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GROUNDWATER RESOURCES IN THE AL ASHSHAH PLAIN

Final Report
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1 INTRODUCTION

1.1 INTRODUCTION

A major component of the NORADEP Project (YEM/87/015) is the assessment of the groundwater potential of the Project Region, which covers the northern part of the Sana'a governate and the governates of Hajjah and Sa'dah (see Fig. 2.1). The data for this assessment will be used, together with the results of other specific and general studies carried out within the framework of the project, in the formulation of a Water Management Plan (WMP) for the Project Region. The Regional WMP will be based on WMPs prepared for each of the seven designated Target Areas in the Region.

The well inventory of the Al Ashshah Plain is one of the surveys that will contribute to this plan by supplying the required information on groundwater resources and their use in this target area. The results of the survey are presented in this report.

The activities for the well inventory were carried out during the months of December 1991 and January 1992. Four teams were used, each team consisted of two engineers and a driver. The drivers assisted in effecting measurements at the well site. A list of the persons that participated in the activities is presented in Appendix 4.

Before the start of the survey, each team received training in the field and various background information was given on subjects like local hydrogeological situation, locating the well sites with a compass, the use of the water level measuring tape, the EC-meter and the measuring of well discharge. The basic field equipment of each team comprised a stopwatch, a thermometer, binoculars, an EC-meter and altimeter, one or two water level measuring tapes (100 and 300 metres), a 75 litre bucket for well yield measurements, well inventory questionnaires and the necessary topographic maps (scale 1 to 50 000).

A total of 271 wells were visited in the study area and the same number of questionnaires was filled out each containing about 120 data. Information collected include data on the well location, well details, pump characteristics, measured well observations, water use, well costs, among others. The layout of the questionnaire is presented in Appendix 2. For convenience the most important data are summarized and presented in Appendix 3.

2 PHYSICAL SETTING

2.1 LOCATION AND TOPOGRAPHY

The Al Ashshah Plain is situated in the Central Highlands midway between the towns of Amran and Sa'dah, about 20 km west of Huth. The alluvial plain, consisting of various large wadi tributary valleys, covers an area of about 180 km^2 and has a catchment area of 1360 km^2 (see Figs. 2.2 and 2.3). This catchment area extends from the major water divide of the Central Highlands in the east to beyond Shahara in the west and forms part of the catchment area of Wadi Akhraf, south of the plain. The Wadi Akhraf catchment area is part of the large catchment area of Wadi Mawr.

The plain is located within the UTM (UTM zone 38) coordinates 1 784 000 and 1 817 000 north and 367 000 and 380 000 east (16^0 8' to 16^0 26' north, 43^0 45' to 43^0 52' east of Greenwich) and its length (north-south) is about 33 km. The width of the valley varies from five km in the northern part to 10 km in the south.

The main towns are Al Ashshah in the east and Al Qaflah built on a mountain ridge in the west. Al Ashshah can be reached from Huth by a sinuous gravel road 17 km long. This road continues to Shahara, situated southwest of the plain.

The plain is dissected by several wadi systems draining the surrounding mountains. The most important wadis are, in the north: the Wadis Al Wasi, Jayr and Himarat; in the centre: the Wadis Hibah and Al Muharraq and in the south: the Wadis Al Mahid, Aqidah and Dibanah. The latter wadi functions as the surface water outlet of the plain. Further south its name changes to Wadi Akhraf, one of the main upstream tributaries of Wadi Mawr. Wadi Mawr debouches into the Red Sea near Az Zuhrah.

Topographic elevations in the plain range from 1400 m amsl (above mean sea level) in the north, down to 1120 m at the southern margin of the plain, resulting in a surface level decline of 280 m over a distance of 33 km. This gives gradient of 0.8%.

The surrounding mountain ranges are entirely composed of Tertiary Volcanics. The heights of these mountains range from 2300 m in the west near Shahara, and 2400 m northeast of the plain, down to 1400 m in the northwest.

From the 1986 census the number of inhabitants in the Target Area was estimated at 24 500, of whom 3000 live in the two main villages: Al Ashshah and Al Qaflah. At a growth rate of 3.3% per year the 1992 population would be about 31 000.

2.2 CLIMATE

In 1988 an agro-meteo station was installed at Al Batana State Farm by the Ministry of Agriculture and Water Resources (HWC code W02M04). However, for unknown reasons, no data were available.

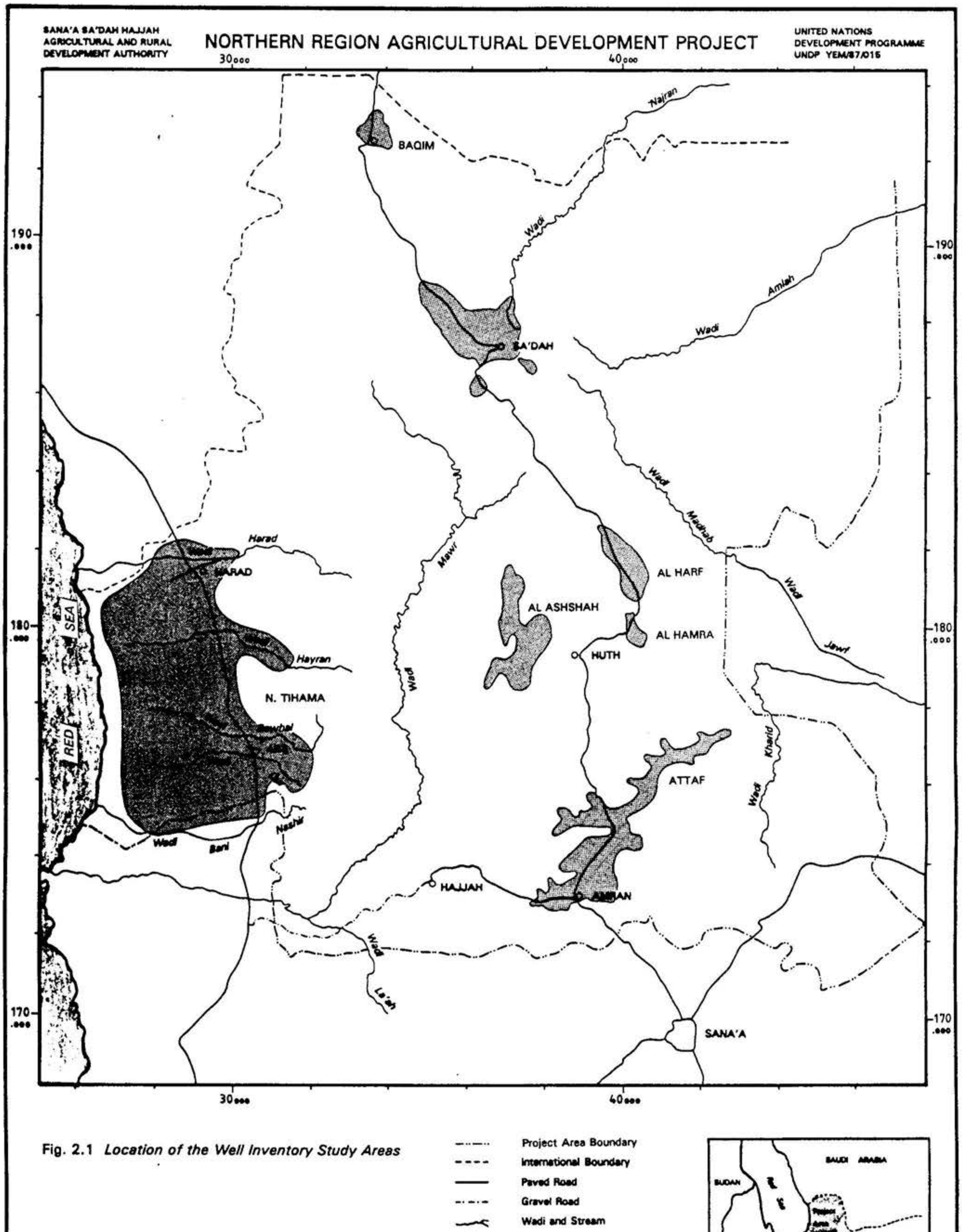


Fig. 2.1 *Location of the Well Inventory Study Areas*

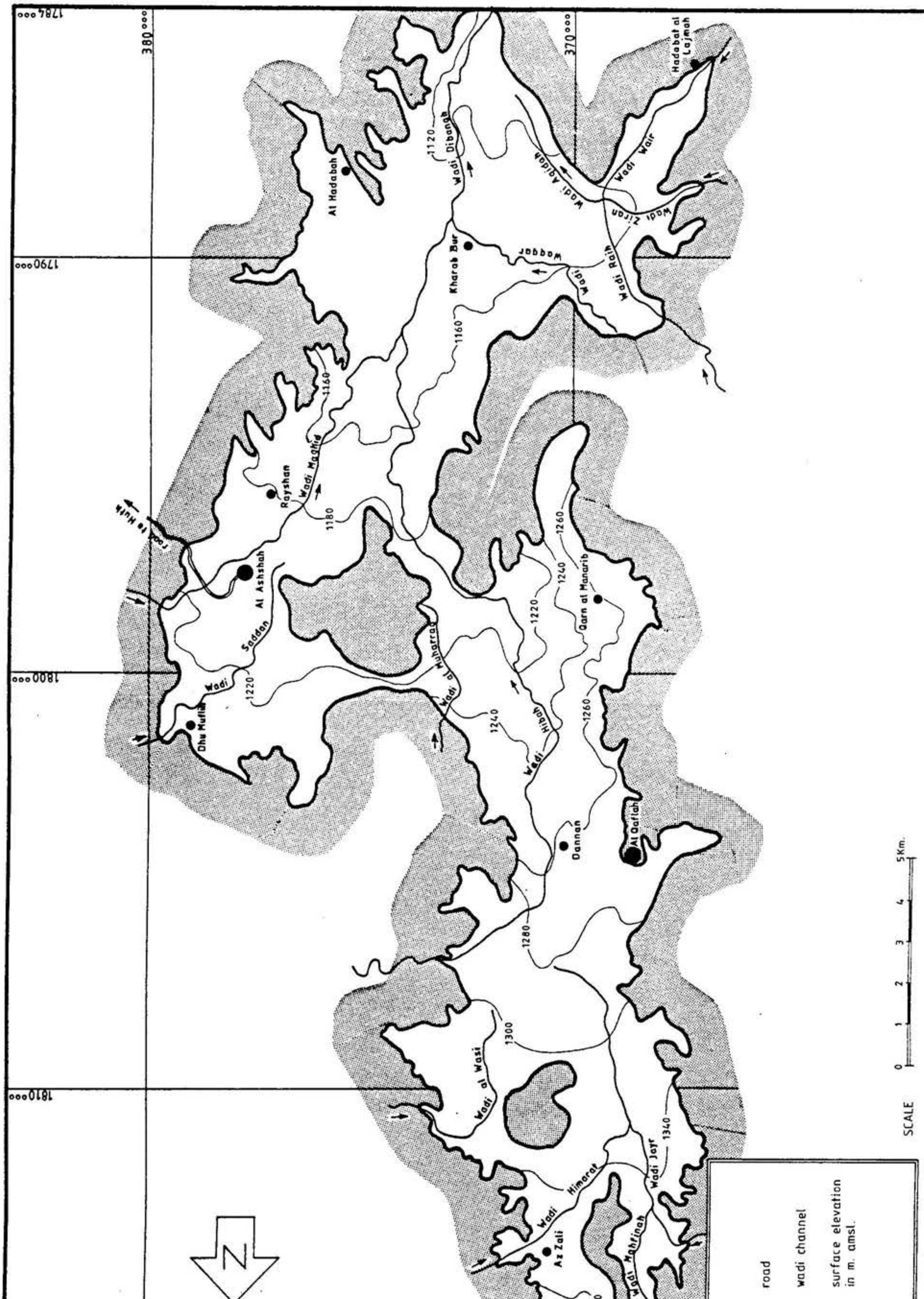


Fig. 2.2 Map of the Al Ashshah Plain study area

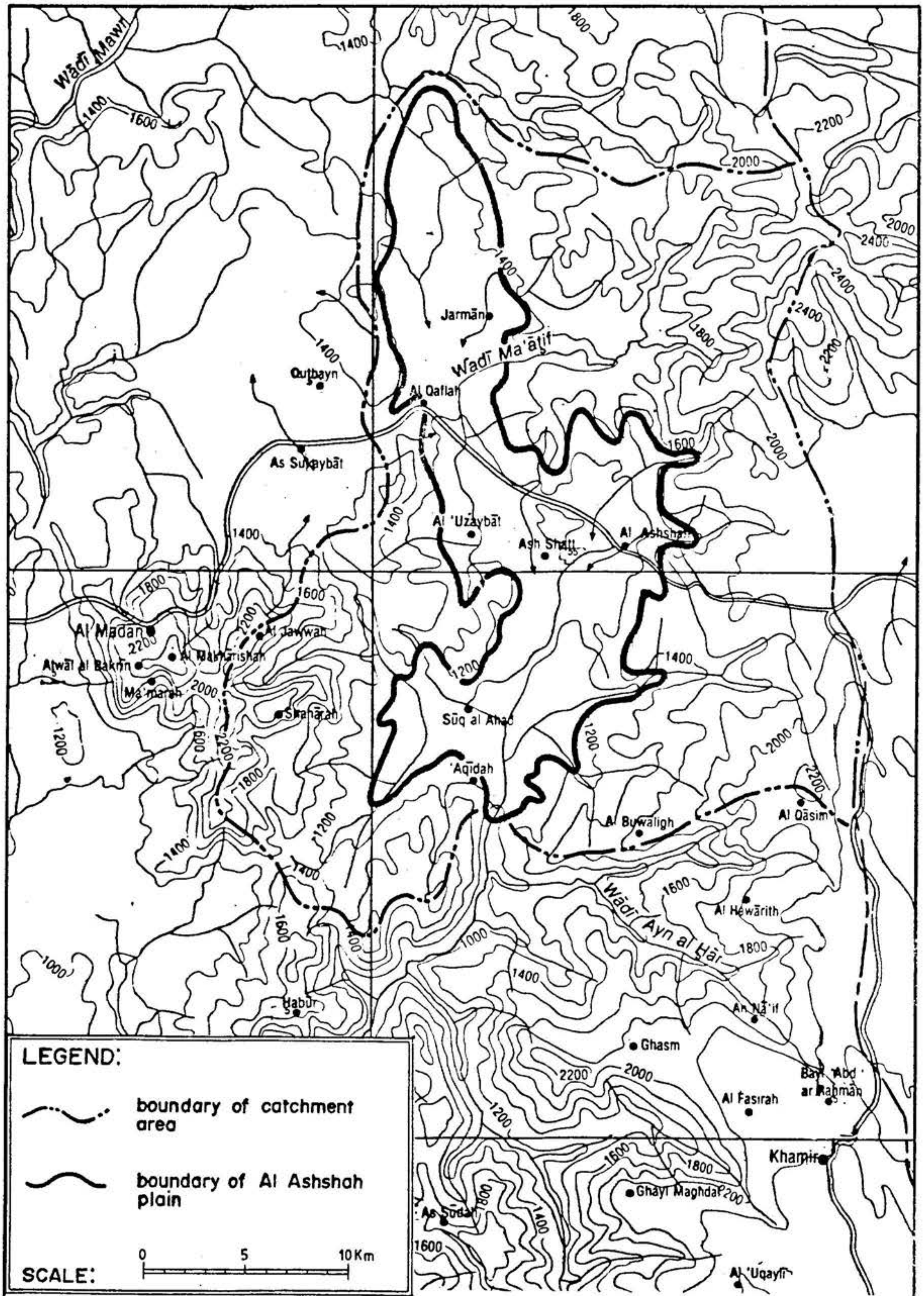
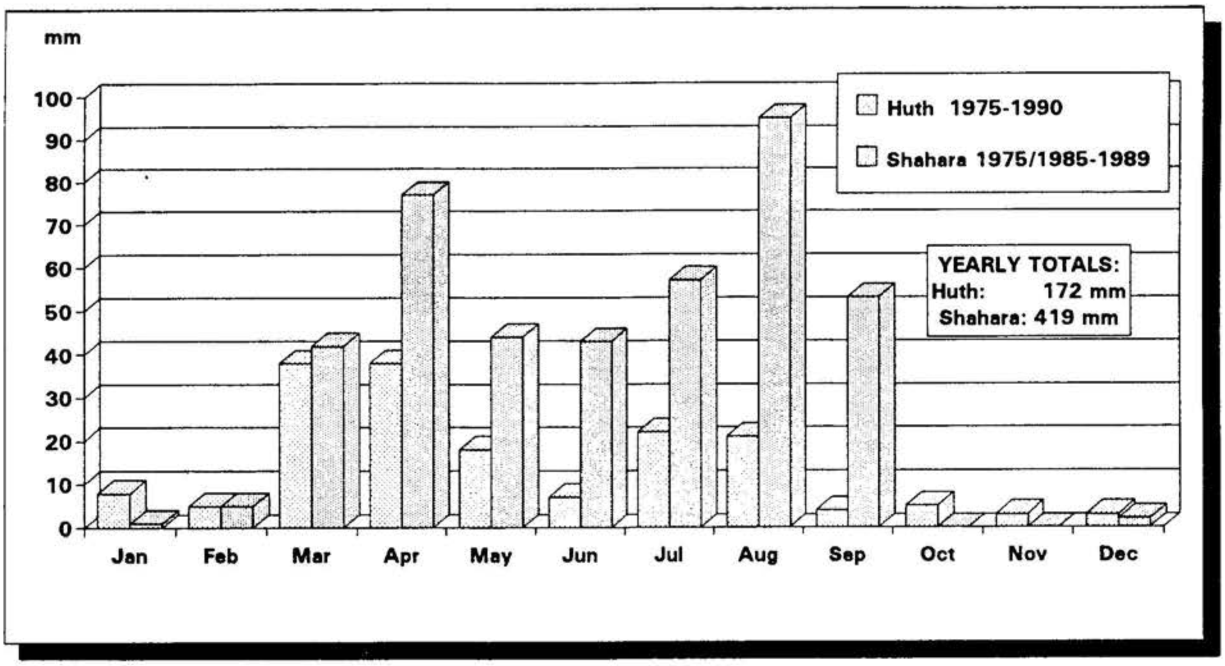


