Chapter Eight

HYDROLOGY AND HYDROGEOLOGY

The chapter discusses surface water and groundwater resources in the Eastern Coast Region of the UAE. The surface water resources include floods, springs and falaj systems "man-made channels or tunnels intercepting shallow groundwater a footslopes of mountains and carrying this water to the land surface, mainly for irrigation purposes" (Rizk, 1998). The groundwater resources in the Eastern Coast Region of UAE are stored in the fractured Ophiolite and gravel aquifers flanking the Northern Oman Mountains in the UAE on the east and west (Rizk and Alsharhan, 2008).

8.1 Hydrology

Despite the absence of permanent surface water resources in the UAE, seasonal floods represent irregular, occasional water source in the Eastern Coast Region. In the past, flood water used to be lost either to the Gulf of Oman on the eastern side of the Northern Oman Mountains or through natural evaporation over desert plains on its western side (Rizk and Alsharhan, 2008). Flash floods in the Eastern Coast Region used to cut roads and destroy homes and farms. Now, about 120 million cubic meters (MCM) of flood water is harvested by about 115 recharge dams, which are constructed near outlets of major wadis and designed to divert surface runoff water down to recharge groundwater.

8.1.1 Seasonal Floods

Desert areas are noted for flash flooding. In the UAE, floods mostly occur in the Eastern Coast Region, in association with strong, short lasting, rain storms. Because the porosity and permeability of the prevailing igneous and metamorphic rocks are low, relatively large volumes of rainwater move over the land surface as surface runoff. This flow begins in the mountainous areas in the east near the proximal end of watersheds and moves towards the Gulf of Oman in the east or towards the desert plains in the west. The western region is dry and lacks surface runoff, because of low rainfall millimeters per year (40 mm/yr) (Rizk et al., 1997), high natural evaporation (3,360 mm/yr) (Ministry of Agriculture and Fisheries, 1993), scarce vegetation cover, and high porosity and permeability of dune-forming sands. Topographic maps, aerial photographs, and satellite images show that the mountain ranges of the Eastern Coast Region have 70 drainage basins, 58 of them within the UAE (Figure 8.1). The catchment areas of these basins vary between 5 km^2 (Wadi Dadinah, Al Fujairah) and 500 km^2 (Wadi Al Bih, Ras Al Khaimah) (Al Shamesi, 1993). Some large wadis have more than one runoff event per year, others may have surface runoff once in several years, and the rest of the wadis may remain dry for even longer periods. The annual contribution of seasonal floods to water resources of the UAE, as estimated as the Ministry of Agriculture and Fisheries in 1993, is 125 MCM.

The Ministry has constructed 45 large dams across the outlets of main wadis, providing a total surface-water storage capacity of 75 MCM (Table 8.1). By the end of 2002, the total number of dams in the UAE reached 88 dams with total storage capacity of 100 MCM. These dams protect against flood and assist the recharge of groundwater.

Table 8.1 Main groundwater recharge dams constructed in the Eastern Coast Region, and capacities of their reservoirs in million cubic meters (MCM) (Rizk and Alsharhan, 2003).

No.	Name	Capacity (MCM)	No.	Name	Capacity (MCM)
1	Ham	7.0	8	Kidaa	0.220
2	Hadf	0.3	9	Ramth	0.134
3	Zikt	3.5	10	Mai	0.113
4	Shi	3.0	11	Dalm	0.272
5	Wurayah	5.5	12	Safad, Thyib	0.260
6	Eden	0.05	13	Merbih, Kadfaa	0.242
7	Gheli	0.12	14	Burak	0.280

The advantages of dams in the UAE, as summarized by Al Asam (1994) include: groundwater recharge, conservation of floodwater lost to the sea or desert, storage of surface water for irrigation, preservation of agricultural soil and prevention of soil and plant scourage by floodwater, protection against flood damage, and accumulation of silt in artificial reservoirs of these dams and improvement of soil properties.

Comparing Figure 8.2 and 8.3 to Ghoniem 2008, the analysis of the hydrological characteristics of the drainage basins data showed that the eastern drainage basins discharge, on average, 70% of the total precipitation in the form of sharp peaks.

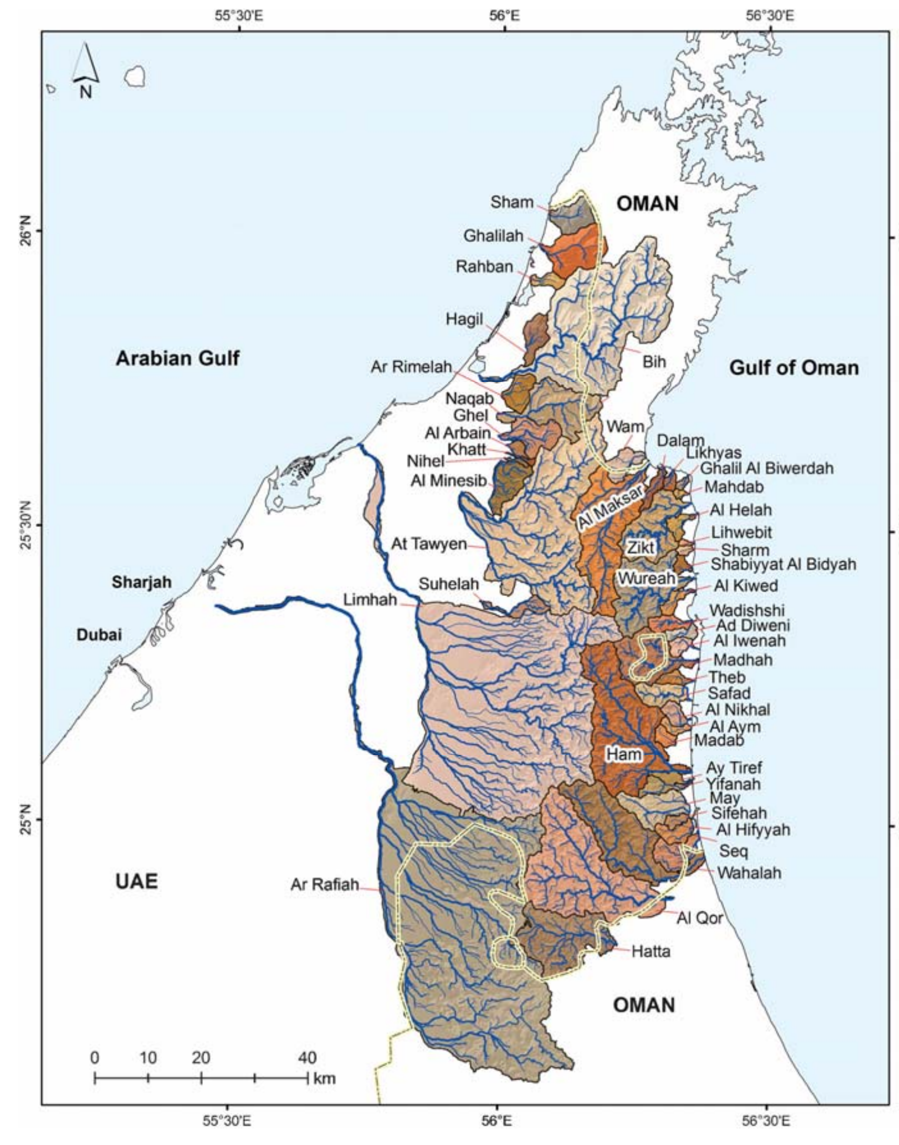

Figure 8.1 Forty-eight DEM-derived drainage basins of the northern UAE and their associated channel networks, superimposed on the hill-shade (Ghoneim 2008).

The eastern basins are characterized by high surface runoff. This can be attributed to their rock types, which are mainly composed of basement rocks with low matrix permeability. Such characteristics enable surface runoff to proceed faster with the reduction in the surface absorption capability.

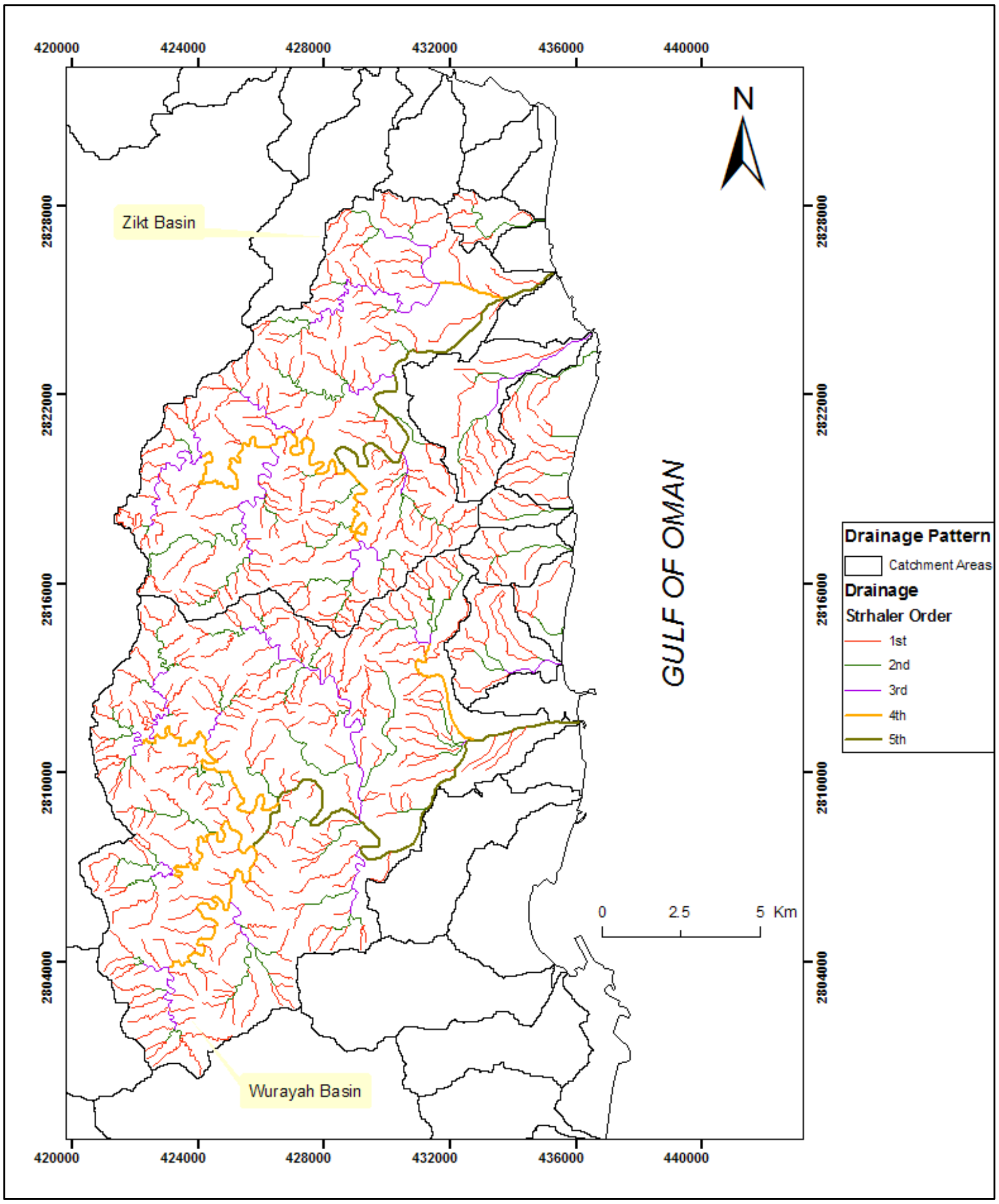

Figure 8.2 Drainage basins analysis for the area of study using Strhaler Method (modified from the topographic map of UAE).

