.2. Institutional issues

Water policy-making rests with the ruler or shaikh of an emirate, who is the highest political level in the emirate. The policy-maker initiates a water project and sees it through to completion. The water organization in the emirate related to the project acts, with the help of a consultant, as the overseer of the project. Water decision-making is a politically sensitive issue at both the emirate and federal levels. The existing fragmented water institutional make-up may be hard to change because of the prevailing economic, political and social set-up. The salient institutional issues facing water resource management in the Emirates are:

(i) the failure of both the supplier and consumer to recognize that water is not a free commodity. It has been shown (Chapter 8) that the consumer is charged for water less than the production cost; the revenues collected from water sales hardly cover the maintenance of water production installations.

(ii) the absence of water laws on the emirate and national levels. Water bye-laws are an important instrument for regularizing water use and may help in conserving water.

(iii) the lack of separation by statutes of water quality and quantity. This would involve defining water use according to the type and quantity of water available.

(iv) the total divorce between local and federal water schemes owing to the piecemeal and localized implementation of isolated water projects.

(v) the lack of any effective local or federal mechanism for defining priorities in water use.

(vi) the permanent rift between the decision-makers and the water managers. This is embodied in the inability of the decision-makers to learn about the scientific realities of water resources, and also the inability of the water managers to influence the decision-makers by presenting to the decision-makers comprehensible data on the various aspects of the water resources.

(vii) the inability of water institutions at the emirate and federal levels to coordinate their programmes and eliminate competition and even conflict.

(viii) the changes effected during the course of implementation of a water project leading to delays and high costs, such as the decision to transfer the Al Mamzar power and desalination project in Dubai from the original location to the DEC power and desalination complex at Jabal Ali. Also,

the inadequate planning and lack of coordination between the producing and distributing sections of the same department, such as the completion of Stage 'A' desalination plant at Al Taweelah in Abu Dhabi before the provision of a pipeline of adequate capacity to transfer the quantity of desalinated seawater produced to the town of Abu Dhabi (Chapter 8).

(ix) the absence of environmental safeguards in all the water resource programmes.

(x) the non-existence of a water supply grid system within an emirate or between the seven emirates of the federation to allow any interemirate transfer of water.

11.4.3. Water-managing organizations

The infrastructure of the water-managing organizations is given in Fig. 11.3. These organizations are outlined in Chapter 8 (Section 8.2.). They are basically domestic water supply organizations, are water development-based and are little concerned with management aspects that involve data analysis, planning, monitoring of water quality and quantity and appraisal of the overall water resource availability. They have evolved over the years, particularly in the post-federation period (since 1971), and within their local and federal levels, have duplicated responsibilities, inefficiencies and even conflict. They are thriving as long as the development of new water sources characterizes the existing era of water resource 'management'. This institutional fragmentation of water resource management poses the question: what is to be done to optimize water resource planning, development and management? The national option appears far-fetched at present as is evident by the shelving of the General Water Resource Authority Law (see Section 11.4.1.2.). The amalgamation of the water-managing organizations on the emirate level is viewed by the present study as the more likely option of the two to be reached on the basis of public ownership of water resources. This is a vital step towards rationalizing water resource management.

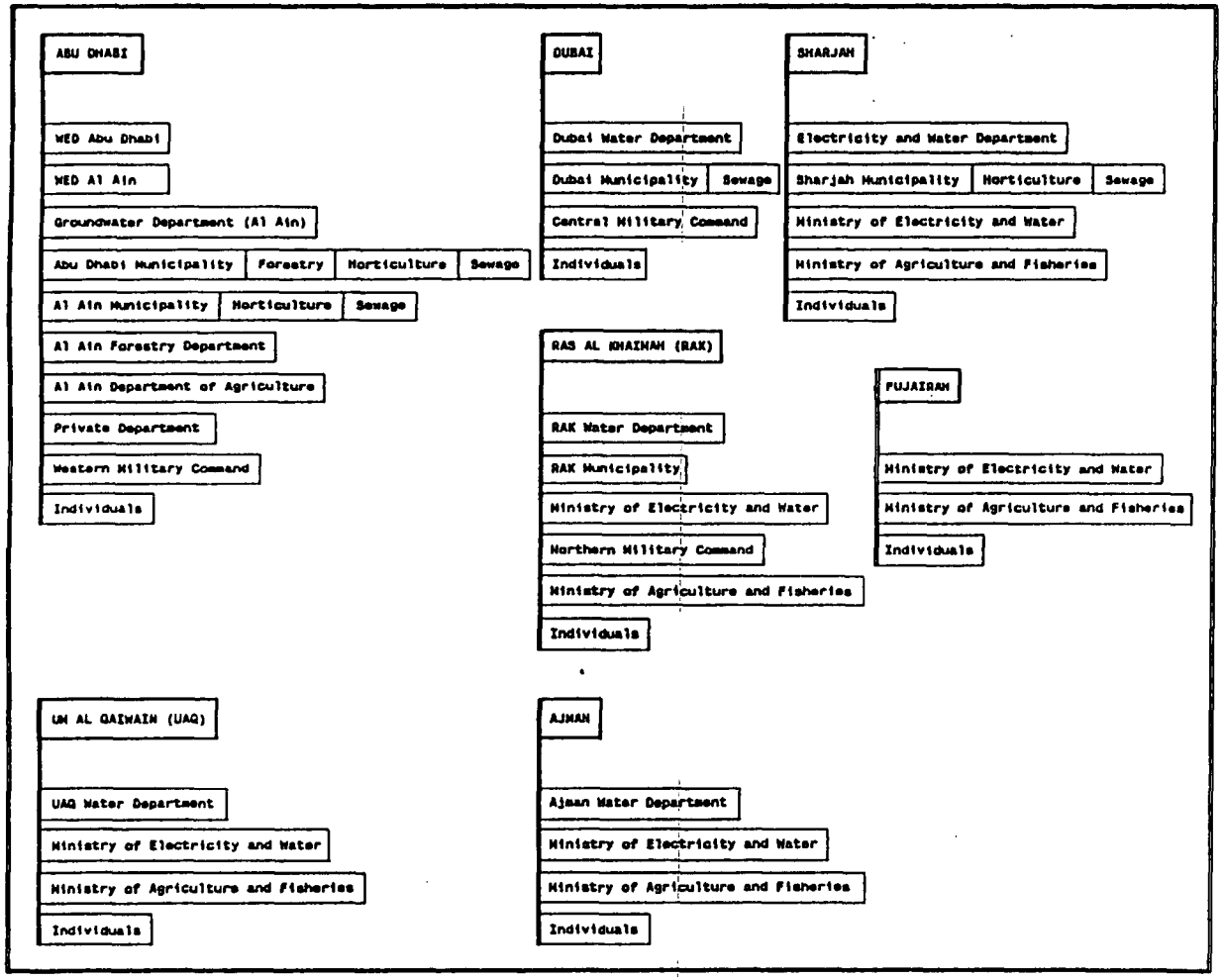


Figure: 11.3.

The main water resource developing and managing organizations in the Emirates (1990-91).

These water-related institutions are outlined in Chapter 8 (Section 8.2). They are basically domestic water supply organizations, are water development-based and are little concerned with management aspects that involve data analysis, comprehensive planning, monitoring of water quality and quantity and appraisal of the overall water resource availability. They have evolved over the years, within their local and federal levels, have duplicated responsibilities, inefficiencies and even conflict. They are thriving as long as the development of new water sources characterizes the existing era of water resource 'management'. Such fragmentation of water resource management is proving detrimental to the status of the water resources of the Emirates. Their amalgamation on the basis of the public ownership of water resouces is a vital step towards rationalizing their management.

11.4.3.1. Aptitude and efficiency of the staff of the water organizations

In a monitoring programme of the actual performance of water departments carried out for this study (1988-90), it was found that usually a well-informed expatriate member of the staff of a water-related organization carries out the field work, the coordination with both the users and the water organization and the preparation of reports. Among the remainder of the organization (department) staff, a few know 50% of the place-names of relevant villages and locations. First- and second-ranking officials, including geologists, generally make one field visit evey 6-12 months. Some remain mostly office-based and others read and collect groundwater level recorder charts, a task that can otherwise be entrusted to less qualified technicians. Place-names are frequently confused and their locations mistaken to the extent that officials commonly find themselves looking into a water problem in the wrong place, after entailing a long time and travelling effort. Heads of sections or area offices belonging to one emirate rarely visit localities in other emirates, which lie within the sphere of influence of their own sections or area offices.

11.5. Water resource planning

Planning for the conservation and future water use in the Emirates is not only necessary because water is essential to life, but also because of its dwindling supplies and deteriorating quality. Planning is a means of securing water supplies to meet the needs of the present and future generations, of providing a mechanism for resolving recurring and unexpected water resources problems and of safeguarding the Emirates against dependence on foreign water imports. Planning can only be feasible when all the components of the plan are based on sufficient data and sound economics so that a water resource plan can provide a strategy for coping with the expected economic progress. Nevertheless, planning is not an exact mechanism even in cases where all the components of a plan are economically-based, let alone when cost-effectiveness is not important, as is the case with water and agricultural development in the Emirates. A water resource development

plan, therefore, can only suggest steps to meet what may happen in future water demand.

Planning must be considered as a dynamic process if it is to be effective and up-to-date. Both continuous data collecting and identifying problems and changes call for continual adjustment to the original plan. Revision of programmes creates flexibility in the water resource plan. By such dynamism of the planning process, emerging trends can be accommodated and possible future trends allowed for.

Any water resource management plan for the Emirates should have **requirements** necessary for its formulation; **objectives** or goals to reach and **elements** defining the water issues the plan should address.

11.5.1. Requirements of a water resource management plan

Any water resource management plan requires an adequate data-base. As water planning is concerned about securing water supplies for future demands, a thorough comprehensive appraisal of the various water resources and their management is essential. Such an appraisal can only be attained through an assembly of data fedback from detailed studies and investigations of all aspects of water resources and related topics.

11.5.1.1. Institutional requirements for the water resource plan

Before the important assembly of the physical and economic data for the water resource plan, the following more important institutional prerequisites are needed for the success of the plan:

(i) the recognition by all concerned that water resources are a public property.

(ii) the upgrading of the professional capability of the water-managing institutions with indigenous permanent staff. This would not only make available expertise to meet all contingencies during the implementation of the plan, but also provide continuous training for the existing and newly recruited staff that would allow all to take any surveys

further from where they would have been left by foreign experts hired for initial studies and surveys.

(iii) the water resource planners should be formed of both water resource specialists and well-placed politicians (the decision-makers and fund-raisers). Both groups should be well informed with the details of each other's domain so as to be able to formulate realistic plans with a good chance of success.

(iv) the establishment of legislation with laws and bye-laws to regularize water production and use and to ensure the effective performance of the water resource plan.

11.5.1.2. **Data assembly**

Good water planning requires a sufficient and well-documented data-base. The data should cover the physical and economic aspects of all topics related to water resources. The assembly of such data should include the following:

Economic data

(i) Demographic, economic, land use and related data for the prediction of future demand on water expected during the period covered by the plan.

Hydrological data

(i) Data on surface runoff measurement, based on a well-distributed network of flood-gauging stations, in order to determine the mean annual volume of surface flow contributing to the recharge of the groundwater system.

Meteorological data

(i) Meteorological data are directly related to surface runoff through a well-distributed rain-gauging network. Data on radiation, wind, temperature and evaporation are all important to understand the effect these climatic elements have on surface flow and direct rainfall and the net volume of recharge water reaching the groundwater system.

Hydrogeological and general data

(i) Detailed and accurate determination of aquifer characteristics by geophysical prospecting, pump-tests and continuous monitoring of groundwater levels.

(ii) Detailed routine areal investigations to evaluate the physical, chemical, radiological and biological characteristics of groundwater by emirate or region. Also, continuous monitoring of groundwater for contamination by chemical and organic fertilizers and other toxic sources.

Such quality monitoring of groundwater is important for a water plan in that it would help define priorities in water use according to type (drinking, irrigation, industry and recreation). It would also provide the necessary information on quality should water in a certain area require treatment.

(iii) Accurate estimates of volumes of fresh and brackish groundwater in storage and their exact occurrence.

(iv) Exact quantification of uses of water resources by type in both the towns, where the greater part of the water supply is desalinated water, and the agricultural areas and rural settlements, where the supplies are wholly from groundwater.

(v) Continuous studies, based on experimentation, regarding augmentation methods to increase groundwater supplies by means of damming the seasonal flood waters, and also enhancing desalinated and recycled water production.

(vi) Accurate costing of water production and consumption to limit wastage. This is urgently needed for agricultural water consumption that makes up 95% of the total volume of the groundwater abstracted.

(vii) Studies of conservation methods in both domestic and agricultural water consumption to save on water. Also, studies of artificial recharge using desalinated and treated wastewater.

(viii) Studies of environmental aspects, which have not yet been addressed in the Emirates, to find out the effect certain measures proposed by the water plan have on the environment. Matters such as soil erosion, dewatering of aquifers and the sharp recession of water-tables are all important from the point of view of the environment. Data acquired from investigating all these aspects should be taken into consideration when formulating the water plan and testing its phases.

(ix) Continual assessment of the professional capabilities of the staff of the water-related institutions. Ensuring efficient performance of water resource departmental staff is crucial to the success of formulating and implementing a water resource management plan.

(x) Studies of the cost-effectiveness of the use of desalinated water for irrigation or artificial recharge are also important when setting options for water use in the plan.

(xi) Studies, in the case of brackish water desalination, should be carried out on reject brine disposal. This is at present disposed of *in situ*. The eventual infiltration of the brine into the brackish water aquifer would intensify water

salinities and would lead to resorting to more than one desalting stage, which would in turn increase operation costs.

(xii) Data on recycled wastewater quantity and quality are required in considering water from this source for recharge and irrigation options.

11.5.2. Objectives of a water resource plan

All the objectives of a water resource plan should aim at maximizing national economic development by providing adequate and clean water supplies to the various sectors of the economy. The objectives are attained by addressing all the elements of water resource problems. This is done by identifying the water problems and their dimensions. Such identification is only possible through a comprehensive appraisal of water resources on the basis of a well-assembled data base, as has already been discussed in the preceding section on the requirements of a water resources plan (Section 11.5.1). The data-base should cover the physical (water availability in space and time) and human (local and national politics, agriculture, economics) aspects. The problems are then addressed with alternative approaches to solving them partially or wholly. This is by no means an easy task to achieve in the Emirates in view of the physical and human disparities. The success of the water plan depends largely on the reliability of the data and the thoroughness of the appraisal of the water resources.

The problems a water resource plan for the Emirates should address are closely related to the data types the plan requires for its formulation (Section 11.5.1). The main problems the water plan should address to achieve its objectives include:

(i) water shortage in the conventional (groundwater) and the non-conventional (desalinated and sewage treated) water resources.

(ii) depletion of the fresh water Quaternary aquifer system and the ever-receding water-tables.

(iii) related to problem (ii) is the deterioration in water quality due to overabstraction and pumping water from the less transmissive Tertiary aquifers.

(iv) competition by various users over groundwater of potable quality in the same locality.

(v) confusion over priorities in water use (the use of desalinated water for irrigation, and brackish water for human consumption).

(vi) provision of adequate water supplies for all users on the basis of available water quantity and quality.

(vii) augmentation of non-conventional water supplies for artificial recharge to achieve water security.

(viii) restructuring the water-managing institutions to correct the professional inadequacies and prepare them to play their role in the formulation and implementation of the water resource plan satisfactorily.

11.5.3. The water resource planning process

A water resource plan should have a process and a scope. The process is the method by which the plan is implemented; the scope is the range of water resource problems to be addressed in the plan, and the level (either the emirate or the federal levels) at which the plan is to be executed. Although there is no set formula for a water resource plan, the broad stages of the process of a water resources plan are as suggested in Fig. 11.4..

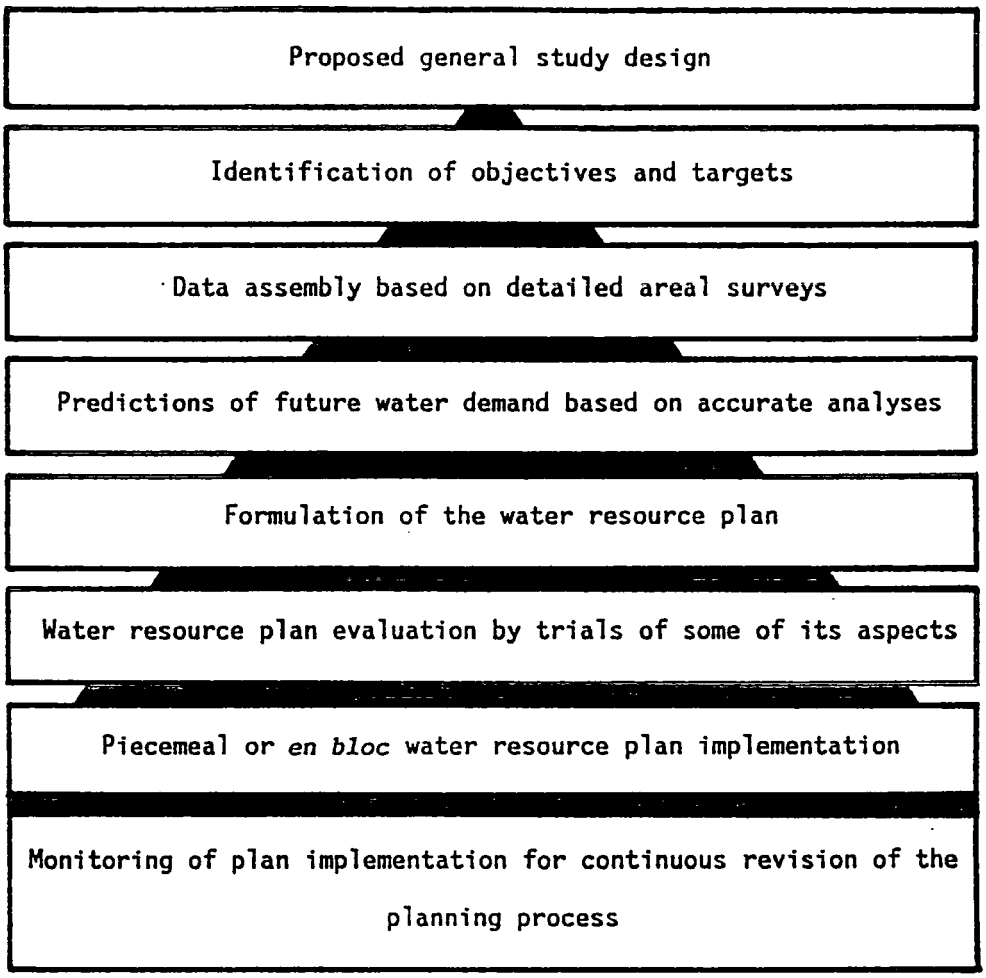


Figure: 11.4.

The broad stages of the water resource plan process.

Although there is no set formula for a water resource plan, these proposed stages for the process of such a plan for the Emirates would require a continuously furnished and revised data base. Such a prerequisite can only be offered by a competent, creative and aggressive water management that is capable of coming to grips with water resource management aspects and even keep abreast of developments in this vital field of activity.

11.5.3.1. The area of responsibility most likely to assume the task of formulating and implementing a water resource management plan in the Emirates

In the light of what has been discussed for the requirements, objectives and process of a water resources plan for the Emirates, it is within context to look into the matter of the area of responsibility most likely to assume the task of formulating and implementing a water resource development and management plan.

In their existing form, despite the revision of their hierarchical organizations (1990), the MEW and the MAF are the least qualified water-related organizations to assume the responsibility of water resource planning and management on a national scale. Whereas the MEW is strictly a water developer and supplier for the villages of most of the Northern Emirates, the MAF has no authority over agricultural wells. Neither ministry has a presence in the emirates of Abu Dhabi, Dubai or the main towns of the emirate of Sharjah.

On the other hand, the local water departments of the emirates of Abu Dhabi, Dubai and Sharjah are managing their public supply water sources relatively more efficiently than, for example, the MEW. The reason for this relative success is that these local water authorities collect a price for the water they supply to the town consumer, and this not only pays for the development of water sources but also provides an important source of revenue for the local governments. Whereas the local water departments of Al Ain, Dubai and Sharjah measure the groundwater they abstract from their public supply wellfields, the federal MEW does not measure the abstracted groundwater from its wellfields and single wells and the volumes are mere estimates. All the local and federal water-related institutions employ consultants to carry out water studies for them, or to help these organizations to solve certain problems, such as leakage in the supply system. Thus, the water organizations are not self-sufficient in expertise, and remain strictly suppliers of water and not managers of water resources in the comprehensive sense.

The central water resource management, that is management through a single federal organization, has not met with success. The delay in

implementing the High Water Resource Authority Law (1981) is evidence of that. The economic, political and social conditions for implementing a national water resource plan, development and management are not yet favourable.

The same difficulties would be met if planning and management are considered for the Emirates on the regional level (piedmont plains, the desert foreland or the east coast), because a region may be shared by more than one emirate. Thus, planning on this level is also ruled out for the time being.

The local (emirate) level appears, for the present, the most realistic of the approaches for the planning and management of water resources. This would not only make the area, in which water development is taking place, manageable by the local water department, but would also eliminate such problems as land rights and other related institutional matters. Thus, in the light of the existing local political conditions, the water plan on the local (emirate) level is more likely to succeed than that on the regional or national levels.

The only general cooperation between the emirates would be in the context of contingency measures. This would involve the transfer of water from an emirate that has a surplus, to another emirate that has a shortage. This in turn would necessitate setting up a water supply grid system within an emirate with linking facilities across interemirate borders to form a national water supply network operational at times a transfer of water to another emirate becomes necessary.

As most of the emirates (other than those of Abu Dhabi and Dubai) are short of funds to assume such water planning, development and management responsibilities, budget allowances, allotted at present to the MAF and the MEW, would have to be diverted to the local emirate water authorities. Water resource planning could be entrusted to a planning body as part of an emirate's water department or attached to the diwan of the ruler of an emirate. Representatives from each planning division in each emirate would have to meet at intervals to regularize any water transfer between the emirates.

11.6. Environmental considerations

11.6.1. Introduction

The impact of the overdevelopment of groundwater resources of the Emirates on the environment is yet totally unaddressed. Neither the decision-makers nor the water resource managers, nor the scientists, have developed the knowledge or concern about environmental issues. The large-scale development of the groundwater resources is bound to result in environmental problems as was depicted by the UN Water Conference in Mar del Plata (1977):

> "Large-Scale water development projects have important environmental repercussions of a physical, chemical, biological, social and economic nature, which should be evaluated and taken into consideration in the formulation and implementation of water projects. Furthermore, water development projects may have unforeseen adverse consequences affecting human health in addition to those associated with the use of water for domestic purposes "
>
> (UN Water Conference, Mar del Plata, 1977)

11.6.2. Water quality issues

11.6.2.1. General

Groundwater contamination is caused mainly be seepage of organic and inorganic chemical pollutants into the water-bearing strata. Toxic industrial pollutants are not yet of a dangerous level in the Emirates, although they are on the increase. The main seepage is from agricultural land, where there is heavy application of organic and inorganic fertilizers, some of which find their way with the recirculating irrigation water to the aquifer system. Other sources of contamination are: from septic tanks (which are the dominant sanitary disposal system in the Emirates); from leakage in the water supply system; from seawater intrusion and from abandoned or leaky boreholes.

Septic tanks form the main source of pollution in the towns and villages. Through and besides the septic tanks pass the plastic pipes

that carry fresh public supply water. The life of these pipes, before they develop cracks, is between 5-10 years. Agricultural activities pose the main source of pollution in the rural areas. Overapplication of organic and inorganic fertilizers, pesticides and leachate from animal feedlots, must lead some of these contaminants to find their way into the aquifers aided by the highly permeable sandy or gravelly soils. (Appendix 6).

Seawater intrusion in coastal areas is the main source of contamination in coastal aquifers (Chapters 5, 6 and 7), and in many areas, as in the Ras Al Khaimah coast, groundwater has been rendered useless for human consumption by excessive pumping. Besides seawater intrusion that is directly felt by the increasing chloride content in coastal waters, the effects of groundwater pollution have not received their due attention from both the government and the public. Specialized quality detection is rarely carried out by the laboratories of the water organizations beyond that of the usual ionic composition of groundwater.

11.6.2.2. **Management problems in water quality monitoring**

Of the water managing organizations in the Emirates, WED Al Ain keeps the most detailed, best-documented groundwater quality results for water samples taken more than once from the same well during the year. However, as wells are laid off for as long as two months to partially recover their levels, and other wells are deepened or cleaned, but in all cases still retain their old well numbers, the chemical analyses of a particular well may present inconsistent results, especially when there are no accompanying notes drawing attention to the circumstances at the time the sample was taken from a particular well. Such results should therefore be used with care. Nevertheless, they are the best available results from which trends in groundwater quality have been detected for the present study (Chapter 6).

Furthermore, the laboratory of WED Al Ain has recently started compiling results of water analyses for wells since their inception. Thus, the chemical composition of the water in these wells can be traced historically, while bearing in mind the reservation expressed above, as these analyses are not accompanied by explanatory notes. The results of

the water chemical analyses are completed promptly and are well documented, though they are presented in hand-written form.

The Groundwater Department of the Diwan in Al Ain has a record of most of the wells it drilled for the various water and agricultural organizations in the Al Ain region before handing them over to these organizations. The results of the chemical analyses are expressed in parts per million (ppm) (i.e., milligrams per litre (mg/l)) and there is a gross error in their presentation whereby the total sum of the cations adds up equally to that of the anions, which can only be the case in an accurately tested water chemical analysis in which the values of the ions are expressed in milliequivalants per litre (meq/l). An example of this erroneous presentation of water chemical results is included in Appenix 5. It points to the need in this water organization for the necessary knowledge in water resource quality management.

The MAF has the largest best-equipped laboratory in the Emirates (at Al Awha in Al Ain), and another old, small laboratory in Digdaga in Ras Al Khaimah. Both laboratories analyze soil and water solely for the MAF in the field of agriculture. Water chemical analyses for the MAF are few and the results are not made available to the public.

Although the MEW has 195 operating wells (including the wellfields) under its authority in the Northern Emirates, they are not all monitored for quality and for most of them not even the electrical conductivity is measured. Some wells appear in a list of results for a certain year, but are not included in the list for the following year, although these wells may still be operating. As the MEW laboratory attendants themselves collect the samples, a number of wells are missed out for reasons of accessibility or because they are judged as of secondary importance. The MEW water chemical results are not made available to public.

Dubai neglected groundwater quality monitoring of its wellfields when desalinated water started to comprise the larger part of its supply by 1980. The same can be said of Sharjah, which shares with Dubai the misfortunes of having most of the boreholes in its wellfields below MSL, besides lacking a good laboratory for water analysis.