Fig. 2.3 Catchment area of Al Ashshah plain

Therefore, rainfall data from the nearby stations Huth (about 17 km east of Al Ashshah) and Shahara (about 20 km southwest of Al Ashshah) were used. Rainfall data from the stations differ immensely: the mean annual rainfall at Shahara since 1980 is more than double that at Huth (419 mm and 172 mm). Interpolating these data would result in average annual rainfall for Al Ashshah of about 300 mm. However, according to the local farmers, a severe drought has afflicted the area during the last five years. This is neither reflected by the rainfall data of Shahara nor by the data of Huth (see Figs. 2.4 and 2.5). So, probably, the stricken area was limited to only the Al Ashshah Plain itself.

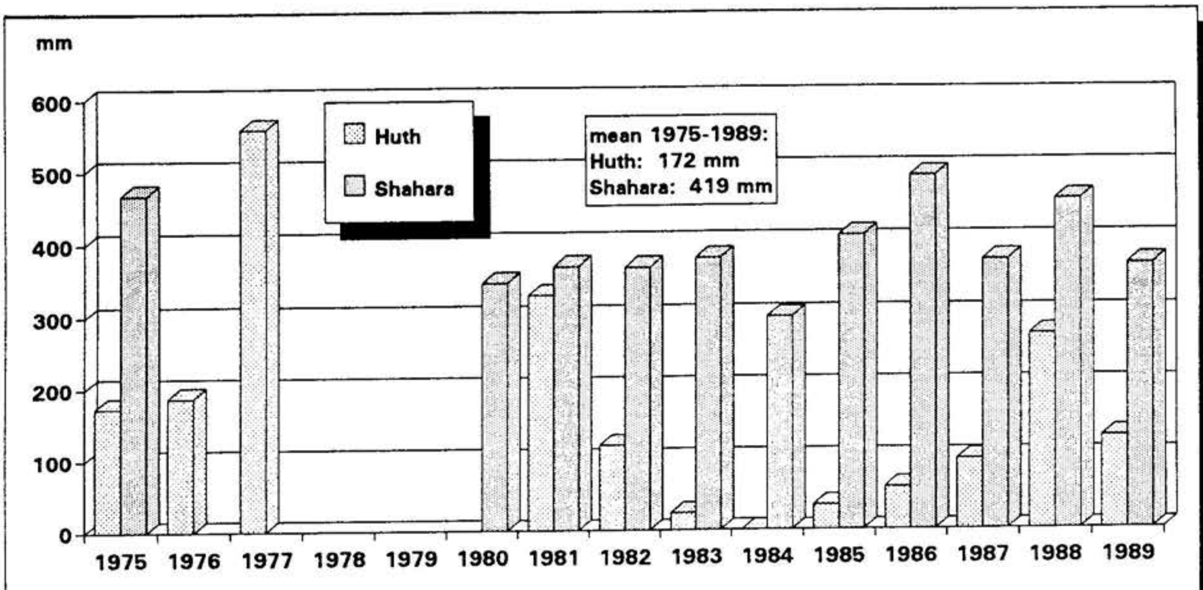
Fig. 2.4 *Mean Monthly Precipitation Near Al Ashshah Plain*



A preliminary estimate of 200 mm for the yearly rainfall was assigned to 1991 to enable the calculation of the volume of the yearly total rainfall in the plain (see Section 5).

Fig. 2.4 shows the mean monthly rainfall in Huth and Shahara, while Fig. 2.5 represents the total annual rainfall at the same rainfall stations for the period 1975-1989. Yearly totals in Huth range from 24 to 559 mm and in Shahara from 297 to 491 mm. Most rain falls during the period March to September, but the monthly distribution of rainfall is rather variable. In general, two peaks occur during the year: March-April and July-September. The wettest month in Huth is April and in Shahara August.

Fig. 2.5 *Total Annual Precipitation Near Al Ashshah Plain (1975-89)*



Note: Of 1976, 1978, 1979, 1980 and 1984 no data of Huth available, of 1976-1979 no data of Shahara

3 GEOLOGY AND HYDROGEOLOGY

3.1 GEOLOGY

3.1.1 Tectonics

Several faults, aligned north-north-west/south-south-east, which probably originated during the late-Tertiary, traverse the study area. They would have been responsible for the creation of grabens by the downthrow of blocks of Yemen Volcanics. Afterwards, during the late-Tertiary and Quaternary, they were filled up with wadi-terrace deposits and alluvial fans. This alluvial cover is rather thin, ranging from 6 to 20 m. Fig. 4.20 shows the thickness of the alluvium.

3.1.2 The Quaternary Volcanics

During the Quaternary, volcanic activity resulted in the buildup of basaltic cones at two locations about four km east and northeast of Dhu Muflih: the Jabals Al Hawl and Kawkab, which extend up to 2080 m amsl, about 800 m above the plain level. Near the Amran and Attaf Valley, the age of the Quaternary volcanic activity has been determined at between 100 000 and 1700 years. The basalts are dark grey to black coloured. Table 3.1 shows the description of the geological formations and their hydraulic characteristics.

3.1.3 The Quaternary Alluvium

The filling up of graben during late-Tertiary and Quaternary times was with clastic material derived from the surrounding Tertiary Yemen Volcanics by backward erosion. Figs. 4.21 and 4.22 present two cross-sections through the plain, indicating the thickness of the alluvium and the depth to groundwater. They clearly show, that water is pumped not from the alluvium but from the volcanic bedrock below it. The alluvium functions here as a sponge or a surface and rain water collecting medium, from where the water can infiltrate into the underlying bedrock.

3.1.4 The Tertiary Yemen Volcanics

The Al Ashshah Plain is underlain and enclosed on all sides by volcanic deposits of Tertiary age, made up of alkali basalt flows, composed of andesites, rhyolites and tuffs, and pyroclastic basalt rocks, interbedded with lenticles of wadi alluvium such as sand, clay and shale. West of the Al Ashshah Plain and north of Magharibah, this lithological unit is represented by old-Tertiary felsic and tuffaceous volcanics. Elsewhere the plain is surrounded and underlain by younger Tertiary volcanics including various basaltic flows.

3.2 AQUIFER SYSTEMS

3.2.1 Alluvium

Only in upstream wadi fills does the Quaternary alluvium function as a temporary

Table 3.1 *Geological Formations and their Hydrologeological Characterisitcs in and Near Al Ashshah*

Stratigraphic Age	Litho-stratigraphy	Lithology	Hydrogeology
Quaternary	Wadi terrace deposits and alluvial fans	Loam, silt, clay, sand loess, gravel, boulders.	Alluvium does not act as an aquifer, because water level is mainly situated below it in the bedrock Alluvium functions as surface and rain water collector, where after it infiltrates in the volcanic bedrock below.
Tertiairy	Yemen Volcanics	Volcanic flows, sills, tuffs, basalts and intrusives.	Groundwater circulates only through secondary porosity like fissures, fractures and faults. Poor aquifer, unless fractured.
Tertiairy/ Cretaceous	Medj-Zir Series and Tawilah Group	Cross-bedded fine to coarse grained quartz sandstones with gravel and conglomerate horizons.	In principle, a potential aquifer. No data are available on the saturated thickness in the study area.
Jurassic	Amran Series	Limestones, dolomites, marl, shale layers and Quaternary basalt dykes.	In general poor hydraulic properties,except in or near fractured zones. No indications for the occurrence of karst. Probably underlying the Yemen Volcanics in the study area.
Triassic	Kohlan Series	Fine grained. partly cemented quartz sandstones with conglomerate horizons.	Not significant for the water supply of the Al Ashshah Plain. Not outcropping in or near the study area. Probably underlies the Amran Limestone Series.
Precambrian	Basement complex	Granite, gneiss and mica schists.	Practically impermeable and little water storage. Aquiclude and aquifuge, no outcrops in or near the study area.

perched aquifer and, where saturated, it represents a relatively good aquifer. The highest permeabilities are in the interbedded gravel layers. However, in most of the plain the alluvium is situated above the water table and is not saturated. General groundwater movement in the plain is directed towards the south. Fig. 3.1, the hydrological cycle, presents a schematic model of the movement of water in the Al Ashshah Plain and its catchment area.

3.2.2 Yemen Volcanics

It is supposed that the alluvium in the Al Ashshah Plain is underlain by the Tertiary Yemen Volcanics. In most of the study area, the groundwater table is situated below the alluvium-bedrock contact. This means that groundwater is abstracted only from these volcanic strata.

The rate of well discharge is a function of various parameters, including the hydraulic capacity of the aquifer. No data were available from pumping tests in the volcanics. Most wells in the area were shallow dug wells. When comparing the mean well discharge rate of the drilled wells equipped with lineshaft pumps with well yields obtained under the same conditions in the other target areas, it could be concluded that the hydraulic capacities of the volcanics are rather low (mean well discharge 4.5 l/s).

Groundwater only circulates through secondary porosity, like fissures, fractures and faults. Good water-bearing and water-transporting capacities would only be expected in fractured zones, along dykes, bedding planes and in scoriaceous (tuff) intercalations.

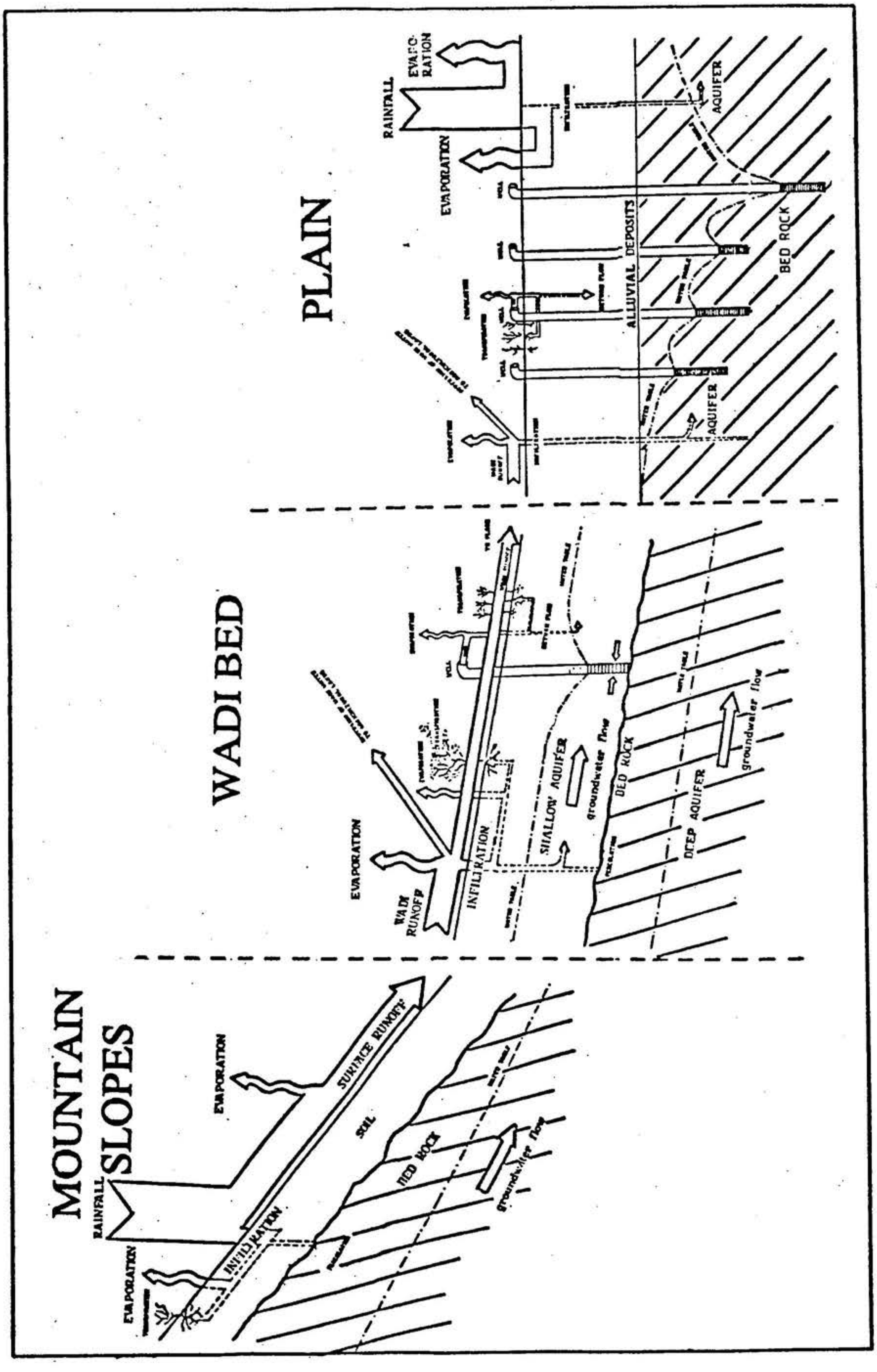


Fig. 3.1 Hydrological cycle

4 GROUNDWATER GENERAL

4.1 DISTRIBUTION OF WELLS

Fig. 4.1 shows the locations of the wells visited; a total of 271 were inventoried. it was assumed that about 90% of all existing wells were surveyed and that the remaining 10% were evenly distributed over the area. Large areas with lower well densities are apparent.

Several parts of the plain are not suitable for agriculture, because the topography is irregular and/or soil properties are inferior , and in an area east of Al Qarfah rainfed and spate irrigated cultivations dominate. The water applied is from the Wadis Al Wasi, Al Atif/Hibah and Himarat. The same applies to the areas around Qarn Al Manarib in the west and Al Hadabah in the southeast.

4.2 NUMBER OF WELLS

Of the 271 wells visited, 53 (about 20%) were not operational for the following reasons: 47 were dry because of the decline of the water table during the drought; another four were not in use because they were being deepened; and at two wells the pump was broken.