Figure 8.2 shows that the drainage basins of Zikt and Wurayah could be considered to be a low groundwater potentiality and primarily distinguished by steep slope and high channel gradients, which trigger a rapid concentration of overland flow with small magnitude, but strong flash-flood effects. Therefore, it is necessary to benefit from these floods for improving the storage of wetland, improving water quality and enhancing recharge of groundwater.

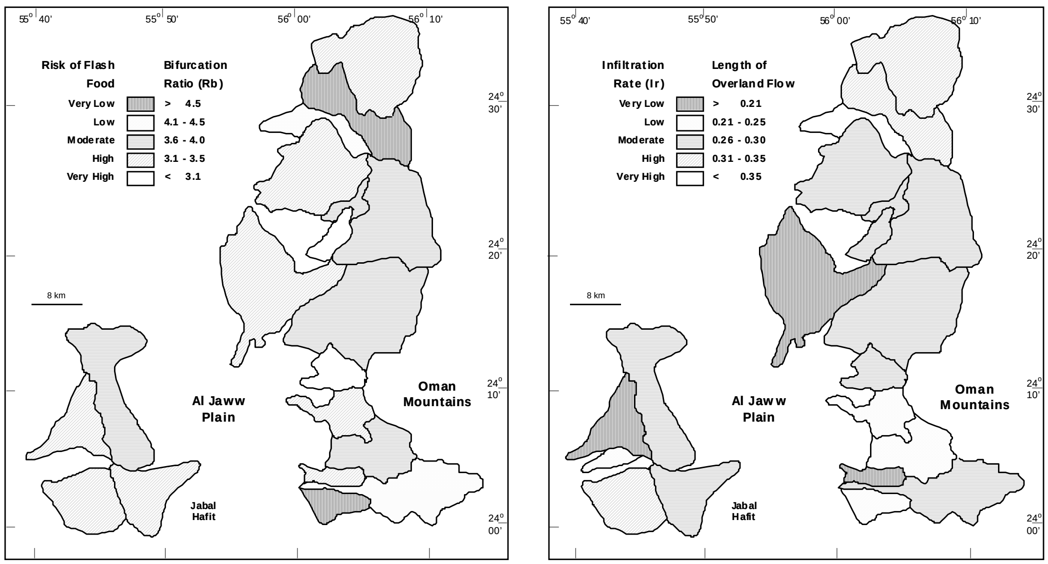

Figure 8.3 Flash flood and infiltration potential of major drainage basins in the Eastern Coast Region of the UAE (Rizk and Alsharhan, 2003).

8.1.2 Springs

A spring is a groundwater "outcrop" (Meyboom, 1966) or concentrated groundwater discharge at the ground surface (Todd, 1980). Accordingly, they are used as indicators of discharge areas in arid and semiarid regions. The UAE springs tend to discharge from local and intermediate groundwater-flow systems (Rizk and El-Etr, 1997). These include mineralized and thermal springs with therapeutic value. In the UAE, several springs, such as Khatt (Ras Al Khaimah), Maddab and AlGhamour (Al Fujairah) and Bu Sukhanah or Ain Al Faydah (Al Ain), belong to this category, and have been utilized as recreational and touristic sites. Siji spring lies about 50 km west of Fujairah and 75 km east of Sharjah, at the contact between the Ophiolite sequence and the western gravel plains (Figure 8.4) (Alsharhan et al., 2001).

The annual discharge of permanent springs in the UAE was estimated by the Ministry of Agriculture and Fisheries (1993) as 3 MCM. Records of annual spring discharge for the period 1984-1991 indicate that the Bu Sukhanah spring has the highest discharge (2.50 MCM), whereas Siji spring has the lowest discharge (0.06 MCM). Discharge of all springs shows wide variations during the 1984-1991 period, with a net increase of Khatt south and Bu Sukhanah springs, and a net decrease of Khatt north spring. According to their discharge and Meinzer's classification (1923), the studied UAE springs belong to the second (Bu Sukhanah), fourth (Khatt south and Khatt north) and fifth (Siji) orders.

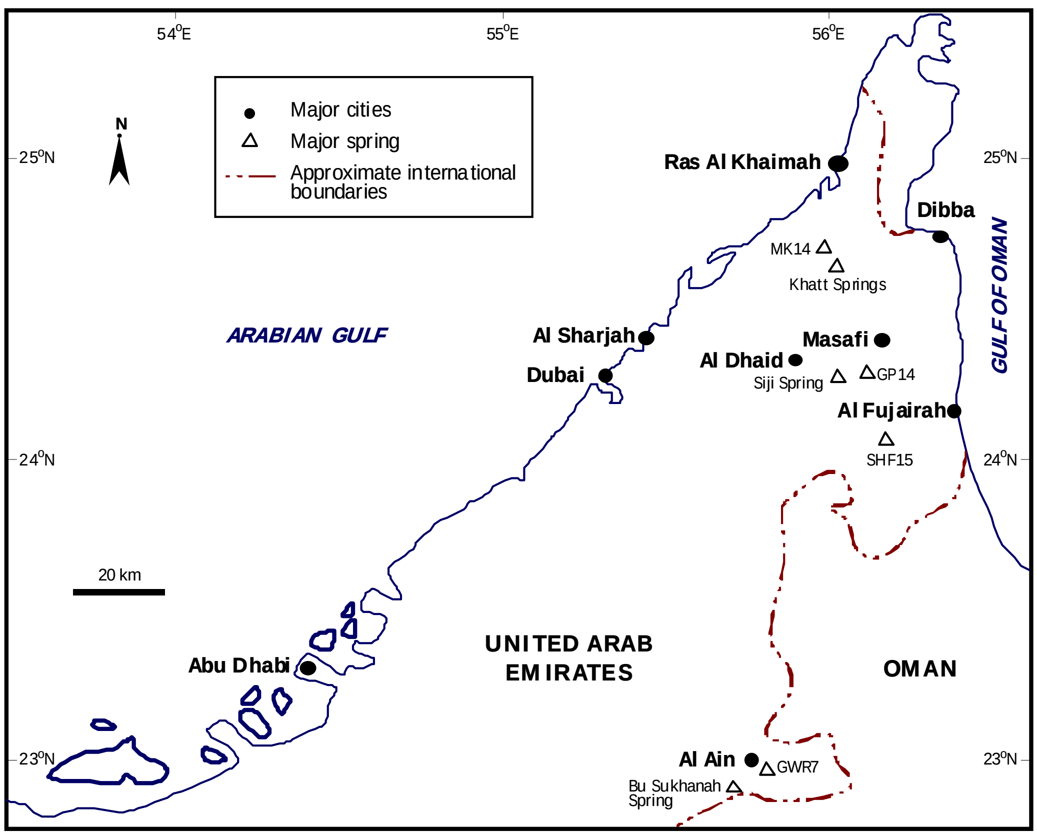

Figure 8.4 The Locations of permanent springs and the closest observation wells in the UAE (Rizk and Alsharhan, 2003).

The Khatt north, Khatt south, Siji and Bu Sukhanah springs can be divided into two categories: springs with discharges that are directly related to rainfall (Khatt north and Khatt south) and springs with discharges that are indirectly related to rainfall (Siji and Bu Sukhanah). High-temperature water represents the most important physical property characterizing the UAE springs (≈40°C).

It is believed that the high-temperature water of springs is related to deep circulation of groundwater. Waters of springs discharging from local groundwater-flow systems are normally of low salinity with a temperature close to the mean annual air temperature. In contrast, water of the springs discharging from regional groundwater-flow systems may be highly mineralized and have elevated temperatures (Fetter, 1988).

The Bu Sukhanah spring derives most of its water through a deeply circulating intermediate groundwater-flow system that recharges to the east in the Northern Oman Mountains. This could explain the spring's high-temperature water and high salinity. Terratest (1975) has identified black organic deposits with 21 ppm uranium along the joints and bedding plains of some calcareous rocks of Jabal Hafit. The lack of these deposits in other layers is attributed to leaching by water which discharges into the Bu Sukhanah spring. The heat associated with radioactive decay of uranium may contribute to the rise in the water temperature of the spring. Khalifa (1997) reported high radon activity in this spring. Except for Siji spring, the Total Dissolved Solids content of water from the studied springs has increased from 1968 to the present by 10% (Khatt south) and 50% (Bu Sukhanah).

This increase is mainly related to intensive groundwater extraction in recharge areas of these springs and low rainfall during the last few years. However, the increase in Total Dissolved Solids content, from 5,500 milligrams per liter (mg/l) in 1977 to 10,228 mg/l in 1994 for the Bu Sukhanah water, occurred at a time of increasing discharge, from 0.96 MCM/yr in 1984 to 2.50 MCM/yr in 1991, and needs further study. The dissolution of evaporite deposits of the Miocene, through which the spring water moves, may contribute to the high-salinity water of the spring. Concentrations of the major ions vary from one spring to another, according to their local geologic and hydrogeologic conditions.

Chemical analysis of water samples has indicated a small increase in concentrations of all ions within the same spring from 1991 to 1994. But, there was a great variation in concentrations of the same ions among different springs. Despite the fact that both the Khatt and Bu Sukhanah springs drain limestone, chemical analyses of spring water samples show that the concentration of calcium ion varies between 60 mg/l at Khatt south and 1,100 mg/l at Bu Sukhanah in 1991. This reflects the difference in the groundwater-flow systems feeding the springs.

The water of the Khatt spring has a rapid circulation and response to rainfall and water-table fluctuations. In contrast, water chemistry of the Bu Sukhanah spring results from slow circulation and is insensitive to rainfall and water-table fluctuations. Sodium-ion concentration varied between 2 mg/l at the Siji spring and 1,600 mg/l at the Bu Sukhanah spring in 1991, reflecting the differences in the hydrogeologic conditions between the two springs (Alsharhan et al., 2001).