Each water organization analyzes its water samples according to its needs and there is no standardized presentation of the results. Whereas WED Al Ain has the most acceptable presentation of water chemistry results for drinking water, those of the MEW, also supplying drinking water to the villages in the Northern Emirates, do not include the physical properties of potable water: appearance, colour, odour and taste, as do the analyses of WED Al Ain.

All the laboratories express their water chemical results in mg/l except the MAF laboratory at Al Awha in Al Ain, which presents its results in milliequivalent per litre (meq/l).

With regard to groundwater pollution, analyses are carried out more in response to rare complaints from members of the public than routinely for suspected wells, especially by the institutions responsible for the supply of potable water. The MEW has a more pressing duty to fulfil in this connection since most of its wells pump unchlorinated water directly to the consumers in the rural areas, and also because most well-heads are unprotected from the intrusion of pollutants through the borehole tube. In addition, there are more than 50 settlements in the mountainous areas of the Northern Emirates that receive their water supply by road-tankers (hired by the MEW) whose hygiene is doubtful (the exposed hoses used for filling the tanker as well as those for emptying its contents to the ground level tank near the households). In the MEW laboratory in Sharjah there are a few records of sewer-polluted private and government wells in the rural areas samples from which were brought in voluntarily by individuals (Appendix 6).

Thus, there is no standardization in the monitoring, analysis and presentation of water chemical and quality results. Bacteriological monitoring is occasional and causes of natural (seawater intrusion) or human (septic tanks and application of organic and inorganic fertilizers) contamination are not investigated and eliminted.

11.6.2.2.1. <u>Pollution hazards of water supply in the towns</u>

Pollution hazard in the water supply systems in the towns is a cause for concern. As long as the majority of households in the towns dispose of their sewage into septic tanks, which are normally dug within the

compound of a villa or just outside its main gate, the danger of bacteriological pollution remains a quality issue yet to be addressed. Domestic water is supplied to consumers through plastic pipes, which may theoretically have a life-span of more than 15 years, but the intermittent cutting off of the water supply and the trapping of air in these pipes reduces this life-span to between 5-10 years. In the event of a burst pipe, the two ends are joined by a smaller-gauged piece of pipe slid into either opening and tightened with metal clips. Such points of repair form sources of leakage and pollution. Another important source of pollution are the cracks that develop with age in the plastic pipes, especially just above ground level. Water supply pipes reach house connections after crossing or circumventing septic tanks and saturated sabkha soil containing infiltrates from such tanks. This situation is worsened by the shutting off of the water supply for a few hours daily, as happens frequently in Sharjah town, causing air to be sucked, and with it contaminants, ranging from chemical to bacteriological. There are many examples of private wells, dug in gardens in town households to water date palms, having been contaminated with infiltrates from the ubiquitous nearby septic tank (see Appendix 6).

In Sharjah in 1986 water supply to the houses in the then Chinese quarter (near the Government House) was also polluted from sewerage. In Dubai, in the police headquarters, drinking water was contaminated by brackish water from a separate pipeline supplying water for irrigation, by a mistaken cross-connection of the different unidentified pipes.

Large areas in most towns are still without a sewerage system and the situation becomes extremely critical during the rainy season when low-lying areas of the towns are flooded by storm water, which stagnates for several days, mingling with the contents of raw sewerage contents of the septic tanks. Al Ghubaibah in Sharjah, Hor Al 'Anz in Dubai and Mussafah in Abu Dhabi are examples of such areas. Abu Dhabi has almost completed its drainage system, while Dubai is fast taking steps to connect its various town sectors to the new sewerage plant at Al Aweer, which will greatly minimize the danger of bacteriological pollution.

A new source of contamination, that is fast on the increase, is the reject brine from the commercial reverse osmosis distillers, large and

small, installed in shops in the towns or in gardens and, in most cases, connected to the public supply system for their intake water. The reject brine is disposed of behind the shop or in the garden close to the distilling unit. In towns, the infiltrating brine can be sucked in by defective pipes of the public supply system; and in rural areas, it can find its way ultimately into the aquifer.

Licensing such distilling plants is on a commercial basis, by both the municipality and the local water department, regardless of the health hazards. The water department charges for the metered quantity used from the supply system; the municipality is supposed to be looking after the hygiene aspects of this activity.

11.6.2.2.2. Contamination hazards of groundwater outside the towns: Nitrate (NO_3), fluoride (F) and sulphate (SO_4) monitoring

Fluoride and sulphate contents are high in the groundwaters of the wellfields of central Abu Dhabi (Table 11.2.). Most of the groundwater in central Abu Dhabi is brackish, but there is a belt of fresh water in Al Qafa north of Liwa with TDS ranging from 966 to 1600 ppm. As can be seen in Table 11.2., sulphate values of the waters of Al Mariyyah, Attarq and Bida' Khalfan are within the maximum allowable limit for drinking water (400 mg/l), but are between 2-3 times the maximum limit for the other places (Dhafeer, Jaww Al Oad and Huwailah). Fluoride content in all the waters is extremely high, being between 3-9 times the maximum allowable limit for drinking water (which is 0.8mg./l).

The highest fluoride content is in the waters of Liwa where it is between 4.0-7.0 mg/l. Fluoride used to be excessive in the groundwater of Sharjah in the 1960s, when it was as high as 14.0 mg/l and was responsible for non-malignant skeletal fluorosis at a rate of 50 patients a year (McDougal and Sjovall, Arab Journal of Medicine, Vol. 2, No. 10). Present day water in Sharjah has a fluoride content maintained at less than 1.0 mg/l by mixing groundwater with desalinated water. Usually, waters with high calcium content above 75 mg/l (3.8 meq/l) do not contain more than 1.0 mg/l of fluoride (De Wiest, 'Hydrogeology', 1966), but the groundwaters of central and southern Abu Dhabi possess high values of both (Chapter 6, Sections 6.5.3.4 to 6.5.3.6.).

In the Northern Emirates, sulphate values are between 500-600 mg/l in potable water at Nuslah, Jareef and Riyamah; and are much higher in the brackish water at Sirrah, where the values are between 500-1000 mg/l and at Ruwaiyyah, where they are between 1000-2000 mg/l (MEW, Chemical Analyses, 1987).

Detection of nitrate (NO_3) is very limited, appearing occasionally in MEW yearly water analyses for a limited number of points. It is not monitored by all the agricultural departments because of the view that nitrate is favourable to plant growth. Few people here recognize that humans who consume water with a nitrate concentration of more than 50 mg/l may contract cancer of the colon.

The most direct cause of high nitrate concentration in groundwater is the intensive application of both nitrogenous fertilizers and dry organic animal manure, both of which are being applied to farm soils of the Emirates at a rate of 4-5 tons per annum, and this has been the practice for more than one-and-a-half decades of cultivation. Organic manure makes up 80-90% of the fertilizer applied to soil in the farms and, together with the decomposition of plant matter, becomes the largest contributor of nitrate in groundwater.

In temperate lands, lower concentrations of nitrate have similar effects to those of higher concentrations in the tropics. These have been outlined by Jensen (1982) who has shown that 30 mg/l of nitrate in the drinking water of the Danish town of Aarlborg, between 1943 and 1972, were thought to have been the cause of cancer of the abdomen. In the Emirates, there are a number of cases of cancer of the colon in Tawam Hospital in Al Ain, though these cases cannot be attributed definitely to nitrate in drinking water due to the lack of analyses of the waters in the areas of the Emirates the patients come from, and also the absence of any medical history for the patients.

30.4 mg/l of nitrates were reported in Sfini in 1987. This increased the following year to 48.0 mg/l (MEW, Water Analyses for 1987 and 1988). Sfini is situated on highly permeable wadi alluvium capable of high infiltration. There is however a time lag between the introduction of the fertilizers on the land and the effect these may have on the water-

table. This time lag is universally thought to be between 10-12 years. As the water-tables are receding progressively in the Emirates, the infiltration time becomes longer, but seasonal fluctuations in the water-table help to enhance the transfer of accumulated nitrate from the unsaturated zone down to the water-table.

Location	TDS (500-1500)* ppm	Fluoride (0.6-0.8)* mg/l	Sulphate (200-400)* mg/l
Jaww Al Oad 1/2	2457	6.0	700
Jaww Al Oad 2/8	3115	4.0	1000
Al Mariyyah (Liwa)	1160	6.3	230
Attarq (Liwa)	1575	5.5	400
Dhafeer (Liwa)	3985	7.0	1225
Huwailah (Liwa)	5095	4.0	1300
Bida' Khalfan	966-1600	2.0-4.7	170-500

* Values in brackets denote international allowable drinking limits.

Source: Water and Electricity Department (WED), Abu Dhabi, 1987.

Table: 11.2.

Fluoride and sulphate content in the waters of of the wellfields of WED Abu Dhabi in central Abu Dhabi and Liwa (1987).

As seen in Table 11.2, sulphate values are 2-3 times higher than the maximum allowable limits for drinking water in Dhafeer Jaww Al Oad and Huwailah. Fluoride content in these waters is between 3-9 times the maximum allowable limit for drinking water (0.8mg/l). Theoretically, such waters are expected to be used for drinking but practically they are being used for that end, especially by the farm labourers.

Countries all over the world are taking pollution by nitrate of potable water very seriously, and although it may not be easily detectable in the Emirates because of the time lag noted above, its impact may be felt

in the near future. Thus, detection of NO_3 is vital and this should be done by all the water-managing bodies.

Places where high nitrate content is suspected are under old-established date gardens, where there may also be decomposition of plant matter in addition to the generous application of both chemical and organic fertilizers, the leaching of which down the soil profile is aided by heavy watering. It is also likely to be found in agricultural areas where the water-table is relatively close to the surface, as at Liwa in the interior, and Dibba and Kalba on the east coast (on the lower parts of outwash fans). Another likely spot is on cultivated old indurated wadi terraces where ground-water is almost stagnant.

With the help of heavy fertilizing, the most widely grown crop in the Emirates is alfalfa, and it is also the most water demanding, using 10,432 m^3/a with the sprinkling and 11,518 m^3/a with the flooding, irrigation methods, per hectare. Although the roots of the alfalfa grass have an exceptional ability to absorb NO_3, some of the ion finds its way to the water-table, aided by excessive irrigation and flood flows.

With the suspected nitrate pollution areas noted above in mind, some samples were collected for the present study to test such a possibility. These samples were analyzed for nitrate (NO_3), fluoride (F), sulphate (SO_4) and electrical conductivity (EC). The results are given in Table 11.3.

As seen in Table 11.3. there is a high concentration of nitrate in the water of Al Hayer (Al Ain), Hisan, Malqatah and Al Rudoom (Liwa). The water in Al Hayer is used for drinking and irrigation. The maximum limit for nitrate is 50 mg/l. Fluoride concentrations are within the acceptable limit, while sulphate is higher than the recommended maximum limit (400 mg/l) in half of the samples.

Location	EC mmhos/cm	NO_3 mg/l	F^- mg/l	SO_4 mg/l
Al Kharran	9100	10.0	1.1	600
Al Hamraniyyah	2250	20.0	0.5	198
Al Manama (well)	860	5.0	0.3	162
Al Manama (falaj)	860	20.0	0.4	150
Al Muraqqab	3050	20.0	1.2	410
Al Hayer (gov't nursery)	2800	100.0	0.4	396
Shah (Liwa)	5500	70.0	1.1	921
Hisan (formerly Himar,Liwa)	9800	138.0	1.0	1100
Malqatah (Liwa)	10100	121.0	1.1	1300
Al Rudoom (Liwa)	9050	105.0	0.9	1060
Sfini	5800	53.0	0.7	980
Kalba	2850	66.0	0.9	550
Dibba	3100	67.0	0.6	400
Falaj Al Mualla	2650	42.0	0.8	89

Table: 11.3.

Results of water analysis showing Nitrate (NO_3), Fluoride (F^-) and Sulphate (SO_4) occurrences in selected locations in the Emirates (June 1989).

Notice the high NO_3 values in Al Hayer, Hisan, Malqatah and Al Rudoom. In Al Hayer, such water is used for drinking by at least the farm workers of the government plant nursery, the water sample was collected from, and possibly in the surrounding private gardens. Al Hayer is a sizeable modern village that gets its supplies from wells *in situ*.

Generally, there is a marked inadequacy in chemical, and almost total absence in bacteriological monitoring. From the foregoing, it is clear that there is a pressing need for upgrading routine quality and contamination monitoring, at least in areas where hazardous amounts of the above-mentioned, and other contaminants, are suspected to occur. The presentation of water analyses should be standardized, however limited the interest of the water-testing party may be.

11.6.3. Water quantity issues

11.6.3.1. General

The main groundwater quantity issue is the severe mining of the Quaternary fresh water aquifer in various parts of the Emirates. This is more pronounced in the piedmont plains, especially in the southern parts of the plains in the Al Ain region where groundwater levels have sunk in the past decade from 10-15m. to more than 500m. Such continuous drop of the groundwater levels must lead to the compressibility of the dewatered aquifer material and an eventual subsidence of the land. The continuously receding groundwater levels have also led to the deepening of boreholes in pursuit of these levels, and so adding to pumping and irrigation costs. This is not felt by the water users as economic considerations related to water production are not taken into account. Groundwater overabstraction has already led to reduced base-flows, the drying up of most of the aflaj and the inducement of mixing of fresh to marginal groundwater with saline to supersaline groundwater in both inland and coastal aquifers.

11.6.3.2. The problem of seawater intrusion

It is an established fact that, due to the overpumping and interception of groundwater flow, seawater intrusion has advanced inland along the fresh water alluvial tongues, such as that of Wadi Sha'am in Ras Al Khaimah or that on which are situated the main wellfields of Dubai and Sharjah of Aweer, Hibab and Badea'. As has been noted in Chapter 5 (Section 5.5), most of the boreholes in these wellfields have their pump-levels below MSL, and seawater intrusion reaches up to 20km. inland. Salinities increased in Al Aweer wellfield from 1100 ppm. in 1963 to 2100 ppm. in 1988. In Al Badea' wellfield salinities have even worsened more and only mixing groundwater with desalinated water helps dilute the high water salinities in the water supply of both Dubai and Sharjah.

In Ras Al Khaimah, the Sha'am group of four wells, developed in 1978, was, except for one well, shut down in 1985 due to high salinities

attributed to seawater intrusion. Well No. 4 still gives water of reasonable quality, as this well may be tapping groundwater from a buried fresh water wadi channel. The MEW developed a new wellfield upgradient, in Dhuhuriyyeen, in 1982. Even this new wellfield started with a TDS value of 470 ppm. (1982) and seven years later (1989) the TDS increased to 1450 ppm. despite its location 8 km. upstream from Sha'am on the coast.

Again, in the Seih Al Fahlain wellfield in Ras Al Khaimah (15 km. inland) salinities have risen to unpotable levels forcing the MEW and the government of Ras Al Khaimah to develop new wells nearer to the foothills to the east (1988-89). In a recent analysis of a water sample collected by the present study from a date garden in Al Kharran (June 1989), the TDS measured 6000 ppm.(EC 9100 mmhos/cm.). Al Kharran is half-way between the Ras Al Khaimah coast and Seih Al Fahlain (Table 11.3.).

Sahwat wellfield, about 6 km. inland from Khawr Khuwair, provides a classic example of seawater intrusion. This has been proved by a chemical analysis showing a marked increase in TDS, especially in chlorides, accompanied by isotopic enrichment with more contribution of chlorides from intruding seawater. A reduction in the tritium value from 6.7 TU (tritium units) to 3.7 TU in just one year (1985-86) indicated less recharge with fresh waters getting salinized into a mixed water zone of fresh and seawater (see Chapter 7, Section 7.7.3.1). Well No. 4 in Sahwat increased in TDS from 480 ppm. in 1982 to 1987 ppm. in 1987, to 3600 ppm. in 1988 (MEW chemical analyses for 1982, 1987 and 1988), and it is still deteriorating because of excessive pumping rates from the wells of above 9000 m3/h (2.0 mgd).

Facilitated by the narrowness of the coastal strip, seawater intrusion is more pronounced on the east coast than on the Ras Al Khaimah coast. In Sharm, the TDS was 370 ppm. in 1982 and became 1500 ppm. in 1987. In Fujairah, salinities turned two-fold from 1000 ppm. in 1982 to 2000 ppm. in 1988. However, the worst case of seawater intrusion is at Sakamkum, where the salinity worsened by four times from 900 ppm. in 1976 to 4000 ppm. in 1988 (tested on site for the present study). The two unfavourable water salinities for Sharm and Sakamkum have been dropped from the MEW 1988 Water Analyses handbook.

The solution to which the MEW resorts wherever there is a seawater intrusion, is to develop new groundwater abstraction points upgradient of the older contaminated ones. In many cases, where in a single wellfield there are wells with reasonable quality water, and others brackish, abstraction from the former is increased and that from the latter decreased. However, the MEW resorts to the easy option and starts drilling upgradient and, with this uphill movement, moves the saline seawater front. The limiting factor in moving further up the wadi may be the cost of a pipeline that may be required to transport the water from the new wellfield to the consumers rather than the ill-advised drilling upgradient.

11.6.3.3. Land subsidence as a result of groundwater level decline and aquifer depletion

The dewatering of aquifers and the progressive recession of water-tables to great depths are the likely cause of subsidence of the overlying land. These two closely related conditions have already been reached in several parts of the Emirates, but their repercussions in the form of land subsidence are unconsidered and no attempt, however small, has been made to monitor any signs of change on the surface. The land subsides as a result of compaction of the dewatered water-bearing strata and the increase of the pressure by the weight of the overlying layers as the 'buoyancy' effect, that was provided by the water in the interstices, is removed.

Areas where subsidence may be happening include the vicinity of Al Ain town where groundwater levels were only 2-3 m. below the surface in hand-dug wells less than two decades ago. A visit was made (January, 1990) to the well in the garden of Ahmad bin Sultan Al Salami in which the water-table dropped from about 2.0m. below the surface in 1971 to 33.0m. in 1983 to 210.0m. by 1985. Other areas, such as Al Hamraniyyah and Al Dhaid further north, are also centres of heavy groundwater abstraction and fast-falling water-tables. In Al Dhaid, extensive tracts have been dewatered as discussed in Chapter 5. Also in large wadis such as Wadi Al Beeh, where both water-table and confined aquifer conditions occur, groundwater levels have sunk deep in the past two decades. In

central Abu Dhabi, the great volumes of brines abstracted from the deep carbonate aquifers of the Simsima, Um Er Radhmah and Dammam for oil operations, may also lead to subsidence of the thick overlying strata.

The study of land subsidence may provide good scientific training for the students of the Faculties of Science and Engineering of the Emirates University or the recently established Colleges of Technology. At present no such research is carried out. With regard to the effects of the withdrawal of groundwater from the deep carbonate aquifers, the oil companies should be compelled to monitor any signs of subsidence of the land.

All water and engineering organizations ought to be bound by law to study the likelihood of land subsidence. This is important owing to the irreparable repercussions of subsidence involving the permanent destruction of groundwater storage capacity of aquifers by the compaction and the filling of the interstices with clay and silt, disturbing overland elevation (survey) points, the dislocation of the aflaj and the clogging of borehole screens with fines causing great stresses that might lead to the caving-in of wells. This last phenomenon is already of widespread occurrence in many parts of the Emirates.

The possibility of land subsidence due to the dewatering of aquifers should not be underestimated. A drop of 30m. in the piezometric level in the vicinity of Mexico City caused by continuous pumpage from 2200 wells, at a total discharge rate of $7m^3/sec$. led to subsidence of the land within the city limits at a rate of 1.0mm/d (Carillo, 1948) . All the physical prerequisites of land subsidence, such as reduced discharge rates of wells, the continuous drop of groundwater levels and the dewatering of aquifers are already being experienced in more than one area in the Emirates.

11.7. Conservation and augmentation of water resources

11.7.1. General

The Longman New Universal Dictionary (1982) defines conservation as the "careful preservation and protection, especially of a natural resource, the quality of the environment, or plant or animal species to prevent exploitation, destruction, etc." In the field of water resources, this means conservation of the resources by planned management. This would involve augmenting supplies as well as conserving the resources by regulating their use according to priorities based on the available quantity and quality of water.

In the Emirates, water conservation is not yet fully realized and all the steps taken to that end have been limited to public announcements, mostly addressing the urban water consumer, urging the public to economize in the use of water; and also to the introduction of modern methods of irrigation, which will be discussed in detail in the next section (11.7.2). There has been more emphasis on augmenting than conserving water resources. The achievements in augmenting water resources include:

(i) The construction of earth retention dams across Wadi Al Beeh, Wadi Ham, Wadi Idhn and Wadi Gulfa, and a weir in Wadi Al Ghail.

(ii) Limited falaj repairs up to 1984.

(iii) Large-scale production of desalinated water since 1978, which has to a great extent taken the burden of water demands by the large towns.

(iv) Expansion in sewage water treatment in the four towns of Abu Dhabi, Dubai Sharjah and Al Ain.

As noted above, publicity for water conservation is directed to the town consumer, although the aggregate domestic water consumption is hardly 5% of the total volume of groundwater abstracted every year. Domestic consumption can be controlled to some degree by crude methods, such as

reducing the pumping pressure in the town's water supply system or even shutting off the supply for part of the day, which is a common daily practice in most of the towns of the Emirates. The consumption of groundwater by agriculture is hardly addressed despite being responsible for the remaining 95% of the total volume of groundwater abstracted in the Emirates. Thus, the wisdom and usefulness of such conservation publicity by emphasis on urban consumption is questionable.

The attention of water conservation should be directed to the agricultural sector, where most of the irrigation water is lost through inefficient irrigation methods and wrong water application practices to a largely unnecessary cultivation. The modern irrigation techniques (the sprinkler, bubbler and drip methods) become less water conserving by the longer time of water application without adherence to actual crop water requirements. The general water conservation issues in the agricultural sector include:

(i) Avoidance of overwatering in the farms.

(ii) Adherence to crop water requirements.

(iii) Proper use of modern irrigation methods to ensure efficient irrigation.

11.7.2. Modern irrigation techniques versus water consumption

It has been shown in Chapters 8 and 10 that irrigation water use accounts for 95% of the total groundwater abstracted in the Emirates. In Chapter 8, the crop water requirements were discussed. In this section of the present chapter, the actual contribution, if at all, of the modern irrigation techniques, sprinkler, bubbler and drip methods, to water saving, is examined.

Modern irrigation methods were introduced in the Emirates a little more than a decade ago, and are being adopted in the farms on an increasing scale. In the emirate of Abu Dhabi, where subsidies for installing and maintaining modern irrigation methods amount to 50% of their total cost, the ratio of the land under modern irrigation to the total cultivated

land, is 59%. Almost all the 'forest' projects are using drip irrigation. In the northern emirates, on the other hand, the subsidies that once matched those in Abu Dhabi, have been discontinued and farmers in this part of the country bear the full cost of any irrigation method they wish to install on their farms. As a result, the ratio of the land under modern irrigation methods to the total cultivated land is only 19% (Table 11.4.).

The basic intention for installing modern irrigation techniques was to save on irrigation water. The adoption of the modern irrigation methods has been coupled with an extensive development of agricultural land, with a large proportion of the agricultural holdings being more of the recreational type (private gardens, not crop farms). Contrary to the official statements that the modern irrigation techniques economize up to 50% on irrigation water, the percentage is in reality less. All the three types of modern irrigation methods, taken together, consume only 20-25% less water than the traditional furrow-and-basin (inundation) method.

In a study by the FAO irrigation engineer Loucas Savvides (1984) on modern irrigation systems in the Emirates (carried out for the MAF), it was found that 4560 hectares (ha.) under modern irrigation systems consumed 112.10 MCM/a of water, at a rate of 24,583m^3/ha/a. On the other hand, 17,722 hectares under the traditional irrigation techniques used up 537.40 MCM/a, at a rate of 30,324m^3/ha/a. Thus, the consumption per hectare of land by modern irrigation is about 81% of that by the traditional, mostly basin flooding, method.

Observed in the field for the present study, the sprinkler irrigation method is on the increase and is fast replacing the drip method (May, 1989). Sprinklers of 12 x 12 m. spacing with a 3/4" riser, had a water discharge rate of 1.75m^3/h. Since they were operated for an average daily duration of 14 hours, the daily volume discharged by the sprinkler was 25 m^3/ha/d. Basin flooding, on the other hand, took an hour to apply a volume of 30 m^3/ha, which was done once a day. This makes the volume of water used by the sprinkler irrigation method about 83% of that used by the basin flooding method.

It is estimated that in Ras Al Khaimah alone 60% of the farms that once used the drip irrigation method have changed recently to the sprinkler method (1990). Drip irrigation has salinized the soil, not only horizontally for about 20 cm. around trees, but also vertically through the soil to a depth of 30 cm. Farmers rarely stir the soil to spread out salt encrustation and are less enthusiastic to adopt leaching methods repeatedly recommended by the agricultural guidance schemes of the MAF. The sprinklers also cause salinization of the soil, and this is even more widespread corresponding to the coverage of the field by the sprinkler. The vertical extent of salinization by the sprinkler irrigation method is, however, less concentrated and shallower (5-10cms.) than that caused by drip or the bubbler methods.

It was also observed that the sprinklers would be left in operation for many hours, which in some places extended to 20 hours, unattended. Even in the case of the drip irrigation, the drip regulators were opened fully and were allowed to run for a long time, and in some places were seen in operation round the clock.

Statistically, for the country as a whole, the ratio of the land under modern irrigation methods to the total irrigated land is given in Table 11.4., which presents data for the agricultural year 1987-88. Only agricultural land is portrayed; forest land being excluded.

It should be noted that despite the increasing adoption of modern irrigation systems, water consumption by the agricultural and forestry sectors has increased phenomenonally. Even in the days when the federal government subsidized the installation of the modern irrigation system, the MAF had no control over their operation. It has no power to make the beneficiaries from the subsidies adhere to the stipulated crop water requirements. The result has been that the soil has been overwatered and so has become a breeding ground for fungus and bacteria that have taken their toll of the crops over the past few years. The striking observation is that modern irrigation methods are being used by people with the old farm irrigation habits in their minds. Like many other new methods introduced to other sectors in the Emirates, the modern irrigation methods are left to take care of themselves. Conservation in concept and practice is still far from being realized by both the authorities and the public alike. Only by the enforcement of a

legislation regularizing water use in the agricultural sector can any advance towards conservation be made.

Region	Area under modern irrigation methods	Area under traditional irrigation methods
Al Ain	15,513 ha (59%)	10,688 ha (41%)
Northern Emirates and western Abu Dhabi	9,392 ha (19%)	39,878 ha (81%)
Total for the Emirates	24,907 ha (33%)	50,566 ha (67%)

Bracketed percentages show the ratio out of total irrigated land.
Source: Statistical print-outs, Central Computer Office, 1988.

Table: 11.4.