The total number of operational wells in 1991 was estimated as 242 (assuming that 90% of the wells were visited and 20% of the wells were dry).

Despite the water table decline as a result of the drought, water levels in absolute terms were still very shallow. Their depths ranged from five to 30 m over most of the plain. This also helped to explain why most wells (92%) were still hand dug shallow wells and only 8% were boreholes (see Fig. 4.5). Another reason was that the tribal head of the area restricted access for drilling rigs.

Only four of the total of 271 surveyed wells were constructed during the period 1930-1970. Thus real groundwater development only started in the early 1970's about eight years later than the Amran Valley. Statistical analysis of the well construction data revealed that most of the wells (65%) were dug or drilled during the period 1983 to 1991, and the average age of the wells was 7.5 years. The oldest well encountered was dug in 1930. Figs. 4.2 and 4.3 shows the total number and the cumulative number of the wells that were dug/drilled during the period 1930 to 1991. It is clear that wells were also dug before 1930. Probably these wells were abandoned a long time ago. The first impression was that the peak of the yearly drilling rate has not yet past. During the last five years, many wells were reported to have been deepened.

In the past, water was abstracted by buckets lifted by donkey power. However, most of these wells are now pumped with centrifugal pumps, and some by turbine (lineshaft) pumps.

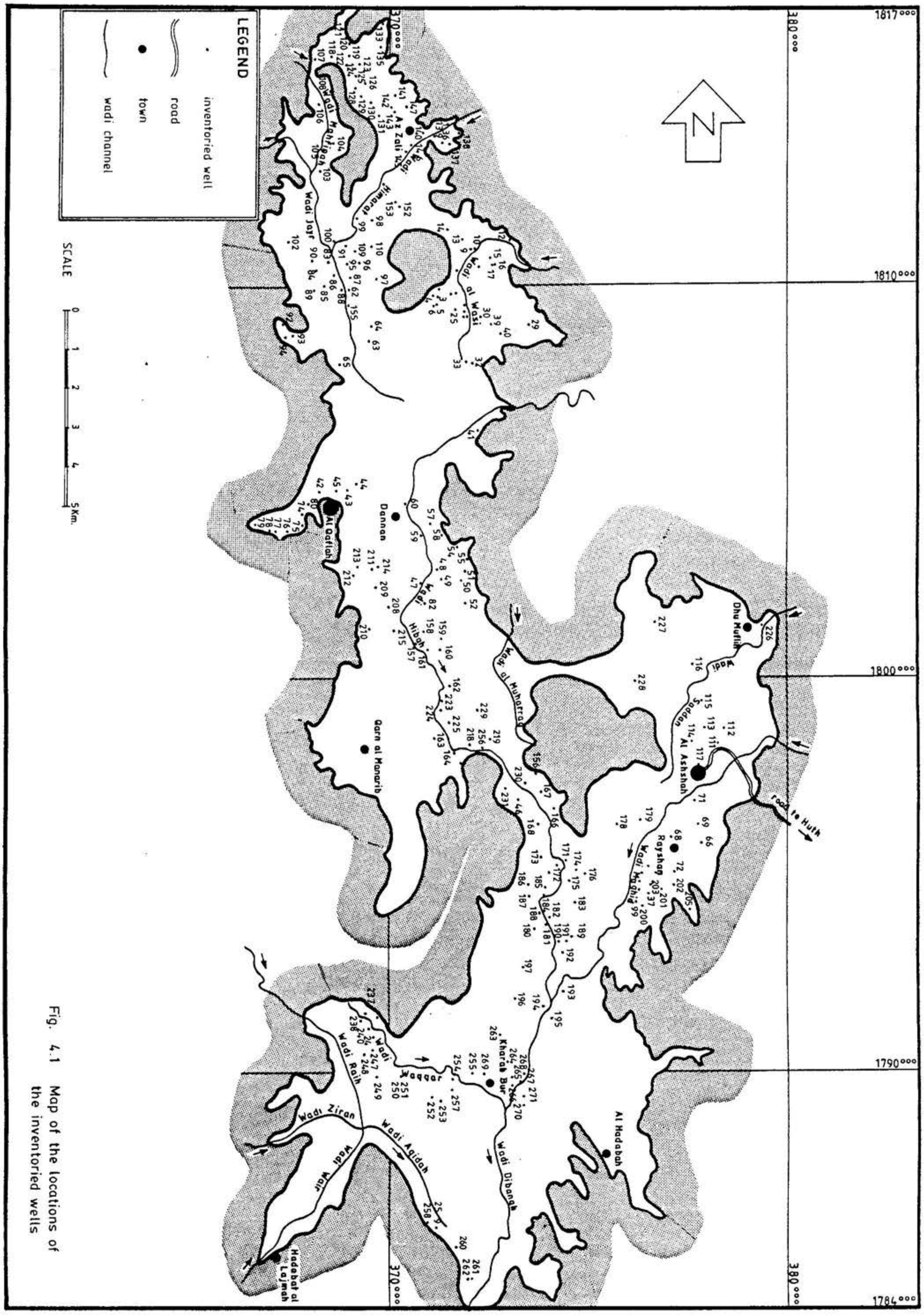


Fig. 4.1 Map of the locations of the inventoried wells

Fig. 4.2 *Number of Wells Constructed to 1991*

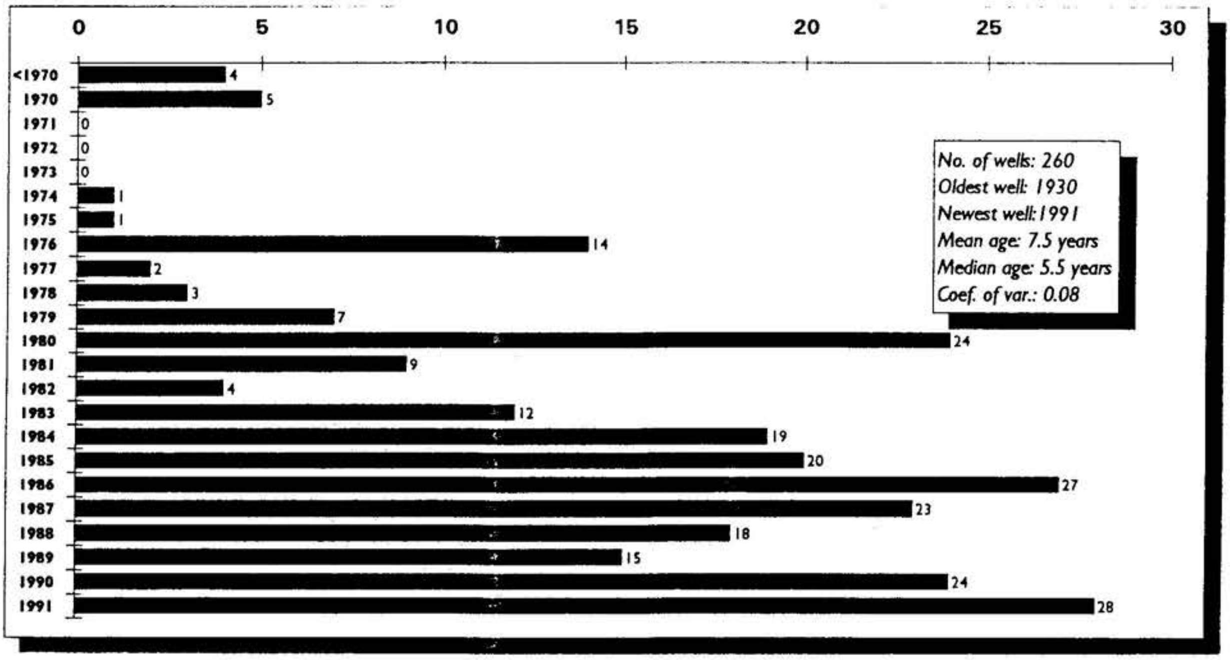


Fig 4.3 *Cumulative Number of Wells Constructed Up to 1991*

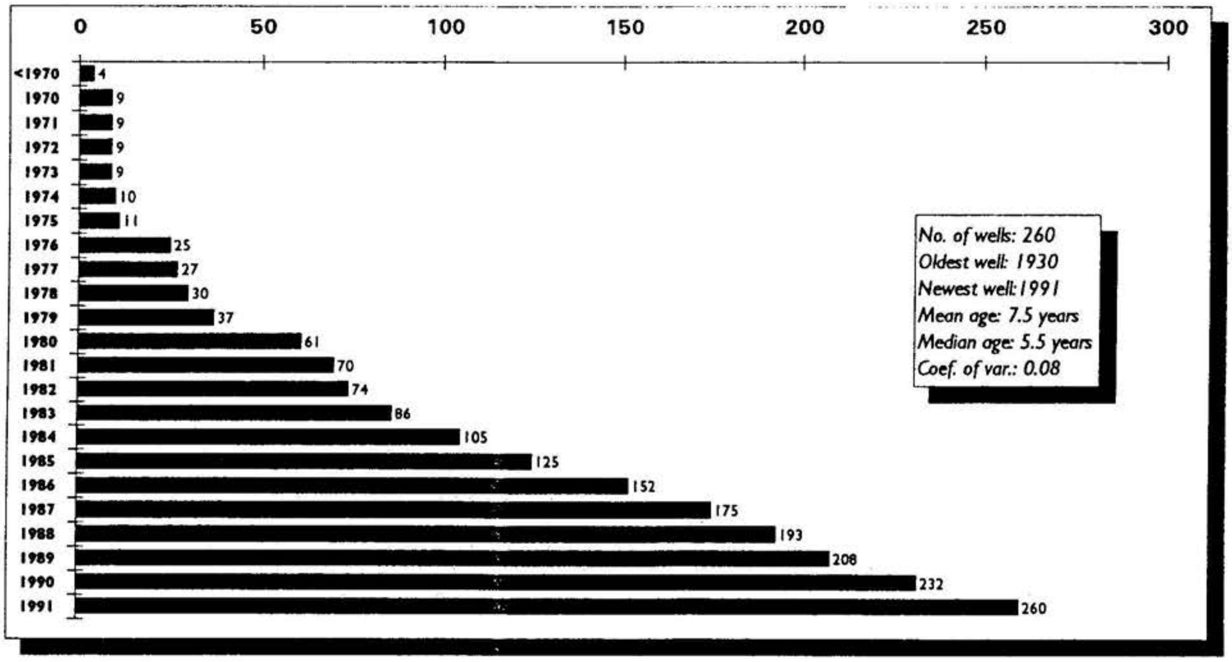
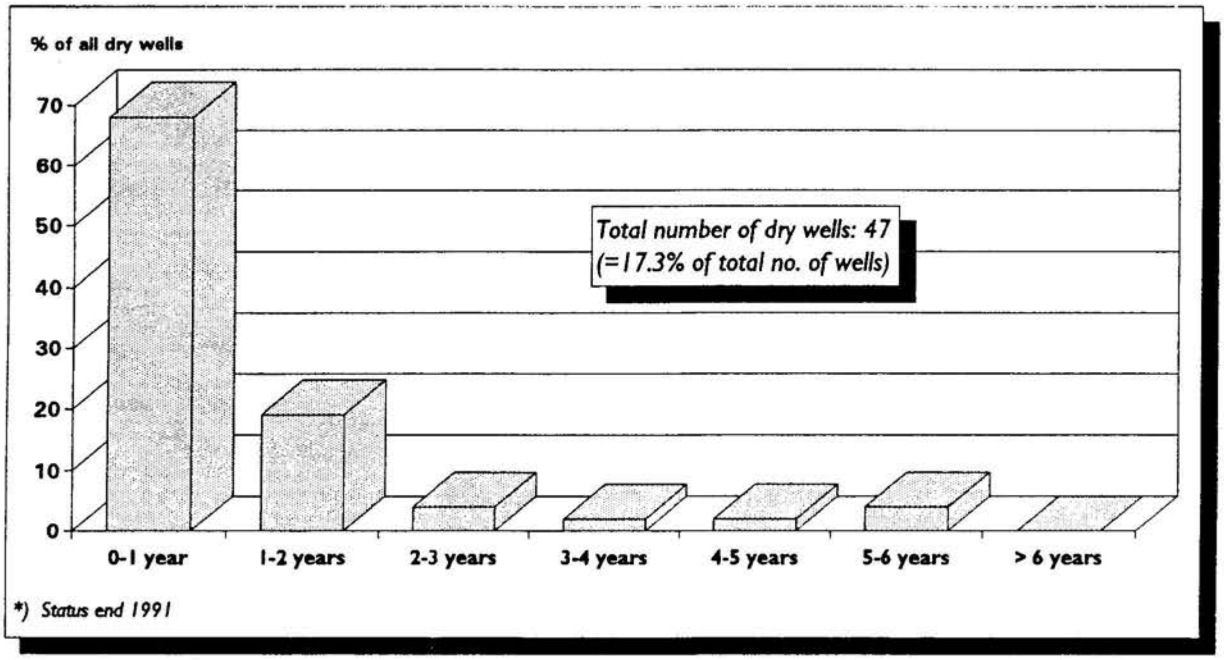


Fig. 4.4 shows the distribution of the wells that fell dry during the period of drought. Most of these wells dried up during 1991 (68% of all the dry wells) and 1990 (19% of the dry wells).

Fig 4.4 *Years Since Wells Became Dry*



4.3 WELL CHARACTERISTICS

The walls of the shallow wells are of masonry. A severe drought had afflicted the area during the last five years, causing a decline of several metres in the water table over most of the plain. Therefore, many farmers had to deepen their wells. 38% of the dug wells had been deepened one to four times during this period (26% were deepened four times, 2% three times, 4% two times and 6% once).

The deep wells (80% of all wells) were drilled by the rotary method. All these wells were cased throughout by steel pipes of six m length. Casing diameters differed significantly from those in the nearby Al Harf Plain. Here, large (10") diameter casings dominated (57%), followed by 8" diameter casing (24%) and 12" casings (14%). The lower section contained a series of 6 m long slotted pipes as a screen.

Fig. 4.5 shows the distribution of well depths in the plain. The depth to water, in general, was rather shallow, ranging from five to about 30 m over most of the plain (see also Fig. 4.18). As a consequence, well depths were not very great.

A division was made between hand dug shallow wells and drilled deep wells. Depths of dug wells ranged from 5 m to 50 m and were on average 18 m. Drilled wells were much deeper and varied from 110 m to 360 m, with a mean of 199 m. The diameter of the shallow hand dug, wells ranged from 1.2 to 7 m (mean and median 3 m).

4.4 WATER COLUMN HEIGHTS

To indicate to what extent the wells are prepared for falling water levels, or in other words how much water column is available inside the wells, the "water column height" of the well was analysed. The water column height is the difference between the well depth and the depth to the static water level.