According to Chebotarev's (1955) sequence, the high sulphate-ion concentration of Bu Sukhanah spring suggests an old water source. In contrast, the high bicarbonate-ion concentration of Khatt springs may suggest a recent water source. The relatively low bicarbonate-ion concentration in the Khatt springs (200 mg/l), in 1994, can be explained by a decrease in recharge rates, especially for the Khatt north spring. The decrease in recharge reduces the more rapid, low solute local flow leaving a larger component of deeper, higher solute regional flow.

Although there is a wide variation in sulphate-ion concentration, the chloride-ion content shows only an insignificant increase in the Bu Sukhanah water between 1991 (4,000 mg/l) and 1994 (4,040 mg/l). The results of chemical analyses of water samples from the UAE springs show that none the spring waters are potable. A plot of the specific conductance in μS/cm at 25°C against the Sodium Adsorption Ratio (SAR) indicate that, except for the water of the Siji spring, water of studied springs are also not suitable for irrigating traditional crops. However, the waters can be used for irrigating specific crops in well- drained soils.

8.1.3 Falajs

Until recently, falajs represented the main arteries of life in the eastern UAE. At their outlets palm oases flourished, permanent communities were established, with the agricultural way of life dependent upon their water. At the present time, many UAE falajs are dry because of excessive groundwater pumping. However, several falajs still flow and supply water to large palm oases (Figure 8.5).

The design, construction, and maintenance of falajs are interesting topics and relics of historical water-distribution systems still exist near Al Hili archeological garden in the Al Ain area (Rizk, 1998; Alsharhan et al., 2001). During the period 1978-1995, the total falaj discharges in the UAE varied between a minimum of 9.0 MCM/yr, in 1994, to a maximum of 31.2 MCM/yr in 1982 (which represents 2.8 to 9.7 % of the total water use in the UAE).

Discharge varies from one falaj to another depending on the location of the source well(s), nature of the source aquifer, amount of seepage from tunnel sides, and mean annual rainfall. Some falajs cease to flow during periods of low rainfall while others are relatively unaffected.

Picture 8.1 Falaj System used in the Eastern Coast Region of the UAE.

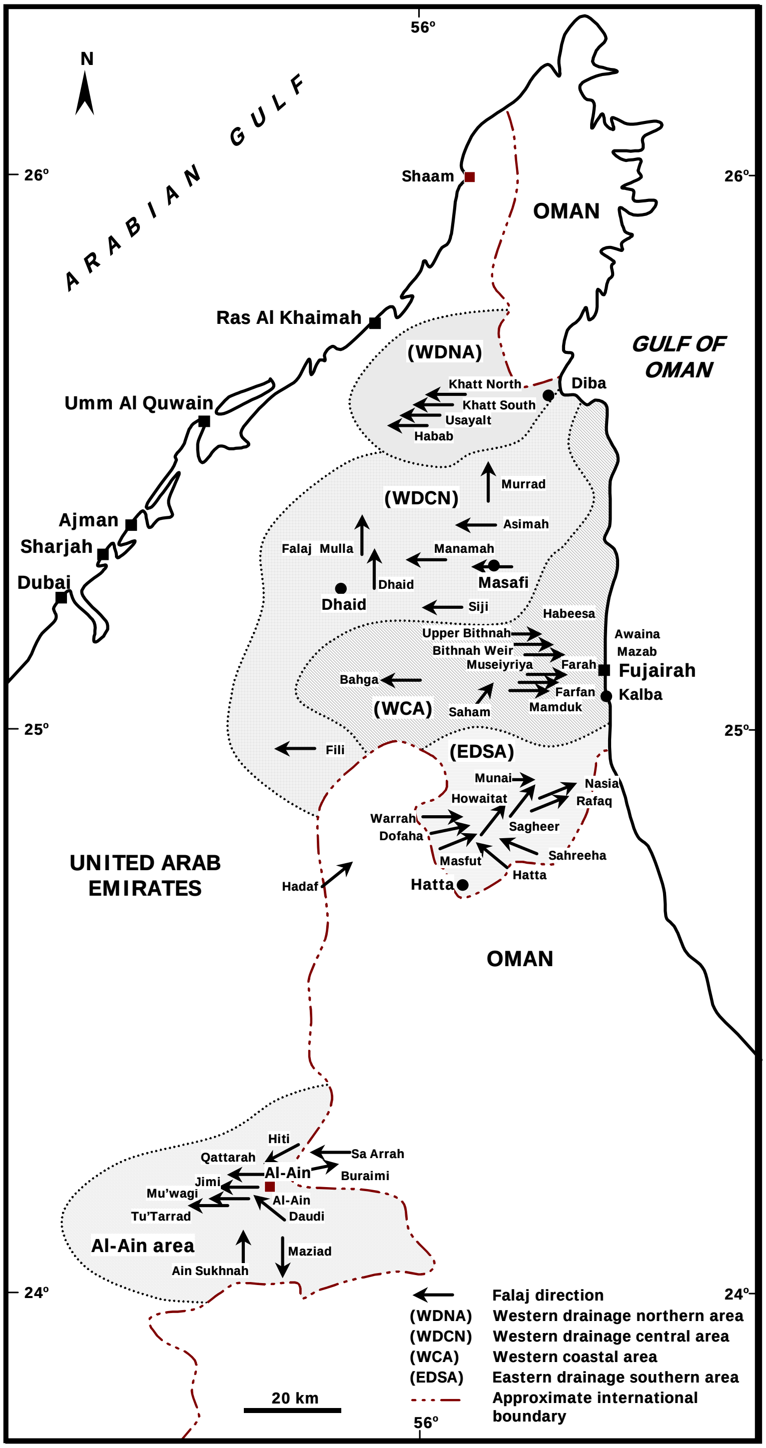

Figure 8.5 The Location and drainage areas of the UAE falajs (Rizk and Alsharhan, 2003).

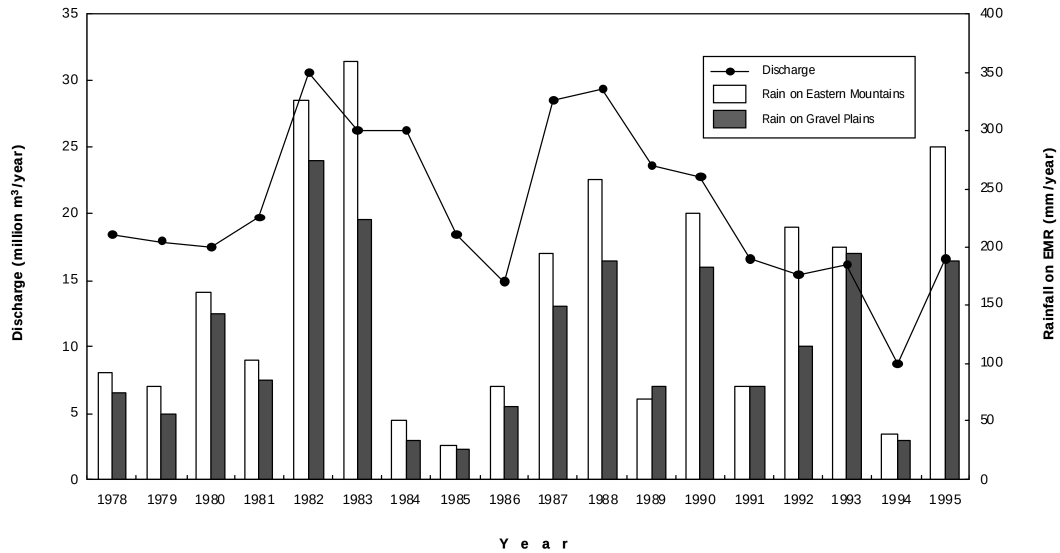

Figure 8.6 Total annual discharges (MCM/yr) of UAE falajs versus the mean annual rainfall (mm) on the eastern mountain ranges and gravel plains (Rizk and Alsharhan, 2003).

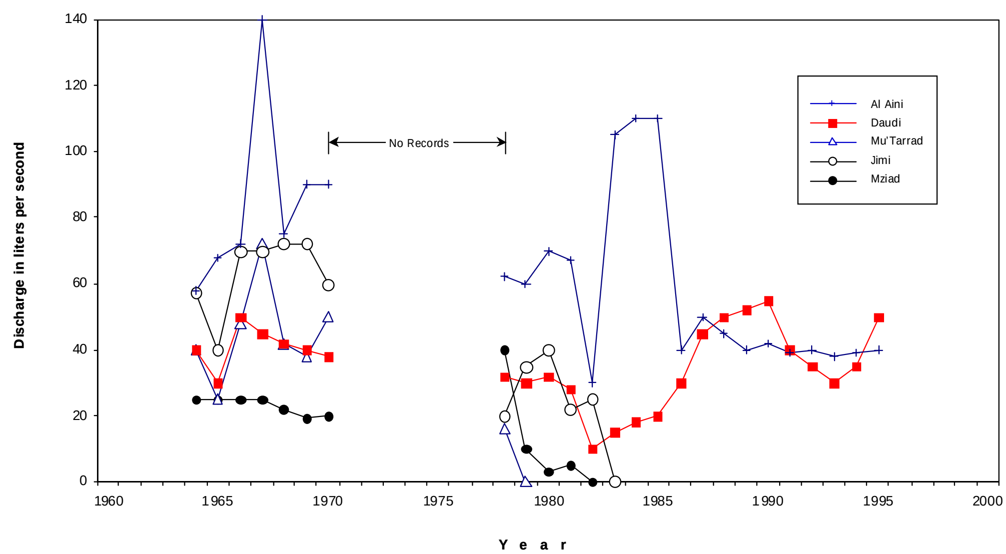

Figure 8.7 Hydrographs of Al Ain falajs for the period 1964-1996 (compiled data based on studies of Gibb and Partners, 1970; Ministry of Agriculture and Fisheries, 1993; and Rizk and Alsharhan, 2003).

Average discharges of UAE falajs for the period 1984-1996 varied from 2.38 Liter per second (L/sec) in Falaj Habeesa to 89.77 L/sec in Falaj Bithnah. Falajs are classified according to discharge into three types, locally designated as Al Gheli, Al Daudi and Al Hadouri (Al Aidrous, 1990). Al Gheli-type falajs carry water only in winter and their discharge is directly dependent on rainfall. Despite their limited supply, water of Al Gheli falajs is renewable and has good quality.