The ratio of irrigated land by modern and traditional methods to the total irrigated land by region (1988)

The modern irrigation methods use only between 20-25% less water than the traditional inundation method and this is provided water is applied according to the stipulated crop water requirements. With the long application by these modern methods, the benefits of water saving hoped for from these methods is greatly minimized.

The principle of encouraging agricultural development with the aim of achieving food self-sufficiency or diversifying the income of citizens is sound, but such development should be related to economics whereby the various cost inputs into the agricultural production process are considered. Foremost among these inputs is the cost of water. To allow other forms of 'greening' by greatly increasing the cultivated area, most of which can appropriately be described as recreational (private

non-food producing gardens), is unaffordable; at least as far as water is concerned.

11.7.3. Methods of conserving and augmenting domestic water supplies

The average actual per capita consumption of water in the towns of the Emirates is 317 lpcd. (Table 11.1.) As all domestic water consumption accounts for only 5% of the total water consumption of the Emirates, residential water conservation methods, if effected, would contribute little to conserving water. Water conservation methods in domestic consumption may include water-saving devices installed on existing water supply fixtures in the household to minimize water use, especially in bathrooms and home gardens, which are the largest consumers of domestic water. The consumption of water for gardening may be reduced by fixing automatic time-controlled sprinklers and opting for drought-resistant plants, not only for the home garden, but also for the town municipal landscaping schemes.

To rely on the consumer to conserve water by cutting back on use is not likely to succeed as the use of water for domestic, gardening and industrial use come from the same single supply source. There is no segregation of water types for the different uses in separate supply systems, such as brackish or recycled water for general purpose, and desalinated water for human, use.

Changing water rates may be a powerful regulator of water saving. The flat rates or low metered rates may not encourage a reduction in water consumption; a higher charge for the water consumed may help to some extent in cutting back water use. However, when applying water charges, there should be no discrimination between a consumer and another. For example, a small town-consumer may pay the high water rate though his water consumption is small. On the other hand, a large town-consumer, may be exempted from paying for the water he consumes, though his water consumption is large. Moreover, all these conservation measures are strictly aimed at the domestic user and the water saving from his consumption may be a fraction of the 5% for domestic consumption out of the total water supply of the Emirates.

11.7.3.1. Urban storm runoff

Urban storm runoff is the storm water that flows in the streets of towns, after every winter rainstorm, and eventually finds its way to the town's sewerage system. However, as there are neither the facilities in the sewerage works to receive this storm water, nor are there perennial streams into which this urban runoff may collect, the definition of urban storm runoff may be extended to include all storm water in urban areas that ponds for days in several quarters of the towns, and is pumped into road-tankers to be disposed of in the outlying desert areas. Though such a resource is of occasional occurrence, and is not recognized as important by the municipalities in charge of the sewerage works, it is nevertheless a potential resource that may be collected in central ponds from where it may either be recycled with urban wastewater, or led by a separate pipeline to selected points in recharge areas and allowed to infiltrate into the groundwater system. By the latter method, no physical or chemical treatment is required as the sand would act as a filter in the vertical passage of the water to the aquifer.

11.7.3.2. Recycled wastewater for recreational use

Recreational water used directly (ponds, lagoons) and indirectly (as irrigation water for the town reserves and parks) is largely made up of treated wastewater. In Lake Khaled in Sharjah, half-treated wastewater (the excess from the sewerage plant) is directly disposed of into the Lake, which is used for skiing and other water sports. The town road reserves and parks in the towns of Abu Dhabi, Dubai, Sharjah and Al Ain are mostly irrigated with treated sewerage water that is not totally devoid of pathogenic organisms. These open green spaces are recreational outlets for the public, whose members come into contact with the spray of the irrigation water on the lawns. Reused treated sewerage water for irrigation or recreation purposes must not contain more than 2-3 coliforms per 100 ml.

The problem in looking at this resource as a possible avenue for water conservation to use as irrigation water for non-edible crops, or as a source for aquifer artificial recharge, is that it is fully utilized and is even short of meeting the demand of the municipal town reserves.

Only limiting the expansion of horticultural areas in the towns can allow water from this source to be directed to other uses.

11.7.3.3. Weather modification to augment water resources

There are two methods of inducing precipitation in clouds:

i) by adding ice nuclei in the ice-deficient cloud; and

ii) by adding seeding material to the cloud to change its dynamics and increase its size.

Both methods have not met with much success. Cloud seeding operations in the Emirates are restricted to the Air Force at Al Dhafrah (Western Military Command). In the United States, cloud seeding resulted in only 10% increase in precipitation [1], and in the Emirates it has not produced any clear positive results.

11.7.4. Ways of conserving and augmenting agricultural water supplies

11.7.4.1. General

As irrigation water consumption forms 95% of the total volume of water abstracted in the Emirates, and since agriculture is everywhere competing with potable water sources, and agricultural water consumption is not charged, all water conservation efforts must be directed towards water consumption by agriculture.

The question to be asked is: what form of conservation policy should be pursued in relation to the water resources of the Emirates? Should the water conserving measures be implemented on a permanent basis *in lieu* of prospecting for new sources of water? or, should such measures be implemented as an emergency resort whenever there was an acute shortage, while at the same time developing new water sources?

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(1) Congressional Research Service, Library of Congress, Weather Modification; Programs, Problems, Policy and Potential, committee print, 95th. Cong., 2nd Sess., Gov't Print Off., Washington, D.C., 1978.

The water resource status in the Emirates is so critical that nothing less than an established permanent conservation policy is needed to redress it. To implement conservation measures on existing water use practices would be a recognition of the existing wasteful uses of water in avenues that are not economically viable or doing enough to achieve food security. It is therefore important, before embarking on any conservation measures, that priorities in water use, especially that of agriculture, should be corrected.

The obvious grading of priorities in water resource management puts water for potable use before all others. However, this is not the case in the Emirates in all the areas of groundwater abstraction for domestic purposes. The best example of confused water exploitation is in the northern dune and alluvial areas of Al Ain. There was no agricultural development of any size in this area prior to 1975. Once the chain of public supply wellfields had been developed between 1975 and 1982, agricultural land was extensively allotted so that at present private and government agricultural wells are competing for water with wells of the public supply meant for human consumption. Large commercial farms occur between the Al Hayer North public supply boreholes, and this is especially noticeable between Al Awha and Al Faqa'. The Al Awha government wheat farm, north of Al Ain, is situated in the same vicinity as the Ghashabah public supply wellfield. Salinities in the boreholes of the government wheat farm have increased sharply since 1977, and the discharge rates in both the public supply and wheat farm boreholes have decreased. Similarly, farms have sprawled around the public supply wellfield of Um Ghafah since it was commissioned in 1982. Besides the rise in groundwater salinities, parts of the aquifer in Um Ghafah have been exhausted. Water for the farms in Um Ghafah has been supplied from the potable public supply reservoir since 1988.

11.7.4.2. Artificial recharge

Aquifers in arid regions, such as the Emirates, are depleted by overpumping. Artificial recharge poses as the likely option, not only to redress the depleting groundwater reserves, but also to help push back the seawater front in coastal aquifers. It also completes the treatment of half-treated wastewater, if this is used as a source water for artificial recharge, by sand filtration. The following are the

common methods of carrying out artificial recharge of aquifers in an arid environment lacking perennial streams that may be hydraulically connected with the water-table:

i) **Surface spreading**: This refers to periodic flooding of shallow basins in a favourably permeable soil. The process is helpful in ameliorating rising groundwater salinities. The method befits unconfined aquifer systems, as is the case in most regions in the Emirates. Infiltration of the recharge water is direct into the saturated groundwater zone.

On the same principle are the earth retention dams built across some of the major wadis of the Emirates. Flood waters pond behind dams and, despite the high evaporation from these waters and the silting of the wadi floor, part of the waters recharge the aquifer through the wadi alluvium. However, the benefits are short-lived due to the fact that mountain wadis are low in storage capacity because of horizontal and vertical physical limitations. As a result the recharged water quantities are either pumped out within a short time of recharge, or spread out extensively in the outwash fan of the wadi concerned a short distance downstream of the retention dam (see section 11.7.4.3 on Wadi Ham).

ii) **Direct injection**: This method involves injecting the recharge water through boreholes into the aquifer system. The method is suitable for aquifers underlain by a confining impermeable layer that impedes the continuous free movement of water to depths. The process is most effective in coastal aquifers affected by seawater intrusion, such as the east coast at Fujairah and Dibba and the west coast of Ras Al Khaimah. Its major failing is that the pores of the aquifer deposits become clogged by fine particles or organic matter (the latter problem occurs if the recharge water used is half-treated wastewater). This clogging limits the storage capacity of aquifers, and is almost impossible to repair.

Both recharge methods require excess water that should be made available for artificial recharge. As the availability of such excess water is at

present remote, any artificial recharge should be part of a comprehensive water conservation policy. More treated wastewater can become available if its existing application in the municipal horticultural schemes is reduced. With regard to the other augmented water source, desalinated water, which is already being used to irrigate town reserves and some forestry projects, may as well be directed to artificial recharge with even more beneficial long-term results to groundwater reserves. The enhancement of desalinated water production, and that of treated wastewater, to provide surpluses for artificial recharge, can only be achieved by placing a ceiling on the 'greening' drive that may absorb any new volumes of water made available by extension schemes to the desalination and wastewater treatment plants.

The feasibility of using desalinated water for artificial recharge may be disputed on economic grounds. If cost-effectiveness is not taken into consideration, as is evident in using desalinated water for economically unviable agriculture, forestry areas and parks or the laying of a 45-km. pipeline to transfer part of the 1.0 mgd desalinated brackish water from the RO plant at Al Wagn to the consumers in Al Qoa' (both villages lie to the south of Al Ain), why should it be a disputed issue to use any desalinated water surplus for artificial recharge? In the desperate groundwater resource situation that exists in the Emirates, redressing groundwater depletion is bound to be unconventional and expensive. There is no escape from redressing the unfavourable groundwater imbalance by artificial recharge, however delayed is the action to implement this option.

11.7.4.3. The recharge potential of the Wadi Ham flood retention dam

The Wadi Ham flood retention dam was constructed across Wadi Ham at a point about 9 km. upstream from Fujairah. The earth dam was built over 40m. of both less compact Quaternary and compact Tertiary alluvium. As described in Chapter 5, mountain wadis exhibit extreme fluctuation in groundwater levels owing to their limited storage capacity. The construction of the dam (1983) was followed by extensive agricultural development downstream of the dam-site with a subsequent heavy demand on water far exceeding the volume expected as recharge from the retention dam. The result has been the pumping of the recharged water in the

alluvium and the fractured bedrock. Farm owners have continued complaining of water shortages as they did before the construction of the dam, especially in the old date gardens.

The acute water shortages drew attention to the groundwater potential of the Wadi Ham basin and its outwash fan. The MAF, the overseer of the Ham dam project, invited two teams of water experts: from the US Department of the Interior, and the National Engineering Services of Pakistan (NESPAK). The two teams were asked to find answers to two specific questions: is the Wadi Ham dam contributing to recharge? and, is the dam underlain by a structural fault suspected of siphoning the recharge water?

The answer to the first question lay obviously in the marked fluctuation of groundwater levels in the wadi alluvium, which is particularly pronounced in the piezometric Well BHF-15 situated 900m downstream of the retention dam (refer to Figs. 5.29 and 5.43, Chapter 5 for the location of this and other wells referred to in this subsection), but getting less marked further downstream. The investigations of both teams of experts were undertaken after the rains of March 1987 and involved single-day field visits to the site for each team. The fluctuations in groundwater levels were a clear indication of changes in groundwater storage caused by recently recharged water. It was determined by NESPAK that groundwater movement before the March 1987 rains was 15,000 m^3/d, and after the rains it was 17,000 m^3/d. The difference of 2000 m^3/d was the volume that flowed across the line of Wells BHF-9A and BHF-9B (Figs. 5.29 and 5.43, Chapter 5). for the period of 8 months (April to December 1987), the total volume of water was 480,000 m^3, which was the recharge amount into the aquifer. This correlated with an earlier design estimate by Electrowatt (the designers of the dam in 1979) of 700,000 m^3/a. The annual demand by Fujairah town in 1987 alone was 3.0 MCM/a, in addition to the unquantified volume abstracted by agriculture in the Wadi Ham and its outwash fan.

With regard to the second question about the fault-line, again the MAF data from previous studies were used, especially those of the seismic profiles across Wadi Ham. Bedrock velocities were estimated by Geoconsult-Iwaco (1982-86) to be 2000-5000 m/sec. As no lower velocities were indicated at the profiles, it was concluded by both

NESPAK and the US Geological Survey that the bedrock was tight with no major fault detected into which recharge water might disappear. Furthermore, the Lavalin infrared thermal imagery (1980) did not detect any submarine springs off the Fujairah shoreline, which is the outer limit of the Ham outwash fan at whose head the Ham Dam was located.

The conclusion of the investigations were that there was recharge on average of about 0.7 MCM/a, there was no fault-line into which recharge water may drain away and that it was only the heavy groundwater abstraction, by both the agriculture and domestic sectors, which far exceeded the expected recharge volume, that were the obvious cause of the shortage in the groundwater supplies of the lower Wadi Ham basin (Groundwater Recharge through Wadi Ham, National Engineering Services Pakistan (PVT.) Ltd. (NESPAK), (unpublished report), 1987).

The fact that available MAF data were used to find the answers to the two questions, and that such questions should have been answered by MAF staff with its long association with previous projects from which the data for answering the two questions were borrowed, attests to the inadequacy of knowledge and paucity of ministry studies of the outstanding problems that a good water management would obviously be able to conduct.

11.7.4.4. Steps to conserve and augment water resources

The limited effect of the modern irrigation methods on saving water has already been demonstrated (Section 11.7.2.). It has also been shown how the domestic consumer is charged for the water he uses, while the agricultural user has no obligation towards water resource use at all. Any publicity that urges the rationalization of domestic water use has reaped limited dividends. The government, which allots agricultural land, drills wells in it (especially in Abu Dhabi) and fits these wells with motor-pumps, subsidizes seeds and fertilizers and offers free veterinary and agricultural guidance services, is the only area of responsibility qualified to effect any conservation measures to agricultural water use by tying all these facilities to a regulated and responsible use of irrigation water on the farm. However, the various government departments concerned are apparently unable to do so.

In principle, the following two broad approaches may be suggested to attempt conserve water use by the agricultural sector:

i) Accepting the existing arrangement of one or more wells in a farm, but strongly advising farmers to adhere in their application of water on the land to the published crop water requirements. This can be enforced by official inspection from the local agricultural offices, and penalties can be applied ranging from fines to the imposition of charges for the free services outlined above.

ii) Implementing the recommendations of the UN Water Conference of Mar del Plata (1977) within the context of the "use of groundwater on the basis of communal distribution system" for which the following steps were suggested:

a) to develop groundwater within the available resources;

b) to encourage the sharing of water by all users;

c) to drill communal wells;

d) to construct common irrigation canals;

e) to put an end to friction and competition;

f) to rationalize the use of groundwater resources;

g) to use water within a viable economic context.

It must be stressed that communal use of water is not new to this part of the world. The falaj was a common water source used by a whole community according to a well-established regime by which all agricultural plots received their quotas of irrigation water. Even domestic use had its respected priorities whereby water for human consumption was taken from the first point at which the falaj appeared, while sections of the falaj channel further downstream were for other uses such as washing, bathing and irrigation. Individualism in water use has taken roots with the sudden affluence caused by the oil boom and

will be hard to shake in the process of implementing the above suggestions for collective water use.

In detail, conservation in water use by the agricultural sector may be achieved by attempting to set the following priorities in order:

i) To establish the economic viability of agricultural production according to a carefully studied agricultural plan the main aims of which should be to achieve food security in order to justify the large amounts of water used by agriculture and also the subsidies offered to agriculture.

ii) To discourage agricultural activity of a purely recreational nature, such as the unproductive private gardens. Those private 'recreational' gardens that already exist, should be screened on the basis of one garden for one owner only, and should be charged a water tariff for the water they use, even though they may adhere to the rules of crop water efficiency as may be endorsed by the agriculture inspectors. In the long-term these gardens should be encouraged to transform gradually to crop production. The reason is that such agriculture at present is economically unjustifiable and is not contributing to food security in an environment where water is scarce and cannot be afforded on such an unnecessary agricultural activity.

iii) To follow closely the proper application of water by the modern irrigation methods based on the actual crop water requirements reached after actual experimentation in the agricultural trial stations in the Emirates with the technical assistance of FAO expertise in Digdaga, Hamraniyyah and Dhaid (1975-84).

iv) To seek official advice on the type and quantity of crops to be grown as dictated by a well-prepared national agricultural production plan. This would initially require the official authorities concerned to formulate such a plan.

v) To gear agriculture to serve the goals of self-sufficiency in many crops. Accordingly, the extensive production of alfalfa

for export to Saudi Arabia by no means serves the goal of national food security. It has been shown that alfalfa is the largest water consumer of all the crops grown in the Emirates (Chapter 8, Section 8.4.2.2). The acreage under alfalfa is the largest among all the crops. To grow this crop for export is uneconomical from the water resources point of view.

vi) To fit flow-meters on all points of agricultural groundwater abstraction, at least for the purpose of monitoring the overall quantity abstracted from the aquifers. Flow-meter fitting should be stipulated as a condition to licensing well drilling.

vii) To encourage citizens to diversify their income by agricultural activities is sound, provided the citizen works his land himself so as to be as answerable for violations in water use as he is eligible for the various benefits.

11.8. Outlook for the water resources of the Emirates

11.8.1. Trends in water use:

This final section ties together all the salient elements of water resource management discussed in the previous sections of this chapter. Recognizing the problems pertaining to water resources of the Emirates, which are embodied in the water practices of the past two decades, the future trends in water use are not going to differ much from those of today.

Groundwater abstraction would continue in the same widespread uncoordinated way in the absence of both water and agricultural policies. Desalinated water production is likely to be enhanced and present trends already show that by 1993 the desalinated water production capacity will have increased by more than 70%, in the three main producers of Abu Dhabi, Dubai and Sharjah, from 170 mgd in 1990 to 290 mgd in 1993. The development in desalinated water may even be greater should it be used, as at present indicated, as a source of irrigation water.

Should the existing trends in water use be allowed to continue, it is most likely that better water-using technological methods would be adopted that would in turn lead to more water-intensive applications, particularly in the agricultural sector. Thus, the existing wasteful use of water is most likely to continue aided by even better facilities in its use.

These likely future trends in water use should therefore be counteracted by an effective water resource management that should come up with ways and means of optimal water-conserving methods. This in turn cannot be achieved without a revision of past practices in both the water decision-making and development levels. Development and management trends should concentrate on augmenting water availability by strict conservation rather than developing new water sources alone.

11.8.2. Critical water resource management issues and the potential for their resolution:

The critical water resource management issues in the Emirates can be identified as follows :

i) Shortage of water supplies owing to the depletion of groundwater resources, the related deterioration of water quality and the impact these have on the environment.

ii) Escalation in desalinated and recycled wastewater production to meet demands of secondary importance (irrigating horticultural and forestry areas) rather than to increase water availability to redress the existing groundwater resource imbalance.

iii) Identification of water use priorities and the allocation of water to the different competing users.

iv) The existing service-orientated fragmented water resource management on the local and federal levels, with all the professional inadequacy and limiting political, social, economic and technical elements.

As things stand now, there is limited potential for resolving the major water resource management issues by the existing water-related organizations due to their strictly service-orientated character. There appears to be little chance, for some time to come, in bringing together all these organizations in a state of cooperation to implement a coordinated comprehensive management.

A central (national) water resource management organization might be the ideal system. This would entail managing the water resources of the whole Emirates on a country-wide basis within a national framework of aims and priorities. Experience of the past decade, since the ratification of the General Water Resource Authority Law (1981), has, however, shown that centralization cannot overcome irreconcilable local politics.

The other water resource management option for resolving the critical issues may be of a responsibility on the regional level. However, as the important groundwater potential regions (the piedmont plains and the east coast) fall within more than one emirate, this level of management would meet little success because of the same irreconcilable local politics as at the national option.

The option of a water resource management on the local (emirate) level would be the most practical of the three options and would be in harmony with the fragmented economic, political and social realities.

The resource management system should be the *total water management*. This would involve looking after all aspects of the conventional and non-conventional water resources as a coherent whole with the aim of maximizing water use, while at the same time conserving the available water resources. However, the implementation of such a total water resource management would face the following two major constraints:

i) the strong local political identities of each emirate that would inhibit any sharing or water transfer even in emergencies.

ii) the existing agricultural land-use trends that are intensive-water using and less food-producing owing to their predominantly recreational nature (private gardens).

The second constraint might eventually be tackled if the total water management, in its analysis of the complete water use system, succeeds in guiding cultivation according to the crop water requirements. This is by no means an easy task; it would require a great technological and professional ability on the part of the water resource planners and managers. With regard to the first constraint, it is difficult to achieve such a goal short of forming a national water authority that would actually control water resources and allocate water according to the type of agriculture.

At whatever level, the national, regional or local, the total water resource management system adopted should rely on strong technical studies based on aggressive and continuous analysis of all the problems, for which also continuously revised options should be worked out. Such a total water management would have to be restructured and reinforced with the necessary experts to enable it to break away from past moulds that are responsible directly or indirectly for the present critical state of the water resources of the Emirates.

11.9. Synopsis

Results from all the preceding chapters have been collated, as the economic, social and political contents of the total system have been correlated with the physical aspects. The hydrometeorological networks have been examined and critisized. All aspects of water resource development have been analyzed to the level of specific equipments, areas of the country and types of water. The vital interrelated topics of legislation, policy and management have been given detailed consideration as a necessary background to the theoretical and practical aspects of planning. Environmental considerations have been raised with a focus on water quality, water quantity and pollution. From the results discussed earlier in the study, the most definitive guidelines yet available have been produced on the conservation and augmentation of

water resources. In this section, particular emphasis has been placed on appraisals of irrigation and recharge. Finally, an assessment is made of likely future developments.

CHAPTER TWELVE

CONCLUSIONS AND RECOMMENDATIONS

12. CONCLUSIONS AND RECOMMENDATIONS

12.1. Introduction

To conclude this study of the water resources of the Emirates, the salient features of the conventional (surface and ground water) and the non-conventional (desalinated sea and brackish, and recycled sewage, water) are summarized. The recommendations presented in this chapter include general recommendations related to key institutional water resource management aspects, and recommendations related to specific matters concerning each of the three water resources: ground, desalinated and recycled waste water. These recommendations are based on observation during the course of the study and are the result of close association with the different water management organizations and familiarization with the professional and administrative details of the functioning of these water-related institutions. The recommendations treat important water resource topics, that are regarded by the present study as directly influencing both the technical (development and monitoring water resources), and the administrative (the staff, technical and organizational) water resource management.

12.2. Conclusions

Groundwater abstraction far exceeds not only natural recharge but also that gained through infiltration from irrigation returns. Total groundwater abstraction for domestic use for the whole Emirates is more than 100 mgd. or **166.0 MCM/a**. Desalinated water production for domestic consumption is 180 mgd. or **300 MCM/a**, of which 85% is produced in the three west coast main towns of Abu Dhabi, Dubai and Sharjah. From a combined total volume from these two sources of domestic water of 417 MCM/a, the volume regained through the recycling of sewage in the four towns of Abu Dhabi, Dubai, Sharjah and Al Ain is **80 MCM/a** or 17% of the total volume. The ratio of the recycled sewage water, out of the total volume actually consumed domestically in these towns, is 69%.

Total groundwater abstraction is estimated to be of the order of 3359.41 MCM/a, of which about 30% is fresh groundwater (1107.80 MCM/a). The gain from irrigation return through percolation is about 8%, or 255.10 MCM/a of which 50% is recoverable (128 MCM/a). Such recirculating irrigation water is by no means water of prime quality as, besides becoming mineralized in its downward journey through the strata, it also becomes contaminated as a result of the heavy application of chemical fertilizers at an annual rate of 4-5 tons per hectare. The most serious of these chemical contaminants is nitrate (NO_3), which has been found in the groundwater of Al Hayer, in Al Ain, to be of a concentration of more than 100 mg/l after nearly eight years of fertilizing sandy soils. (Table 11.3, Chapter 11).

Natural recharge to the aquifers (both from direct rainfall and surface runoff) is estimated to be 412.20 MCM/a, with the largest contribution being from direct rainfall (333.51 MCM/a). This exceeds by 31% the total contribution from the recirculating irrigation water noted earlier. The ratio of recharge from natural sources (412.10 MCM/a) to that of the aggregate groundwater abstraction (3359.41 MCM/a) is 1:8. The ratio of the overall recharge input (including the contribution from irrigation return of both agriculture and forestry together with that from recirculating recycled sewage water used on landscaping (255 + 7 MCM/a) amounting to 677.30 MCM/a) to the overall abstraction volume (3359.41 MCM/a), is 1:5. (Table 10.19, Chapter 10)).

The gravity of this state of imbalance of groundwater resources can be realized when it is remembered that it is happening in a situation of depleting groundwater reserves in which aquifers have been 'mined' since the days of the Trucial States (Halcrow) Study of 1966-69. The Quaternary aquifer system has been dewatered over large areas and groundwater is now being abstracted from deeper, in many places fossil, sources thousands of years old, as in the wellfields of Dhuhuriyyeen, Sahwat, Al Beeh and Al Burairat (3000-17000 years old); Bujair, Bida' Rashed, Jaww Al Oad, Bida' Khalfan and Al Hilew (600-39,000 years old) (Carbon-14 dating, MEW-IAEA Isotopic Report, 1988). The dual, and in places multi-layered aquifer system in the Quaternary has been exhausted and water at present (1990) is being abstracted from deeper, less transmissive strata out of reach of present-day recharge. Estimates for this study of the recharge volumes from direct rainfall in the desert

sands and those for irrigation return are crude, though slightly generous. Large-scale studies of these two aspects of recharge based on actual field measurements are required to determine the volumes replenishing the groundwater system. Recharge from irrigation return is a leachate that gets more saline with time, not to mention the liability to become chemically contaminated as noted earlier, that may render it useless in a comparatively short time from now.

With the naturally limited groundwater resources, typical of an arid environment, a more thorough understanding of their potentiality is needed before such ambitious agricultural schemes as these, which have been introduced in the Emirates in the past decade and a half, are undertaken. The lack of understanding what is available of groundwater resources has directed development as though the untapping of such resources previously was due to shortage of capital and not to their natural limited occurrence. It is true that capital from oil has been the driving force behind the overdevelopment of the groundwater resources that followed the formation of the federal state (1971), but there should have been a realization that once exhausted, groundwater resources would be hard, or even impossible, to replace. Capital also made possible the large-scale development of desalinated seawater that has so far met the demands for water supply in the large towns.