Fig. 4.5 *Distribution of Well Depths*

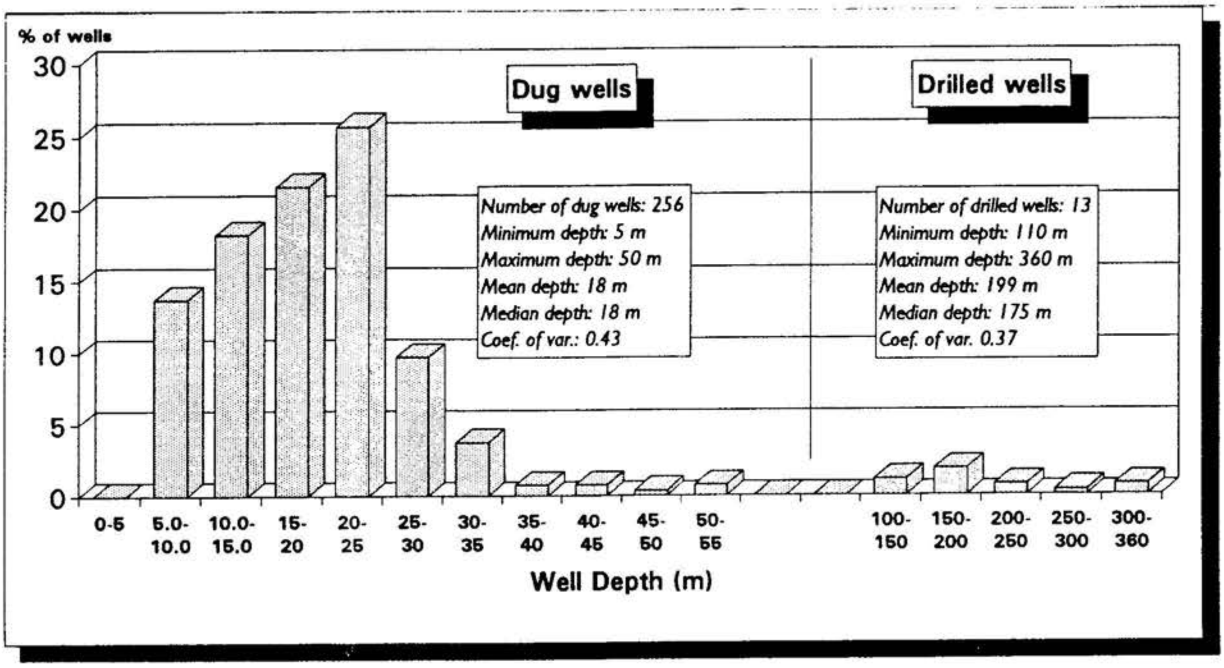
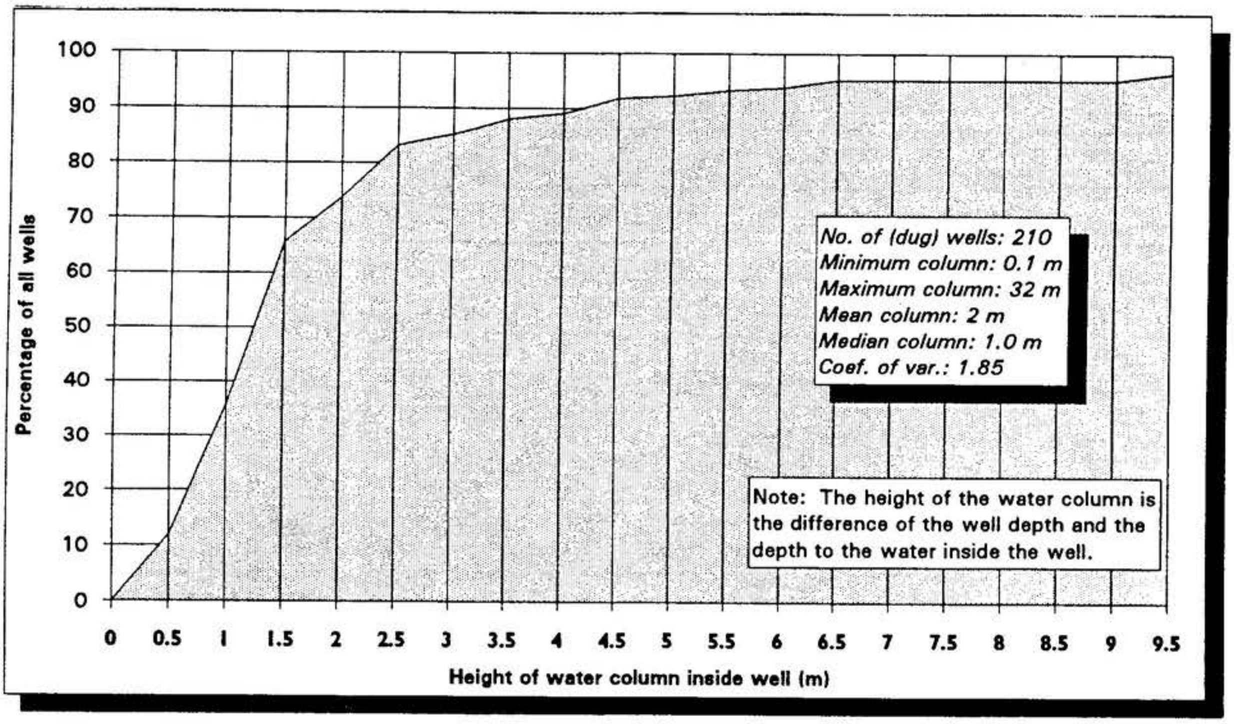


Fig. 4.6 *Cumulative Distribution of Water Column Heights*



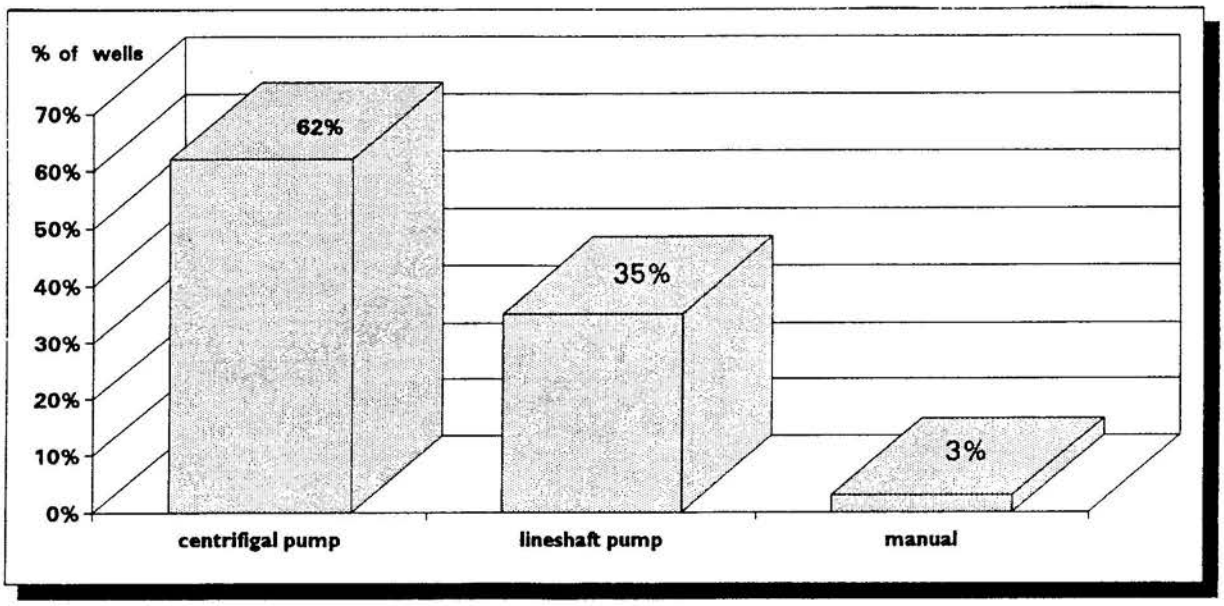
By analysing the cumulative distribution plot of the water column heights of all the wells, the percentage of wells that would fall dry if the water table should drop by a certain amount can be deduced. Fig. 4.6 confirms what was demonstrated by Fig. 4.4, ie. the drought had caused a severe groundwater problem. A drop of the water table of only 1.5 m would cause 65% of the dug wells to fall dry. A decline of 4 m would result in the drying up of 90% of the wells.

The water column height ranged from a very low 10 cm to 32 m, with a mean of only 2 m. As a consequence, the typical pumping schedule in the plain involved pumping a short period until the well was empty (say 0.5 hour), followed by several hours of recovery for the water table, before pumping again for a short time.

4.5 PUMPING EQUIPMENT

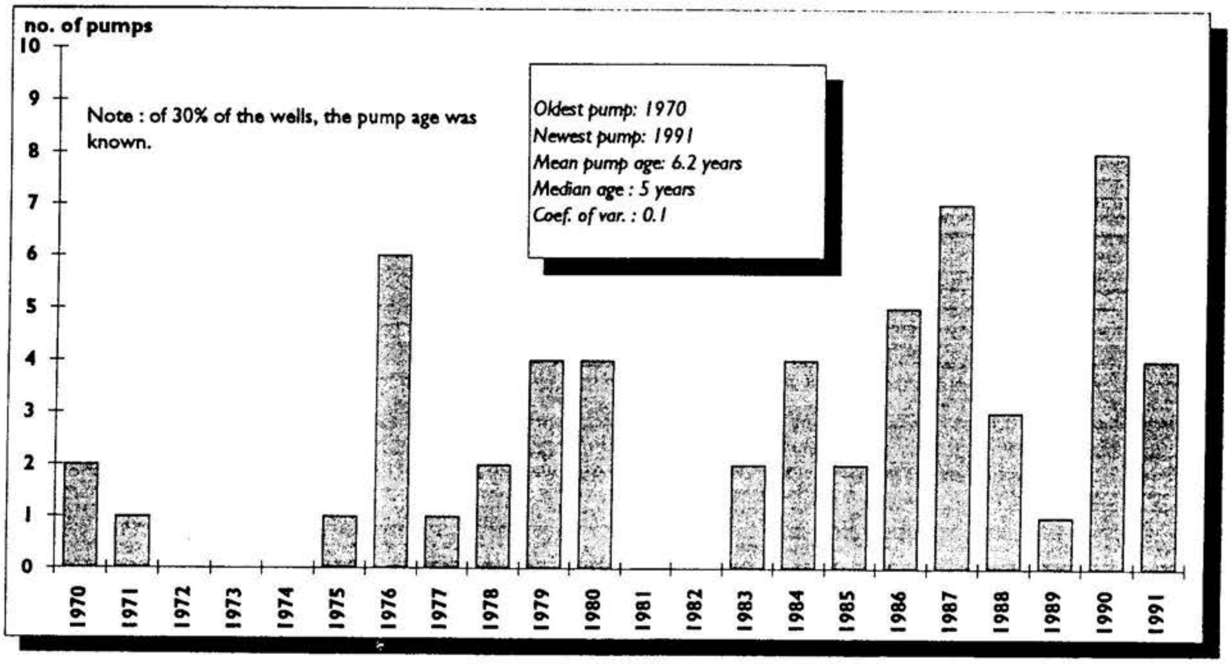
Groundwater was abstracted by centrifugal pumps (62% of wells) and lineshaft turbine pumps (35%). In 3% of the cases the water was taken out manually (see Fig. 4.7). In the shallow dug wells the most common pump type was the centrifugal pump, but lineshaft pumps were installed in 26% of the wells. This pump type was coupled via crossed webbing belts to diesel engines.

Fig. 4.7 *Methods of Water Abstraction*



The age was known of only 30% of the pumps. Nevertheless, Fig. 4.8 seems to indicate a slightly increasing yearly number of pump installations. The mean pump age was 6.2 years, while the mean well age was 7.5 years. The oldest pump observed was installed in 1970.

Fig. 4.8 *Number of Pumps Installed*



A moderate level of standardization in engine and pumping equipment was observed. 33% of the lineshaft pumps were supplied by Caprari and 18% by Porcelli. Because water levels were shallow, the capacity of the pump was restricted to an average of only seven bowls (the median was 4). Most centrifugal pumps were made by Basan (67%), followed by Honda (19%) and Robin (11%). These pumps usually had a capacity of 3.5 to 4 HP and were mostly running on petrol. The average diameter of the hose or pipe was 2.15" (minimum diameter was 1") and maximum 3"); pump column diameter was mostly three and four inch (58% and 31%). A higher level of standardization was noticed among the engines that powered the turbine pump. Japanese Yanmar (Yamaha) engines, models NP22Y, NP28 and NP30 accounted for about 52% and Mitsubishi for 18%. The engines had in most cases a capacity ranging from 21 to 35 horsepower.

4.6 WELL YIELDS

The magnitude of the well yield is determined by several parameters such as the capacity of the pump, the well efficiency, the screen length (if any), the depth to the water and aquifer parameters like transmissivity and storage coefficient.

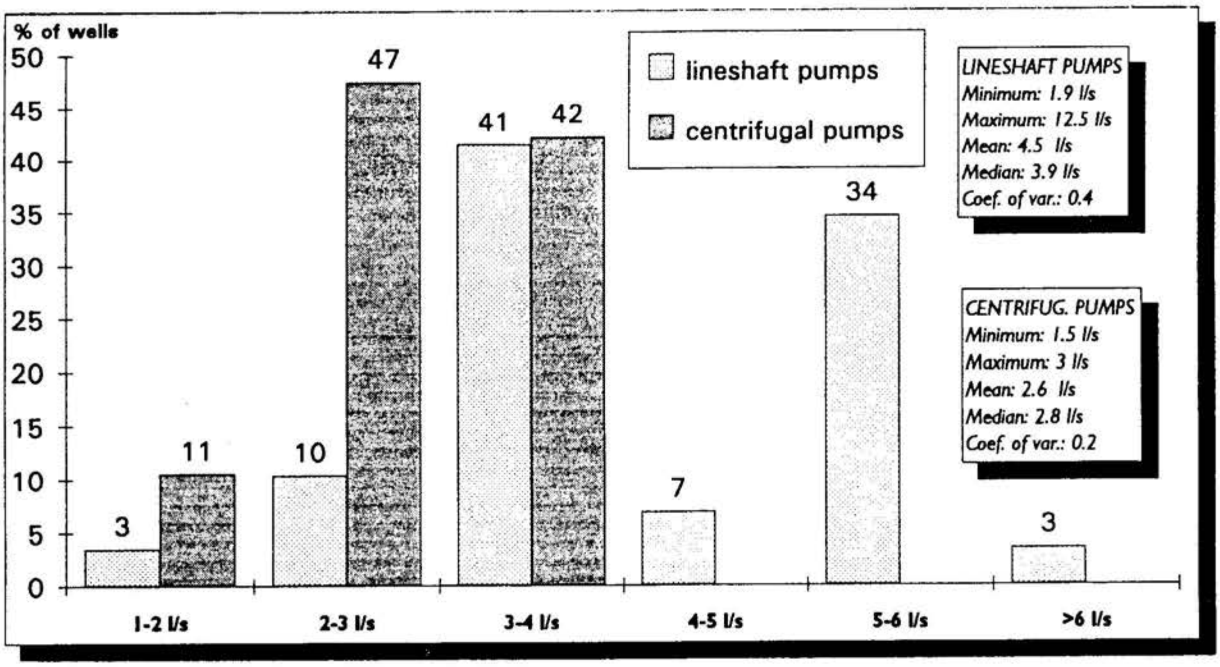
Data on well yields of wells with centrifugal pumps and wells with lineshaft pumps were analysed separately. As could be expected, yields from centrifugal pumps were restricted: they ranged from 1.5 to 4 l/s and had a mean of 2.6 l/s (see Fig. 4.9). Lineshaft pumps had a higher capacity and produced on average 4.5 l/s (from 1.9 to 12.5 l/s).

In most of the plain the groundwater table is situated below the alluvium (see Figs.

4.21 and 4.22). This means that the majority of the wells abstract water from the Tertiary Yemen Volcanics below the alluvium top layer. it is clear that this rock possesses low hydraulic capacities (see Section 3), because groundwater only circulates through fissures and fractures.

The specific discharge, defined as the discharge divided by the drawdown in the well, can give a fair indication of the permeability of the aquifer near the well. The higher the specific discharge, the better the water transporting capacities of the aquifer. However, no measurements of the dynamic water level could be carried out.

Fig. 4.9 *Distribution of Well Discharge Rates (/s)*



4.7 COSTS OF WELL CONSTRUCTION AND PUMPING EQUIPMENT

Data on costs of well construction are presented in Fig. 4.10. The costs of well construction include the digging and/or drilling of the well and for a borehole the installation of the casing, the screen (slotted pipes), the gravel pack and the development (air lift). For dug wells, additional costs comprise the construction of the masonry lining. Costs ranged from YR 2 200 (a shallow dug well) to YR 600 000 (a drilled well). Average well construction costs were close to YR 115 000.

The pumping equipment costs involved a more variable package of items. In all cases the costs of the pump (centrifugal or lineshaft) were included. For some dug wells and all of the drilled wells, the engine was also included. In many cases a small stone house was constructed around the engine and well. Most farmers built a reservoir where the pumped water is collected and from where it is distributed to the fields. In addition the costs may include for installation of pipes, tubes and hoses to convey the water.