In fact, because most of the UAE falajs belong to the Al Gheli type, discharges show a clear response to rainfall events. Because aquifers are the main water source, Al Daudi falajs have a permanent discharge. Al Daudi falajs, exhibit very little change in their discharge rates throughout the year, because groundwater storage is the main source of water for these falajs, and maintains their flow during the whole year.

Al Hadouri falajs are typically connected to deep artesian aquifers. These falajs intercept the groundwater as it moves upward through fissures and fractures. A plot of the total annual discharge of UAE falajs versus the mean annual rainfall on the eastern mountain ranges and gravel plains, shows a direct correlation (Figure 8.6) (Rizk, 1998).

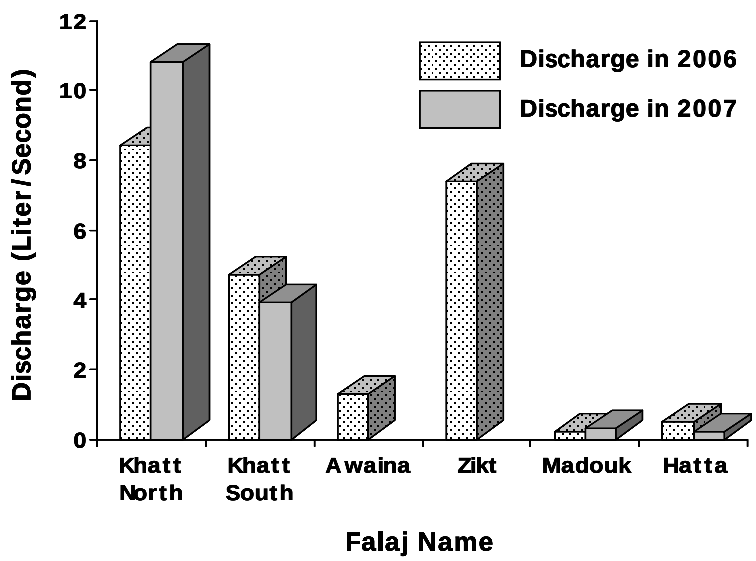

Figure 8.8 Discharge of the remaining falajs in the northern UAE during 2006 and 2007 (Rizk and Alsharhan, 2008).

Because of heavy groundwater pumping in many areas of the UAE, several falajs have ceased to flow. Historical discharge records of Al Ain falajs (Figure 8.7) were obtained from Halcrow and Partners (1969), Gibb and Partners (1970) and the Ministry of Agriculture and Fisheries (1993). These records indicated that Al Jimi, Al Mu'waji, and Al Qattarah falajs were dry in 1979, whereas Al Mu'Tarrad, Maziad and Al Hili falajs were dry in 1981-1982. Discharge of the remaining UAE falajs in northern UAE is illustrated in Figure 8.8.

Because of continuous maintenance, extension and pumping groundwater into their channels, the Al Aini and Al Daudi falajs in the Al Ain area are still active at the present time (Alsharhan et al., 2001). The Electrical Conductivity (EC) of falaj waters varies between 450 μS/cm in Falaj Asimah (AI Fujairah) and 10,940 μS/cm in Falaj Ain Sukhnah (Al Ain). Generally, the Electrical Conductivity values are low for water samples collected from the falajs which drain Ophiolite rocks (Fujairah areas), indicating low water salinity.

In contrast, the Electrical Conductivity values are higher in water samples from the falajs draining limestone rocks in Ras Al Khaimah and west of Al Ain areas. The iso-EC contour map shows that the electrical conductivity values of falaj waters are low near the watershed of the eastern mountains, and increase further east and west, with distance from the recharge area (Figure 8.9).

The iso-EC contours also show that the groundwater salinity increases from the watershed towards the east and west. A trilinear plot of the chemical analyses of water samples collected from the UAE falajs shows that most of the samples lie in the upper triangle of the diamond-shaped field (Figure 8.10), pointing to the dominance of Na-Mg and chlorideand bicarbonate water types. Water of the UAE falajs is enriched in Mg^{2+} dissolved from Mg-rich ophiolitic and dolomitic rocks.

Because the water of the falajs is mainly used for irrigation purposes, a United States Salinity Laboratory Staff (1954) diagram was used to plot values of EC and Sodium Adsorption Ratio (SAR). The water of all the UAE falajs, except Khatt South and Hubhub falajs, are good to fair for irrigation purposes (Figure 8.11).

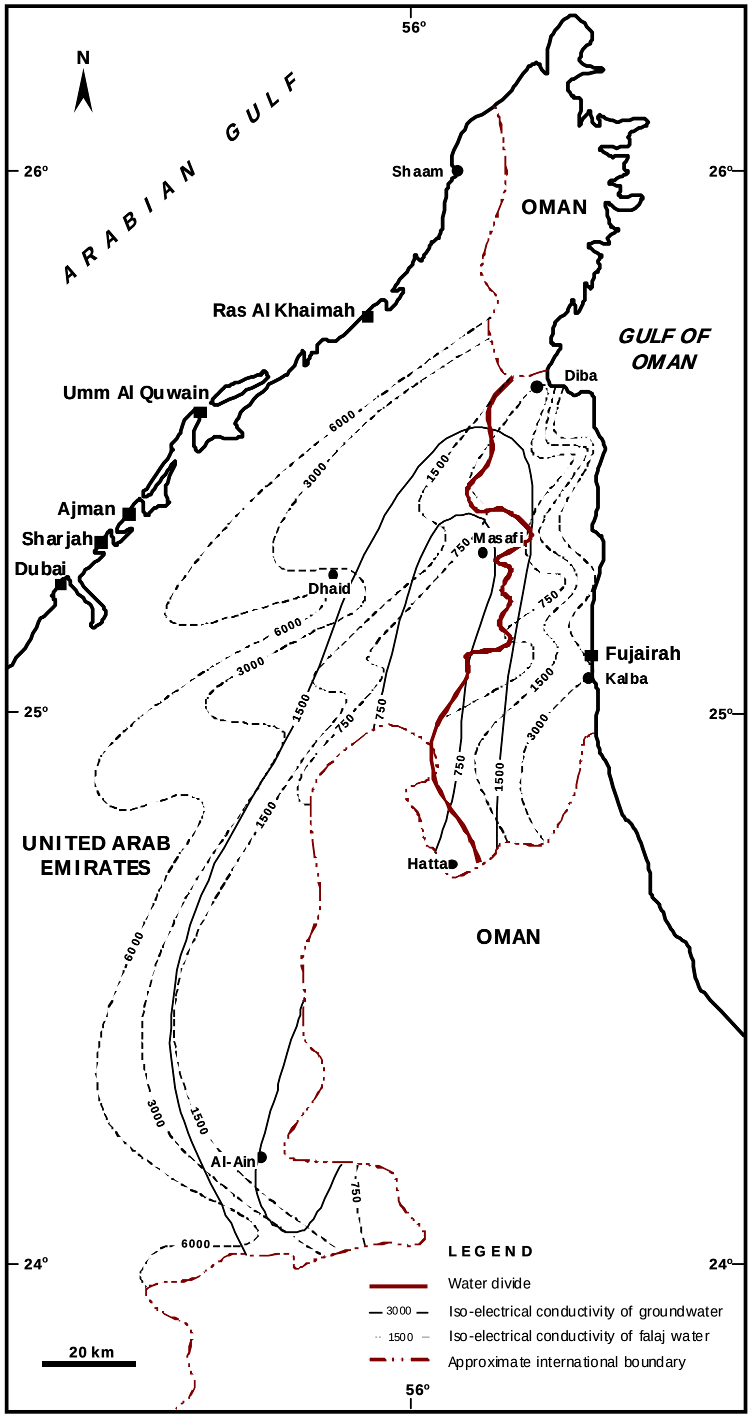

Figure 8.9 Iso-electrical conductivity (μS/cm) contour map of groundwater and falaj water during early 1996 in northeastern region of the United Arab Emirates (Rizk and Alsharhan, 2003).

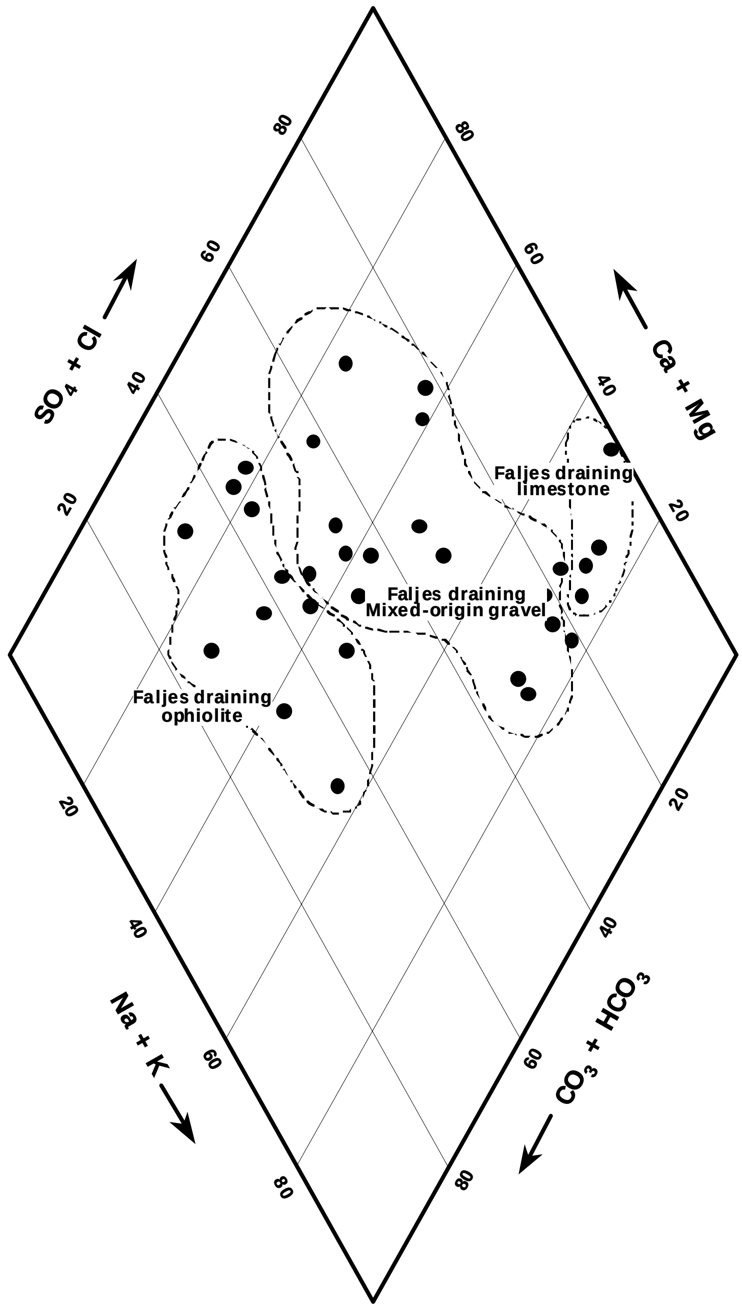

Figure 8.10 The trilinear plot of chemical analyses of water samples collected from UAE falajs during early 1996 (Rizk and Alsharhan, 2003).