The development of the desalinated water resource, like that of groundwater, is escalating unabated. In the absence of a water policy and plan, there does not seem to be a limit to this ever-increasing uncoordinated expansion. Desalinated water is already being used to irrigate the lawns of the golf course in Dubai, the 'forests' of Al Reef and 'Ajban along the Abu Dhabi-Dubai road, and it is also expected to be used on the farms in Al Sulaimat and Al Sad in Al Ain (due to dwindling groundwater resources in those areas). For this a 165-km. pipeline will be laid down to transport water from Al Taweelah power and desalination plant on the Gulf coast through 'Ajban, Suwaihan, Busamrah and finally to Al Sulaimat, to the west of Al Ain. This is different from the pipeline that already exists from Al Khadher wellfield in Al Ain transporting brackish water to the Gulf coast.

The marked technical and administrative inadequacy in the management of the water resources and the irreconcilable rift between the water

managers and the decision-makers is as important a cause of the critical water situation as is the natural factor of their limited availability. Fragmentation and duplication of responsibility, in a field that necessitates a well-informed concerted effort, is also detrimental. Satisfying the ever-increasing demands by desperate efforts to obtain new water sources is not always possible and some such projects are behind schedule owing to last-minute changes in decisions and the haphazard implementation of phases of, or even whole, projects.

To recommend ways of developing groundwater resources in their existing critical state of imbalance, as did Iwaco by suggesting:

> " groundwater development . . . . must be directed to the mining of the resources of fresh or brackish groundwater "
> (Iwaco, Final Report,1986, Vol. I, p. 127.),

should be unforgivable professionally and callous practically, to say the least. Development cannot be imagined within the context of the 'mining' of groundwater resources, which is the advanced stage of groundwater overdevelopment. To recommend organized or systematic depletion of what remains of groundwater reserves would be extremely ill-advised.

The widespread expansion in implementing modern irrigation methods, which can only save at best 25% of the water in comparison to the traditional inundation method, provided these modern methods are properly managed, does not seem to be conserving groundwater in view of the prolonged operating time, which, in the majority of farms using sprinklers, was seen to extend round the clock. Thus little saving of groundwater can be hoped for by the modern irrigation techniques. Additionally, modern irrigation methods result in increased soil salinity. Thus, the reiterated official assumption that these modern irrigation methods are big water savers (of up to 50% of water) is deceptive. Accurate monitoring of the amounts of irrigation water actually used on the fields by prolonged water application is needed, especially since farms are increasingly transferring from the drip and bubbler systems to the sprinkler irrigation method. Sprinklers are easy to operate and are frequently left unattended for long periods

contrary to the principles of crop water requirements and conservation of water use.

Few people seem to be aware of the impending exhaustion of the groundwater resources of potable quality. Besides artificial recharge using an enhanced production of desalinated sea and recycled waste water, conservation could be effected through government-guided public sharing of irrigation water sources and their distribution networks. There should also be strict inspection to ensure adherence to crop water requirements, flow-metering of all groundwater abstraction points and the definition of water use priorities based on modern economics and national needs.

Efforts to centralize water resource management, such as the General Water Resource Authority set up by law in 1981, which has never actually functioned, may not be the ideal option for managing the water resources of the Emirates in view of the irreconcilable local social, political, economic and management realities. A water resource management authority, such as this one, might only become a water-managing institution additional to the many already in existence. A step in the right direction would be to reform the local water departments, by upgrading their professional composition, amalgamating water-related authorities within an emirate or region and establishing a planning section in each.

In the absence of water legislation, policy and plan on the local and national levels, not to mention the regional one concerning the shared water resources with Oman, little can be expected to be done to salvage this seemingly irremediable water resource situation.

The state of the water resources in the Emirates has reached a stage where rethinking of existing water use practices is urgently needed. Groundwater resources are being depleted at an alarmingly pronounced and consistent rate and, together with the huge desalinated and recycled water production, are totally absorbed by largely economically unviable outlets. The gravity of the situation calls for the awakening of all, and a salvage plan, based on behavioural change towards water use, must be realized before the existing persistence of the well-intentioned, wrongly-directed ambitions lead to a calamity of widespread proportions.

12.3. Recommendations

12.3.1. General recommendations for key institutional aspects of water resource management in the Emirates.

It is deemed necessary to explain the existing state of the institutional water management aspects to which the recommendations in this section relate so that such recommendations can be justified. The recommendations themselves reflect the views strongly held as a result of the present study and acquired from actual involvement in the field in the various levels of water management, in both the private and public water-related organizations. The general recommendations that concern institutional aspects of water resource management in the Emirates are:

1) Water-managing institutions be reformed and organized:

Nearly all the problems in the water resource sector in the Emirates can be attributed to two main causes: natural limitation of water, and water management inefficiency. The former cannot be reversed, but the latter, unless reformed and reorganized, could worsen the state of the former irrevocably. To optimize water resource management efficiency, it is recommended that the expert group in the water organizations (both national and expatriate) should be rigourously screened on the basis of relevant educational and practical qualifications. Only those with the required level of aptitude in the field of water resources should be retained.

2) Knowledge of the availability of water resources be improved:

A major issue in the critical state of groundwater resources of the Emirates is the result of either poor or total lack of knowledge about the hydrogeology and availability of the resources It is recommended that a widespread programme of educating all users of water about the natural setting of groundwater and the

proper means of conserving its application be conducted as part of teaching at all levels of education that should be ritually repeated in the spoken and visual media. Greater emphasis should be given to the assessment of agricultural consumption. The professionals concerned in the development and management of the groundwater resources must be engaged in regular hydrogeological surveys to build up a reliable data-base of the physical limitations of groundwater resource availability. Generally, the water resource decision-makers and the managers should be included in this educational effort on resource availability.

3) **The relationship between the overdevelopment of groundwater resources and conservation be addressed:**

The question intentionally avoided by all is that which concerns the extent to which the development of new sources of groundwater, in the already overdeveloped groundwater resources, can go. Some previous studies put targets on the total exhaustion of aquifers. According to Iwaco (1986), by 1989 the bottom of the Quaternary system in Al Dhaid should have been reached. Similarly, Edworthy and Brandt, in the public utilities section of the Al Ain 2000 Master Plan (1983), concluded that the fresh water exhaustion target in Al Ain would be reached in 10-15 years (by the years 1993-1998), and the ultimate total groundwater exhaustion target for the usable resources would be in 30 years (by the year 2013). It should be pointed out that groundwater not only becomes exhausted quantitatively, but also deteriorates qualitatively to an unusable level that renders it effectively exhausted in a practical sense.

Targeting potential groundwater exhaustion dates is helpful in signalling impending disasters to societies capable of improved conservation and of finding alternative ways of balancing the resources. Such targeting of exhaustion must be based on accurate determinations of what groundwater is actually in storage together with its input and output components. An important factor in the worsening groundwater resource situation is that such exhaustion groundwater targets have been based on inaccurate hydrogeological data. Some of such depletion targets have passed

and groundwater, regardless of its quality, is still available. This invalidates such warnings in the minds of both the public and decision-makers.

The regular determination of the groundwater in storage by the water institutions, relying on permanently appointed qualified extra staff, is strongly recommended. This is more meaningful in technical and financial terms than the short, academic and expensive surveys.

Even if, according to the above recommendation, all is known about what groundwater remains in storage, the groundwater resource situation is not encouraging both quantitatively and qualitatively. Depletion continues, and will do so until perhaps total exhaustion is reached. What is to happen after that stage is reached?

While desalinated water would meet human demand for water supply, its cost precludes its use as irrigation water. Before the stage is reached at which agriculture might be widely sustained with desalinated water, already partially happening in the 'forest', town reserves and some farms, priorities in agricultural practices must be drawn up and water use by agriculture must be clearly defined.

Stringent water conservation measures are therefore urgently required and recommended as the state of the water resources has gone beyond temporary remedies. Harsh controls on water use are needed that should consider 'rationing' and the apportionment of water on the basis of the classification of agricultural land for economic and useful produce within the general context of national food security. When depletion reaches deeper aquifers where water, though relatively fresh, is fossil, being thousands of years old (Chapter 7), then even the most callous of water users must awake from the current senseless draining of the limited groundwater resources.

4) **Conservation be deemed the option for future water resource management:**

The established trends in water resources so far have been the incessant mining of groundwater and the relentless discovery of new sources to meet the unlimited water supply demands. The way to achieve 'water security' is through conservation, as what remains of the usable groundwater is ultimately going to be exhausted.

It is strongly recommended that a national plan be drawn up in which water-related priorities are clearly laid down and hard choices are made, particularly in the field of agriculture. Greening for the sake of it would have to be reappraised, though this would mean touching on a sensitive ambition. An agricultural policy based on economic viability would have to be seriously considered. In view of the scarcity of water in such an arid environment as that of the Emirates, agriculture ought to be strictly related to the availability of water, which should be taken as the main cost input in total agricultural production costs.

5) **Water resource planning be implemented:**

Water resource planning, which hardly exists even on a low-profile basis in almost all water-related organizations, is indispensable, and its absence explains the regrettable state of water resources in the Emirates. Once planning as a principle is accepted by both the water managers and decision-makers, planning for water resources should be for five years ahead of the commencement of a particular water project. Planners should always allow in their plans for the sudden changes expected from the decision-makers.

Whereas an applied geologist or a trained hydrogeologist, both of which are extremely rare in water-related institutions, can tackle limited engineering aspects in groundwater development, water resource planning requires multi-disciplined water resource specialists who should be conversant with all the complex ingredients that go into a full-fledged water resource plan.

As water resource specialists are unavailable in the water organizations, it is recommended that such a group of experts be trained and made available so the resources are viewed in their wider management spectrum rather than in that of limited engineering development or day-to-day supply aspects.

6) **Geophysical and hydrogeological surveys be undertaken:**

It is strongly recommended that geophysical and hydrogeological studies, and their ancillary modern aids of satellite imagery and digital modelling should be carried out by the water organizations concerned with the help of a permanently based local staff rather than, as at present, with invited foreign firms. This is to ensure that all the raw data acquired by these studies are available for future reference as not all that is discovered by these surveys is included in the reports submitted. It is recommended that any further investigations in the field of water resources by foreign consulting engineers be discouraged in favour of official locally-based expertise. Apart from being logical practically, it is cost-saving in line with present budgetary rationalization.

7) **Water resource surveys be used as a training ground for indigenous staff:**

All previous water resource surveys, whether part of full-fledged projects or terminated at the feasibility stage, were carried out by foreign consulting engineering firms that relied largely on local subcontractors for the execution of these surveys. All the basic data required for these studies were supplied by the commissioning water institution in the Emirates to which these data were returned rearranged and neatly presented in a 'feasibility', an 'assessment' or an 'evaluation' study. None of these surveys, though this was not entirely the fault of the consulting firms, involved the commissioning institutions in their work. No clauses were included in the contract agreements with the consultants allowing for the training of national staff by sharing field and office work with consultancy staff so that follow-up of the

projects can be continued by local staff after the consultants have completed the surveys.

A great number of large and small water projects, both on the local or national scales, could have provided the ideal training ground for many local trainees who could have later effectively continued the work. Particular reference is made here to two important water resource surveys: the Deep Wells Project of Bin Ham-Geoconsult-Iwaco-MAF (1982-86), and the current NDC-US Geological Survey project in the Al Ain and Liwa regions (1988-). The former did not, and the latter does not, involve nationals in their operations.

Such important national projects should have been fully utilized as a means of transfer of technological knowledge, assuming that the imported foreign staff for these projects are of the expected level of expertise. The fact that such training possibilities have not been considered by the local and federal commissioning institutions of the Emirates attests to the inadequacy of management and absence of both capable local counterparts that appraise these surveys, as well short- and long-term planning.

Although the basic recommendation is against any more water studies for the execution of which foreign consulting contractors are invited, yet if such invitations are to continue for any reason then these consultants, UN or bilateral cooperation organizations, should be asked to allow for the training of local water staff throughout the phases of the project they are undertaking.

8) **Local counterparts be used to appraise water resource projects:**

The supervision of projects by qualified local counterparts in the commissioning water resource organization or any higher authority in the government is either poor or nonexistent. Qualified local counterparts are much needed, and are strongly recommended, to screen phases of water projects and surveys and appraise their technical substance. Whether isolated, commercially-based projects executed by individual contractors, or through bilateral

arrangement with a foreign country (in most cases of which the the project is paid for by the Emirates) or any of the organizations of the UN, there ought to be some sort of supervision by the local or national commissioning water institution. The current NDC-US Geological Survey project is not controlled by any official supervision, nor is there an authority to appraise the first phase of the project. The NDC-US Geological Survey, the contractor of the project, is its appraiser as well.

Another example involves the relationship between the local counterpart, the MEW, and the IAEA in the latter's execution of of the isotopic study in the Emirates. The visits of the local counterparts organized by the IAEA to its headquarters in Vienna were not of the required level for effective training, and the local counterparts did not show enough interest to participate in the activities of the project.

It is recommended that such projects be appraised by local expertise so as to ensure optimum results as advertised by the executors of the surveys, because the water institutions are going to live with these results long after the contractors have gone.

9) **Water resource data be disseminated**:

The basic idea of carrying out water resource investigations is to provide information that will better the understanding of the resources. To erect a cordon of secrecy around the findings of such studies, even to members of the staff of the very commissioning institution, is neither scientific nor legal. This also applies to almost all forms of data, however insignificant. Such a negative attitude compounds the problems of water resources by inhibiting free research by those, interested in this field of study, who might offer solutions to the many problems.

Only two water-related institutions publish information about their activities in a satisfactory annual statistical form. These are the Power and Desalination Section of WED Abu Dhabi and the Department of Agriculture in Al Ain. If these two organizations publish and circulate freely facts about their operations, why should not the

other water organizations do the same? There is no law in the Emirates condoning withholding scientific data that relates to a public utility such as water.

It is recommended that water resource data should be accurately assembled, computed, presented and stored in a modern easily retrievable data system. The most important duty in all this is that the data should be published and made readily available. The MAF is the particular water-related organization that must do that before all others as it attends to important raw data sources of direct bearing to water resources.

10) **Professionals be trained in the field of water resources:**

Institutes of learning in the Emirates are not doing enough in the practical training of engineers and technicians in the various aspects of water resources. Many of the surveys that have been carried out by consulting contractors could have been done by undergraduates of the Faculties of Engineering and Science of the Emirates University as part of their training. The newly established Higher Colleges of Technology do not have any course relating to water resources included in their curriculum (1990).

It is the recommendation of the present study that the training of professionals for the various aspects of water resources should be organized locally in the very work organizations the trainee is to join.

11) **Imports of Foreign water be banned**

Import of water from foreign countries is not recommended and should not even be contemplated because it is detrimental to national security. In most cases imported water would be costlier than even that produced from small-scale reverse osmosis plants. In addition, imports of water from foreign countries would be subject to national contingency plans at times of relative drought in those exporting countries.

Imports of water would also open added responsibilities of

handling and, most likely, treatment of the water, that might prove too much for water departments that can hardly cope with existing duties.

12.3.2. Specific recommendations of the conventional and non-conventional water resources of the Emirates.

12.3.2.1. Groundwater

1) **Groundwater development in the fractured bedrock and the limestone massif of Ru'us Al Jibal be pursued:**

The question to be asked is whether to recommend the development of groundwater resources on a rational basis and pursue the path of conservation or go along the present dominant trends in overdevelopment and recommend newer sources of usable water, wherever these may exist, to be systematically exhausted? (as recommended by Iwaco, 1986).

To recommend the development of groundwater in the fractured zone of the bedrock or in the structural fissures in the ophiolites is not sound as either source has limited storage capacity and therefore would not sustain heavy and continuous abstraction rates.

Sources of groundwater in the northern limestone massif of Ru'us Al Jibal have so far been proved plane-guided and their uniformity of occurrence within the blocks bounded by these planes is not determined as the limestone here is of the massive type. Even cavernous karstification is questionable, besides the fact that such supposedly " good water-bearing potential" aquifer with " groundwater reserves .... estimated at 14,000MCM " (Iwaco, Vol. 1, p. 25), may be floating over seawater.

It is recommended that further and more systematic investigations be carried out to reveal the real hydrogeological situation and actual potential that would guide the course of development of this source in the limestone massif in an area (Ras Al

Khaimah) with very limited existing groundwater resources. As this is a resource shared with the Sultanate of Oman, on whose side of the border falls the larger part of the Ru'us Al Jibal peninsula, a concerted effort with Oman is recommended, which might involve a better groundwater resource potential than in the less endowed shared Al Ain-Al Buraimi front further south.

2) **Groundwater resources in the Lower Fars evaporites of Abu Dhabi be investigated:**

The Miocene Lower Fars evaporites and the underlying Oligo-Miocene Sahil clastics, though locally having porosities of up to 30%, consist of marls, shales and clays that have been proved to contain brackish to supersaline waters even at surface or near surface depths with or without a Quaternary alluvial or aeolian mantle. Their being hundreds of metres thick does not imply the aquifers in them are equally thick as there are numerous interbedding sealants of mud and clay.

It is recommended that attention be given to the vast area between the eastern region of Abu Dhabi (Al Ain), Sabkhat Matti in the west and Liwa in the south. The NDC-US Geological Survey project should be urged to complete its investigation by including this zone.

3) **The coastal aquifer of the east coast be recharged:**

In view of the limited groundwater potential of the alluvial embayments of the east coast, it is recommended that agricultural expansion should be limited and serious thinking be given to artificial recharge schemes with both desalinated and recycled water, with more of the latter. This would mean setting up large desalination and recycling plants. There are at present two small desalination plants being established at Qidfa'(1990) but no sewage treatment exists along the whole coast. The abandoned federal plans of the mid-1970s to establish two large desalination complexes on the east and west coasts appear the ideal option. Desalinated water should be used primarily for drinking purposes and any excess should be directed to

artificial recharge. Recycled water should be used for irrigating non-edible crops and any excess should also be used for artificial recharge. The problem of seawater intrusion is widespread in the coastal aquifers of the east coast and only consistent artificial recharge would help push back the intruding seawater front.

4) **Prospecting be undertaken for groundwater in the geosyncline under the Ghareef Plain:**

The recommendation by the Bureau De Recherches Geologiques Et Minieres (BRGM) to investigate the water potential of the Upper Cretaceous Juweiza and Simsima and the Tertiary Dammam and Um Er Radhmah (and their basinal conglomerates of the Simsima), at depths of between 1000-2000m., in a geosynclinal basin between the main ophiolite mountain block in the east and the outlying anticlinal ridges of Jabals Fayah-Mileiha in the west (BRGM report on Groundwater Resource Assessment of the Dhaid-Madam Plain, Identification and Evaluation Survey, October, 1988), had already been carried out by Geoconsult (1983). There was then limited geophysical investigations of the upper 400m. but with tentative electrical sounding down to about 700m. in Wells GP-6 (in Mileiha), GP-7 (south-east of Mileiha) and GP-11 (at the foot of Jabal Rumailat east of centre of Jabal Fayah). All these wells are in the Ghareef Plain under question, and all the wells penetrated the Aruma shales of the Upper Cretaceous Juweiza (a flysch sequence of eroded carbonates and silicified shales) with groundwater with ECs of 2000-3000 mmhos/cm.

The possibility that there is hydraulic connection between the strata of the geosyncline under the Ghareef-Madam Plains and those of the middle and upgradient portions of the Dammam and Um Er Radhmah formation aquifers in the rest of the Arabian Peninsula, as is thought to be the case with the huge geosyncline of central Abu Dhabi with the middle and upper gradients of the Um Er Radhmah and the Dammam in eastern and central Saudi Arabia, is remote. If the latter, despite the the supposed hydraulic connection, contains waters with such high salinities reaching brine levels in all the three deep carbonate aquifer system of the Simsima, Um Er Radhmah and Dammam

(110,000-235,000 TDS), the Ghareef-Madam geosyncline to the south of Dhaid, though not as deep as the syncline of central Abu Dhabi, may possibly contain saline water. If shallow underground water ponding occurs in the upper alluvium immediately behind the Fayah anticline, with waters of ECs exceeding 4000 mmhos/cm, and if these waters are assumed to be in hydraulic connection, through the carbonate-shale sequence of the Juweiza, with the Simsima, Em Er Radhmah and Dammam aquifer system, they would not be expected to float over less saline waters that are implied by BRGM to occur in these formations. Waters trapped in a geosyncline, with little or no groundwater movement, would naturally become mineralized and acquire high salinity levels because of their long residence.

Geophysical prospecting has been extensively carried out by Amoco (the petroleum company with oil concession in Sharjah emirate) during its prospecting for oil, but the water-related information is not made available by this company. Geoconsult, as part part of the Deep Wells Project (1982-86), also carried out tentative geophysical prospecting. Information from Geoconsult's work pointed to the presence of clayey formations below 700m., and the electrical resistivities in Well GP-15 (S.E. of Dhaid) of around 5.2 ohms denote to either bedrock or clayey low-permeability formations (Deep Wells Project, Geophysical Report, p.5, Geoconsult, 1985; Iwaco, Final Report, Vol. 3. p.92, 1986 (both reports are two versions of the same Deep Wells Project Study))

Geophysical prospecting is not very expensive and it is recommended that such investigations could be entrusted to local expertise. Besides recommending this to determine if the limestone formations in this geosyncline are likely to be holding water of usable quality, it is also recommended that geophysical and drilling information from the oil companies operating in the Emirates should be assembled and assessed in an overall evaluation of the resources in this geosyncline and other areas. The petroleum companies have not done enough in the field of water resources though they use the best available groundwater for domestic use in their personnel camps in the oilfields, and have in their possession all the geophysical and geological

information relating to it. They also have the means for further investigation. The ADCO hydrogeological reports on groundwater in Shah and Asab are strictly academic and the other oil companies in Dubai, Sharjah, Ras Al Khaimah and Um Al Qaiwain have produced no reports on water resources despite the data they must have on these resources.

It is recommended that all available geophysical information held by the oil companies be obtained by official acquisition by the local water departments. A number of questions may be answered by these data, including those relating to the Ghareef-Madam geosyncline, parts of the northern piedmont plains in Ras Al Khaimah and also large areas of the desert foreland.

5) **Groundwater depletion in parts of the Quaternary aquifer system be assessed:**

Several parts of the Quaternary aquifer system in Al Dhaid, Ras Al Khaimah and Al Ain have been exhausted as is evident by the drying up of wells in farms and the eventual abandoning of these farms. This should have been taken as a warning to stop further dewatering of other parts of the Quaternary aquifer, and to reappraise agricultural activities in these areas and their importance in achieving food self-sufficiency.

Taking Al Dhaid as an example, it is recommended that groundwater abstracted outside the vicinity of Al Dhaid and transported to it by pipeline must be re-evaluated as such abstraction would eventually lead to a widening of the cone of depression and the extension of the area of exhaustion of the aquifer beyond Al Dhaid. Such water cannot be equally provided for the producing farms and those that are purely recreational gardens, both of which lie side by side and compete for fresh groundwater.

6) **Agricultural abstraction be regularized:**

Domestic water consumption can be regularized to the best possible level by metering all consumption points or by raising the water charge on the town resident. As has been shown

(Chapters 5, 8 and 10), domestic water consumption is far less than that of agriculture, and that for strictly human consumption is even less again. It is recommended that agricultural water abstraction should be controlled by fitting flow-meters on all abstraction points, whether private or governmental, at the cost to the user, with regular inspection from the local water or agricultural offices. The fee would certainly be much less than that for water consumption in the towns. Users of water for irrigation should be advised as to the required amounts for the the different crops and also warned against the use of excesses beyond crop water requirements.

Water used for irrigation in private gardens that are of a purely recreational nature in which the green area contributes little to national food security, should be taxed at a higher water rate on the basis of metered consumption. Allotment of such recreational private gardens should be strongly discouraged.

12.3.2.2. **Desalinated water**

1) **Desalinated water production in Abu Dhabi be rationalized:**

The cost of desalinated water in Abu Dhabi is kept high by the continued operation of the two low-output high-cost plants of the Gas Turbine Station (GTS) and the Steam Diesel Station ((SDS, at Sa'adiyat). Together, these two stations produce hardly 1% of the total desalinated water output of Abu Dhabi. The cost per 1000 gallons of their water is 303 dhs. and 184 dhs. respectively. The cost of 86% of the desalinated water of Abu Dhabi, produced in the two Um Al Nar plants, is 16.0 dhs. per 1000 gallons (1988).

As the GTS Station has already been dismantled (late 1990), it is recommended that the small SDS plant at Sa'adiyat should also be phased out in view of the low output and high cost of operation.

2) **Desalinated water production in Dubai be rationalized:**

Because of the high cost of desalinated water produced by Dubai Aluminium (DUBAL), despite the free waste heat used for its production, it is recommended that expansion in water production in DUBAL should not be contemplated and development should be encouraged in Dubai Electricity (DEC), as is already the trend in Phases 'E' and 'G' in Jabal Ali. DEC desalinated water has lower production cost which was in June 1989 0.81 fils. per gallon (8.1 dhs. per 1000 gallons or $ 0.5 per $1m^3$), as against 1.61 fils. per gallon (16.1 dhs. per 1000 gallons, or $ 1.0 per 1 m^3) for DUBAL. DEC also has the lowest overall operation and maintenance costs among all the desalination plants in the Emirates.

3) **Small commercial RO plants and groundwater contamination be investigated:**

There is a booming trade in small RO distillers. These desalination units have two negative aspects:

a) the reject brine disposed of *in situ* eventually percolates into the aquifer; and,

b) the handling of the produced 'potable' water is unhygienic.

The adverse effects of brine disposal will become more serious when more machines are sold over the years. It is recommended that the serious effects of this activity be investigated and steps be taken to stop this trend from developing into an extremely difficult problem affecting groundwater quality.

4) **Local qualified expert groups be used for maintaining and operating desalination plants:**

In a country where desalinated water meets most of the demands for the domestic consumption of the population (100% in Abu Dhabi and 80% in Dubai towns) the Emirates should have developed by now enough local expertise in such an important field. Instead,

despite two decades of development in desalination, this is a realm totally dominated by foreign technicians.

It is recommended that there must be a clear and serious plan for placing national trainees in all the desalination plants. Any administrative reasons that have so far discouraged nationals from working in the desalination plants must be removed. There should simply be the principle of appointing for every expatriate technician, a national second-line and target date for hand-over.

It is also strongly recommended that a nationally-based industry embracing all aspects of the desalination process be established so as to manufacture parts of or whole desalination units and be self-sufficient in the maintenance of all aspects that concern the desalination plants.