The analysis of the pumping equipment costs were subdivided into pumping equipment costs for wells with centrifugal pumps and wells with lineshaft pumps (see Fig. 4.11).

Fig. 4.10 *Distribution of Well Construction Costs.*

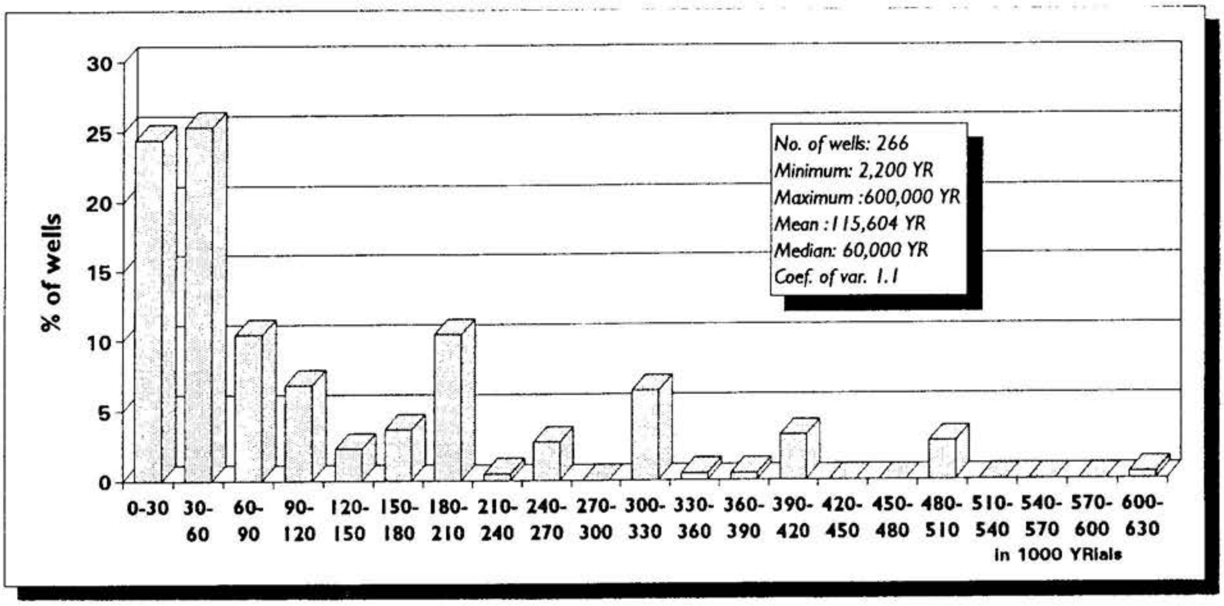
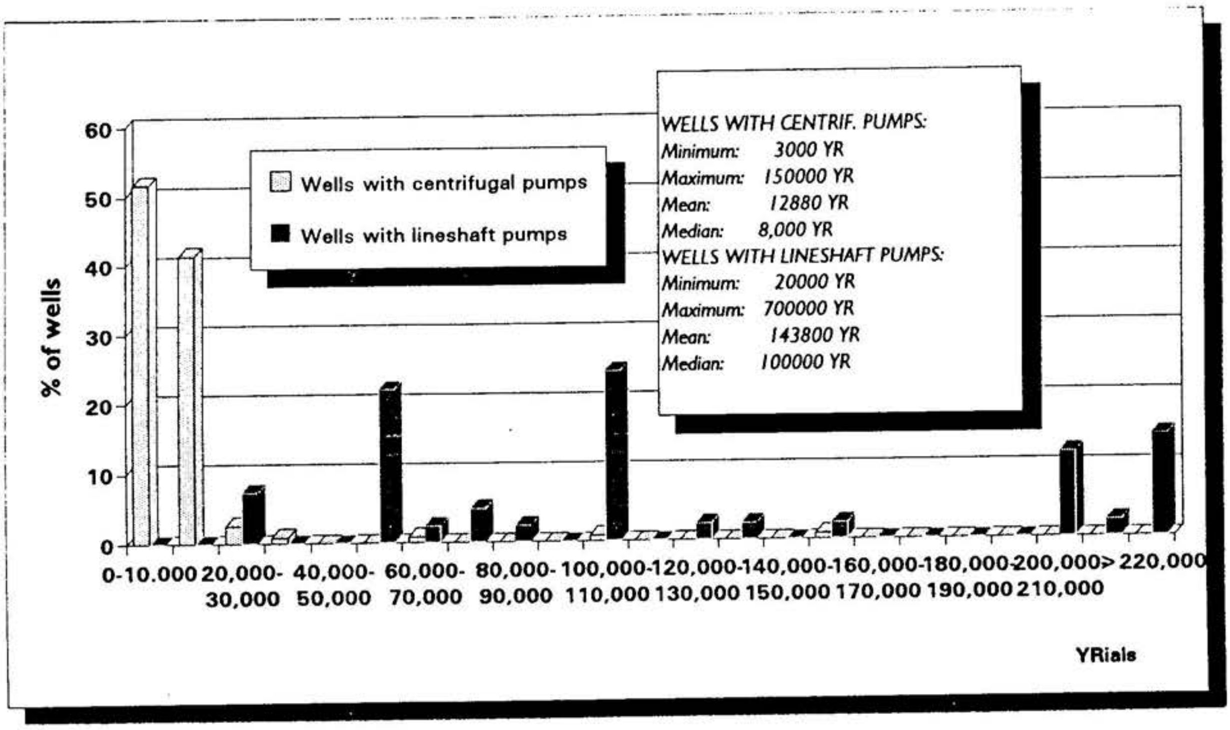


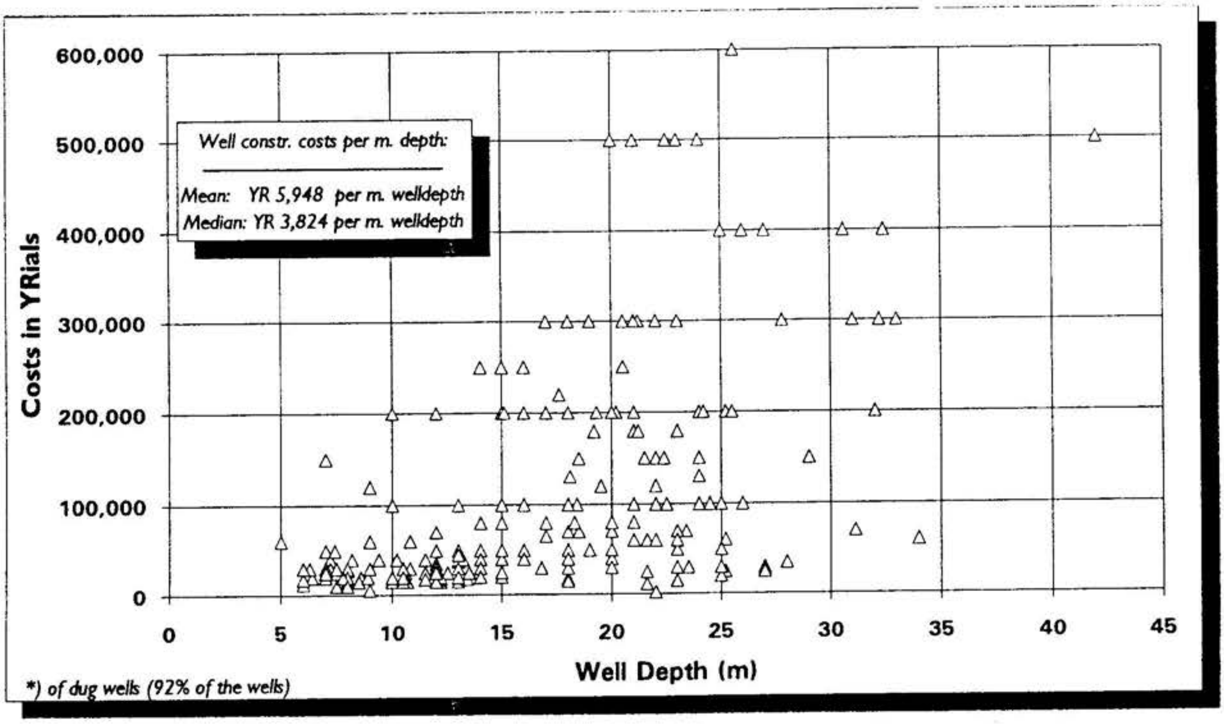
Fig. 4.11 *Costs of Pumping Equipment*



For wells with centrifugal pumps, these costs varied from YR 3000 (a simple pump and hose) to YR 150 000 (a centrifugal pump with a network of pipes). Average costs were about YR 13 000. Costs for wells equipped with turbine lineshaft pumps were much higher: from YR 20 000 to YR 700 000 and had an average of about YR 144 000.

Fig. 4.12 shows the relation between the dug well depths and the construction costs. Disregarding the (wrong?) upper and lower extreme data the median of YR 3800 per metre well depth clearly indicates that relatively high costs were involved in digging a well by manual and/or animal force. These costs amounted to more than double the (rotary) drilling costs per metre well depth. It must be remembered that the costs were costs at the time of construction or purchase and that the data concerned wells constructed during the period of about 1970 to 1991. As a consequence of currency inflation, the mean current costs (1991 YRials) would be higher.

Fig. 4.12 *Construction Costs Versus Dug Well Depths*



4.8 PUMPING SCHEDULES

Water column heights in most of the wells were very small and many wells fall dry during the rainless winter season. Therefore, the capacity of most of the wells was very limited and the majority of the farmers could only pump for a very short time.

Fig. 4.13 shows the daily number of pumping hours. The median of only two hours per day demonstrates the pumping schedule of the average farmer. Pumping activity is lowest during Shita (winter).

Over the whole year the average number of pumping days per month was 27 (see

Fig. 4.14); the average number of pumping, hours per month was, from Rabia' to Kharif about 126, and during Shita 116.

Fig. 4.13 *Seasonal Distribution of Daily Pumping Hours*

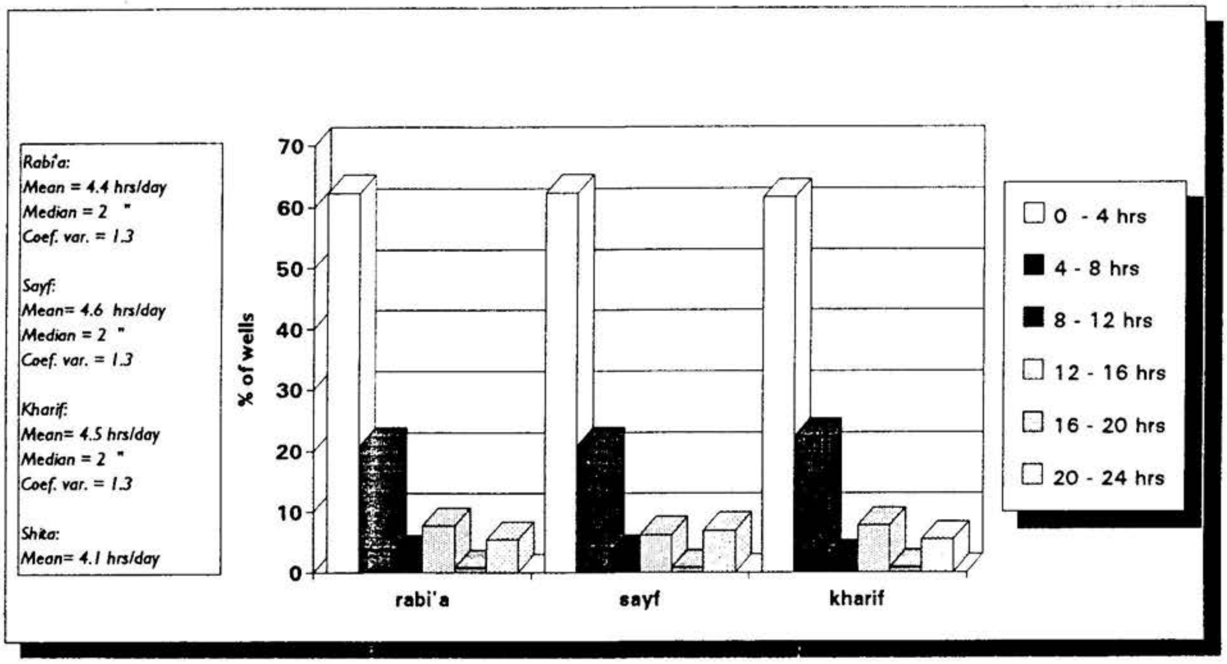


Fig. 4.14 *Monthly Pumping Days*

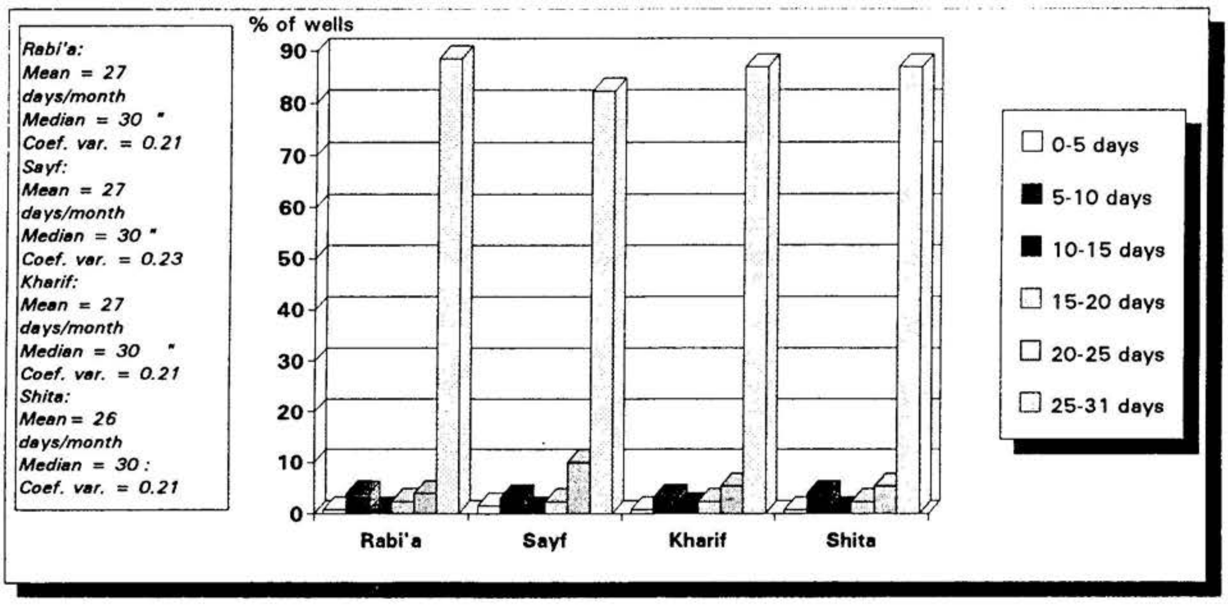
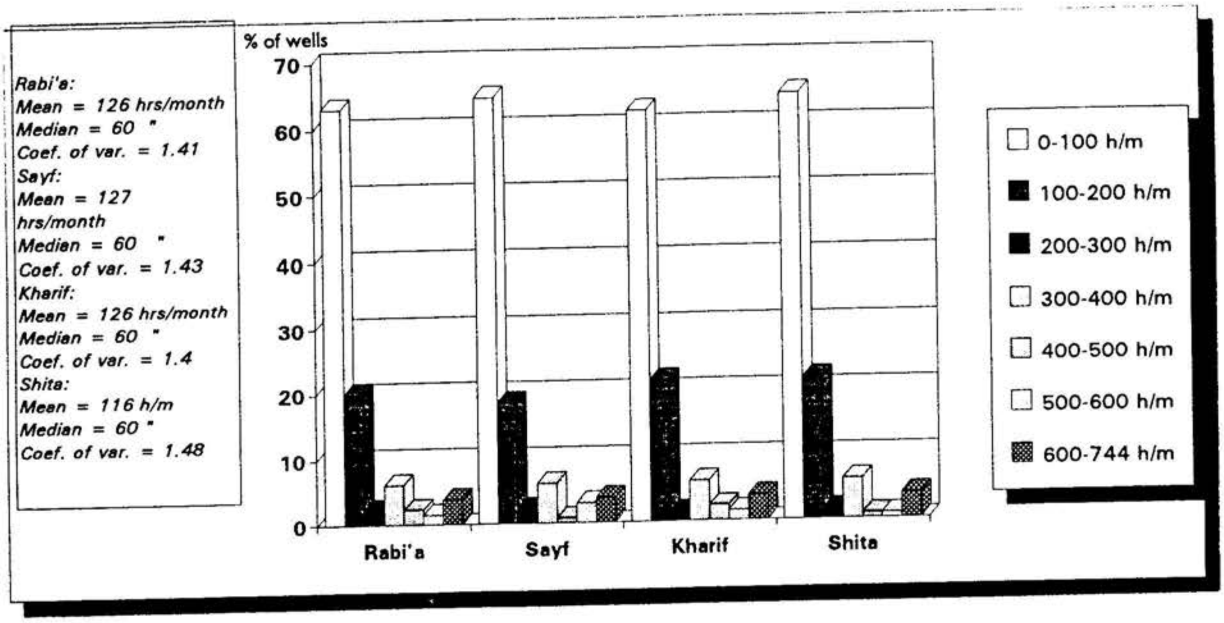


Fig. 4.15 *Monthly Pumping Hours*



4.9 GROUNDWATER ABSTRACTION

To enable assessment of the total groundwater abstraction in the Al Ashshah Plain, a reasonable estimate had first to be made of the total number of operational wells. At 52 wells (of the total of 271 wells visited) both the discharge could be measured and data collected on the pumping schedule. At the remaining wells these data could not be collected for the following reasons: the well was dry (47 wells), the well was being deepened, the pump was broken or absent, no fuel was available or there was just nobody to switch on the pump and/or to give information on the pumping activities. This resulted in a sample of 27 wells from which the seasonal and yearly discharge were calculated. 19.6% of the wells were permanently out of order. For the calculation of the yearly total discharge in the plain, these wells were not taken into consideration. The number of operational wells in the Al Ashshah Plain was estimated in Section 4.2 at 242.