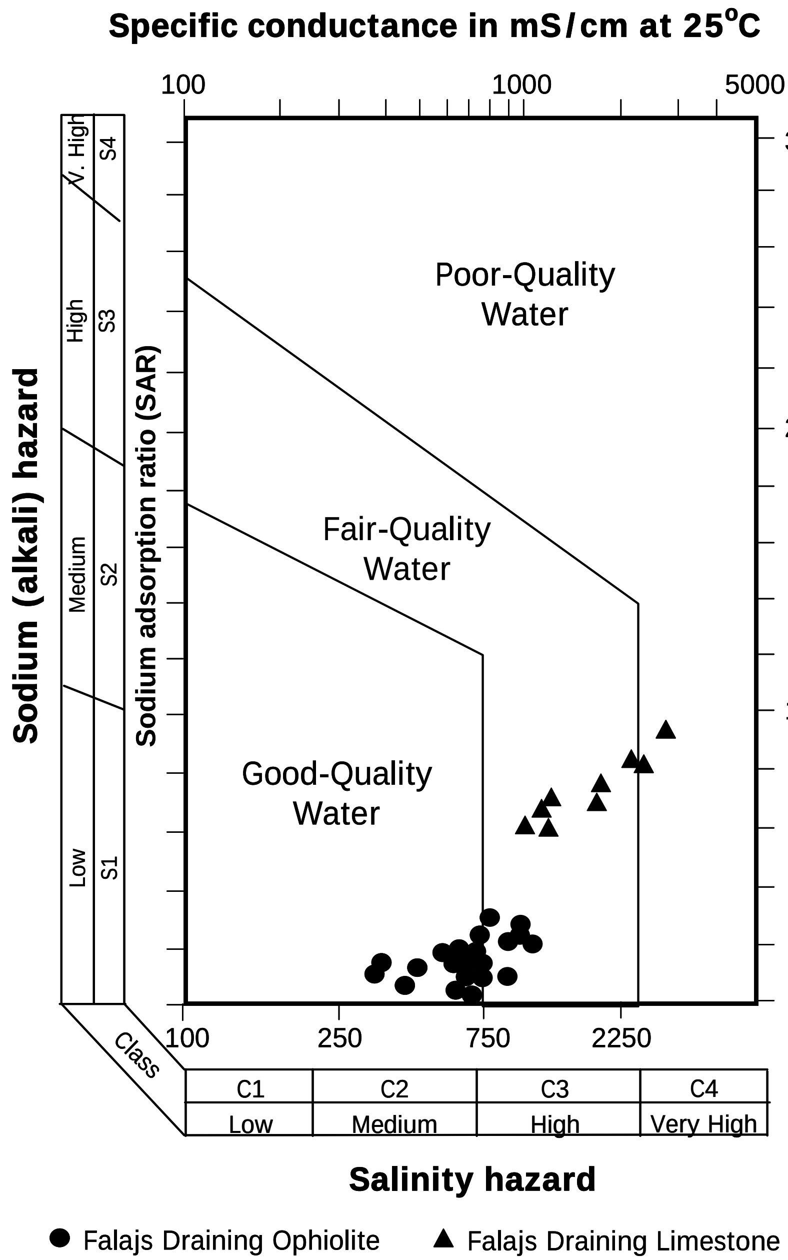

Figure 8.11 Evaluation of falaj water suitability for irrigation, based on EC (μS/cm) and SAR (Rizk and Alsharhan, 2003).

8.2 Hydrogeology

The main aquifers in the UAE include the limestone aquifer in the north, fractured Ophiolite aquifer in the east, gravel aquifers flanking the eastern mountain ranges on the east and west and sand dune aquifers in the south and west (Figure 8.11) (Rizk and Alsharhan, 2008).

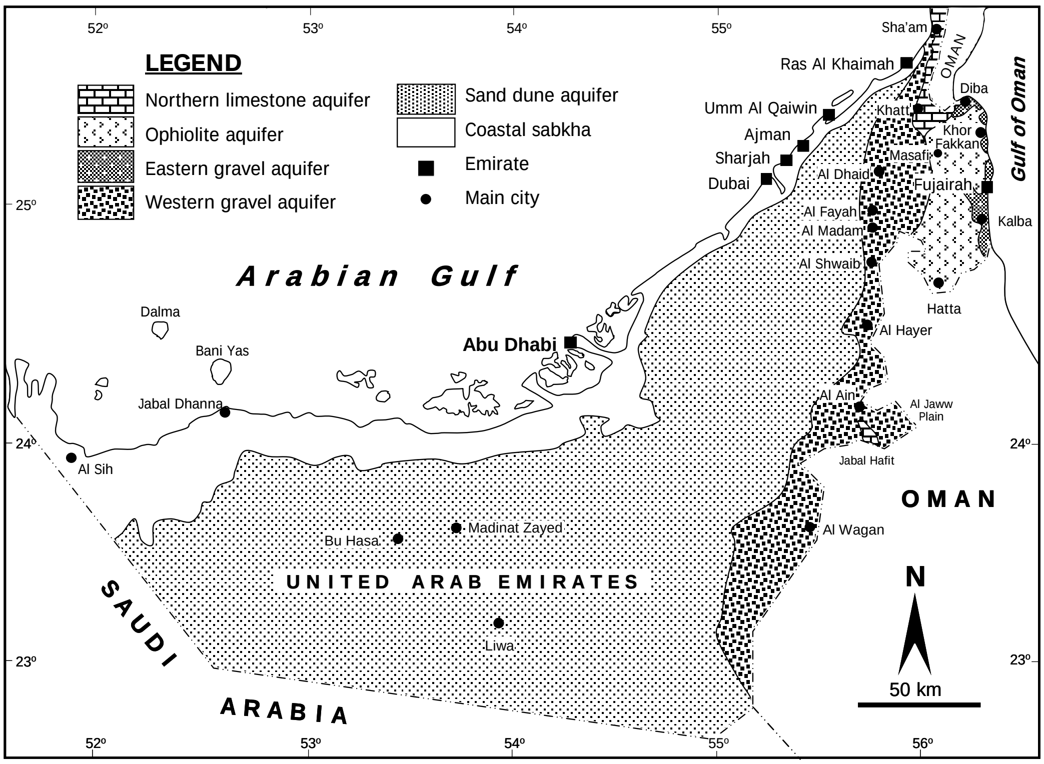

Figure 8.12 Map showing the major aquifer in the UAE. The Eastern Coast Region is dominated by Ophiolite and gravel aquifers (Rizk and Alsharhan, 2008).

8.2.1 Hydrogeologic Conditions

The groundwater in the eastern coastal area of the UAE is stored in the eastern gravel aquifer and fractured Ophiolites aquifer. Together with the western gravel aquifer, on the western side of the Northern Oman Mountains in the UAE, the eastern gravel aquifer store the largest fresh groundwater reserve in the UAE. Most importantly, this water is renewable and receives recharge during the rare, sporadic rainstorms. In area affected by intensive fractures, the Ophiolites aquifer may have high transmissivity

(776 m^2/d) and specific yield (0.24) (Murad and Kirshnamurthy, 2004). In addition to their influence of the aquifer yield, the lineaments affecting the Ophiolites aquifer also control aquifer recharge and groundwater quality (Rizk and Garamoon, 2006).

8.2.1.1 Aquifers Lithology

Based on interpretation of the available data and constructed hydrogeologic maps (Figures 8.13 to 8.16), two aquifers were identified within the study area, namely: the Quaternary alluvial aquifer and the fractured Ophiolites aquifer.

The Quaternary sediments, which constitute the main aquifer within the study area, are composed of unconsolidated alluvium gravel and course sand. Electrowatt (1981) subdivided sediments of the Quaternary aquifer into recent and old sediments. The recent sediments are slightly silty sand gravel with some cobbles and boulders. The old sediments are silty sandy gravel with many cobbles and boulders which are weathered and cemented.

8.2.1.2 Recharge

The natural isotopes in groundwater indicate that the eastern gravel aquifer receives recharge from rains falling on the Northern Oman Mountains in the UAE. The wells tapping the aquifer receive water from a local groundwater flow system characterized by low salinity, high tritium (^3H) and carbon-14 (^{14}C) activities and short residence time (Figure 8.17). However, excessive groundwater pumping may lead to a serious salt-water intrusion problem.

8.2.1.3 Discharge

Groundwater in Wadi Ham is exploited intensively from the sand and gravel aquifer for irrigation in the coastal plain between Fujairah and Khawr Kalba. Several well fields are in operation for the domestic water supply by the FEWA including:

a. Fujairah well field: The total pumping from this field used to be 3.2 million cubic meters per year (MCM/yr) until 1988, after which very limited groundwater is pumped.