12.3.2.3. **Treated sewage water**

1) **Treated sewage water be used as irrigation water for non-edible crops and a source of artificial recharge:**

Treated sewage water in the Emirates is of the high quality of 5-10 (BOD) and 10 (TSS), with pre- and post-chlorination and sand filtration. In all the four sewage treatment plants of the Emirates, the treatment of sewage is of the tertiary stage plus filtration and chlorination. If secondary-stage unfiltered treated sewage water is recommended elsewhere in the world for use as irrigation water for forage, truck crops and municipal landscaping, treated sewage water from the plants in the Emirates can, therefore, more than qualify for all these uses. Salinity levels of the treated effluent in Abu Dhabi, Al Ain and Dubai are below 3,000 mmhos/cm. However, the salinity for the Sharjah treated effluent is more than 11,000 mmhos/cm. owing to seepage into the influent from the sabkhas that form the larger part of the town's subsoil through which the limited sewage network runs. Recycled sewage is regarded in many parts of the

world as providing potential for irrigation water for non-edible crops.

It is recommended that such a water source be used for agriculture, though limited only to non-edible crops. This appears at present to be remote as all treated sewage water is wholly dedicated to the irrigation of the municipal horticultural schemes in the towns, a use that has become an established tradition. There is also the trend that whatever volume of treated sewage water is produced from any expansion of the sewage treatment plants, it is matched by an increase in the green areas of the town reserves. No sooner does additional treated effluent becomes available than it is absorbed by these new town reserves.

The present study regards recycled wastewater as an important water resource that should play a role in the near future. It must be viewed as a reserve to be used as:

a) irrigation water for non-edible crops; and,

b) groundwater recharge.

Although both these options appear remote at present, they are yet strongly recommended for the future should the importance of this source of water be recognized by both the decision-makers and the municipality managers.

Any argument against the use of treated effluent towards these two ends is refuted on the grounds that treated sewage water has been partly augmenting falaj flows in Al Ain for several years and is used for watering the traditional date gardens there.

The total output from the four sewage treatment plants in the Emirates is at present 80 MCM/a (1990), which is equivalent to about about 69% of the volume of water actually used for human consumption.

Maximizing the sewage treatment capacity in the four large towns

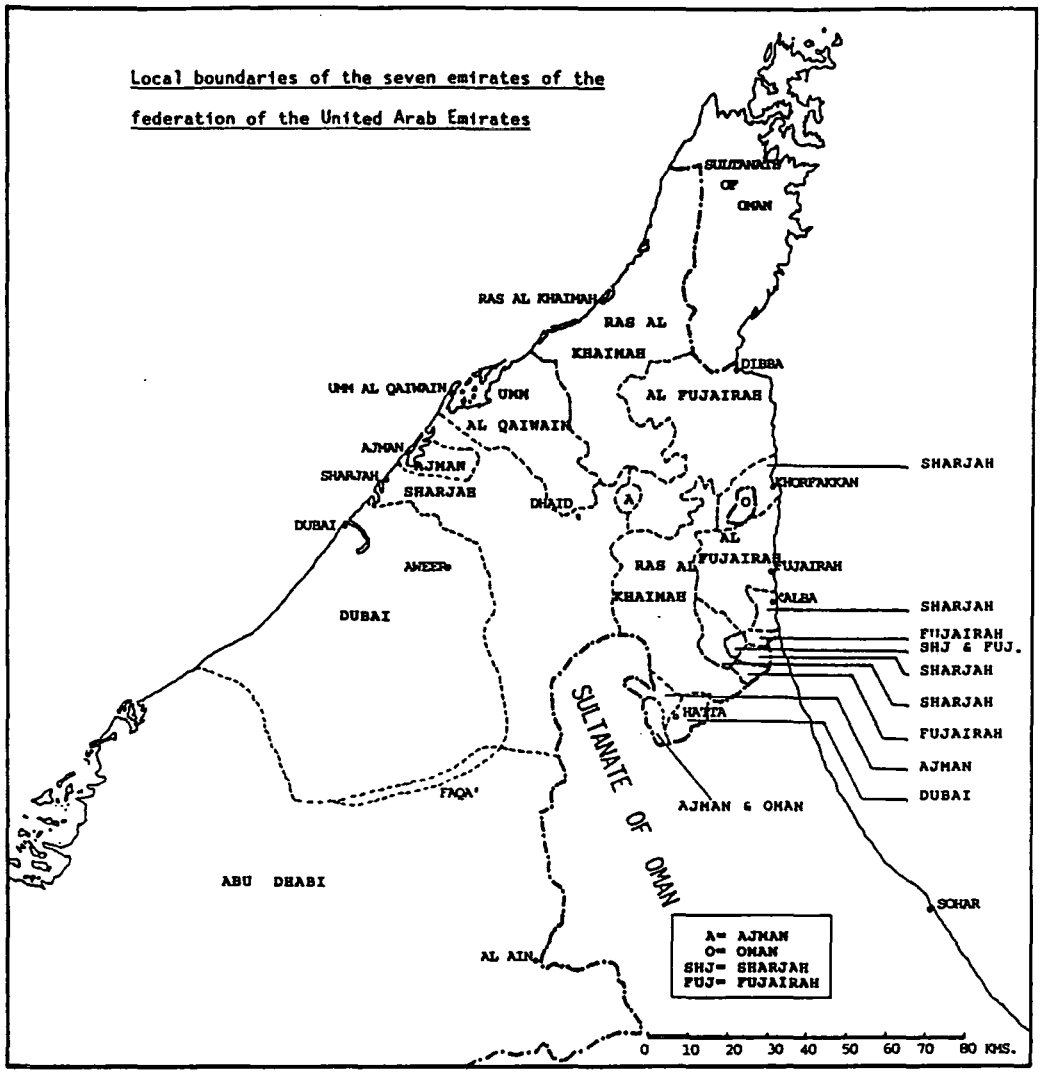
would make available more than 100 MCM/a of sewage treated water, and if other urban centres are served by treatment plants, then a substantial volume of treated sewage water could be regained for other uses.

2) **National operators be introduced into the sewage treatment plants:**

Sewage treatment plants, like desalination plants, are water resource producers where the local or national labour element is almost non-existent. The presence of the national professional is very much needed in this sector. It is recommended that national civil and chemical engineers be encouraged to join the teams in the sewage treatment plants. It is also recommended that, in view of the absence of technical supervision of the treatment plants by the municipalities, there should be follow-up of operations in the sewage plants by qualified staff.

APPENDICES

APPENDIX 1



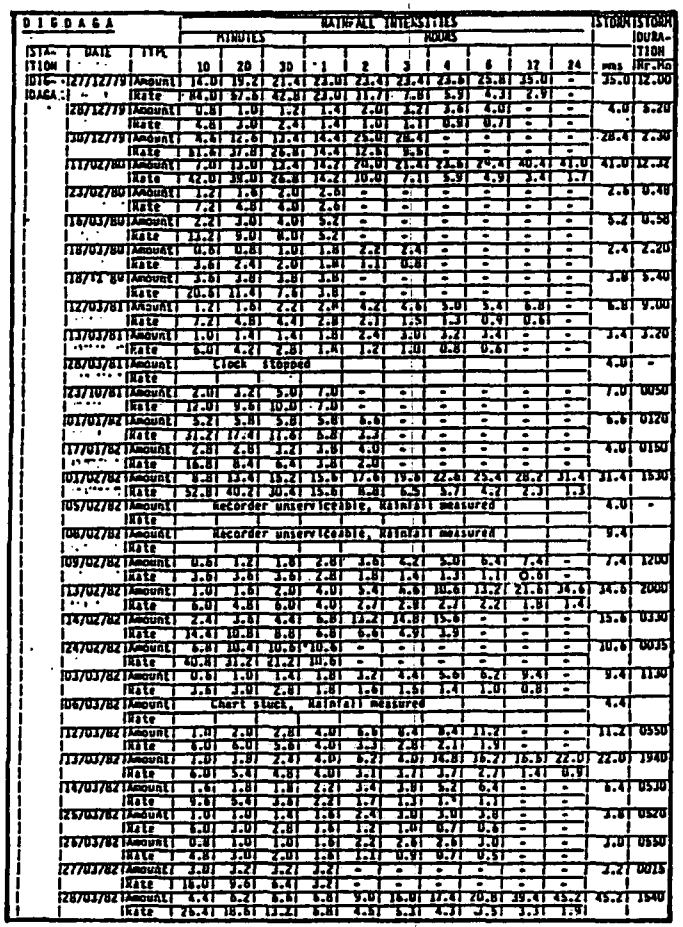
Sources: (1) The map of " Boundaries of the Trucial States" by Julian Walker, British Political Agent, 1962.

(2) "From Trucial States to United Arab Emirates" , Frauke Heard-Bey, 1982.

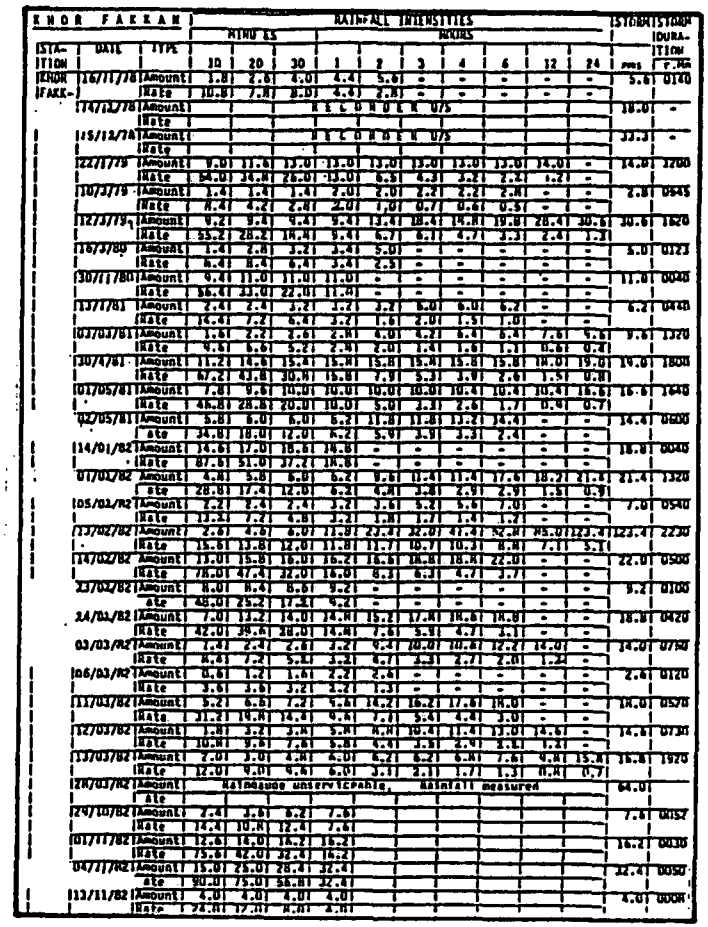
Appendix 1.

The interemirate boundaries of the seven Emirates of the UAE.

APPENDIX 2



DIGDAGA			RAINFALL INTENSITIES										STORM	STORM
			MINUTES			HOURS								DURATION
STATION	DATE	TYPE	10	20	30	1	2	3	4	6	12	24	mms	Hr.Mn
DIGDAGA	27/12/79	Amount	14.0!	19.2!	21.4!	23.0!	23.4!	23.4!	23.6!	25.8!	35.0!	-	35.0!	12.00
		Rate	84.0!	57.6!	42.8!	23.0!	11.7!	7.8!	5.9!	4.3!	2.9!	-		
	28/12/79	Amount	0.8!	1.0!	1.2!	1.4!	2.0!	2.2!	2.6!	4.0!	-	-	4.0!	5.20
		Rate	4.8!	3.0!	2.4!	1.4!	1.0!	1.1!	0.9!	0.7!	-	-		
	30/12/79	Amount	4.6!	12.6!	13.4!	14.4!	25.0!	26.4!	-	-	-	-	28.4	2.30
		Rate	51.6!	37.8!	26.8!	14.4!	12.5!	8.8!	-	-	-	-		
	31/02/80	Amount	7.0!	13.0!	13.4!	14.2!	20.0!	21.4!	22.6!	26.4!	40.4!	41.0	41.0	12.32
		Rate	42.0!	39.0!	26.8!	14.2!	10.0!	7.1!	5.9!	4.9!	3.4!	1.7		
	23/02/80	Amount	1.2!	1.8!	2.0!	2.6!	-	-	-	-	-	-	2.6	0.40
		Rate	7.2!	5.4!	4.0!	2.6!	-	-	-	-	-	-		
	16/03/80	Amount	2.2!	3.0!	4.0!	5.2!	-	-	-	-	-	-	5.2	0.50
		Rate	13.2!	9.0!	8.0!	5.2!	-	-	-	-	-	-		
	18/03/80	Amount	0.6!	0.8!	1.0!	1.8!	2.2!	2.4!	-	-	-	-	2.4	2.20
		Rate	3.6!	2.4!	2.0!	1.8!	1.1!	0.8!	-	-	-	-		
	18/11 80	Amount	3.6!	3.8!	3.8!	3.8!	-	-	-	-	-	-	3.8	5.40
		Rate	20.6!	11.4!	7.6!	3.8!	-	-	-	-	-	-		
	12/03/81	Amount	1.2!	1.8!	2.2!	2.4!	4.2!	4.6!	5.0!	5.4!	6.8!	-	6.8	9.00
		Rate	7.2!	4.8!	4.4!	2.4!	2.1!	1.5!	1.3!	0.9!	0.6!	-		
	13/03/81	Amount	1.0!	1.4!	1.4!	1.8!	2.4!	3.0!	3.2!	3.4!	-	-	3.4	3.20
		Rate	6.0!	4.2!	2.8!	1.4!	1.2!	1.0!	0.8!	0.6!	-	-		
	28/03/81	Amount	Clock stopped										4.0	-
		Rate												
	23/10/81	Amount	2.0!	3.2!	5.0!	7.0!	-	-	-	-	-	-	7.0	0050
		Rate	12.0!	9.6!	10.0!	7.0!	-	-	-	-	-	-		
	01/01/82	Amount	5.2!	5.8!	5.8!	5.8!	6.0	-	-	-	-	-	6.0	0120
		Rate	31.2!	17.4!	11.6!	5.8!	3.0	-	-	-	-	-		
	17/01/82	Amount	2.8!	2.8!	3.2!	3.8!	4.0!	-	-	-	-	-	4.0	0150
		Rate	16.8!	8.4!	6.4!	3.8!	2.0!	-	-	-	-	-		
	01/02/82	Amount	8.8!	13.4!	15.2!	15.6!	17.6!	19.8!	22.8!	25.4!	28.2!	31.4	31.4	1530
		Rate	52.8!	40.2!	30.4!	15.6!	8.8!	6.6!	5.7!	4.2!	2.3!	1.3		
	05/02/82	Amount	Recorder unserviceable, Rainfall measured										4.0	-
		Rate												
	08/02/82	Amount	Recorder unserviceable, Rainfall measured										9.4	
		Rate												
	09/02/82	Amount	0.8!	1.2!	1.8!	2.8!	3.8!	4.2!	5.0!	6.4!	7.4!	-	7.4	1200
		Rate	3.6!	3.6!	3.6!	2.8!	1.8!	1.4!	1.3!	1.1!	0.6!	-		
	13/02/82	Amount	1.0!	1.6!	2.0!	4.0!	5.4!	6.6!	10.6!	13.2!	21.6!	34.6	34.6	2000
		Rate	6.0!	4.8!	6.0!	4.0!	2.7!	2.2!	2.7!	2.2!	1.8!	1.4		
	14/02/82	Amount	2.4!	3.6!	4.4!	6.8!	12.2!	14.8!	15.6!	-	-	-	15.6	0330
		Rate	14.4!	10.8!	8.8!	6.8!	6.1!	4.9!	3.9!	-	-	-		
	24/02/82	Amount	6.8!	10.4!	10.6!	10.6!	-	-	-	-	-	-	10.6	0035
		Rate	40.8!	31.2!	21.2!	10.6!	-	-	-	-	-	-		
	03/03/82	Amount	0.6!	1.0!	1.4!	1.8!	3.2!	4.4!	5.6!	6.2!	9.4!	-	9.4	1130
		Rate	3.6!	3.0!	2.8!	1.8!	1.6!	1.5!	1.4!	1.0!	0.8!	-		
	06/03/82	Amount	Chart stuck, Rainfall measured										4.4	
		Rate												
	12/03/82	Amount	1.0!	2.0!	2.8!	4.0!	6.6	8.4!	8.4!	11.2!	-	-	11.2	0550
		Rate	6.0!	6.0!	5.6!	4.0!	3.3!	2.8!	2.1!	1.9!	-	-		
	13/03/82	Amount	2.0!	3.8!	4.4!	6.0!	8.2!	8.8!	14.8!	16.2!	16.6!	22.0!	22.0	1940
		Rate	6.0!	5.4!	4.8!	4.0!	3.1!	2.7!	2.7!	2.7!	1.4!	0.9		
	14/03/82	Amount	1.6!	1.8!	1.8!	2.2!	3.4!	3.8!	5.2!	6.4!	-	-	6.4	0530
		Rate	9.6!	5.4!	3.6!	2.2!	1.7!	1.3!	1.3!	1.1!	-	-		
	25/03/82	Amount	1.0!	1.0!	1.4!	1.6!	2.4!	3.0!	3.0!	3.8!	-	-	3.8	0520
		Rate	6.0!	3.0!	2.8!	1.6!	1.2!	1.0!	0.7!	0.6!	-	-		
	26/03/82	Amount	0.8!	1.0!	1.0!	1.6!	2.2!	2.6!	2.6!	3.0!	-	-	3.0	0550
		Rate	4.8!	3.0!	2.0!	1.6!	1.1!	0.9!	0.7!	0.5!	-	-		
	27/03/82	Amount	2.0!	2.2!	2.2!	2.2!	-	-	-	-	-	-	2.2	0015
		Rate	16.0!	9.6!	6.4!	2.2!	-	-	-	-	-	-		
	28/03/82	Amount	4.4!	6.2!	8.6!	8.8!	9.0!	16.0!	17.4!	20.8!	39.4!	45.2	45.2	1540
		Rate	26.4!	18.6!	13.2!	8.8!	4.5!	5.3!	4.3!	3.5!	3.3!	1.9!		



KHOR FAKKAN			RAINFALL INTENSITIES										STORM	STORM
			MINUTES			HOURS								DURATION
STATION	DATE	TYPE	10	20	30	1	2	3	4	6	12	24	mms	Hr.Mn
KHOR FAKK-	16/11/78	Amount	1.8!	2.6!	4.0!	4.4!	5.6!	-	-	-	-	-	5.6!	0140
		Rate	10.8!	7.8!	8.0!	4.4!	2.8!	-	-	-	-	-		
	14/12/78	Amount	MISSING U/S										18.0!	-
		Rate												
	15/12/78	Amount	MISSING U/S										33.2!	-
		Rate												
	22/1/79	Amount	9.0!	11.6!	13.0!	13.0!	13.0!	13.0!	13.0!	13.0!	14.0!	-	14.0!	1700
		Rate	54.0!	34.8!	26.0!	13.0!	6.5!	4.3!	3.2!	2.2!	1.2!	-		
	10/3/79	Amount	1.4!	1.4!	1.4!	2.0!	2.0!	2.2!	2.2!	2.8!	-	-	2.8!	0545
		Rate	8.4!	4.2!	2.8!	2.0!	1.0!	0.7!	0.6!	0.5!	-	-		
	27/3/79	Amount	9.2!	9.4!	9.4!	9.4!	13.4!	18.4!	14.8!	19.8!	28.4!	30.6	30.6!	1820
		Rate	55.2!	28.2!	18.8!	9.4!	6.7!	6.1!	4.7!	3.3!	2.4!	1.3		
	16/3/80	Amount	1.4!	2.8!	3.2!	3.4!	5.0!	-	-	-	-	-	5.0!	0123
		Rate	8.4!	5.6!	4.4!	3.4!	2.5!	-	-	-	-	-		
	30/11/80	Amount	9.4!	11.0!	11.0!	11.0!	-	-	-	-	-	-	11.0!	0040
		Rate	56.4!	33.0!	22.0!	11.0!	-	-	-	-	-	-		
	1/1/81	Amount	2.4!	2.4!	3.2!	3.2!	3.2!	6.0!	6.0!	6.2!	-	-	6.2!	0440
		Rate	14.4!	7.2!	6.4!	3.2!	1.6!	2.0!	1.5!	1.0!	-	-		
	03/03/81	Amount	1.6!	2.2!	2.6!	2.8!	4.0!	4.2!	6.4!	6.4!	9.6!	9.6	9.6!	1320
		Rate	9.6!	6.6!	5.2!	2.8!	2.0!	1.4!	1.6!	1.1!	0.8!	0.4		
	30/4/81	Amount	11.2!	14.6!	15.4!	15.8!	15.8!	15.8!	15.8!	15.8!	19.0!	19.0	19.0!	1800
		Rate	67.2!	43.8!	30.8!	15.8!	7.9!	5.3!	3.9!	2.6!	1.5!	0.8		
	01/05/81	Amount	7.8!	9.6!	10.0!	10.0!	10.0!	10.0!	10.4!	10.4!	10.4!	16.6	16.6!	1640
		Rate	46.8!	28.8!	20.0!	10.0!	5.0!	3.3!	2.6!	1.7!	0.9!	0.7		
	02/05/81	Amount	5.8!	8.0!	8.0!	8.2!	11.8!	11.8!	13.2!	14.4!	-	-	14.4!	0600
		Rate	34.8!	18.0!	12.0!	8.2!	5.9!	3.9!	3.3!	2.4!	-	-		
	14/01/82	Amount	14.6!	17.0!	18.6!	18.8!	-	-	-	-	-	-	18.8!	0040
		Rate	87.6!	51.0!	37.2!	18.8!	-	-	-	-	-	-		
	01/02/82	Amount	4.8!	5.8!	8.0!	8.2!	9.6!	11.4!	11.4!	17.6!	18.2!	21.4	21.4!	1320
		Rate	28.8!	17.4!	12.0!	8.2!	4.8!	3.8!	2.9!	2.9!	1.5!	0.9		
	05/02/82	Amount	2.2!	2.4!	2.4!	3.2!	3.6!	5.2!	5.6!	7.0!	-	-	7.0!	0540
		Rate	13.2!	7.2!	4.8!	3.2!	1.8!	1.7!	1.4!	1.2!	-	-		
	13/02/82	Amount	2.6!	4.0!	6.0!	11.8!	23.2!	32.0!	41.4!	52.8!	85.0!	123.4	123.4!	2230
		Rate	15.6!	12.8!	12.0!	11.8!	11.7!	10.7!	10.3!	8.8!	7.1!	5.1		
	14/02/82	Amount	11.0!	15.8!	16.0!	16.2!	16.6!	16.8!	18.8!	22.0!	-	-	22.0!	0500
		Rate	78.0!	47.4!	32.0!	16.0!	8.3!	6.2!	4.7!	3.7!	-	-		
	23/02/82	Amount	8.0!	8.4!	8.6!	9.2!	-	-	-	-	-	-	9.2!	0100
		Rate	48.0!	25.2!	17.2!	9.2!	-	-	-	-	-	-		
	24/01/82	Amount	7.0!	13.2!	14.0!	14.4!	15.2!	17.4!	18.6!	18.8!	-	-	18.8!	0420
		Rate	42.0!	39.6!	28.0!	14.4!	7.6!	5.8!	4.7!	3.1!	-	-		
	03/03/82	Amount	2.4!	2.4!	2.6!	3.2!	6.4!	10.0!	10.6!	12.2!	14.0!	-	14.0!	0750
		Rate	14.4!	7.2!	5.6!	3.2!	3.2!	3.3!	2.7!	2.0!	1.2!	-		
	06/03/82	Amount	0.6!	1.2!	1.6!	2.2!	2.6!	-	-	-	-	-	2.6!	0120
		Rate	3.6!	3.6!	3.2!	2.2!	1.3!	-	-	-	-	-		
	11/03/82	Amount	5.2!	6.6!	7.2!	9.6!	14.2!	16.2!	17.6!	18.0!	-	-	18.0!	0570
		Rate	31.2!	19.8!	14.4!	9.6!	7.1!	5.4!	4.4!	3.0!	-	-		
	12/03/82	Amount	1.8!	3.2!	3.8!	5.8!	8.8!	10.4!	11.4!	13.0!	14.6!	-	14.6!	0730
		Rate	10.8!	9.6!	7.6!	5.8!	4.4!	3.5!	2.9!	2.2!	1.2!	-		
	13/03/82	Amount	2.0!	3.0!	4.8!	6.0!	8.2!	8.8!	9.8!	15.8!	15.8!	19.0	19.0!	1920
		Rate	12.0!	9.0!	9.6!	6.0!	4.1!	2.9!	2.4!	2.6!	1.3!	0.7		
	28/03/82	Amount	Rainhouse unserviceable, Rainfall measured										64.0!	
		Rate												
	29/10/82	Amount	2.4!	3.6!	6.2!	7.6!							7.6!	0057
		Rate	14.4!	10.8!	12.4!	7.6!								
	01/11/82	Amount	12.6!	16.0!	16.2!	16.2!							16.2!	0830
		Rate	75.6!	48.0!	32.4!	16.2!								
	04/11/82	Amount	15.0!	25.0!	28.4!	32.4!							32.4!	0052
		Rate	90.0!	75.0!	56.8!	32.4!								
	13/11/82	Amount	4.0!	4.0!	4.0!	4.0!							4.0!	0008
		Rate	24.0!	12.0!	8.0!	4.0!								