Included in the well inventory questionnaire was a question concerning the yearly number of days that the well was not operational for reasons of maintenance and repair. On average, the wells were not pumping on these grounds 6% of the time. This percentage was also taken into account when calculating the seasonal and total yearly abstracted groundwater volumes.

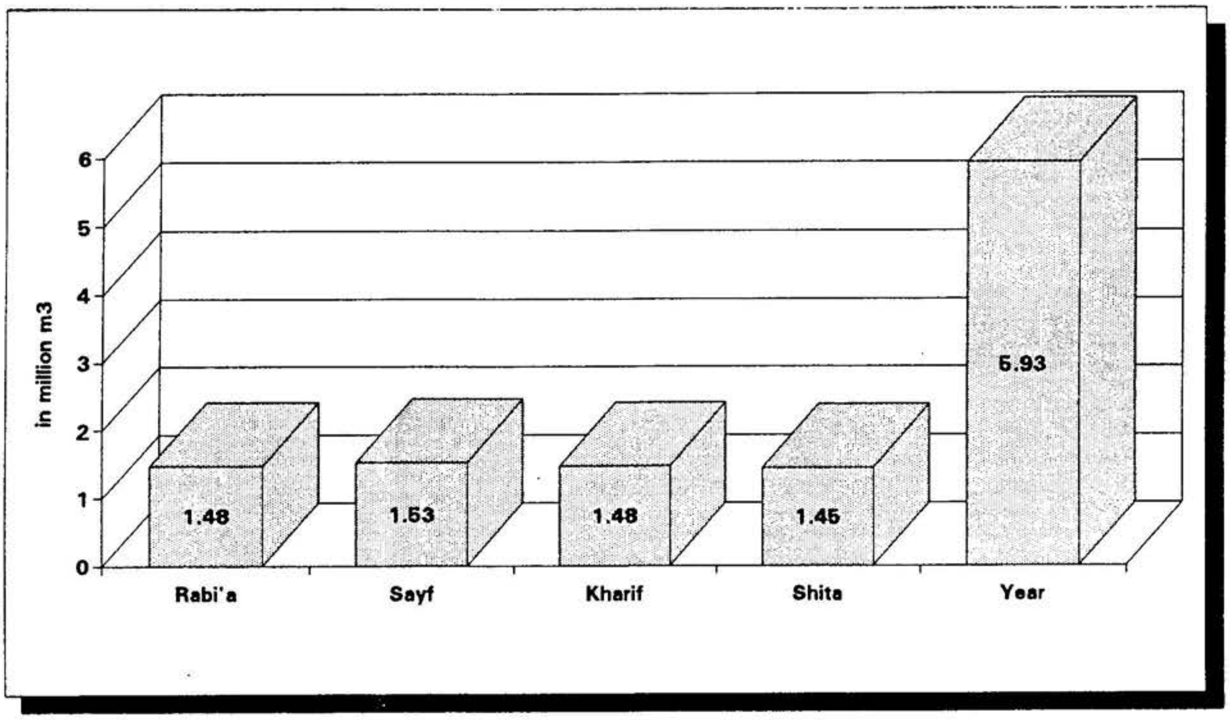
In Table 4.1 and Fig. 4.16 are calculated and presented the seasonal groundwater abstractions. A yearly total of approximately 6 Mcm was abstracted in 1991. The abstracted volumes during the individual seasons were 1.48, 1.53, 1.48 and 1.45 Mcm for Rabi'a, Sayf, Kharif and Shita, respectively.

Fig. 4.17 displays the yearly increase and volumes of groundwater abstraction during the period 1970 to 1991. In contrast with most other plains in the NORADEP PROJECT region the rate of increase of yearly abstraction has not diminished during the last five years.

Table 4.1 *Seasonal Volumes of Groundwater Abstracted (1991)*

	Rabi'a	Sayf	Kharif	Shita	Year
Groundwater abstracted per well (in 1000 m^3)					
Mean	6.1	6.3	6.1	6.0	24.5
Median	1.3	1.3	1.4	1.2	5.4
Minimum	0.08	0.08	0.08	0.07	0.3
Maximum	74	74	74	89	311
Coef. of variance	1.95	1.98	1.95	2.25	1.98
Total volume of groundwater abstracted in Mm^3	0.32	0.33	0.32	0.31	1.3
Based on no. of wells	52	52	52	52	52
Total volume of groundwater abstracted in Mm^3 (extrapolated assuming a total of 242 operational wells	1.48	1.53	1.48	1.45	5.93

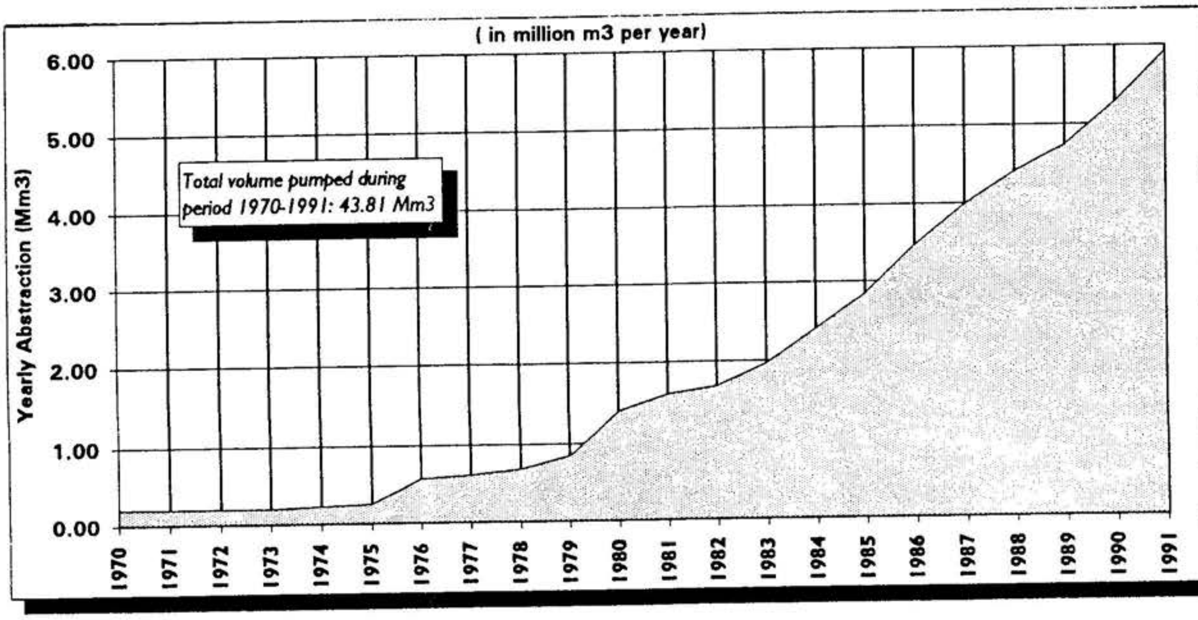
Fig. 4.16 *Volumes of Seasonal and Yearly Groundwater Abstraction in 1991*



A (very rough) estimate of all the groundwater pumped in the Al Ashshah Plain, using figures from 1970 (when abstraction became significant) up to 1991, gave about 44 Mcm. This represents a water layer of 0.24 m depth covering the whole Al Ashshah Plain (180 km^2).

Expressed in terms of lost aquifer, assuming an average effective porosity (specific yield) of the volcanic aquifer of 2%, then the volume pumped during the 21 years corresponds to a lost saturated aquifer thickness of 100/2* 0.24 = 12 metres, over the whole Al Ashshah Plain.

Fig. 4.17 *Estimated Increase in Yearly Groundwater Abstractions 1970 to 1991 (Mcm/Yr)*



4.10 DEPTH TO GROUNDWATER

Data on groundwater levels were collected either by measuring with a sounding tape, or by questioning the well owner.

In many cases it proved to be rather difficult to measure the groundwater level in drilled wells, either because a large number of the wells were completely sealed with masonry, or because the space between the pump column and the casing was so small that the sounding probe could hardly pass through it. During the well inventory several tapes were lost, stuck in the annular space between the two pipes. This was the reason that in many cases the farmer had to be questioned on the water depth. Mostly the depth to the water table was approximately known to him (expressed in the number of three metre long pump column pipes). Besides, many farmers measure the water level regularly with a marked cord. However, because 92% of the wells were shallow hand dug wells, most water depths could be measured without any problem.

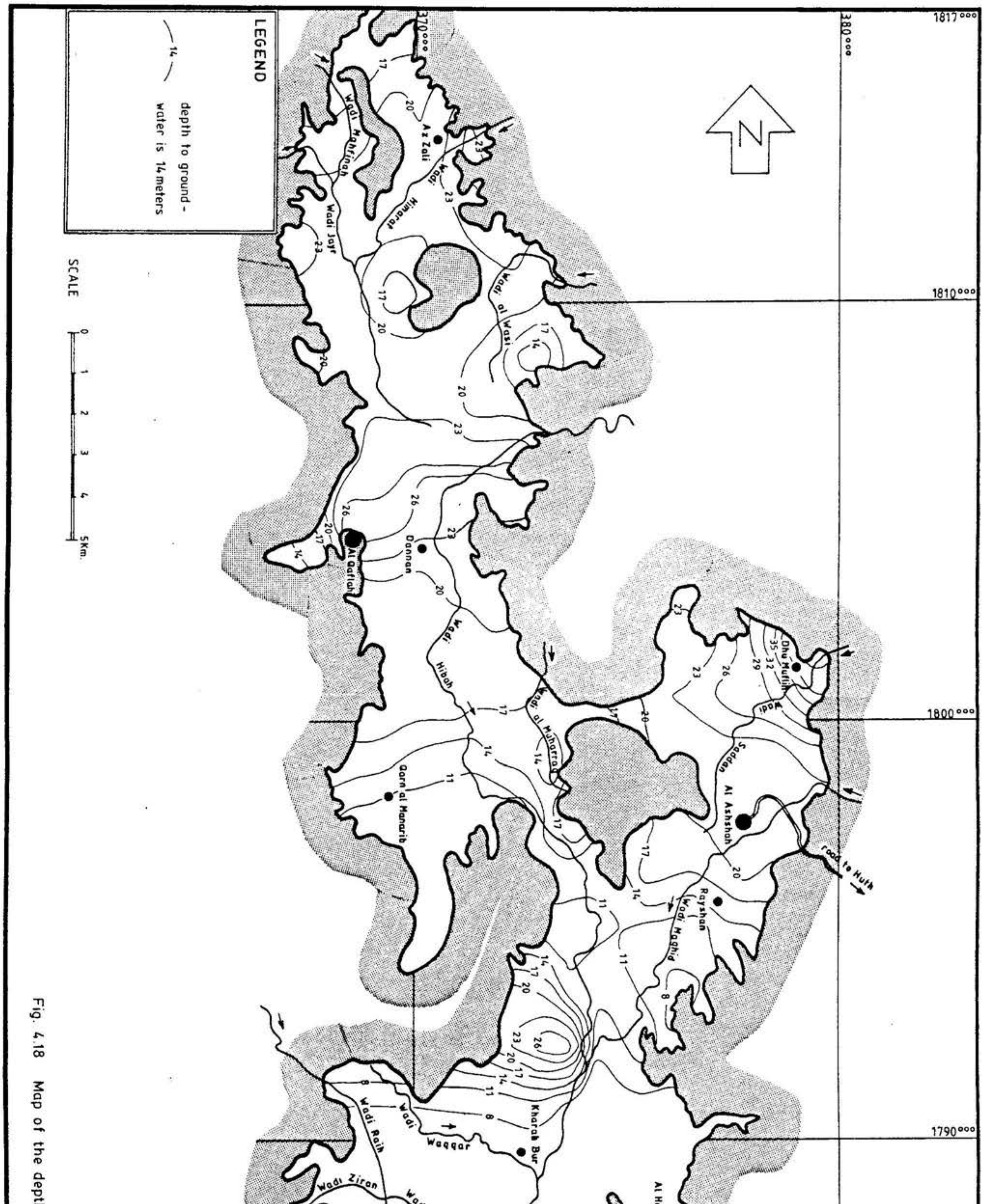


Fig. 4.18 Map of the depth to groundwater

The groundwater table in the Al Ashshah Plain, in general, is rather shallow (see Fig. 4.18). Its depth ranges between five and 35 m. The groundwater depth over most of the plain varies between 10 m to 25 m. Deeper water levels, up to 35 m were observed in the eastern part, near Dhu Muflin. Fig. 4.22 (cross-section CD) shows this area near Wadi Saddan very clearly. North of Kharab Bur a deep well of 300 m (well no. 194) has caused a large cone of depression in the water table around it. Water depth here is the greatest on the plain: 80 m. The topographic surface level here is high.

The southern area has the most shallow groundwater levels. Here depths to water are less than eight m, and 4.5 m near Kharab Bur.

4.11 GROUNDWATER PIEZOMETRIC LEVEL

A piezometric map. (Fig. 4.19) was composed by contouring the piezometric levels, ie. the difference between groundwater depth and ground surface elevation above mean sea level. Thus, the piezometric contour lines indicate the groundwater level, expressed in metres above mean sea level.

The general groundwater flow was from north to south. This is clearly shown by this figure and the cross-sections AB and CD (Figs. 4.21 and 4.22). Their locations are presented in Fig. 4.19. Included in this section are the surface elevation, the groundwater level and the alluvium-volcanics contact (see also Fig. 4.19). All three levels are plotted in m amsl. The sections clearly indicate that the groundwater level was situated in the volcanics. This was true for almost the whole Al Ashshah Plain and means that most of the groundwater was being abstracted from the low permeability volcanics aquifer.

The groundwater level dropped from about 1400 m in the north to about 1100 m in the south. This translates to an average hydraulic gradient, measured in the flow direction, of about 1%.

Hardly any large scale depressions in the groundwater level caused by excessive pumping were observed in the plain.