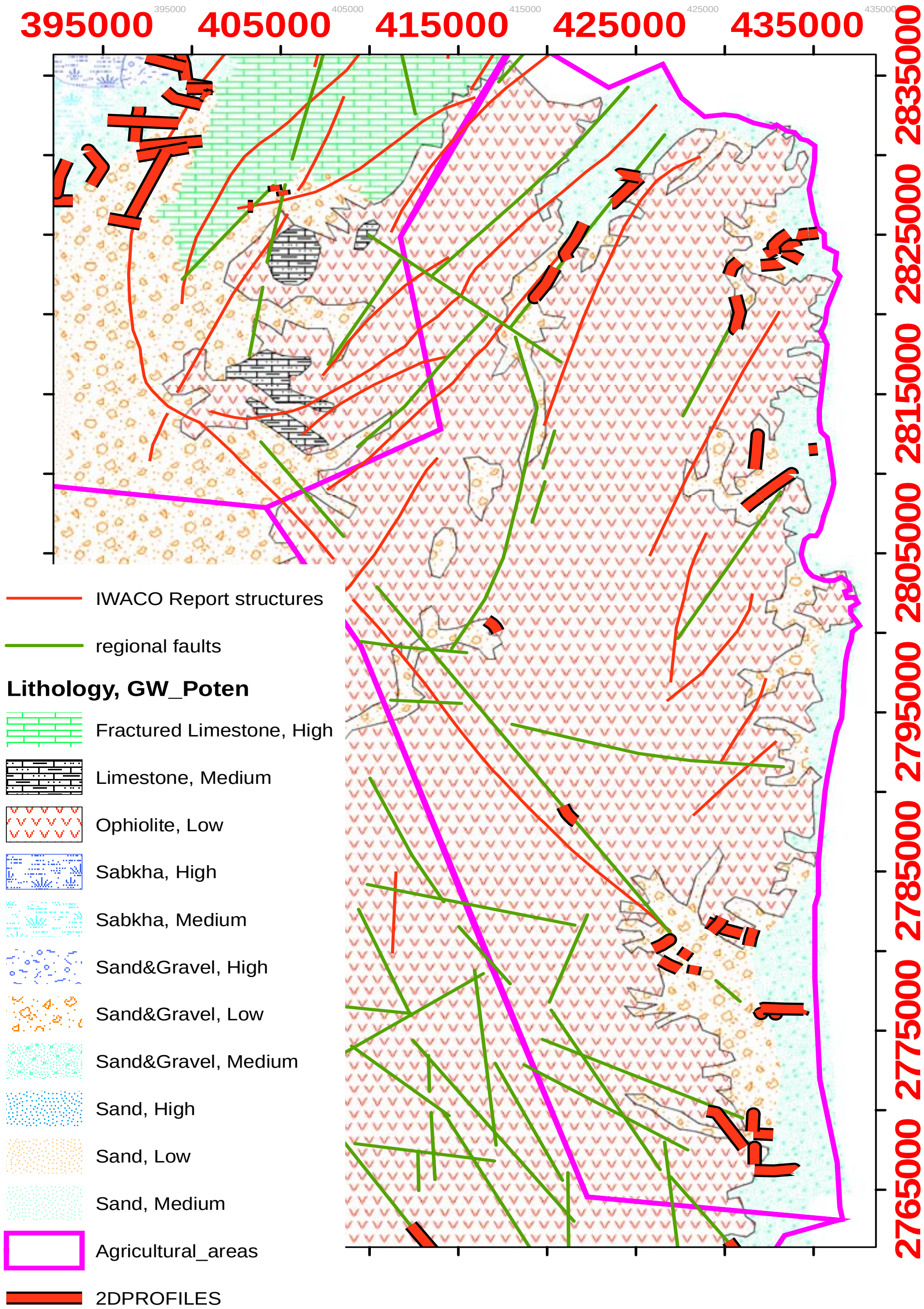

Figure 8.13 Hydrogeologic map of the eastern agricultural region (MAF, 2005). Locations of the 2D earth resistivity profiles and regional faults are also shown.

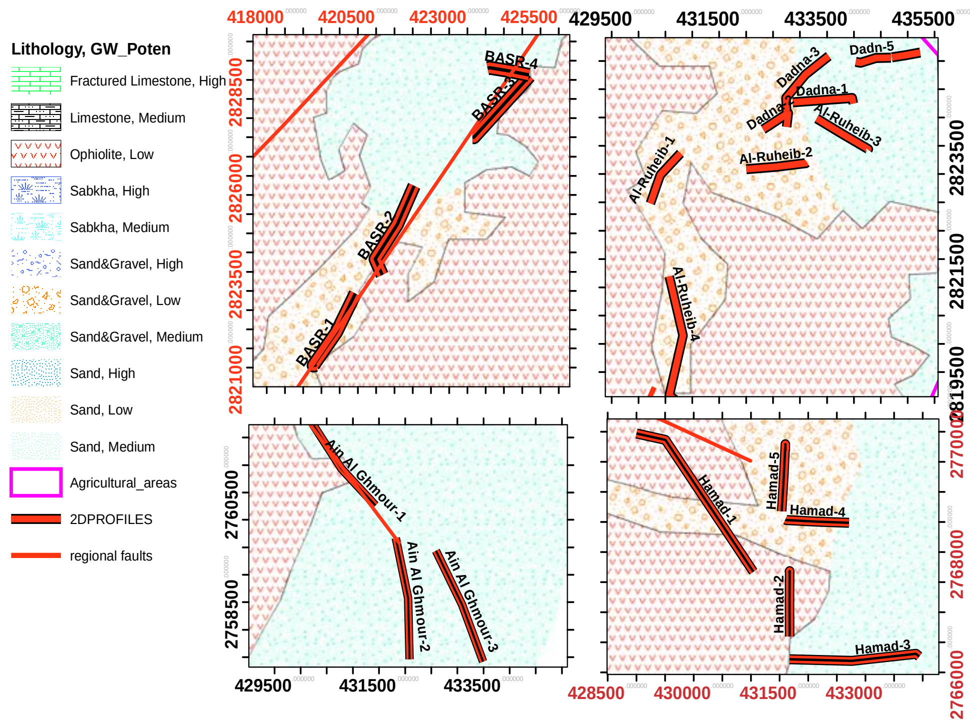

Figure 8.14 Hydrogeologic map of Wadis Basserah, Al Ruheib (Zikt), Al Ghmour and Hamad in the eastern agricultural region (MAF, 2005). Locations of the 2D earth resistivity profiles and regional faults are also shown.

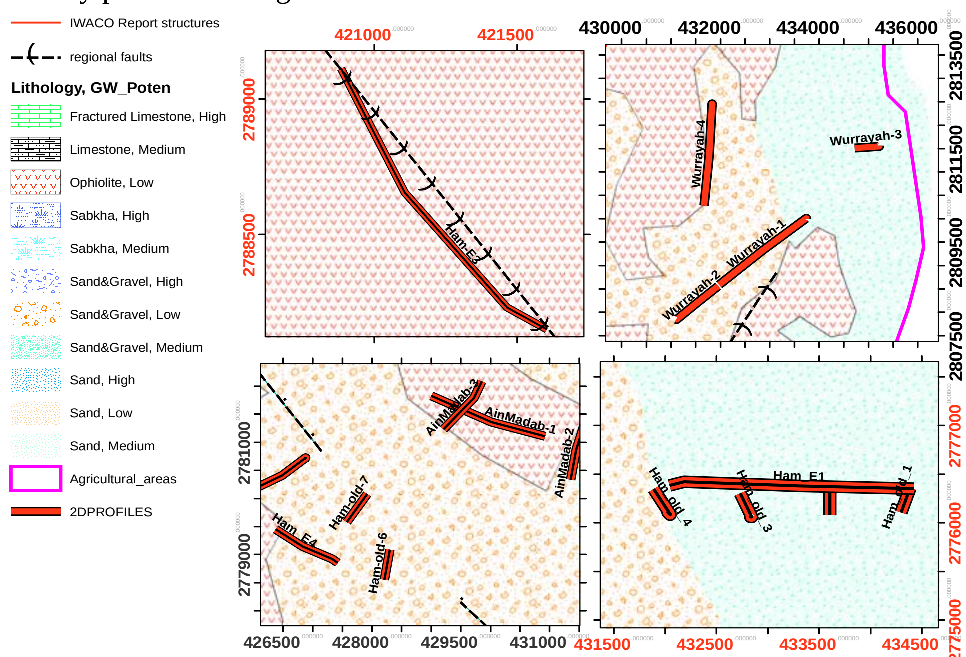

Figure 8.15 Hydrogeologic map of Wadis Ham, Wurayah and Ain Madab in the eastern agricultural region (MAF, 2005). Locations of the 2D earth resistivity profiles and regional faults are also shown.

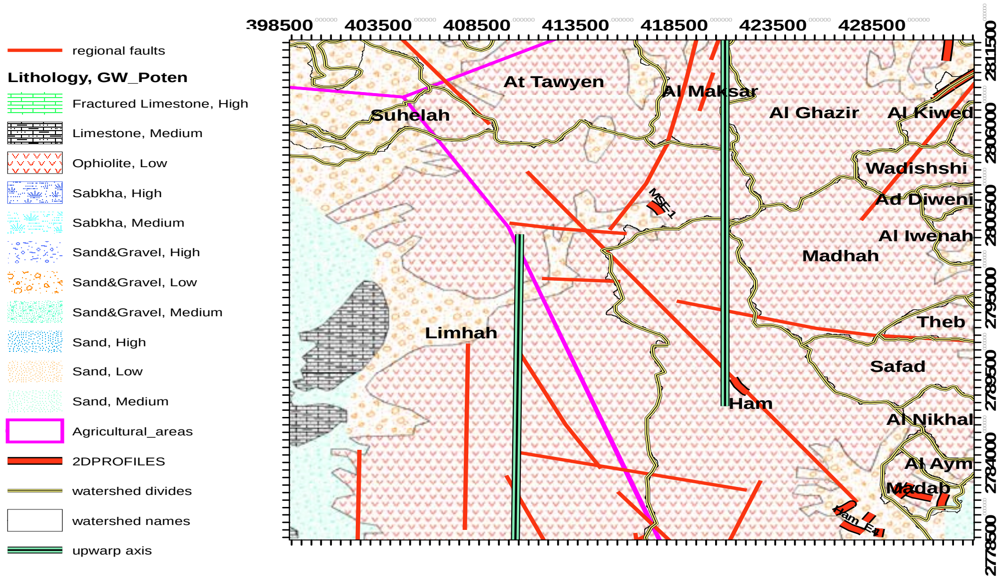

Figure 8.16 Hydrogeologic map of Ain Madab and surrounding area in the eastern agricultural region (MAF, 2005). Locations of the 2D earth resistivity profiles and regional faults are also shown.

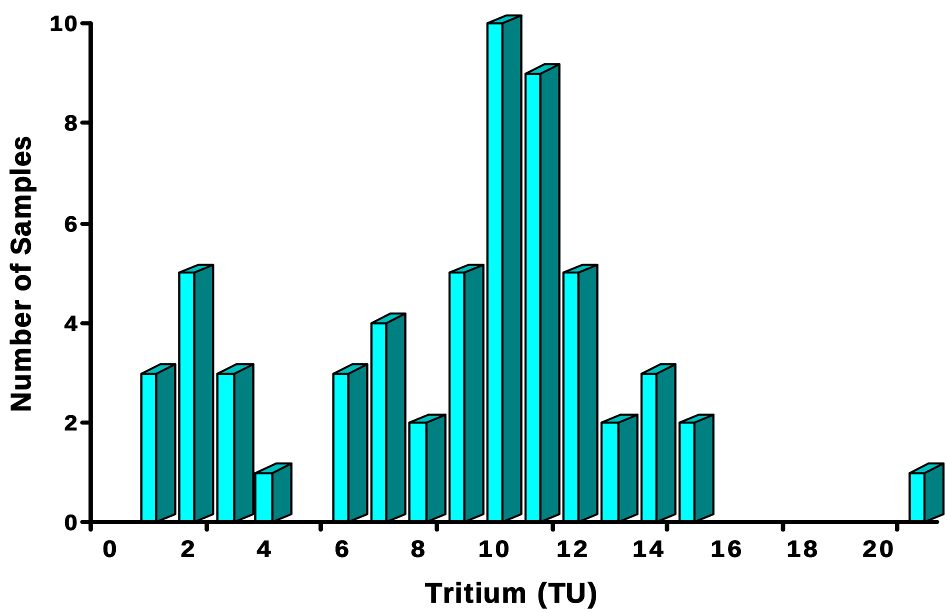

Figure 8.17 Frequency diagram of tritium (^3H) in the alluvial gravel aquifer in the Eastern Coast Region of the UAE (Rizk and Alsharhan, 2008).

b. Shaara well field is located 2 km downstream of Wadi Ham and includes 9 wells. Pumping started in the year 1988 at a total extraction of 1.0 MCM/yr and a pumping duration of 10 hours per day (hr/d). Out of the 9 wells, 5 wells dried up in the year 2003, and discharges of the remaining wells were reduced significantly between 1988 and 2003.

c. Kalba new well field: The field was operated since 1995 with a total pumping of 6.0 MCM/yr.