Appendix 2. (Source of rainstorm intensity sheets: MAF)

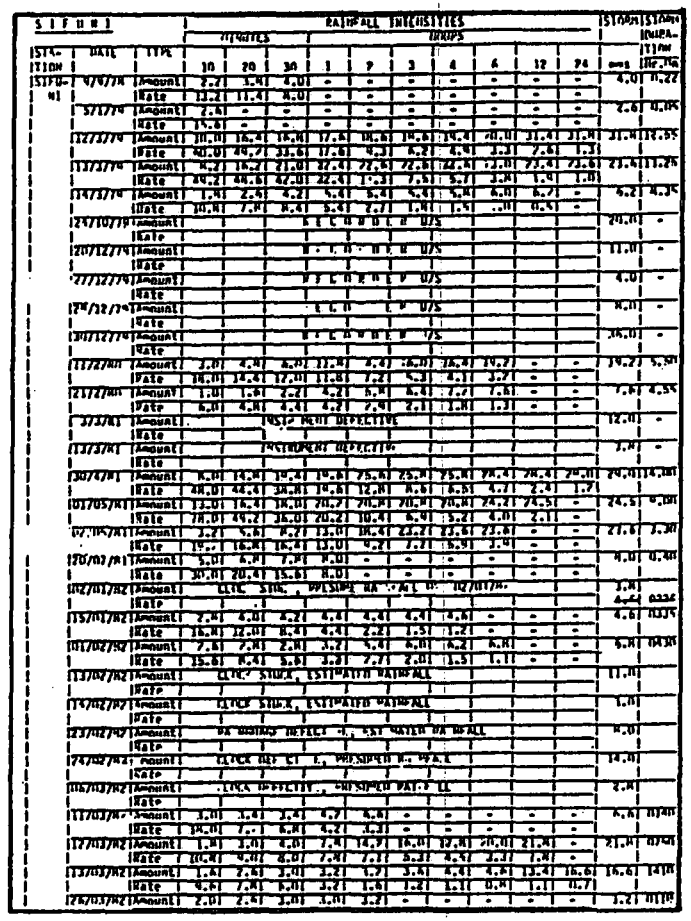
Examples of malfunctioning of some of the rain-recorders in different rainfall stations in the Emirates as seen in these rainstorm intensity sheets for Digdaga, Khor Fakkan, Al Aweer, Sharjah town, Sfini, Al Ghail, Sinnah and 'Asimah. The rain-recorder fails mostly in critical times of a rain storm. (See Chapter 3, Sections: 3.2 and 3.5.2)

APPENDIX 2

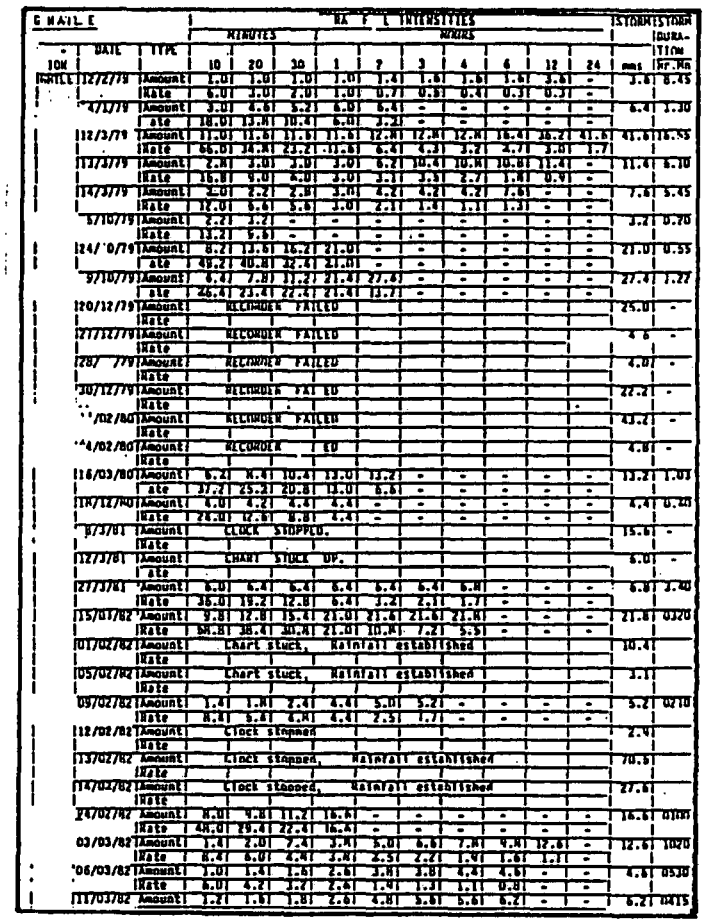
AWIR 11			RAINFALL INTENSITIES									STORM	STORM DURATION
			MINUTES			HOURS							
STATION	DATE	TYPE	10	20	30	1	2	3	4	6	12	24	mms	Hr.Mn
AWIR 11	30/04/81	Amount	Raingauge unserviceable.										26.0	-
		Rate												
	01/05/81	Amount	Raingauge unserviceable.										9.0	-
		Rate												
	02/05/81	Amount	Raingauge unserviceable.										20.0	-
		Rate												
	04/06/81	Amount	Raingauge defective.										14.2	-
		Rate												
	02/01/82	Amount	2.41	2.41	2.41	4.81	6.41	-	-	-	-	-	6.8	0140
		Rate	14.41	7.21	6.01	4.81	3.41	-	-	-	-	-		
	01/02/82	Amount	2.61	3.01	4.81	5.21	6.81	6.81	6.81	6.81	7.21	-	7.8	0400
		Rate	15.61	9.01	9.61	5.21	3.31	2.21	1.71	1.11	0.71	-		
	09/02/82	Amount	CLOCK STOPPED, RAINFALL MEASURED.										5.0	-
		Rate												
	13/02/82	Amount	CLOCK STOPPED, RAINFALL MEASURED.										56.0	-
		Rate												
	14/02/82	Amount	CLOCK STOPPED, RAINFALL MEASURED.										36.4	-
		Rate												
	24/02/82	Amount	1.41	2.81	3.01	3.01	-	-	-	-	-	-	3.0	0030
		Rate	10.81	8.41	6.01	1.51	-	-	-	-	-	-		
	02/03/82	Amount	0.81	1.21	1.61	2.61	3.01	-	-	-	-	-	3.0	0150
		Rate	4.81	3.61	3.21	2.61	1.51	-	-	-	-	-		
	03/03/82	Amount	1.01	1.41	2.21	3.21	3.81	4.61	5.41	7.01	12.81	-	12.8	1130
		Rate	6.01	5.41	4.41	3.21	1.91	1.51	1.31	1.21	1.11	-		
	06/03/82	Amount	0.61	1.01	1.41	2.41	3.01	-	-	-	-	-	3.0	0120
		Rate	3.61	3.01	2.81	2.41	1.51	-	-	-	-	-		
	11/03/82	Amount	1.01	1.41	2.21	2.61	2.61	2.81	-	-	-	-	2.8	0220
		Rate	6.01	4.21	4.61	2.61	1.91	1.41	-	-	-	-		
	12/03/82	Amount	1.81	2.61	3.41	8.01	13.01	13.61	14.21	16.41	19.61	-	19.6	0740
		Rate	10.81	7.81	6.81	8.01	6.51	4.51	3.51	2.71	1.61	-		
	13/03/82	Amount	1.41	2.21	2.81	4.61	9.01	10.81	11.41	13.81	-	-	13.8	0550
		Rate	8.41	6.61	5.61	4.61	4.51	3.61	2.91	2.31	-	-		
	13/03/82	Amount	1.41	1.81	2.21	2.21	2.21	3.61	4.01	-	-	-	4.0	0320
		Rate	8.41	5.41	4.41	2.21	1.11	1.21	1.01	-	-	-		
	14/03/82	Amount	0.41	0.61	0.81	1.01	1.41	2.21	2.61	3.01	-	-	3.0	0305
		Rate	2.61	1.81	1.21	1.01	0.81	0.71	0.71	0.51	-	-		
	27/03/82	Amount	2.21	2.61	3.01	3.01	-	-	-	-	-	-	3.0	0030
		Rate	19.21	10.81	7.61	3.01	-	-	-	-	-	-		
	27/03/82	Amount	3.41	4.01	4.21	5.21	6.01	6.41	-	-	-	-	6.4	0210
		Rate	22.81	12.01	8.41	10.41	3.01	2.11	-	-	-	-		
	28/03/82	Amount	9.61	17.01	19.21	23.41	26.41	35.01	43.21	45.81	58.61	64.4	64.4	1400
		Rate	57.61	51.01	38.41	23.61	13.21	11.71	10.81	7.61	4.91	2.71		
	30/03/82	Amount	1.81	1.81	2.41	3.41	5.61	7.01	-	-	-	-	7.0	0300
		Rate	6.01	5.41	4.81	3.41	2.81	2.51	-	-	-	-		
	10/12/82	Amount	1.41	1.81	1.81	1.81	1.81	2.01	2.01	2.41	5.61		5.6	1030
		Rate	8.41	5.41	3.61	1.81	0.91	0.71	0.51	0.41	0.51			
	20/01/83	Amount	4.61	8.01	10.01	17.61	20.41	20.81	25.41	29.21	31.21		31.2	1050
		Rate	27.61	24.01	20.01	17.61	10.21	7.01	6.41	4.91	2.61			
	10/02/83	Amount	2.81	3.21	3.21	3.21	3.41	5.21	6.41				6.4	0340
		Rate	16.81	9.61	6.41	3.21	1.71	1.71	1.61					
	11/02/83	Amount	3.81	4.21	4.41	6.21	10.61	15.01	17.21	23.01	30.41	(1st	30.4	1040
		Rate	22.81	12.61	8.81	6.21	5.31	5.01	4.31	3.81	2.51	spell)		
	12/02/83	Amount	1.61	2.61	3.21	4.41	4.61	4.61	5.01	(2nd spell)			5.0	0400
		Rate	9.61	7.81	6.41	4.81	2.31	1.51	1.31					
	13/02/83	Amount	1.01	1.41	1.61	3.21	4.01	4.21	4.81				4.8	0330
		Rate	6.01	4.21	3.21	3.21	2.01	1.41	1.21					
	11/03/83	Amount	0.81	1.01	1.21	2.41	2.61	3.41					3.4	0250
		Rate	3.61	3.01	2.41	2.41	1.31	1.11						
	12/03/83	Amount	4.41	4.61	4.81	5.41	6.01	6.21	6.21	6.21	18.21	18.21	18.2	1100

			RAINFALL INTENSITIES									STORM	STORM DURATION
			MINUTES			HOURS							
STATION	DATE	TYPE	10	20	30	1	2	3	4	6	12	24	mms	Hr.Mn
Sharpe Town	03/03/83	Amount	2.21	2.41	6.01	6.21	6.21	6.61	6.61	6.61	6.41	6.41	6.4	1140
		Rate	13.21	10.21	12.01	6.21	3.11	2.21	1.71	1.11	0.71	0.41		
	27/03/83	Amount	4.41	4.41	4.41	4.41							4.4	0120
		Rate	26.41	13.21	8.81	4.41								
	30/04/83	Amount	16.21	16.41	16.61	16.61	28.61	28.61	28.61	28.61	35.21		35.2	0920
		Rate	106.21	58.21	30.21	16.61	14.41	9.61	7.21	4.81	2.91			
	02/05/83	Amount	7.01	2.21	2.41	2.41	5.61	11.21	12.41	12.41	12.61		12.6	0920
		Rate	12.01	6.61	4.81	2.41	2.81	3.71	3.11	2.11	1.11			
	07/02/82	Amount	2.81	2.81	2.81	2.81	3.01	3.01	3.01	-	-	-	1.6	0130
		Rate	15.61	8.41	6.61	2.01	1.51	1.01	0.81					
	09/02/82	Amount	RECORDER UNSERVICEABLE, RAINFALL MEASURED.										1.0	
		Rate												
	10/02/82	Amount	RECORDER UNSERVICEABLE, RAINFALL MEASURED.										2.6	
		Rate												
	13/02/82	Amount	RECORDER UNSERVICEABLE, RAINFALL MEASURED.										50.0	
		Rate												
	14/02/82	Amount	RECORDER UNSERVICEABLE, RAINFALL MEASURED.										16.0	
		Rate												
	17/02/82	Amount	RECORDER UNSERVICEABLE, RAINFALL MEASURED.										9.0	
		Rate												
	17/02/82	Amount	RECORDER UNSERVICEABLE, RAINFALL MEASURED.										7.0	
		Rate												
	13/03/82	Amount	RECORDER UNSERVICEABLE, RAINFALL MEASURED.										30.0	
		Rate												
	14/03/82	Amount	RECORDER UNSERVICEABLE, RAINFALL MEASURED.										11.0	
		Rate												
	24/03/82	Amount	RECORDER UNSERVICEABLE, RAINFALL MEASURED.										24.2	
		Rate												
	03/12/82	Amount	2.	3.21	3.41	5.01	9.01						9.0	1040
		Rate	13.21	9.61	6.81	5.01	4.01							
	13/12/82	Amount	2.41	2.61	3.41	4.21	5.01	6.21					6.2	0950
		Rate	14.41	10.81	7.61	4.21	2.51	2.11						
	30/12/82	Amount	1.01	1.41	2.61	3.41	4.21	6.41	6.21	7.61	11.21		11.2	1100
		Rate	6.01	5.41	5.21	3.41	2.11	1.61	1.61	1.21	0.91			
	20/01/83	Amount	RAINFALL TO GAS POSITION (CLOCK STOPPED)										29.2	
		Rate												
	11/02/83	Amount	Paper stuck; average rainfall										30.0	
		Rate												
	12/02/83	Amount	Paper stuck; average rainfall										3.0	
		Rate												
	14/02/83	Amount	Paper stuck; average rainfall										20.0	
		Rate												
	11/03/83	Amount	0.81	1.41	1.81	3.21	3.21	3.61					3.6	0240
		Rate	5.61	4.21	3.21	3.21	1.61	1.21						
	12/03/83	Amount	2.01	2.61	3.61	3.61	3.61	8.21	8.41	8.41	8.41	11.61	11.6	2120
		Rate	12.01	8.41	7.21	3.61	1.81	1.41	1.21	0.81	0.81	0.51		
	15/03/83	Amount	1.41	2.01	2.61	2.61	2.61	3.21					3.2	0910
		Rate	9.61	6.81	4.81	2.61	1.31	1.11						
	16/03/83	Amount	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	3.01	3.0	1500
		Rate	9.61	6.81	3.21	1.61	0.81	0.51	0.41	0.31	0.21	0.11		
	05/04/83	Amount	2.41	2.61	3.61	3.61	3.61	3.61					2.6	0220
		Rate	14.41	7.81	5.21	3.61	1.91	1.21						
	09/04/83	Amount	1.41	2.01	2.21	2.61							2.6	0000
		Rate	10.81	6.81	4.41	2.61								
	10/04/83	Amount	10.01	10.41	10.61	10.61	11.61						11.6	0140
		Rate	60.01	32.41	21.61	10.61	5.91							
	12/04/83	Amount	2.41	2.61	2.61	2.61	3.41						3.4	0130
		Rate	14.41	7.21	4.81	2.61	1.71							

APPENDIX 2



SIFUNI			RAINFALL INTENSITIES										STORM	STORM DURATION
			MINUTES			HOURS								
STATION	DATE	TYPE	10	20	30	1	2	3	4	6	12	24	mm	hr.Min
SIFUNI	6/6/78	Amount	2.21	3.41	4.01	-	-	-	-	-	-	-	4.01	0.22
		Rate	13.21	11.41	8.01	-	-	-	-	-	-	-		
	5/7/79	Amount	2.61	-	-	-	-	-	-	-	-	-	2.6	0.10
		Rate	15.61	-	-	-	-	-	-	-	-	-		
	12/3/79	Amount	11.01	16.41	16.41	17.61	18.61	19.61	19.41	20.01	31.41	31.41	31.4	12.55
		Rate	66.01	49.21	33.61	17.61	9.21	6.21	4.41	3.21	2.61	1.31		
	13/3/79	Amount	6.21	10.21	21.01	22.41	22.41	22.61	22.61	22.61	23.01	23.41	23.4	11.25
		Rate	49.21	44.61	42.01	22.41	11.21	7.61	5.71	3.81	1.91	1.01		
	14/3/79	Amount	1.41	2.41	4.21	5.41	5.41	5.41	5.41	6.01	6.21	-	6.2	4.35
		Rate	10.41	7.01	8.41	5.41	2.71	1.41	1.31	.01	0.51	-		
	24/10/79	Amount					S L U M B L E	D/S					20.0	-
		Rate												
	20/12/79	Amount					R E C O R D E R	D/S					11.0	-
		Rate												
	27/12/79	Amount					P E N C I L L E D	D/S					4.0	-
		Rate												
	28/12/79	Amount					C L O	D/S					8.0	-
		Rate												
	30/12/79	Amount					R E C O R D E R	D/S					16.0	-
		Rate												
	11/2/80	Amount	3.01	4.41	6.01	11.41	4.41	6.01	16.41	19.21	-	-	19.2	5.30
		Rate	18.01	14.41	12.01	11.61	7.21	5.31	4.11	3.21	-	-		
	21/2/80	Amount	1.01	1.61	2.21	4.21	5.41	6.41	7.21	7.61	-	-	7.6	4.55
		Rate	6.01	4.81	4.41	4.21	2.41	2.11	1.81	1.31	-	-		
	3/3/81	Amount				DUST MONT DEFECTIVE							12.0	-
		Rate												
	13/3/81	Amount				PYCHOMENT DEFECTIVE							2.4	-
		Rate												
	30/4/81	Amount	8.01	14.41	19.41	19.61	25.61	25.41	25.41	28.41	28.41	28.01	28.0	14.00
		Rate	48.01	44.41	38.81	19.61	12.81	8.51	6.31	4.71	2.41	1.21		
	01/05/81	Amount	13.01	16.41	18.01	20.21	20.41	20.41	20.41	24.21	24.51	-	24.5	9.00
		Rate	78.01	49.21	36.01	20.21	10.41	6.91	5.21	4.01	2.11	-		
	07/05/81	Amount	3.21	5.61	8.21	13.01	18.41	22.21	23.61	23.61	-	-	23.6	3.30
		Rate	19.21	16.81	16.41	13.01	9.21	7.41	5.91	3.91	-	-		
	20/05/81	Amount	5.01	6.81	7.61	8.01	-	-	-	-	-	-	8.0	0.40
		Rate	30.01	20.41	15.61	8.01	-	-	-	-	-	-		
	02/01/82	Amount				CLOCK STUCK, PRESUMED RAINFALL OF					12/01/82		3.0	0334
		Rate											Aug	
	15/01/82	Amount	2.41	4.01	4.21	4.41	4.41	4.41	4.61	-	-	-	4.6	0335
		Rate	16.41	12.01	8.41	4.41	2.21	1.51	1.21	-	-	-		
	01/02/82	Amount	7.61	7.41	7.41	7.21	5.41	6.01	6.21	6.61	-	-	6.6	0430
		Rate	15.61	8.41	5.61	3.21	2.71	2.01	1.51	1.11	-	-		
	13/02/82	Amount				CLOCK STUCK, ESTIMATED RAINFALL							11.0	
		Rate												
	14/02/82	Amount				CLOCK STUCK, ESTIMATED RAINFALL							1.0	
		Rate												
	23/02/82	Amount				RA MISSED DUETO L, EST WATER RA OF ALL							8.0	
		Rate												
	24/02/82	Amount				CLOCK DUE TO L, PRESUMED RAFALL							14.0	
		Rate												
	26/02/82	Amount				CLOCK DUE TO L, PRESUMED RAINFALL							2.0	
		Rate												
	11/03/82	Amount	3.01	3.61	3.41	4.21	4.61	-	-	-	-	-	4.6	0340
		Rate	18.01	7.21	5.61	4.21	2.31	-	-	-	-	-		
	12/03/82	Amount	1.81	3.01	4.01	7.41	14.21	16.01	17.81	20.01	21.41	-	21.4	0700
		Rate	10.81	8.01	6.01	7.41	7.11	5.31	4.41	3.31	1.81	-		
	13/03/82	Amount	1.41	2.41	3.01	3.21	3.71	3.41	4.41	4.61	13.41	16.61	16.6	1410
		Rate	8.61	7.01	5.01	3.21	1.81	1.21	1.11	0.81	1.11	11.7		
	26/03/82	Amount	2.01	2.61	3.01	3.01	3.21	-	-	-	-	-	3.2	0110



E MAILE			RAINFALL INTENSITIES										STORM	STORM DURATION
			MINUTES			HOURS								
ION	DATE	TYPE	10	20	30	1	2	3	4	6	12	24	mm	hr.Min
MAILE	12/2/79	Amount	1.01	1.01	1.01	1.01	1.41	1.61	1.61	1.61	1.61	-	1.6	0.45
		Rate	6.01	3.01	2.01	1.01	0.71	0.51	0.41	0.31	0.21	-		
	4/2/79	Amount	3.01	4.61	5.21	6.01	6.41	-	-	-	-	-	6.4	1.30
		ate	18.01	13.41	10.41	6.01	3.21	-	-	-	-	-		
	12/3/79	Amount	11.01	11.61	11.61	11.61	12.41	12.41	12.41	16.41	26.21	41.61	41.6	16.55
		Rate	66.01	34.41	23.21	11.61	6.41	4.31	3.21	2.71	2.01	1.71		
	13/3/79	Amount	2.41	3.01	3.01	3.01	6.21	10.41	10.41	10.61	11.41	-	11.4	6.10
		Rate	16.81	9.01	6.01	3.01	3.11	3.51	2.71	1.81	0.91	-		
	14/3/79	Amount	2.01	2.21	2.81	3.01	4.21	4.21	4.21	7.61	-	-	7.6	5.45
		Rate	12.01	6.61	5.61	3.01	2.11	1.41	1.11	1.31	-	-		
	5/10/79	Amount	2.21	2.21	-	-	-	-	-	-	-	-	3.2	0.20
		Rate	13.21	9.61	-	-	-	-	-	-	-	-		
	24/10/79	Amount	8.21	13.61	16.21	21.01	-	-	-	-	-	-	21.0	0.55
		ate	49.21	40.81	32.41	21.01	-	-	-	-	-	-		
	9/10/79	Amount	6.41	7.81	11.21	21.41	27.61	-	-	-	-	-	27.4	1.27
		ate	26.41	23.41	22.41	21.41	13.71	-	-	-	-	-		
	20/12/79	Amount				RECORDER FAILED							25.0	-
		Rate												
	27/12/79	Amount				RECORDER FAILED							6.6	-
		Rate												
	28/ 7/79	Amount				RECORDER FAILED							4.0	-
		Rate												
	30/12/79	Amount				RECORDER FAILED							22.2	-
		Rate												
	/02/80	Amount				RECORDER FAILED							43.2	-
		Rate												
	4/02/80	Amount				RECORDER FAILED							4.8	-
		Rate												
	16/03/80	Amount	6.21	8.41	10.41	13.01	13.21	-	-	-	-	-	13.2	1.03
		ate	37.21	25.21	20.81	13.01	6.61	-	-	-	-	-		
	18/12/80	Amount	4.01	4.21	4.41	4.41	-	-	-	-	-	-	4.4	0.45
		Rate	26.01	12.61	8.81	4.41	-	-	-	-	-	-		
	3/3/81	Amount	CLOCK STOPPED.										15.6	-
		Rate												
	12/3/81	Amount	CHART STUCK DU.										6.0	-
		ate												
	27/3/81	Amount	6.01	6.41	6.41	6.41	6.41	6.41	6.81	-	-	-	6.8	2.40
		Rate	36.01	19.21	12.81	6.41	3.21	2.11	1.71	-	-	-		
	15/01/82	Amount	9.81	12.81	15.41	21.01	21.41	21.61	21.61	-	-	-	21.6	0320
		Rate	58.81	38.41	30.81	21.01	10.71	7.21	5.51	-	-	-		
	01/02/82	Amount	Chart stuck, Rainfall established										10.4	
		Rate												
	05/02/82	Amount	Chart stuck, Rainfall established										3.1	
		Rate												
	09/02/82	Amount	1.41	1.81	2.41	4.41	5.01	5.21	-	-	-	-	5.2	0210
		Rate	8.81	5.41	4.81	4.41	2.51	1.71	-	-	-	-		
	12/02/82	Amount	Clock stopped										2.4	
		Rate												
	13/02/82	Amount	Clock stopped, Rainfall established										70.5	
		Rate												
	14/02/82	Amount	Clock stopped, Rainfall established										27.6	
		Rate												
	24/02/82	Amount	8.01	9.81	11.21	16.41	-	-	-	-	-	-	16.6	0100
		Rate	48.01	29.41	22.41	16.41	-	-	-	-	-	-		
	03/03/82	Amount	1.41	2.01	2.41	3.41	5.01	6.61	7.81	9.41	12.61	-	12.6	1020
		Rate	8.41	6.01	4.81	3.41	2.51	2.21	1.91	1.61	1.11	-		
	06/03/82	Amount	1.01	1.41	1.61	2.61	3.81	3.81	4.41	4.61	-	-	4.6	0530
		Rate	6.01	4.21	3.21	2.61	1.91	1.31	1.11	0.81	-	-		
	17/03/82	Amount	1.21	1.81	1.81	2.61	4.81	5.61	5.61	6.21	-	-	6.2	0415

APPENDIX 2

SINHAN			RAINFALL INTENSITIES											STORM	STORM DURATION
			MINUTES			HOURS									
STATION	DATE	TYPE	10	20	30	1	2	3	4	6	12	24		mm	Hr.Mn
SINHA	01/11/82	Amount	13.4	20.4	0.0	20.4	20.4	21.0						21.0	0210
		Rate	80.4	61.2	41.6	20.4	10.4	7.0							
	02/11/82	Amount	Pen stuck rainfall estimated											13.5	
		Rate													
	03/11/82	Amount												7.2	
		Rate													
	04/11/82	Amount												4.8	
		Rate													
	10/11/82	Amount	1.0	2.0	2.0	2.0	3.0	3.0	3.0	3.0	3.6	5.0		5.0	1600
		Rate	10.0	6.0	4.0	2.0	1.0	1.0	0.5	0.5	0.3	0.2			
	19/11/82	Amount	2.2	4.2	4.2	4.2	7.4	7.4	7.4	8.0	24.4	24.0		25.0	1620
		Rate	13.2	12.6	8.4	4.2	3.7	2.5	1.8	1.3	2.1	1.0			
	20/11/82	Amount	9.0	10.6	11.2	13.2	15.2	19.0	22.0	23.4				23.4	0510
		Rate	52.8	31.8	22.2	13.2	7.6	6.3	5.5	3.9					
	10/12/82	Amount	4.4	4.2	4.0	4.2	4.2	4.2						8.4	0210
		Rate	26.4	15.6	12.0	8.4	4.2	2.8							
	11/12/82	Amount	2.4	4.4	4.4	8.4	12.4	17.0	20.6	22.4	51.2	55.4		55.4	2020
		Rate	14.4	13.2	10.8	8.4	6.2	5.7	5.2	4.6	4.4	2.3			
	12/12/82	Amount	1.4	4.0	4.4	5.8	6.0	8.4	12.4	(1st spell)				12.4	0320
		Rate	14.8	15.0	10.8	5.8	2.4	2.8	2.1						
	13/12/82	Amount	1.2	2.2	2.4	3.4	5.4			(2nd spell)				5.4	0210
		Rate	7.2	6.6	4.8	3.4	2.7								
	27/12/82	Amount	Clock stuck rainfall upto 27/12/82 estimated by pen											21.0	
		Rate	position.												
	23/12/82	Amount	1.0	4.0	4.4	6.4	11.4	1.4	12.4	13.4	13.4			13.8	1140
		Rate	14.0	14.0	10.8	6.4	5.4	4.4	3.0	2.2	1.1				
	30/12/82	Amount	1.0	4.4	4.4	7.0	9.2	11.2	12.4	13.4				13.8	1420
		Rate	12.0	14.0	11.2	7.0	4.6	3.7	3.1	2.2					
	31/12/82	Amount	1.4	2.2	2.4	3.4	4.4	6.4	10.2	13.4				13.6	0540
		Rate	8.4	6.6	5.6	3.4	2.4	2.1	2.5	2.2					
	01/01/83	Amount	Chart stuck pen position on 1/1/83											17.8	
		Rate													
	10/01/83	Amount	4.2	7.0	7.0	8.4	14.4	22.4	23.2	23.4	24.0			24.0	1040
		Rate	24.0	21.0	15.6	8.4	7.2	7.5	5.8	4.0	2.4				
	11/01/83	Amount	2.0	2.4	2.4	3.2	4.2	6.2						9.8	1540
		Rate	12.0	8.4	6.4	3.2	2.1	2.1							