4.12 LOWERING GROUNDWATER LEVELS

To enable an analysis of the time dependent trends in groundwater levels time series of groundwater depths are needed. However, no long term data on monitored water levels are available in the Al Ashshah Plain.

Most wells were shallow hand dug wells equipped with centrifugal pumps. it is clear that the well configuration cannot abstract large yearly groundwater volumes. Besides, most of these dug wells had a water column of only a few metres. Thus pumping here means emptying the well hole. Although not noticeable from the rainfall data of the nearby stations Huth and Shahara, the period 1986 to 1991 was characterized, according to the local farmers, by a severe drought.

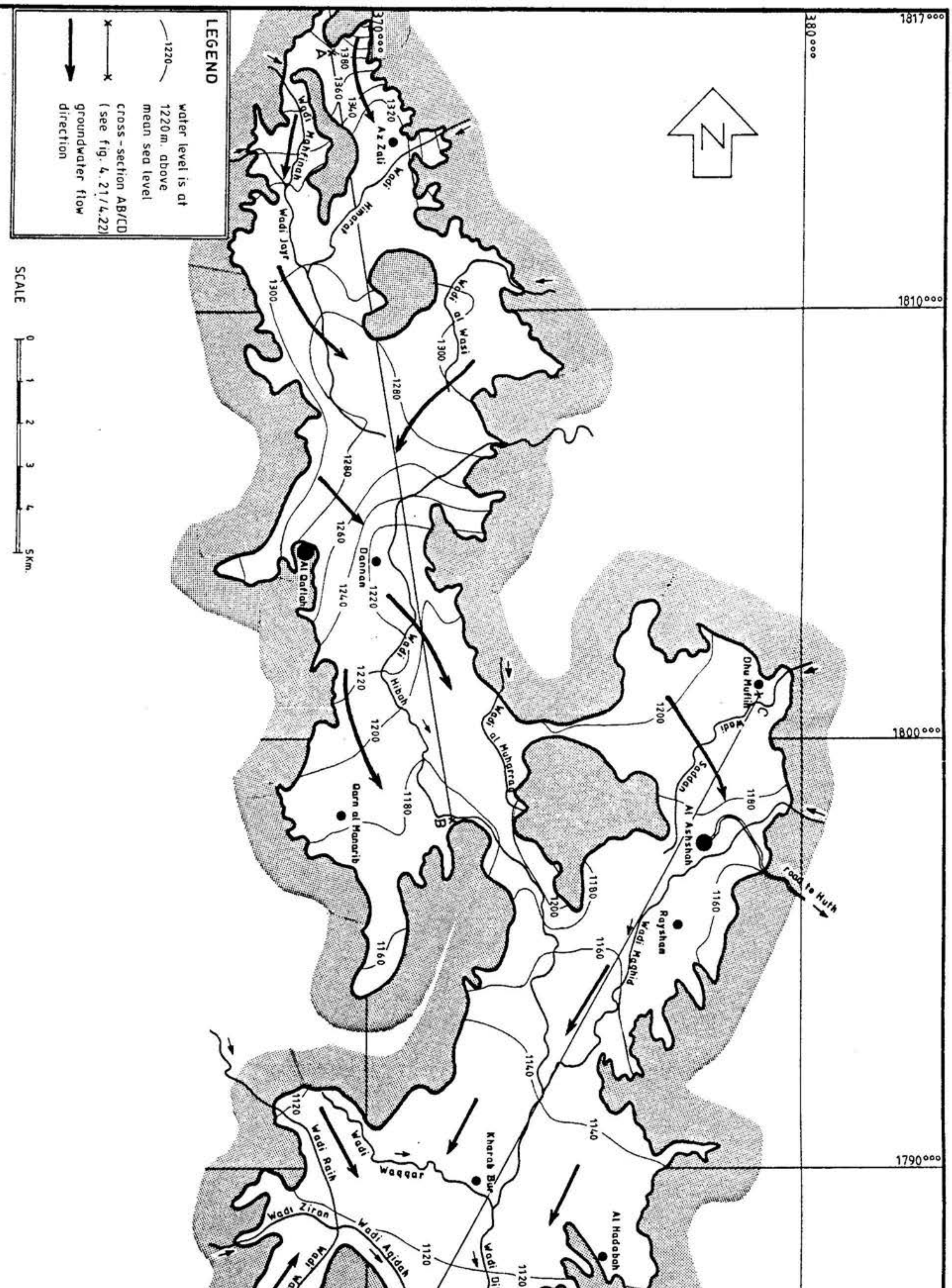


Fig. 4.19 Map of the piezometric groundwater level

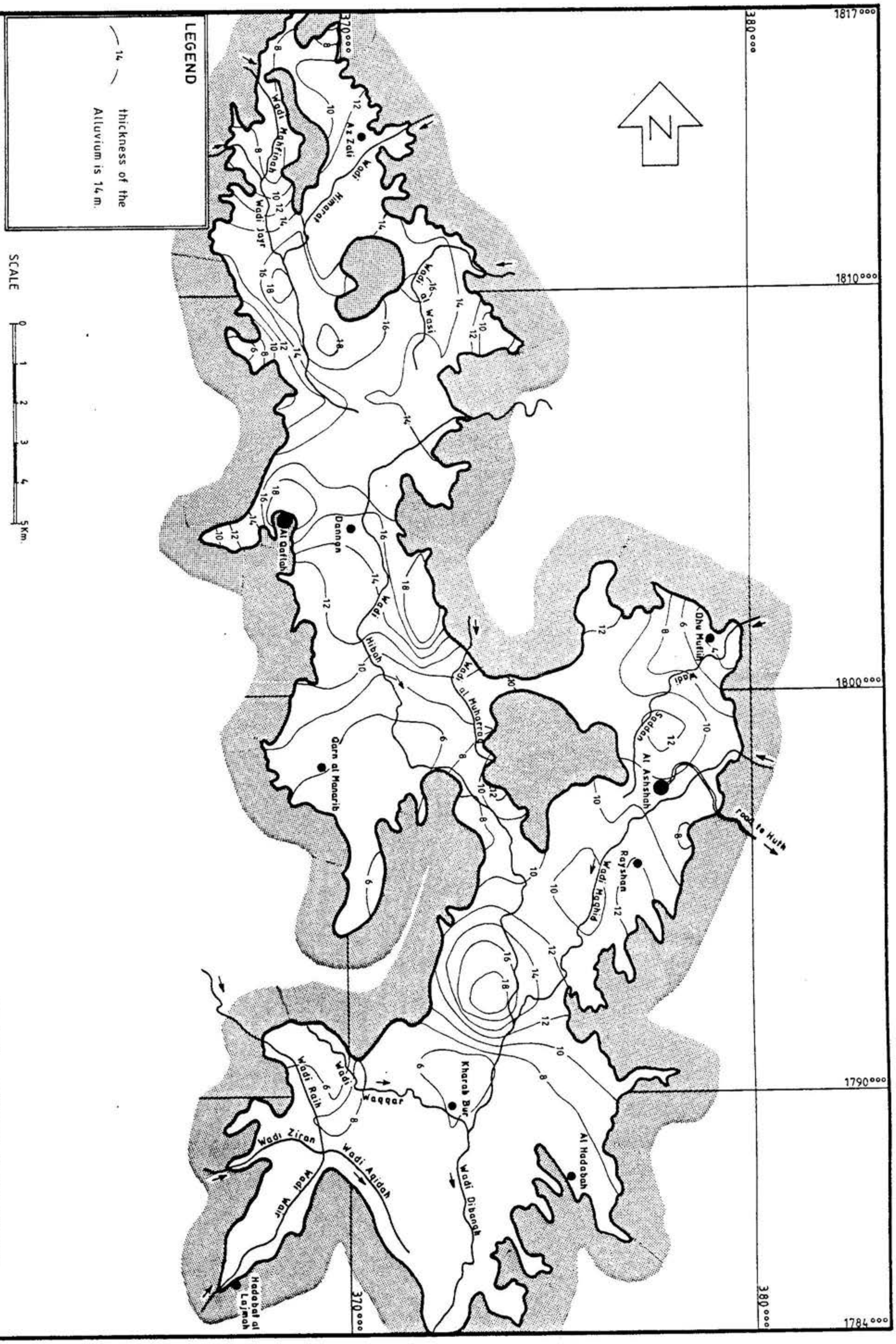


Fig. 4.20 Thickness of the Alluvium

This could be observed in the recently lowered water tables and the number of dug wells (more than 17% of all the wells) that had fallen dry during this period (see Fig. 4.4).

The hydrogeological situation here holds little promise because most water is abstracted from the bedrock aquifer, that has in general rather low water bearing and water transporting capacities. Water only circulates through secondary porosity such as fissures, fractures and faults. This also signifies that a relatively large groundwater level drop can be expected in this area as a consequence of increased pumping.

4.13 GROUNDWATER QUALITY

The electrical conductivity (EC) of water is a measure of its salinity. The more salts that are dissolved, the higher the EC will be. in almost all the visited wells, the EC of the pumped water was measured (in microSiemens/cm at 25 ^{0}C). The measurements not only give an indication of the areal distribution of the water quality, but might also indicate its variation with water depth, because the measured value is sometimes related to the depth from which the water was pumped.

Fig. 4.23 shows the distribution of the electrical conductivity values for all the measurements (234) carried out in the Al Ashshah Plain. The minimum value was 420, the maximum 2610 and the mean 1179 microSiemens/cm.

These figures indicate a relatively highly mineralized groundwater that is about twice as saline as the groundwater in the Amran Valley. As can be deduced from cross-sections AB and CD (Figs. 4.21 and 4.22), most of the groundwater is abstracted from the bedrock, mainly consisting of Tertiary volcanic deposits. As a consequence of its low permeability, the groundwater has a low flow rate and therefore long travel times, probably resulting in the high mineralization of the water.

The coefficient of variation of the measured EC values was calculated as 0.38. It represents a measure of deviation from the mean (standard deviation/mean). This implies, assuming a normal distribution of all the values, that 67% of the EC values are within the range (1-0.38) * mean and (1+0.38) * mean or 67% of the measurements have EC values ranging from 731 to 1627 microSiemens/cm.

The measured values were contoured and presented in Fig. 4.24. The more saline groundwater is situated in the southwest part of the valley, near Al Hadabah, where salinity is more than 1700 microS/cm. In the extreme north, north of Az Zali, values are above 1600 microS/cm. Low groundwater salinity (less than 800 microS/cm) was observed in the area around Al Ashshah town in the east of the plain.

4.14 GROUNDWATER TEMPERATURE

At most of the wells that were visited the temperature of the water was measured, mostly during pumping.

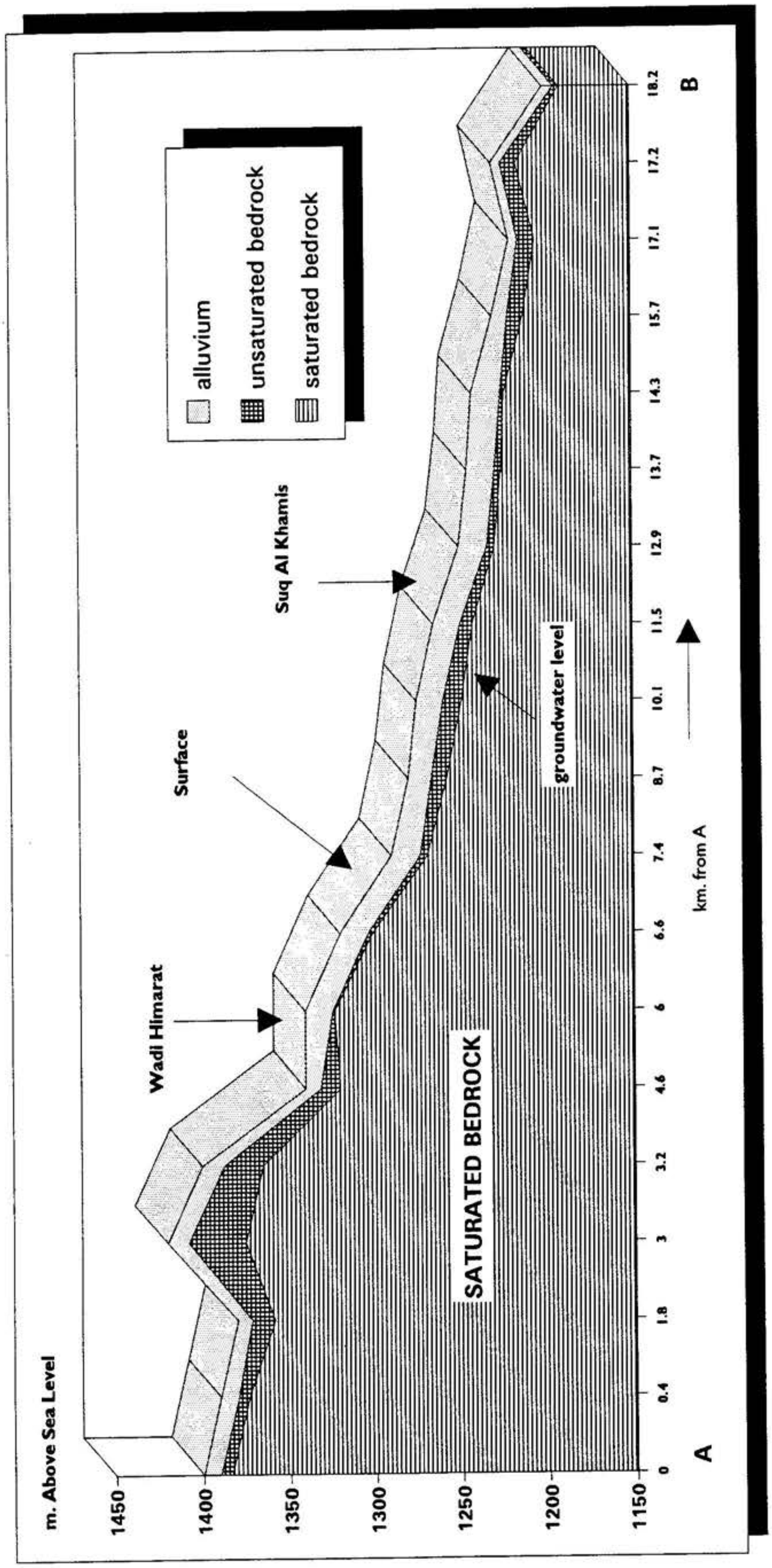


Figure 4.21 Cross-section A-B (for location, see fig. 4.19)