8.2.2 Hydraulic Properties

8.2.2.1 Hydraulic Conductivity

The hydraulic conductivity of the recent sediments tends to be very high, typically in the range of 6 to 17 meters per day (m/d). For the old cemented sediments the hydraulic conductivity (K) is in the range of 0.09 to 0.86 m/d. In the unconsolidated gravels the primary porosity is very high when compared to the porosity cemented gravels. The results of these pumping tests, in addition to the data of one pumping test conducted for well Ob1 (Sherif, 2004).

8.2.2.2 Hydraulic Heads

Generally, groundwater levels are declining all over the UAE. The main reason is the unbalance between limited recharge and excessive pumping for all purposes. The situation the Eastern Coast Region is particularly sensitive because the severe groundwater pumping leads to intrusion of salt water from the Gulf of Oman into fresh groundwater within the gravel aquifer. To assess the impact of pumping on groundwater levels of the study area, the groundwater levels have been measured in several observation wells illustrated in 2005 and 2009 (Figures 8.18 to 8.20). To determine the impact of groundwater extraction and the effect of Wadi Ham dam on the groundwater level at the Fujairah city south to the area of study the former Ministry of Agriculture and Fisheries (MAF), now Ministry of Environment and Water (MEW), has adopted a monthly monitoring program for groundwater levels.

The monitoring network includes 16 observation wells located in Wadi Ham (Figure 8.21). Figure 8.22 presents the monthly rainfall plotted on the same graph with groundwater levels for the period 1987–2004. A significant variation in groundwater levels in response to rainfall events and groundwater extraction is observed. The fluctuation of the groundwater levels varied between 2 and 40 m in the observation wells (Figure 8.21). In both wet and dry periods, the hydraulic gradient of groundwater in the plain area is very mild as compared to the gradient within the wadi valley close to the dam area. In general, groundwater levels in all observation wells are declining since 1996 (the last wet year). The lowest levels were encountered in the year 2004, reflecting a drought conditions. Wells those are located near the Wadi Ham, Wadi Wurayah and Wadi Zikt dams are much more sensitive to rainfall and recharge than the wells in the reservoir area.

Table 8.2 Estimated parameters of the Quaternary alluvial aquifer in the eastern coastal area in the UAE (Rizk and Alsharhan, 2003).

Borehole	UTM coordinate		T (m^2/d) (IWACO ,1986)	Transmissivity m^2/d		Hydraulic conductivity m/day		*S
	Northing	Easting		Cooper & Jacob (1946)	Theis (1935)	Theis (1935)	Cooper & Jacob (1946)	
BHF-1	2779163	429211	30	101	148	7.76	11.4	0.00161
BHF-3A	2779800	432900	3450	6246	744	14	118	$6.21x10^{-8}$
BHF-4A	2776995	433773	8630	11700	9120	203	259	$2.01x10^{-15}$
BHF-5	2773400	432950	4347	8940	1260	105	745	$1.33x10^{-20}$
BHF-10	2780250	431800	1230	480	258	6.79	12.6	0.00197
BHF-11	2781000	430450	386	101	151	4.73	3.16	0.00666
BHF-12	2776432	431865	1340	947	789	15.5	18.6	0.00239
BHF-13	2774900	427800	8.5	4.13	3.83	25.6	27.5	0.0101
BHF-14	2778750	433900	2882	4750	3630	39.4	51.6	$3.03x10^{-7}$

*S = Storativity

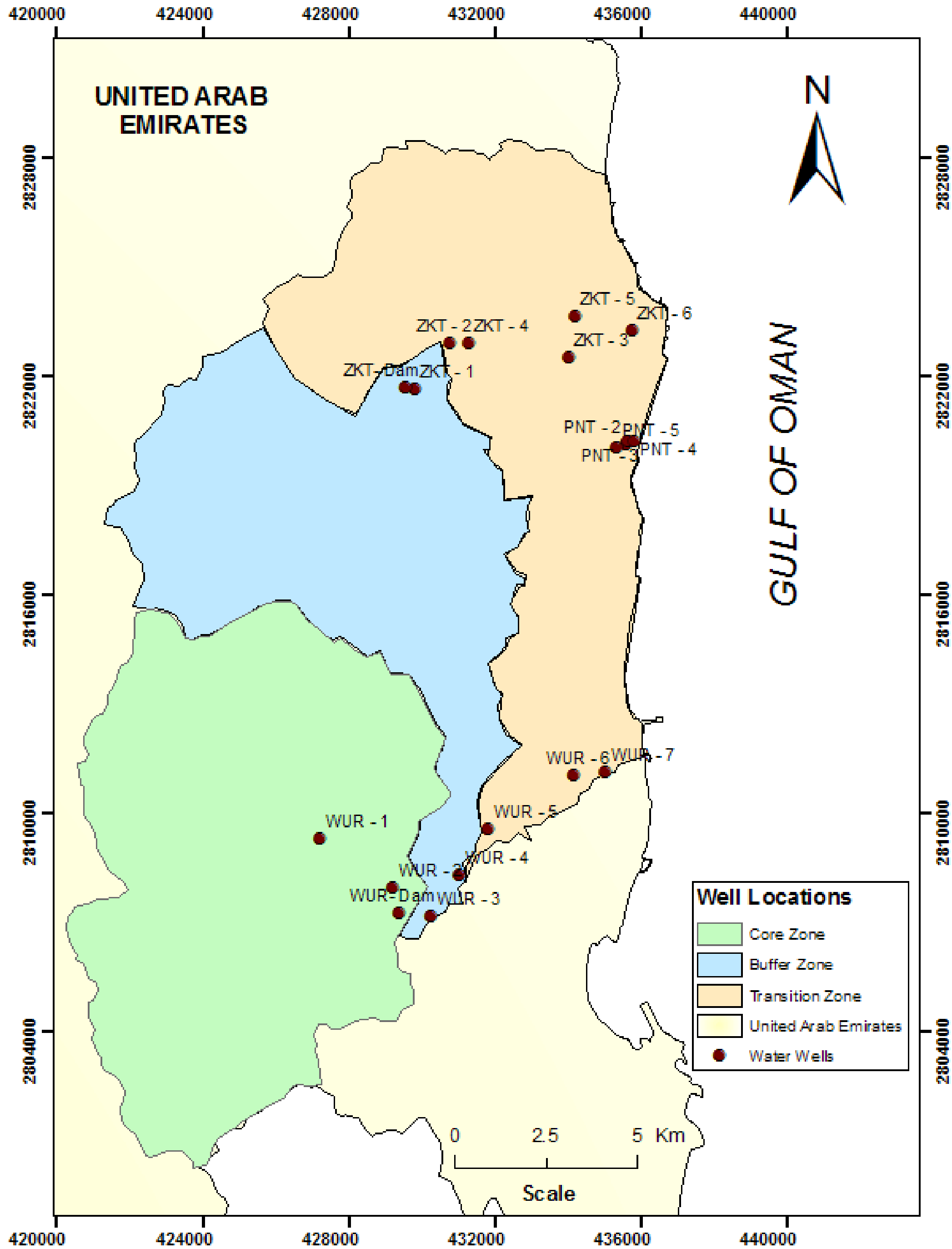

Figure 8.18 Graph showing observation wells (colored circles) surveyed during the period 2005-2009 (ALHOGARATY).