ASINAM			RAINFALL INTENSITIES											STORM	STORM DURATION
			MINUTES			HOURS									
STATION	DATE	TYPE	10	20	30	1	2	3	4	6	12	24		mm	Hr.Mn
ASINAM	26/12/79	Amount	Recorder Failed											19.0	-
		Rate													
	27/12/79	Amount	Recorder Failed											6.5	-
		Rate													
	28/12/79	Amount	Recorder Failed											4.0	-
		Rate													
	30/12/79	Amount	Recorder Failed											32.0	-
		Rate													
	11/02/80	Amount	4.2	8.6	8.2	11.4	16.6	19.0	22.0	25.2	29.4	-		29.4	10.45
		Rate	25.2	19.4	16.4	11.4	8.2	6.0	5.5	4.2	2.5	-			
	27/02/80	Amount	1.0	1.2	1.4	2.2	3.4	4.4	5.0	5.4	-	-		5.4	4.20
		Rate	6.0	3.6	2.6	2.2	1.7	1.5	1.3	0.9	-	-			
	16/03/80	Amount	7.6	9.6	11.0	13.8	14.2	-	-	-	-	-		14.2	1.05
		Rate	45.6	28.8	22.0	13.8	7.1	-	-	-	-	-			
	01/02/82	mount	Raingauge defective, total rainfall measured.											24.1	-
		Rate												4.4	
	05/02/82	Amount	- do -											-	-
		Rate													
	09/02/82	Amount	1.6	2.0	2.6	3.6	4.2	-	-	-	-	-		4.2	0150
		Rate	9.6	6.0	5.2	3.6	2.1	-	-	-	-	-			
	13/02/82	Amount	5.0	6.0	7.0	9.2	13.6	25.0	29.8	38.0	82.6	90.2		90.2	2240
		Rate	30.0	18.0	14.0	9.2	6.8	7.8	7.5	6.3	4.6	3.8			
	14/02/82	Amount	4.2	11.2	12.8	17.2	20.6	24.0	25.2	27.0	-	-		27.0	0555
		Rate	25.2	22.2	25.6	17.2	10.2	8.0	6.3	4.5	-	-			
	23/02/82	Amount	3.8	3.8	3.8	3.8	-	-	-	-	-	-		3.8	0010
		Rate	22.8	11.4	7.6	3.8	-	-	-	-	-	-			
	24/02/82	Amount	4.6	6.2	6.8	8.6	8.8	8.8	10.0	10.2	-	-		10.2	0635
		Rate	27.6	18.6	13.6	8.6	4.4	2.9	2.5	1.8	-	-			
	03/03/8	mount	2.2	2.4	2.4	2.8	5.8	6.6	8.2	10.4	14.0	-		14.0	1130
		Rate	13.2	7.2	4.8	2.8	2.9	2.2	2.1	1.7	0.6	-			
	05/03/82	Amount	0.8	1.0	1.2	2.0	2.8	2.8	3.8	4.2	-	-		4.2	0540
		Rate	3.6	3.0	2.4	2.0	1.4	0.9	0.9	0.7	-	-			
	11/03/82	Amount	1.6	2.4	3.0	4.0	5.4	7.6	8.0	8.4	-	-		8.4	0440
		Rate	9.6	7.2	6.0	4.0	2.7	2.5	2.0	1.4	-	-			
	12/03/82	Amount	0.8	0.8	0.8	1.2	2.2	3.0	3.6	5.2	7.0	-		7.0	0410
		Rate	2.8	1.8	1.6	1.2	1.1	1.0	0.9	0.9	0.6	-			
	13/03/82	mount	Raingauge defective, total rainfall measured.											13.9	-
		Rate													
	28/03/82	Amount	- do -											96.0	-
		Rate													
	01/05/82	Amount	1.0	2.0	2.8	2.8	-	-	-	-	-	-		2.8	0030
		Rate	6.0	6.0	5.6	2.8	-	-	-	-	-	-			
	29/10/82	Amount	2.0	4.0	5.6	5.6	7.4							7.4	0200
		Rate	12.0	12.0	11.2	5.6	3.7								
	02/11/82	Amount	1.0	4.0	5.0	5.0	5.4							6.4	0210
		Rate	16.0	15.0	10.0	5.0	2.7								
	13/11/82	Amount	2.8	3.4	4.2	4.4								4.8	0110
		Rate	16.8	11.4	8.4	4.8									
	10/12/82	Amount	0.4	0.6	0.8	1.6	3.2	4.2	4.4	4.2				5.6	0830
		Rate	2.4	1.8	1.6	1.6	1.6	1.4	1.1	0.7					
	19/12/82	Amount	4.0	11.0	12.6	13.6	13.6	13.6	13.6	15.4	17.0	21.6		21.6	1300
		Rate	48.0	33.0	25.2	13.6	6.8	4.6	3.5	2.6	1.4	0.9			
	21/12/82	Amount	2.0	3.4	6.2	7.4	7.6							7.6	0110
		Rate	12.0	10.2	10.4	7.4	3.8								
	20/01/83	Amount	4.0	6.6	9.0	14.4	23.2	32.0	34.2	34.6				39.6	0530
		Rate	24.0	19.8	18.0	14.4	11.6	10.7	9.1	6.9					
	10/02/83	Amount	1.2	1.8	1.8	2.0	2.8	3.0						3.0	0210
		Rate	7.2	5.4	3.6	2.4	1.4	1.0							
	17/02/83	Amount	1.4	2.8	3.6	5.4	8.2	11.0	13.4	17.2	24.0	31.2		31.2	1400

APPENDIX 3

Return periods of rainfall means fo the 38 rainfall stations in all the topographic regions of the Emirates.

Year	Rainfall	Return Period
(1) MASAFI		
84-85	34.00	1.050000
69-70	40.30	1.105263
73-74	41.00	1.166667
85-86	77.60	1.235294
72-73	83.20	1.312500
80-81	95.00	1.400000
78-79	104.00	1.500000
67-68	106.06	1.615385
83-84	110.40	1.750000
86-87	158.80	2.100000
68-69	181.20	2.333334
79-80	184.60	2.625000
71-72	192.90	2.626575
77-78	179.90	3.000000
87-88	244.90	3.500000
82-83	249.50	4.200001
76-77	263.60	5.250001
74-75	325.50	7.000001
81-82	348.20	10.500000
75-76	357.10	21.000000
(2) 'Asimah		
70-71	20.50	1.066667
73-74	24.70	1.142857
83-84	26.60	1.230709
84-85	40.60	1.333333
78-79	43.00	1.454546
72-73	57.60	1.600000
85-86	95.20	1.777778
80-81	116.60	2.000000
79-80	127.90	2.285715
77-78	130.70	2.666667
86-87	190.20	3.200000
71-72	224.60	4.000000
87-88	230.00	5.333334
82-83	273.40	8.000000
81-82	332.00	16.000000
(3) Bithnah		
70-71	0.3	1.058824
73-74	17.0	1.125000
84-85	22.8	1.200000
85-86	63.8	1.285714
72-73	67.6	1.384615
83-84	76.0	1.500000
77-78	80.2	1.636364
78-79	80.8	1.800000
80-81	104.2	2.000000
76-77	132.3	2.250000
79-80	132.6	2.571429
71-72	155.3	3.000000
86-87	166.0	3.600000
75-76	214.0	4.500001
87-88	252.0	6.000000
81-82	309.4	9.000000
82-83	350.0	17.999999
(4) Sinnah		
72-73	21.00	1.071429
73-74	29.50	1.153846
84-85	36.40	1.125000
83-84	37.40	1.136364
78-79	54.30	1.500000
85-86	66.60	1.666667
86-87	135.60	1.875000
80-81	136.60	2.142857
71-72	137.30	2.500000
79-80	146.20	3.000000
77-78	164.20	3.750000
87-88	213.90	5.000001
82-83	312.50	7.500001
81-82	370.20	15.000000
(5) SIJI		
84-85	34.40	1.076923
77-78	68.10	1.166667
83-84	73.60	1.272727
78-79	77.40	1.400000
85-86	80.80	1.555556
80-81	113.20	1.750000
79-80	149.40	2.000000
86-87	180.80	2.333334
87-88	221.00	2.800000
82-83	243.40	3.500000
76-77	244.30	4.666667
81-82	328.00	7.000001
75-76	334.50	14.000000
(6) Al Ghail		
83-84	15.40	1.062500
72-73	36.00	1.133333
84-85	39.60	1.214286
73-74	60.10	1.307692
78-79	72.90	1.416667
77-78	77.90	1.545455
85-86	88.60	1.700000
80-81	121.40	1.888889
76-77	145.20	2.125000
71-72	156.10	2.428572
87-88	171.50	2.833334
86-87	190.00	3.400000
75-76	193.20	4.250001
79-80	193.60	5.666667
82-83	255.40	8.500001
81-82	296.80	17.000000
(7) Fara'ah		
84-85	22.40	1.125000
83-84	43.40	1.285714
85-86	72.80	1.500000
80-81	108.40	1.800000
86-87	181.40	2.250000
87-88	290.20	3.000000
81-82	312.80	4.500001
82-83	394.20	9.000001
(8) Sfini		
84-85	31.80	1.083333
83-84	36.20	1.181818
77-78	59.40	1.300000
78-79	76.60	1.444444
85-86	97.40	1.625000
80-81	105.60	1.857143
79-80	167.20	2.166667
86-87	210.40	2.600000
76-77	228.80	3.250000
87-88	235.00	4.333334
82-83	311.00	6.500001
81-82	316.20	13.000000
(9) Marbadh		
84-85	34.80	1.142857
83-84	67.00	1.133333
85-86	88.40	1.600000
86-87	212.00	2.000000
87-88	280.60	2.666667
82-83	317.20	4.000000
81-82	454.20	8.000000

(10) Idhn

72-73	25.60	1.062500
84-85	30.40	1.133333
73-74	34.40	1.214286
83-84	40.80	1.307692
78-79	46.60	1.416667
77-78	79.90	1.545455
85-86	88.80	1.700000
80-81	111.60	1.687764
79-80	156.40	2.125000
76-77	157.00	2.428572
86-87	157.40	2.833334
71-72	182.70	3.400000
75-76	211.70	4.250001
82-83	219.40	5.666667
87-88	225.60	8.500001
81-82	329.40	17.000000

(11) Masfut

72-73	4.30	1.047610
70-71	6.30	1.100000
84-85	14.60	1.157895
83-84	18.60	1.222222
78-79	46.00	1.294118
69-70	49.80	1.375000
77-78	66.80	1.466667
85-86	92.40	1.571429
73-74	94.80	1.692308
67-68	109.10	1.833334
80-81	112.20	2.000000
68-69	130.40	2.200000
79-80	150.20	2.444444
76-77	196.80	2.750000
71-72	233.80	3.142857
82-83	264.60	3.666667
86-87	293.00	4.400000
87-88	315.80	5.500000
75-76	325.10	7.333334
81-82	341.60	11.000000
74-75	478.80	21.999999

(12) Dibba

73-74	11.90	1.047619
84-85	14.80	1.100000
70-71	16.30	1.157859
83-84	34.60	1.222222
69-70	60.30	1.294118
86-87	63.40	1.375000
85-86	63.80	1.466667
74-75	72.40	1.571429
79-80	86.00	1.692308
67-68	88.90	1.833334
78-79	90.40	2.000000
72-73	93.70	2.200000
80-81	96.40	2.444444
77-78	96.60	2.750000
68-69	166.00	3.142857
71-72	177.10	3.666667
75-76	197.40	4.400000
87-88	213.40	5.500000
81-82	246.20	7.333334
76-77	246.50	11.000000
82-83	251.00	21.999999

(13) Fujairah

84-85	12.40	1.052632
73-74	20.40	1.111111
72-73	21.90	1.764710
83-84	28.70	1.250000
70-71	44.80	1.333333
85-86	65.40	1.428572
77-78	76.70	1.538462
80-81	86.80	1.666667
79-80	96.00	1.818182
69-70	100.80	2.000000
78-79	103.60	2.222222
67-68	121.70	2.500000
71-72	145.70	2.857143
76-77	175.60	3.333333
86-87	191.00	4.000000
68-69	206.80	5.000000
87-88	290.00	6.666668
81-82	290.80	9.999998
82-83	427.00	20.000000

(14) Al Buraimi

73-74	14.10	1.058824
83-84	21.20	1.125000
85-86	26.20	1.200000
72-73	57.80	1.285714
77-78	72.30	1.384615
72-73	75.80	1.500000
80-81	77.90	1.636364
78-79	84.30	1.800000
79-80	147.60	2.000000
86-87	148.60	2.250000
87-88	152.00	2.571429
71-72	197.60	3.000000
82-83	216.10	3.600000
76-77	234.70	4.500001
75-76	295.40	6.000000
81-82	297.00	9.000001
74-75	330.50	17.999999

(15) Huwailat

70-71	1.20	1.066667
83-84	6.80	1.142857
84-85	14.00	1.230769
77-78	22.00	1.333333
78-79	67.80	1.454546
72-73	81.20	1.600000
85-86	103.40	1.777778
80-81	110.60	2.000000
71-72	147.50	2.285715
79-80	153.80	2.666667
76-77	227.20	3.200000
86-87	273.00	4.000000
81-82	338.80	5.333334
82-83	364.60	8.000000
87-88	371.40	16.000000

(16) Khor Fakkan

84-85	18.60	1.083333
83-84	30.80	1.181818
85-86	65.20	1.300000
80-81	81.20	1.444444
77-78	112.10	1.625000
78-79	124.60	1.857143
79-80	128.40	2.166667
76-77	213.70	2.600000
86-87	239.40	3.250000
87-88	304.60	4.333334
81-82	362.60	6.500001
82-83	418.80	13.000000

(17) Jabal Sharmah

84-85	36.00	1.142857
85-86	77.40	1.333333
83-84	111.60	1.600000
86-87	164.20	2.000000
87-88	252.80	2.666667
82-83	290.80	4.000000
81-82	411.40	8.000000

(18) Hunai'ee

84-85	12.80	1.071429
83-84	35.20	1.153846
73-74	66.20	1.250000
85-86	69.00	1.363636
77-78	74.90	1.500000
78-79	80.40	1.666667
72-73	86.50	1.875000
80-81	106.20	2.142857
71-72	154.60	2.500000
86-87	210.90	3.000000
79-80	227.20	3.750000
81-82	264.80	5.000000
82-83	281.60	7.500001
87-88	305.60	15.000000

(19) Kalba

84-85	12.40	1.052637
72-73	20.20	1.111111
70-71	20.60	1.176471
73-74	23.40	1.250000
83-84	31.60	1.333333
69-70	68.20	1.428572
77-78	78.20	1.538462
78-79	78 60	1.666667
79-80	85.20	1.818182
80-81	95.80	2.000000
67-68	110.00	2.222222
74-75	144.10	2.500000
68-69	223.70	2.857143
76-77	241.80	3.333333
75-76	264.90	4.000000
71-72	271.20	5.000001
87-88	276.20	6.666668
81-82	330.80	9.999998
82-83	421.80	20.000000

(20) Dubai

70-71	1.80	1.047619
83-84	7.10	1.100000
69-70	19.30	1.157895
84-85	24.50	1.222222
73-74	30.20	1.294118
85-86	42.40	1.375000
72-73	48.90	1.466667
78-79	49.20	1.571429
77-78	49.70	1.692308
80-81	62.30	1.833334
79-80	77.10	2.000000
76-77	79.60	2.200000
74-75	80.30	2.444444
68-69	102.80	2.750000
67-68	104.60	3.142857
82-83	125.30	3.666667
75-76	129.70	4.400000
71-72	142.90	5.500000
86-87	169.90	7.333334
81-82	193.90	11.000000
87-88	226.50	21.999999

(21) Sharjah

73-74	3.10	1.047619
70-71	10.80	1.100000
83-84	12.00	1.157895
84-85	17.60	1.222222
69-70	45.40	1.294118
72-73	51.70	1.375000
85-86	55.10	1.466667
78-79	72.20	1.571429
67-68	81.80	1.692309
80-81	82.10	1.833334
77-78	86.20	2.000000
76-77	93.80	2.200000
79-80	125.10	2.444444
68-69	135.20	2.750000
86-87	143.30	3.142857
74-75	167.40	3.666667
75-76	168.10	4.400000
87-88	170.20	5.500000
71-72	174.40	7.333334
82-83	189.50	11.000000
81-82	241.50	21.999999

(22) Zikt

73-74	16.80	1.071429
83-84	17.00	1.153846
84-85	29.40	1.250000
72-73	40.90	1.363636
85-86	67.00	1.500000
77-78	96.80	1.666667
80-81	124.40	1.875000
79-80	130.70	2.142857
78-79	146.20	2.500000
71-72	154.70	3.000000
86-87	193.20	3.750000
87-88	294.80	5.000001
82-83	364.40	7.500001
81-82	372.60	15.000000

(23) Ras Al Khaimah

83-84	15.00	1.083333
84-85	26.70	1.181818
85-86	52.50	1.300000
78-79	77.30	1.444444
80-81	86.50	1.625000
77-78	90.30	1.857143
86-87	129.20	2.166667
79-80	158.50	2.600000
87-88	180.60	3.250000
76-77	195.10	4.333334
81-82	258.30	6.500001
82-83	264.70	13.000000

(24) Abu Dhabi

83-84	1.60	1.058824
78-79	5.70	1.125000
84-85	5.90	1.200000
73-74	11.60	1.285714
77-78	23.60	1.384615
85-86	24.90	1.500000
79-80	26.30	1.636364
72-73	37.80	1.800000
80-81	38.10	2.000000
71-72	62.50	2.250000
76-77	65.30	2.571429
74-75	80.40	3.000000
75-76	83.00	3.600000
86-87	98.20	4.500001
82-83	104.90	6.000000
87-88	179.60	9.000001
81-82	183.10	17.000000

(25) Jabal Addhannah

80-81	6.30	1.125000
85-86	7.90	1.285714
84-85	8.60	1.500000
77-78	16.20	1.800000
79-80	43.50	2.250000
86-87	53.90	3.000000
87-88	94.60	4.500001
81-82	133.80	9.000001

(26) Ain Bu Sukhnah

83-84	0.80	1.100000
78-79	6.40	1.222222
84-85	21.60	1.375000
79-80	23.20	1.571429
85-86	40.20	1.833334
80-81	44.70	2.200000
86-87	57.20	2.750000
87-88	112.90	3.666667
82-83	164.60	5.500000
81-82	220.30	11.000000

(27) Sha'am

73-74	22.50	1.062500
85-86	45.40	1.133333
83-84	52.20	1.214286
72-73	64.00	1.307692
77-78	76.10	1.416667
84-85	80.20	1.545454
78-79	90.20	1.700000
80-81	95.80	1.888889
71-72	150.20	2.125000
87-88	186.20	2.428572
79-80	196.70	2.833334
86-87	200.20	3.400000
76-77	215.30	4.250001
81-82	256.20	5.666667
82-83	281.80	8.500001
75-76	345.00	17.000000

(28) Al Aweer

70-71	2.10	1.055556
69-70	11.90	1.117647
84-85	12.40	1.187500
73-74	14.20	1.266667
83-84	27.10	1.357143
80-81	66.20	1.461538
85-86	67.10	1.583333
77-78	73.80	1.727273
67-68	85.60	1.900000
78-79	88.90	2.111111
68-69	96.30	2.375000
79-80	107.30	2.714286
71-72	116.80	3.166667
76-77	147.90	3.800000
86-87	149.50	4.750001
82-83	185.60	6.333334
87-88	238.40	9.499999
81-82	258.70	19.000001

(29) Al Hibab

83-84	24.20	1.062500
73-74	24.70	1.133333
84-85	25.40	1.214280
78-79	45.70	1.307692
85-86	50.60	1.416667
72-73	51.50	1.545454
79-80	74.80	1.700000
76-77	99.70	1.888889
80-81	101.30	2.125000
77-78	101.50	2.428572
74-75	115.70	2.833334
71-72	148.20	3.400000
82-83	157.60	4.250001
86-87	162.80	5.666667
87-88	238.80	8.500001
81-82	317.10	17.000000

(30) Digdaga

70-71	9.80	1.050000
83-84	22.20	1.105263
69-70	28.50	1.166667
84-85	34.80	1.235294
85-86	54.20	1.312500
72-73	54.30	1.400000
67-68	66.60	1.500000
77-78	72.10	1.615385
78-79	87.20	1.750000
73-74	99.80	1.909091
80-81	102.90	2.100000
68-69	118.60	2.333334
79-80	145.80	2.625000
87-88	149.90	3.000000
86-87	152.20	3.500000
71-72	177.50	4.200001
76-77	218.90	5.250001
75-76	240.30	7.000001
81-82	267.90	10.500000
82-83	275.00	21.000000

(31) Falaj Al Mualla

70-71	18.00	1.047619
72-73	29.70	1.100000
83-84	30.60	1.157895
73-74	45.80	1.222222
77-78	46.40	1.294118
84-85	54.40	1.375000
85-86	64.20	1.466667
78-79	74.80	1.571429
67-68	79.90	1.692308
80-81	80.40	1.833334
69-70	82.20	2.000000
76-77	129.20	2.200000
68-69	129.50	2.444444
74-75	138.10	2.750000
79-80	166.60	3.142857
86-87	167.60	3.666667
82-83	188.00	4.400000
71-72	193.30	5.500000
87-88	195.30	7.333334
75-76	210.70	11.000000
81-82	381.00	21.999999

(32) Mileiha

70-71	3.90	1.047619
84-85	6.20	1.100000
73-74	8.60	1.157895
83-84	56.40	1.222222
78-79	58.10	1.294118
69-70	58.90	1.375000
72-73	65.40	1.466667
77-78	69.90	1.571429
79-80	78.50	1.692308
85-86	80.80	1.833334
67-68	120.20	2.000000
76-77	133.90	2.200000
74-75	134.60	2.444444
80-81	136.30	2.750000
86-87	190.20	3.142857
71-72	198.60	3.666667
87-88	208.00	4.400000
68-69	209.80	5.500000
82-83	249.60	7.333334
81-82	259.60	11.000000
75-76	275.90	21.999999

(33) Khatt

73-74	10.80	1.066667
83-84	22.40	1.142857
84-85	35.00	1.230769
85-86	42.40	1.333333
78-79	68.70	1.454546
77-78	87.20	1.600000
71-72	97.50	1.777778
86-87	109.00	2.000000
80-81	121.00	2.285715
79-80	178.50	2.666667
75-76	209.60	3.200000
87-88	214.80	4.000000
81-82	238.30	5.333334
76-77	271.00	8.000000
82-83	317.60	16.000000

(36) Filli

84-85	21.00	1.166667
72-73	27.10	1.272727
73-74	38.50	1.400000
83-84	91.80	1.555556
85-86	102.20	1.750000
71-72	130.10	2.000000
80-81	179.60	2.333334
79-80	182.60	2.800000
86-87	264.80	3.500000
87-88	268.40	4.666667
82-83	271.20	7.000001
81-82	292.40	14.000000

(34) Al Ain

83-84	1.20	1.058824
84-85	14.00	1.125000
78-79	29.60	1.200000
73-74	42.60	1.285714
74-75	46.20	1.384615
77-78	46.80	1.500000
85-86	52.20	1.636364
80-81	60.80	1.800000
79-80	68.00	2.000000
72-73	77.10	2.250000
76-77	104.30	2.571429
87-88	108.40	3.000000
86-87	122.70	3.600000
75-76	151.50	4.500001
82-83	164.70	6.000000
81-82	240.50	9.000001
71-72	302.50	17.999999

(37) Dhaid

84-85	19.20	1.111111
83-84	22.30	1.250000
85-86	66.30	1.428572
79-80	103.70	1.666667
80-81	117.00	2.000000
86-87	141.40	2.500000
87-88	169.10	3.333333
82-83	175.80	5.000001
81-82	386.90	9.999999

(35) Hamraniyyah

83-84	13.80	1.083333
84-85	28.20	1.181818
85-86	43.90	1.300000
78-79	58.30	1.444444
80-81	84.40	1.625000
77-78	92.70	1.857143
86-87	131.80	2.166667
87-88	161.70	2.600000
79-80	184.30	3.250000
76-77	198.80	4.333334
81-82	250.60	6.500001
82-83	271.30	13.000000

(38) Al Awha

84-85	38.60	1.142857
80-81	65.50	1.333333
85-86	74.50	1.600000
82-83	137.80	2.000000
86-87	180.50	2.666667
87-88	220.60	4.000000
81-82	262.00	8.000000

APPENDIX 4

Crop water requirements of most crops grown in the Emirates in m^3/hectare by agricultural region.

		Agricultural Regions			
Crop	Season	Northern	Central	Eastern	Southern*
Watermelon	Spring	2516	2368	3292	3260
Watermelon	Summer	2920	3044	3252	3332
Tomato	Winter	2064	1816	2424	2308
Tomato	Late winter	-	-	-	3128
Squash	Winter	1300	1344	1392	1420
Squash	Spring	1500	1424	2024	2044
Dry onion	-	1944	1708	2308	2668
Green onion	Winter	880	856	1032	1032
Green onion	Spring	-	-	-	1276
Pepper	-	3156	3004	3584	2872
Cucumber	Winter	1708	1540	1916	1560
Cucumber	Spring	1812	1796	2348	2492
Cabbage	Winter	1524	1340	1868	1852
Cabbage	Spring	-	-	-	2308
Cauliflower	Winter	1284	1124	1540	1728
Eggplant	-	3140	2996	3656	2836
Potato	-	1176	1020	1320	1460
Beans	Winter	1072	964	-	2108
Beans	Spring	-	-	-	1412
Beans	Summer	-	-	2536	-
Lettuce	Winter	1188	-	-	-
Lettuce	Late winter	896	800	-	1072
Lettuce	Spring	-	-	-	596
Okra	Winter	-	1424	-	-
Okra	Spring	-	1716	-	2492
Sun flower	Winter	-	-	-	1764
Sun flower	Summer	-	-	3212	-
Wheat/barley	-	1064	912	1272	1192
Alfalfa	-	6860	6908	8460	8052
Date Palm	-	3040	3036	3420	3272
Citrus	Young	3536	3524	4352	4120
Citrus	Mature	4740	4724	5840	5524

Adapted from Table 8, Crop Water Requirements, Technical Report 2, UNDP/FAO Project For Water And Soil Investigation For Agricultural Development in the UAE, Prashar, C.R.K. and Thanki, S.B. (authors), Digdaga Trial Station, UAE, 1978.