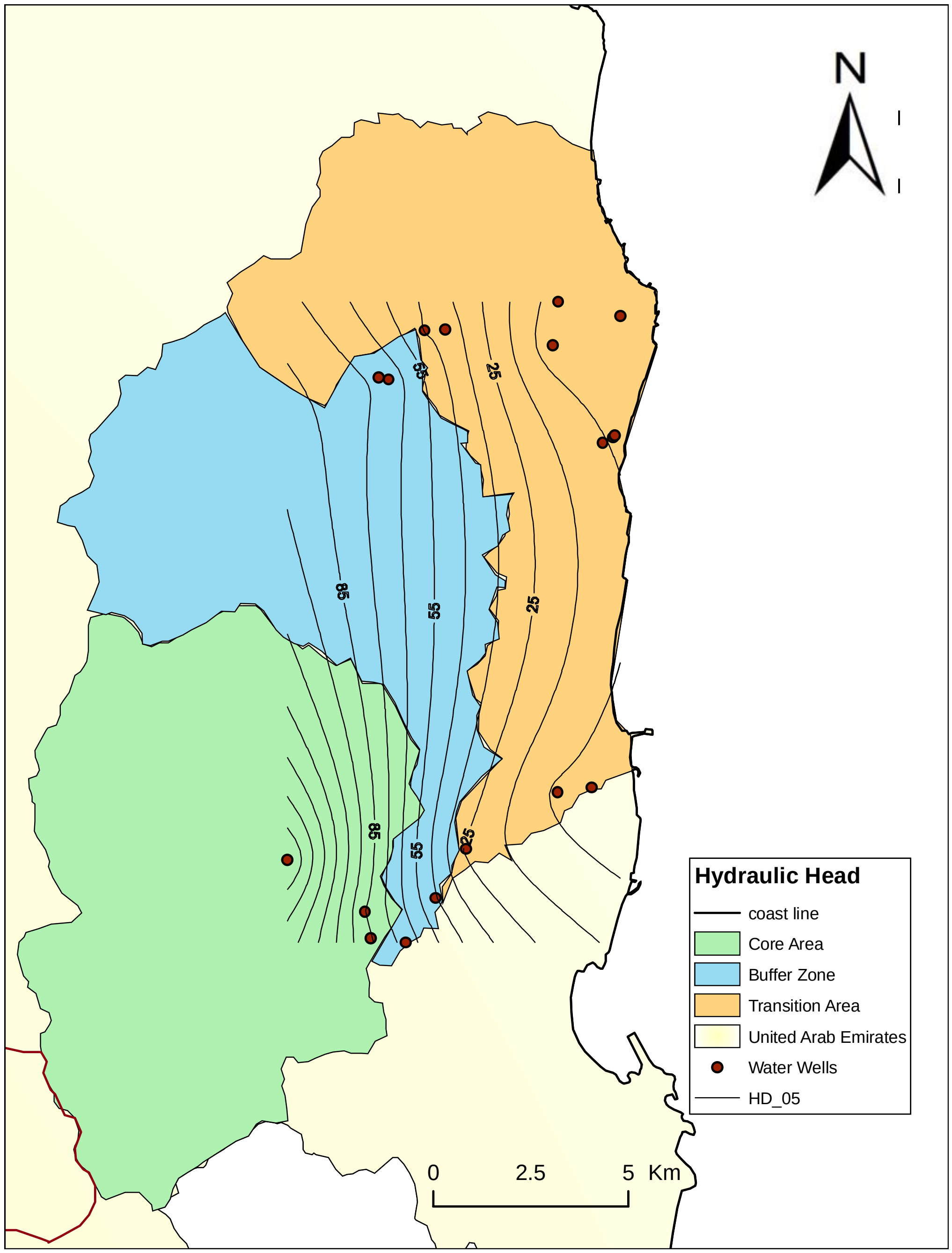

Figure 8.19 Graph showing groundwater levels in observation wells in 2005 (ALHOGARATY).

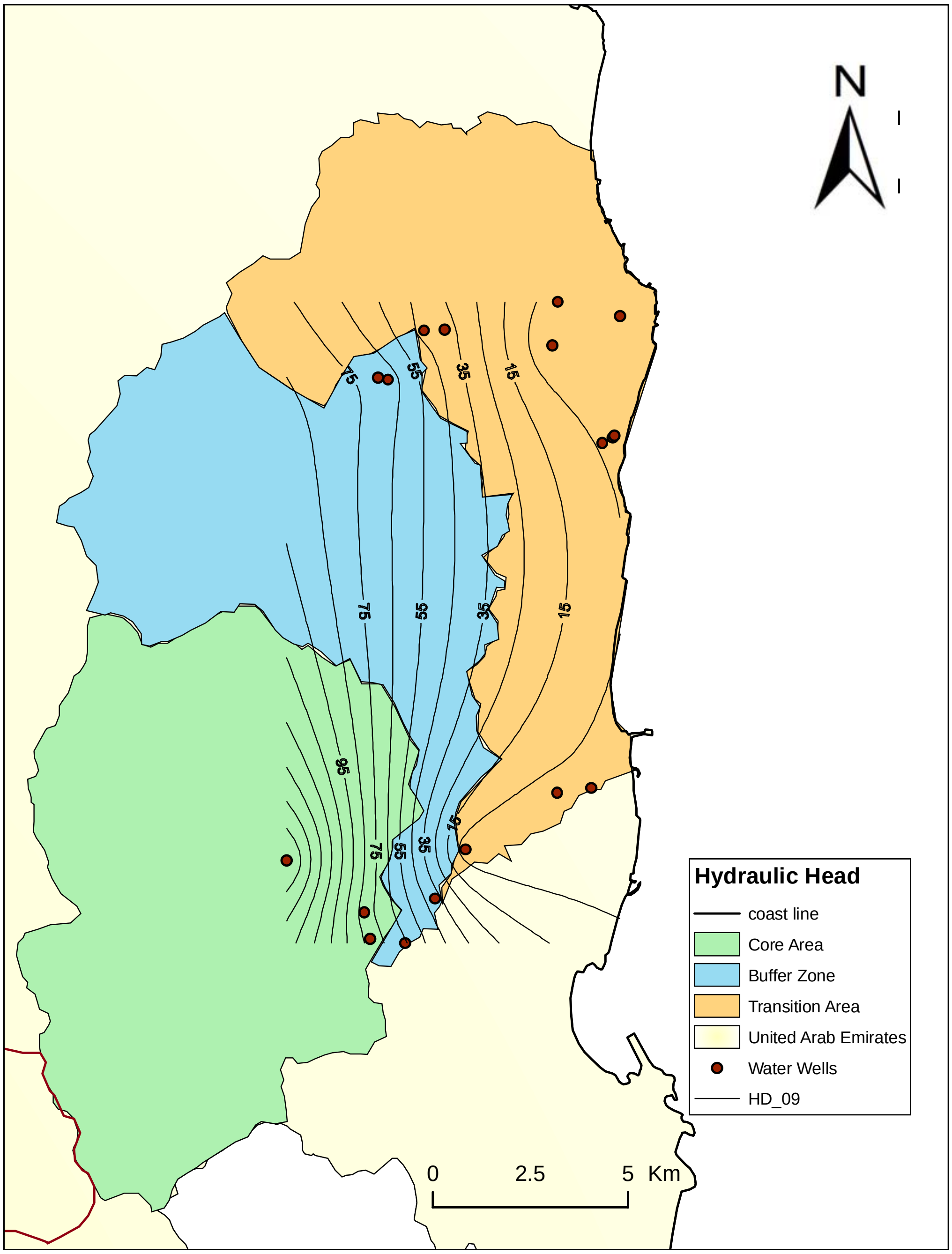

Figure 8.20 Graph showing groundwater levels in observation wells in 2009 (ALHOGARATY).

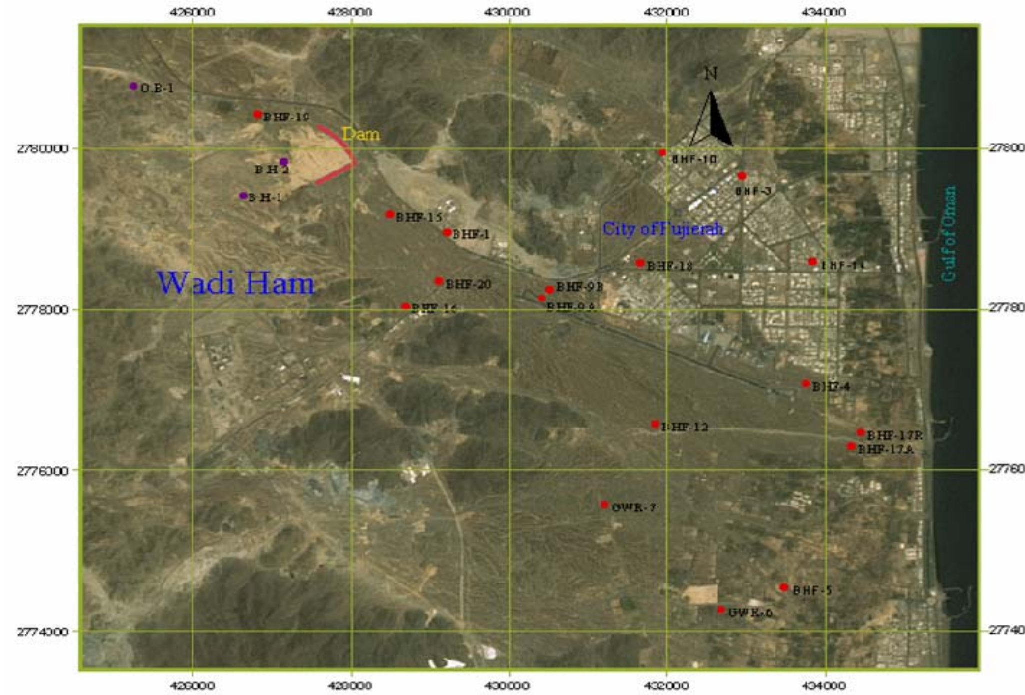

Figure 8.21 Photograph showing location of observation wells in Wadi Ham area. Wadi Ham Dam is illustrated by red lines in the northwest (Almatari, 2010).

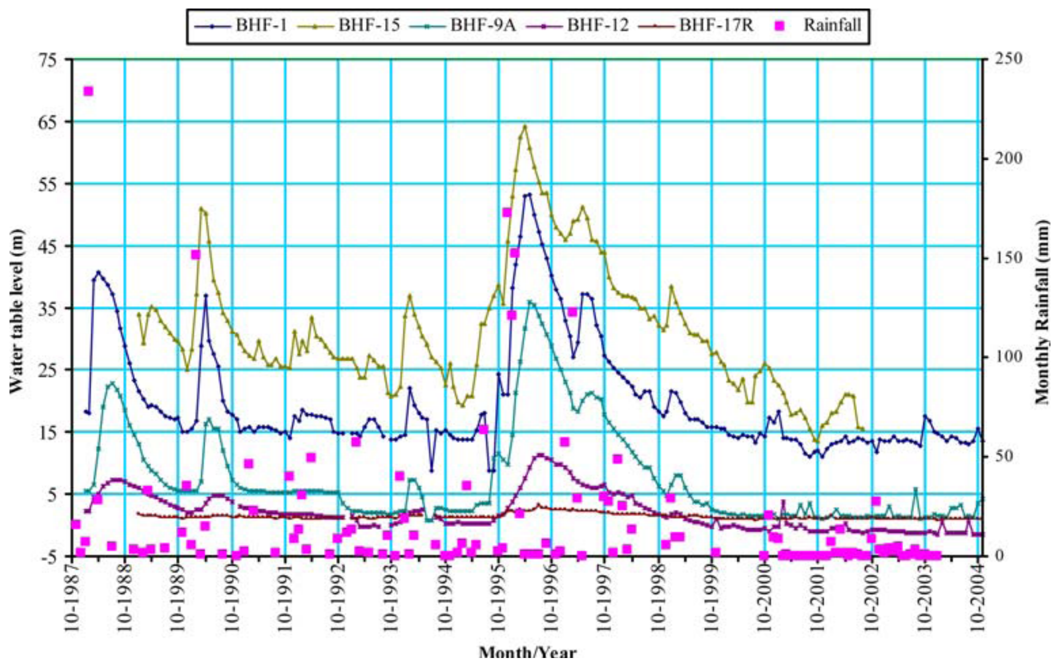

Figure 8.22 Graph showing groundwater levels in observation wells (colored curves) and rainfall events during the period 1987-2004 (colored squares) (Almatari, 2010).

Picture 8.2 General view of the Wadi Wurayah recharge dam.

Picture 8.3 Mud traces after rainfall at the area of the dam

Picture 8.4 General view of the Wadi Zikt recharge dam.

Picture 8.5 One of the water breakers at the area of the study.