* This is the old title of the agricultural region, at present described as the Western Agricultural Region.

Appendix 4.

Crop water requirements for crops widely grown in the Emirates by the FAO experts Prashar and Thanki in the Digdaga agricultural trial station, 1978. (See Chapter 8, Section 8.4.2.).

APPENDIX 5

RUN

EMIRATE OF ABU DHABI
DEWAN RULERS REPRESENTATEVE IN ESTERN REGION
GROUND WATER SECTION
P.O.BOX 1643-TELEPHON 642970
AL AIN

1987-1988

* SO4 CALCULATED ACCORDING TO THIS FORMULA-->SO4=TOTAL CATIONS-TOTAL ANIONS *

AND CO3 = NILL

LOCATION	W.N	W.D	DATE	T.D.S	PH	NA	CA	MG	K	CL	HCO	SO4
		FEET		P.P.M		P.P.M	P.P.M	P.P.M	PPM	P.P.M	PPM	PPM
1-GIRL HOUS	0	396	10/2/87	2728	7.5	1000	200	150	14	1094	85	185
2-AL MOSTRAD	3	396	10/2/87	4400	8	940	650	540	70	1775	122	303
3-AL KWETAT	3	425	13/12/86	1389	8.2	200	289	100	50	390	100	149
4-AL KWETAT	4	425	13/12/86	1768	8.1	200	277	89	7.3	397	85	91.3
5-AL TOWAYA	1	300	13/10/86	12772	7	4786	1000	600	100	5680	390	416
6-ALMOWAGAI	1	480	22/9/86	1942	7.5	400	265	292	14	696	156	119
7-ALMASOUDY	21	391	19/5/86	1600	7.7	105	410	147	14	444	163	49
8-ALMOWAGAY	3	282	10/2/86	5630	7.5	880	507	468	18	1349	227	297
9-ALMASOUDY	5	217	4/1/86	7123	7.5	1969	900	643	52	3195	220	147
10-MOUTRAD	1	600	4/1/86	4244	7.6	987	608	502	25	1846	193	83
11-AIN SCH	2	560	18/12/85	3020	7.7	274	300	287	23	710	122	54
12-AIN SCH	3	830	18/12/85	5440	7.5	905	500	404	30	1596	219	24
13-AL BSRAH	6	375	18/12/85	6570	7.6	973	558	560	44	1562	268	305
14-KHABESY	1	278	14/4/85	1200	7.8	136	139	157	16	255	146	47
15-KHABESY	3	297	14/4/85	5140	7.7	1452	569	528	21	2272	292	6
16-AKABIA	3	312	13/11/85	10880	7.6	2479	924	844	17	3108	1025	133
17-AL HELY	1	347	30/9/86	3104	7.6	663	410	443	36	958	439	155
18-ALYAHAR	8	285	2/1/85	2840	7.8	1251	85	66	18	497	85	838

Appendix 5.

Example of the presentation of water chemistry results of the Al Ain Groundwater Department in which the values are expressed in ppm. (mg/l) showing the total sum of the cations and anions adding up equally, which should only be the case in a well-tested water sample in which ionic values are expressed in meq/l. (See Chapter 11, Section 11.6.2.2).

APPENDIX 6

UNITED ARAB EMIRATES
MINISTRY OF ELECTRICITY AND WATER
DIRECTORATE OF WATER
CENTRAL WATER LABORATORY, SHARJAH

BACTERIOLOGICAL & BIOLOGICAL ANALYSIS.

DATED March..1988...

S.NO.	SOURCE OF SAMPLE	T.B.C. PER 100 ml	COLIFORM PER 100 ml.	FECAL CALIFORM PER 100 ml.	REMARKS. Date of analysis
1.	Qidfa' (hand-dug well) (Fujairah)	0	11	0	18-11-1987
2.	Al Nadd (Sharjah)	20	10	12	22-02-1987 (unfit for drinking)
3.	Tawi Hamdah (Sharjah)	0	0	6	22-02-1987 (unfit for drinking)
4.	Al Bareer (Sharjah)	0	0	5	22-02-1987 (unfit for drinking)
5.	Al Buhayes (Sharjah)	20	12	10	15-02-1987 (unfit for drinking)
6.	Fareej Mubarak (Sharjah)	50	8	40	- - - (unfit for drinking)
7.	Hamad Bin Hilles (Sharjah)	50	10	30	- - - (unfit for drinking)
8.	Al Hiyail (Fujairah)	-	40	50	25-01-1987 (unfit for drinking)
9.	Al Ghail (Sharjah)	0	0	2	- - - (unfit for drinking)
10.	Rafak (Ras Al Khaimah)	0	0	12	- - - (unfit for drinking)

Source: Records of the MEW Laboratory, Sharjah (March, 1988)

T.B.C. = Total Bacteria Count

(A)

Appendix 6.

Examples of bacteriological contamination of groundwater from the MEW laboratory in Sharjah (A) for 1988, and the WED Al Ain (B to D) for 1988-90. (See Chapter 11, Section 11.6.2.2).

APPENDIX 6

(B)

GOVERNMENT OF ABU DHABI

WATER & ELECTRICITY DEPARTMENT - AL AIN

WATER DEPARTMENT

KHABSI LABORATORY

REPORT ON BACTERIOLOGICAL EXAMINATION OF WATER

Job No. (....1808....) Date : (..31/12/1969....)

Source of Sample : ....Sample..collected..and..provided...by...Mr. Sardar.....

Date & time of collection : ....30/12/1969.....

Date & time of commencing examination : ....30/12/1969...at...10.30...A.M.....

REPORT

Plate counts : ....too..numerous..to..count..... Per 1.0 ml.

Coliform organisms : ....300..... Per 100 ml.

Faecal coliform organisms : ....25..... Per 100 ml.

Remarks :

....Water...is...not...potable.....

SACTERIOLOGIST

SR. CHEMIST.

Job No. (.....1361.....) Date: .31/12/1969..

Source of Sample: .....Bnd.Al.Tobn..Mr..House..No./78/31.(Zao).....

Date & Time of Collection: .....12/12/1969..at..09.35..A.M.....

Date & Time of Commencing Examination: .....12/12/1969..at..11.45..A.M.....

REPORT

Plate Counts: .....Too..numerous..to..count..... Per 1.0 ml.

Coliform Organisms (Total): .....5..... Per 100 ml.

Faecal Coliform Organisms (Total): .....5..... Per 100 ml.

Remarks- Water is not potable.

SR. CHEMIST.

GOVERNMENT OF ABU DHABI

WATER & ELECTRICITY DEPARTMENT

KHABSI LABORATORY

AL AIN

REPORT ON BACTERIOLOGICAL EXAMINATION OF WATER.

Job No. (.....650.....) Date: (.29/5/1969.....)

Source of Sample : .....Aslan,s..Farm..Well.No.(2).....

Date & time of collection : .....22/5/1969..at.....

Date & time of commencing examination: 22/5/1969..at..11.25..A.M.....

REPORT

Plate counts : .....Too..numerous..to..count.....Per 1.0 ml.

Coliform organisms (total) .....28.....Per 100 ml.

Faecal coliform organisms (total) .....AO..... Per 100 ml.

Remarks:-

.....Water..is..Not..Potable.....

.....

.....

BACTERIOLOGIST

DR. CHEMIST.

Source: WED, Al Ain.

APPENDIX 6

(C)

GOVERNMENT OF ABU DHABI

WATER & ELECTRICITY DEPARTMENT - AL AIN

GOVERNMENT OF ABU DHABI

WATER & ELECTRICITY DEPARTMENT - AL AIN

WATER DEPARTMENT

KHABIS LABORATORY

REPORT ON BACTERIOLOGICAL EXAMINATION OF WATER

Job No. (....991....) Date : (...30/7/1990....)

Source of Sample : .....Well No.(2) By MR. Abd ALLA Al Hasrouy.....

Date & time of collection : .....29/7/1990...at...09.10...a.m.....

Date & time of commencing examination : .....29/7/1990...at...11.05...a.m.....

REPORT

Plate counts : .....17..... Per 1.0 ml

Coliform organisms : .....4..... Per 100 ml

Fecal coliform organisms : .....2..... Per 100 ml

Remarks :

.....Water...is...not...potable.....

.....

.....

.....
BACTERIOLOGIST

.....
SR. CHEMIST.

GOVERNMENT OF ABU DHABI

WATER & ELECTRICITY DEPARTMENT - AL AIN

WATER DEPARTMENT

KHABISI LABORATORY

REPORT ON BACTERIOLOGICAL EXAMINATION OF WATER

JOB NO. (.....991....) DATE: (.26/3/1990.)

SOURCE OF SAMPLE: .....Hilli.Pub.Gdn.(Under.ground.Tank).....

DATE & TIME OF COLLECTION: .....23/3/1990..at..12.20..p.m.....

DATE & TIME OF COMMENCING EXAMINATION: ....24/3/1990..at..09.30..a.m.....

REPORT

PLATE COUNTS: .....700..... Per 1.0 ml.

COLIFORM ORGANISMS (TOTAL): .....300..... Per 100 ml.

FECAL COLIFORM ORGANISMS (TOTAL): .....260..... Per 100 ml.

REMARKS:-

Water is not potable.

.....
BACTERIOLOGIST

.....
SR. CHEMIST

GOVERNMENT OF ABU DHABI

WATER & ELECTRICITY DEPARTMENT - AL AIN

WATER DEPARTMENT

KHABISI LABORATORY

REPORT ON BACTERIOLOGICAL EXAMINATION OF WATER

JOB NO. (....992.....) DATE: (.26/3/1990.)

SOURCE OF SAMPLE: .....Hilli.Pub.Gdn.(Tomat.Tank.No.8).....

DATE & TIME OF COLLECTION: .....23/3/1990..At..12.30..p.m.....

DATE & TIME OF COMMENCING EXAMINATION: ...24/3/1990..At..09.30..a.m.....

REPORT

PLATE COUNTS: .....TOO NUMEROUS TO COUNT..... Per 1.0 ml.

COLIFORM ORGANISMS (TOTAL): .....70..... Per 100 ml.

FECAL COLIFORM ORGANISMS (TOTAL): .....65..... Per 100 ml.

REMARKS:-

Water is not potable.

.....
BACTERIOLOGIST

.....
SR. CHEMIST

Source: WED Al Ain.

APPENDIX 6

(D)

GOVERNMENT OF ABU DHABI

WATER & ELECTRICITY DEPARTMENT - AL AIN

WATER DEPARTMENT

KHABISI LABORATORY

REPORT ON BACTERIOLOGICAL EXAMINATION OF WATER

Job No. (.....330.....) Date : (..12/3/1990.....)

Source of Sample : .....Khabisi Filling Station (By Al Hausan).... contracting company

Date & time of collection : .....11/3/1990....at....09.00....a.m.....

Date & time of commencing examination : .....11/3/1990....at....12.15....p.m.....

REPORT

Plate counts : .....Too numerous to count..... Per 1.0 ml.

Coliform organisms : .....Nil..... Per 100 ml.

Fecal coliform organisms : .....Nil..... Per 100 ml.

Remarks :

.....Water is suspected to be not potable.....

.....

.....

BACTERIOLOGIST

SR. CHEMIST.

[illegible] GOVERNMENT OF ABU DHABI
[illegible] ELECTRICITY DEPARTMENT
AL AIN.

[illegible]

[illegible]

[illegible]

[illegible] (.....330...) Date: (..6/10/1990..)

[illegible] .....Sample..By..(P.W.D.)(MAH).....

[illegible] .....4/10/1990.....

[illegible] ....4/10/1990..at..12.00..p.m.....

REMARKS

[illegible] .....250..... Per 1.0 ml.

[illegible] .....10..... Per 100 ml.

[illegible] .....0..... Per 100 ml.

[illegible] .....Water is not potable.....

.....

.....

.....

.....

[illegible]

[illegible]

Source: WED, Al Ain.

APPENDIX 7

(A translation from Arabic of Articles 4, 5 and 6 of the General Water Authority Law of the Emirates (1981)).

Federal Law No. 21 for 1981 with regard to the setting up of the General Water Resource Authority in the United Arab Emirates

Introduction

The law consists of 24 articles, of which Articles 5 and 6 detail the main duties and powers of the General Water Authority to achieve its purpose as a central national water authority, while Article 4 explicitly underlines the independence of the other ministries and local governments or individuals by stating that the "initiation, execution of ... of local projects should rest with the relevant authorities".

Articles 4, 5 and 6 are set out below:

ARTICLE 4

The General Water Authority should pursue the conservation of water resources on the basis of available knowledge, to ensure the protection of the resources from pollution and to maintain a balance between water production and use.

The Authority should not interfere in water projects that are being carried out by the ministries, local departments and individuals. The initiation and execution of these local projects should rest with the relevant authorities.

Article 5

1) to collect data concerning water resources, to carry out studies to define their location, types and quantity, to estimate future needs, to develop the resources to find solutions to water problems and to calculate the water balance;

2) to prepare an overall water policy;

3) to prepare a main water plan, to implement it and to revise it as necessary during implementation;

4) to provide coordination between federal and local water projects;

5) to appraise water resource projects;

6) to set up experimental projects in relation to water production, use and conservation;

7) to control water resources through licensing and concession rights to other parties and to keep records of the users of the various sources and the conditions of use, especially those relating to the protection of wellfields from overuse and pollution;

8) to offer advice to the Cabinet of Ministers, or any other party, on all matters concerning water resources;

9) to provide water measures and standards for costs and fees concerning any activity related to water use or disposal of contaminated water;

10) to set up a data bank related to water resources and their use and to publish and circulate these data;

11) to appraise plans concerning prospecting and developing water resources and their revision whenever necessary;

12) to search for alternative or complementary water resources;

13) to guarantee existing water use rights, confirming these rights or altering well locations after appraisal and to allow new water use rights within the type of use applied for;

14) to prepare training programmes to train water specialists for the Authority;

15) to aid the other government bodies in forming delegations to international conferences related to water resources, their use and conservation; and

16) to deepen water consciousness among citizens, urging them to conserve what is available of the water resources and to curtail any activity that leads to their exhaustion, pollution or overuse.

Article 6

The Authority is allowed to achieve the aims, listed in Article 5, by the following means:

1) to enter any property for the purpose of surveying, and related activities, without trespassing households that may exist on that property (i.e., land);

2) to set up, operate and maintain laboratories, research and experimental stations;

3) to conclude agreements and contracts with federal, local or international organizations or individuals to enable the Water Authority to achieve its goals;

4) to decide on compensation for water use rights that may have been cancelled;

5) to monitor and appraise all activities related to water use and to take action to ensure their conforming with the general water policy;

6) to oversee the implementation of regulations and conditions of licensing as well as concession rights;

7) to suggest an inspection policy for water use to limit overuse;

8) to obtain statistical and technical information concerning water from the ministries, government departments and individuals to check that these parties work within the general plan and policy; and

9) to acquire and dispose of any property by any means necessary to ensure the success of the Water Authority in its duties.

The executive committee of the General Water Authority was formed under the same Law as follows:

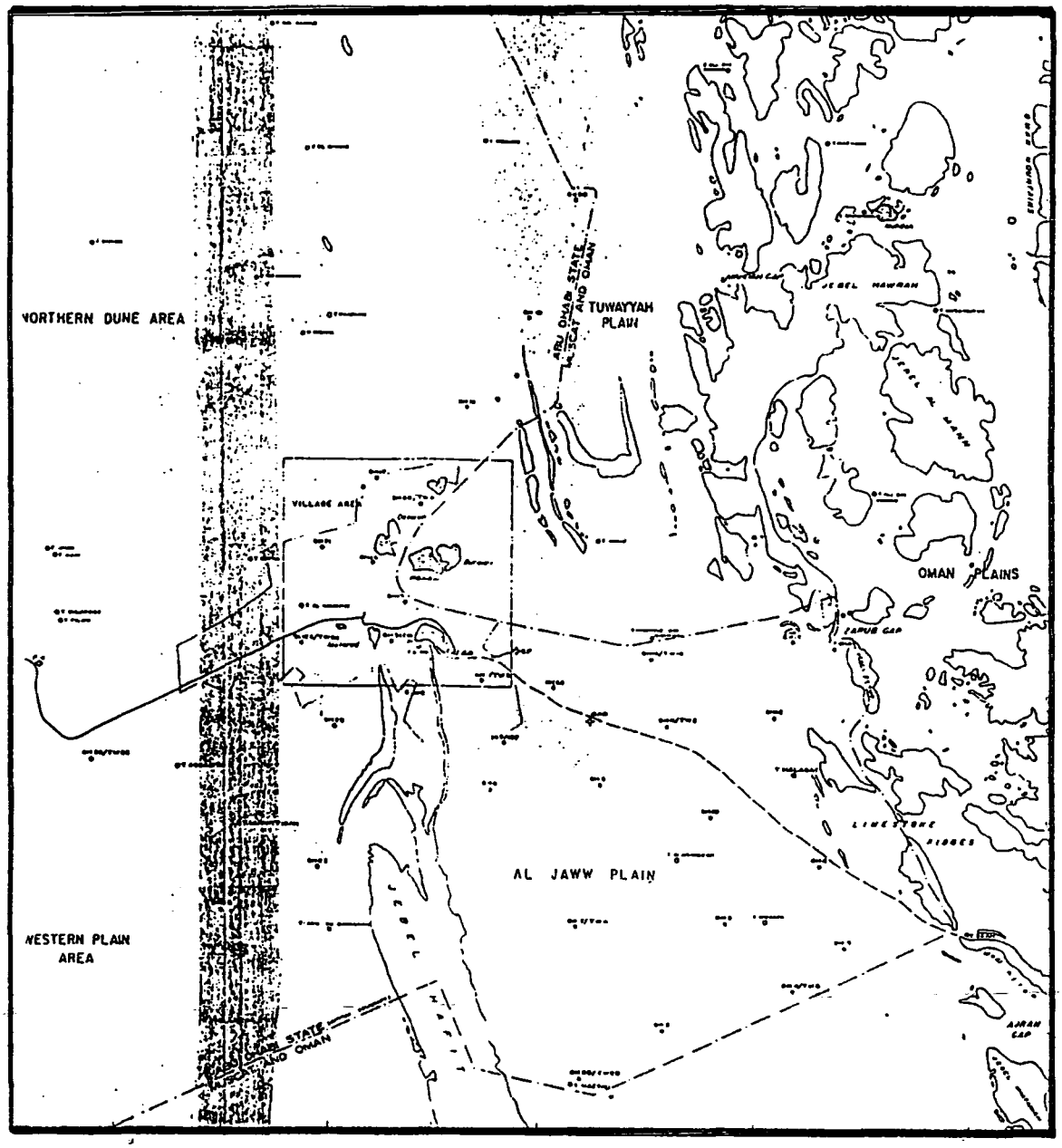
The Minister of Agriculture and Fisheries (Chairman)
The Under Secretary of the Ministry of Agriculture and Fisheries
The Under Secretary of the Ministry of Electricity and Water
The Under Secretary of the Ministry of Planning
The Secretary General of the Municipalities
The Directors of the Local Water Authorities

As can be seen from the clauses of the articles of the General Water Authority Law, the Law does not specify the public ownership of any water source but reiterates individual and institutional rights as well as those of local governments.

N.B.

It would have been wiser if the executive committee, and the managing hierarchy in the General Water Authority had comprised professionals in the water field, both in the planning and day-to-day engineering duties, so the decision-making would have been based on scientific and practical qualifications.

APPENDIX 8



Appendix 8.

Map of the wells of the 'Water Resources Survey of Abu Dhabi', Alexander Gibb, 1969-70 referred to at various places in Chapter 6, Section 6.5.2.4.4).

APPENDIX 9

DIRECT EC MEASUREMENT OF GROUNDWATER IN BOREHOLES IN THE DIFFERENT REGIONS OF THE EMIRATES (1988).

(1) A total of 800 direct EC and TDS measurements were taken for the present study using Hach EC-TDS digital meter (Model 44600) which automatically compensated for any deviation from the set standard temperature of 25°C. The maximum limit of the EC range of the instrument was 20,000 mmhos/cm.; water conductivities higher than that range were determined in the laboratory.

(2) The initial direct EC-TDS readings were plotted in the field on different large-scale maps (of 50,000; 25,000; 10,000 or 5,000 scales). As the present map is of the smaller scale of 1:750000 representative EC values of the range of minimum and maximum values encountered in a group of wells in an area, or an average value for a number of readings, could be accommodated on the map. However, the general EC pattern is maintained in line with the detailed overall areal analysis of the groundwater chemistry and quality presented in Chapter 6.

(3) The plotting of iso-conductivity contours could not be safely attempted for the following reasons:

   (i) The wide horizontal variation of EC readings within short distances.

   (ii) The equally wide vertical variation in EC readings reflecting varied depth of water-bearing strata from which the wells were pumping water.

Such varied EC readings did not offer consistently representative EC values that could be joined by isoconductivity contours.

(4) Only in detailed, localized EC measurement in areas where the pump intake levels and other hydrogeological data are known and correlated, but with similarity in groundwater levels and identical water-bearing material as the common denomenator, can iso-conductivity contours be prepared.

(5) The EC map provides at a glance a general picture of the groundwater quality in the various regions of the Emirates.

(The EC-TDS measurements were carried out during the tours of water sample collection for chemical analysis for the present study mostly during the first half of 1988).

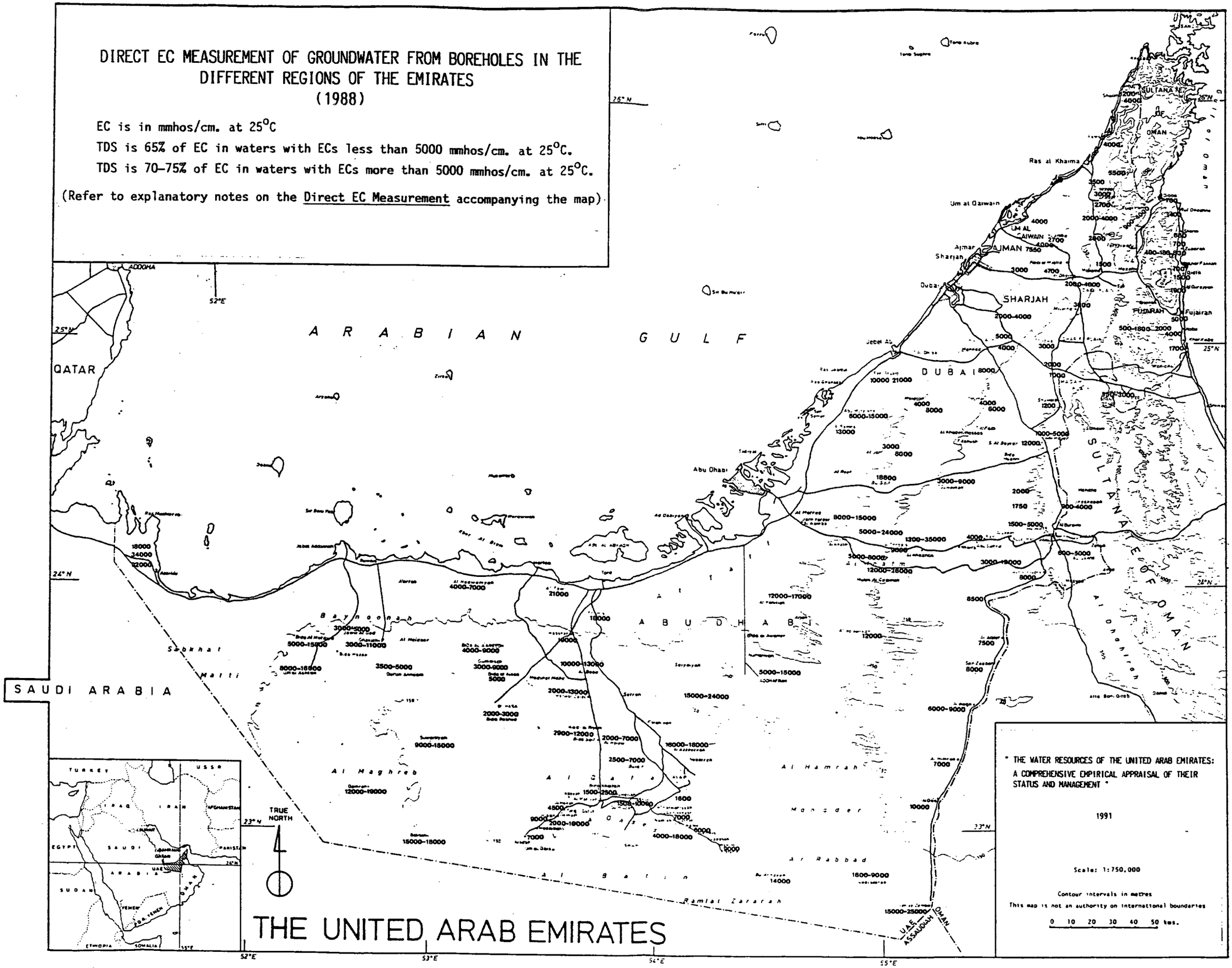
DIRECT EC MEASUREMENT OF GROUNDWATER FROM BOREHOLES IN THE DIFFERENT REGIONS OF THE EMIRATES (1988)

EC is in mmhos/cm. at 25°C

TDS is 65% of EC in waters with ECs less than 5000 mmhos/cm. at 25°C.

TDS is 70–75% of EC in waters with ECs more than 5000 mmhos/cm. at 25°C.

(Refer to explanatory notes on the Direct EC Measurement accompanying the map)


ARABIAN GULF
QATAR
SAUDI ARABIA
ABU DHABI
DUBAI
SHARJAH
AJMAN
UM AL QAIWAIN
RAS AL KHAIMA
FUJAIRAH
SULTANATE OF OMAN
Al Maghreb
Al Hamrah
Al Batin
Ramlat Zararah
Sabkhat Matti
Baynoonah
Liwa
Jebel Ali
Abu Dhabi
Sharjah
Dubai
Ajman
Um al Qaiwain
Ras al Khaima
Fujairah
Al Ain
Buraimi
Mezaira
Tarif
Madinat Zayed
Ghayathi
Mirfa
Ruwais
Jabal Hafit
Jabal Dhanna
Sir Bu Nair
Sir Bani Yas
Das Island
Zirku
Arzanah
Qarnain
Abu Al Abyad
Tarif
Tarif Oasis
Al Ain Oasis
Buraimi Oasis
Liwa Oasis
Mezaira Oasis
Madinat Zayed Oasis
Ghayathi Oasis
Mirfa Oasis
Ruwais Oasis
Jabal Hafit Oasis
Jabal Dhanna Oasis
Sir Bu Nair Oasis
Sir Bani Yas Oasis
Das Island Oasis
Zirku Oasis
Arzanah Oasis
Qarnain Oasis
Abu Al Abyad Oasis
Tarif Oasis

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