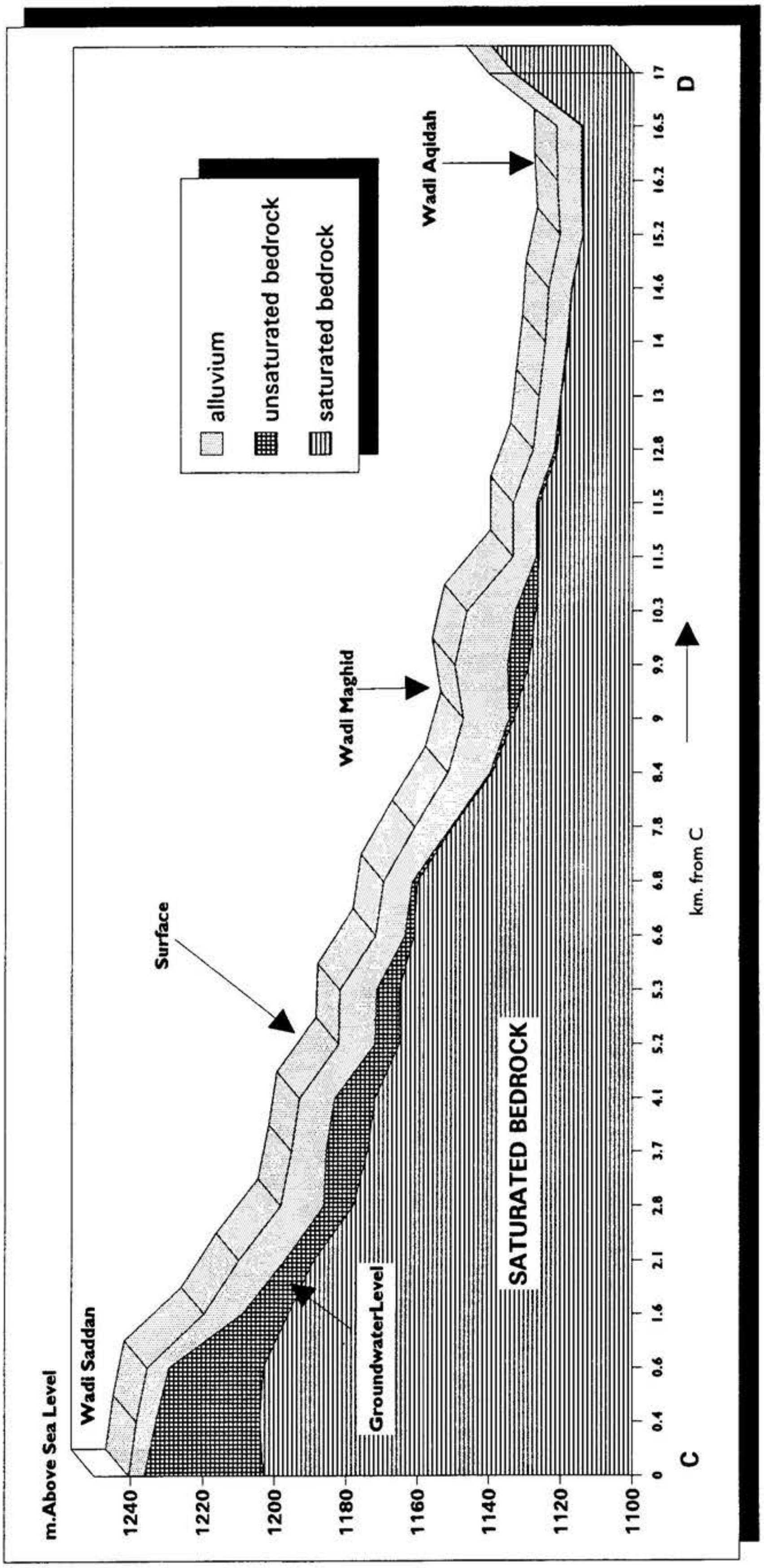


Figure 4.22 Cross-section C-D (for location, see fig. 4.19)

Fig. 4.23 *Distribution of the Electrical Conductivity*

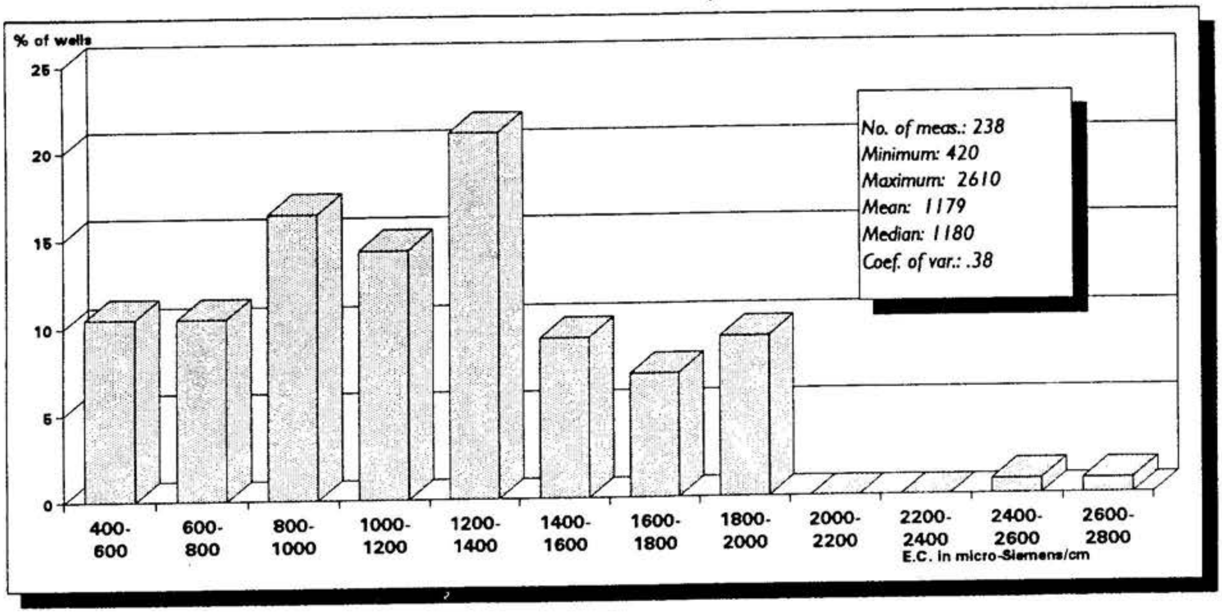
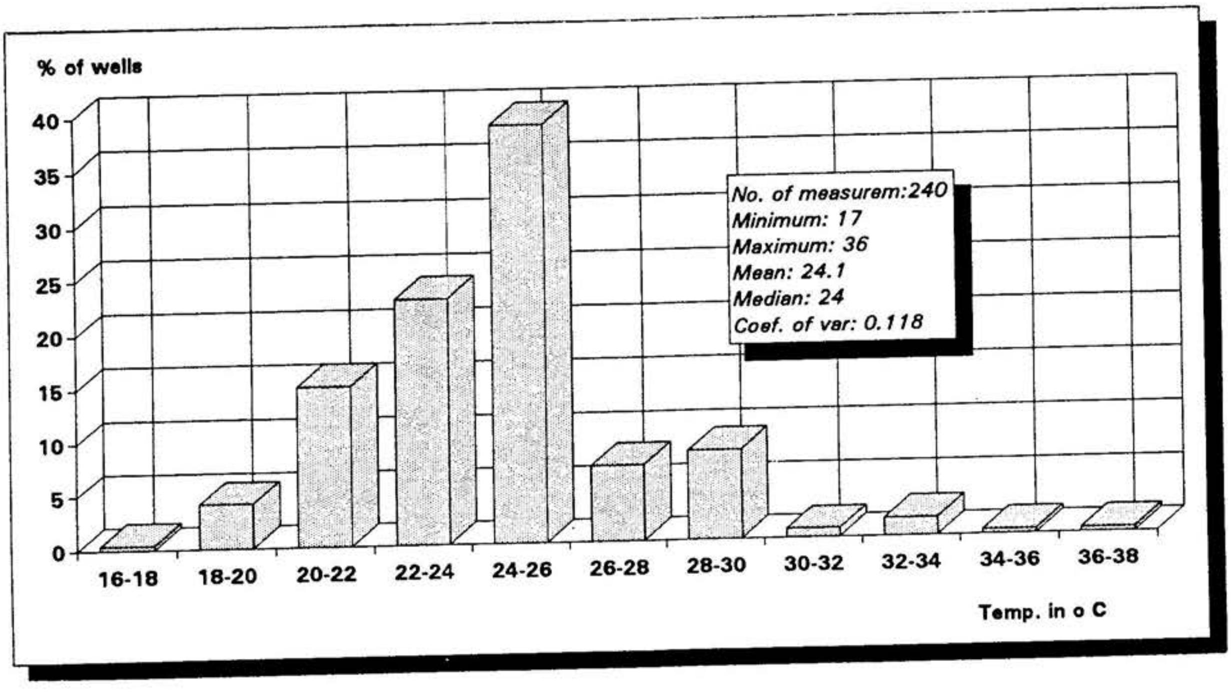


Fig. 4.25 *Distribution of Groundwater Temperature*



The distribution of the temperature values are presented in Fig. 4.25. Temperatures show a wide range and extend from 17 to 26 °C, with a mean and a median of about

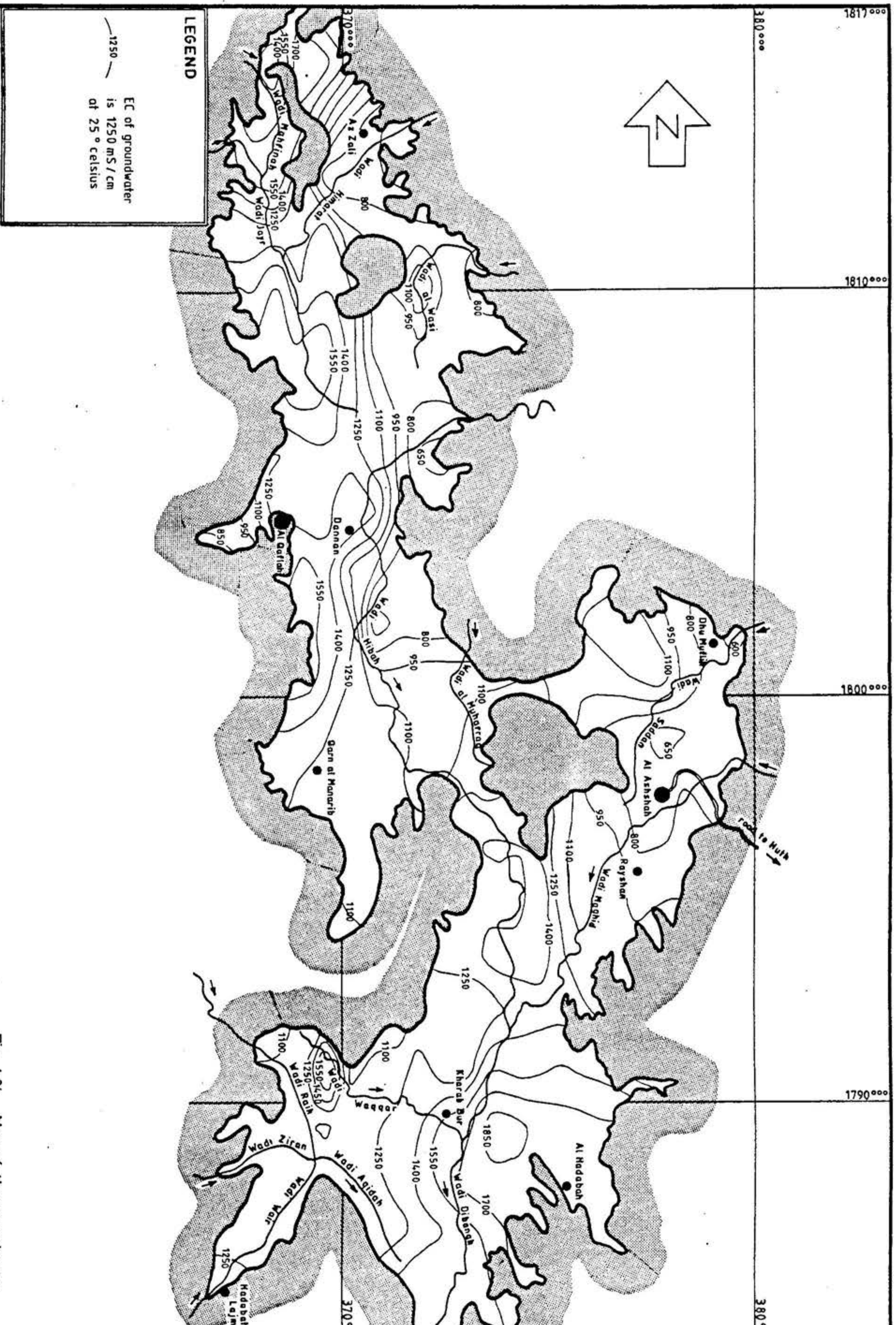


Fig. 4.24 Map of the groundwater electrical conductivity (EC)

24 °C. Dispersion is moderate: the coefficient of variation was 0.12 and most measurements show values that range from 22 to 26 °C. From Fig. 4.26 there are no areas with extreme groundwater temperatures.

Despite the high average temperature in the area, the water temperature was relatively low compared to the other inventoried areas. This might be explained by the relatively shallow depths from where the water is abstracted.

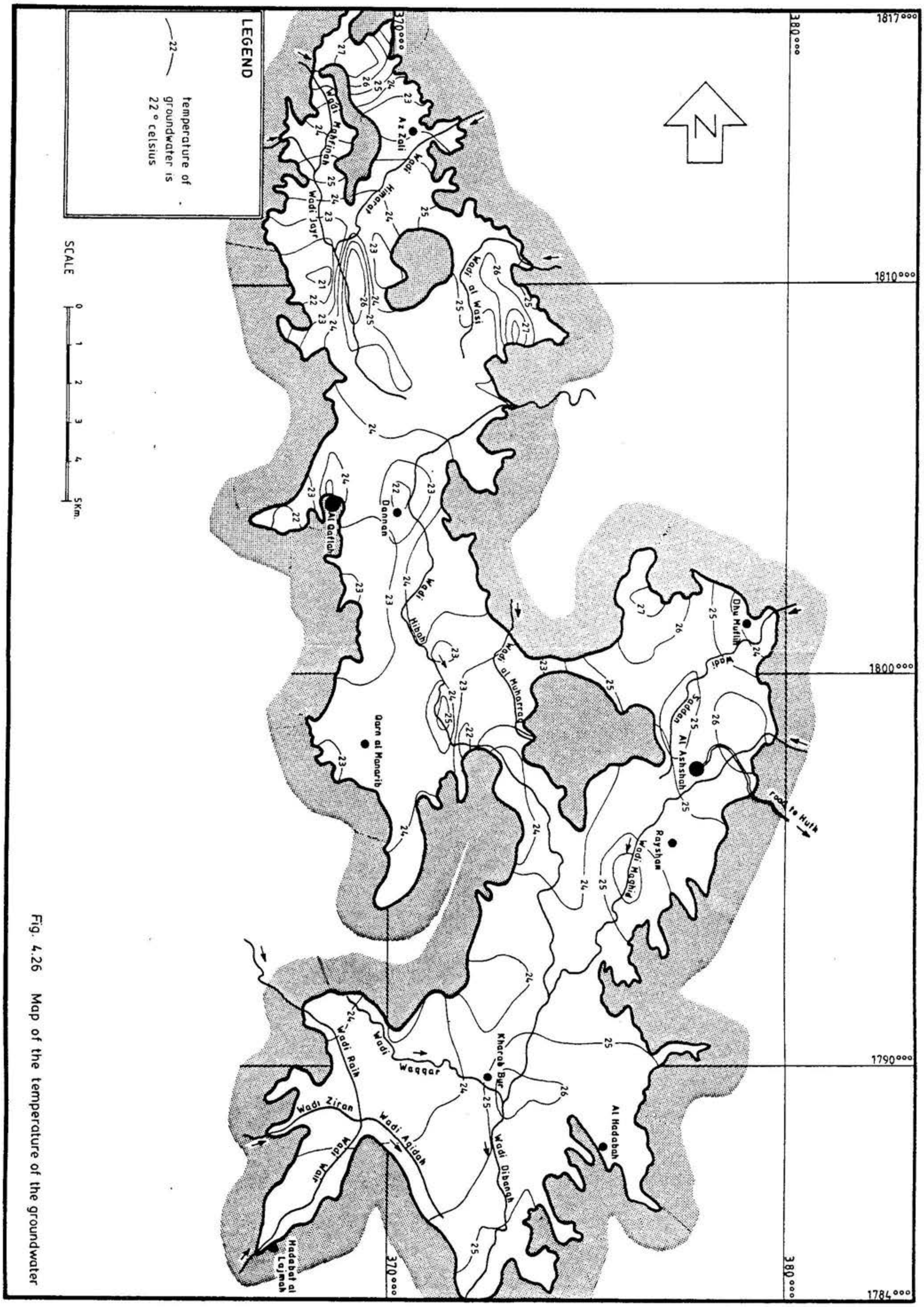


Fig. 4.26 Map of the temperature of the groundwater

5 GROUNDWATER USE

5.1 LAND AREAS

The total area of land associated with the 231 wells visited in December 1991 was 3947 ha, of which 309 ha were cultivated and under irrigation command, and 3638 ha were fallow (assumed local measure 1 libna = 64 m^2). It must be emphasised that this land may well have been divided into more than 231 individual holdings, since wells are sometimes owned in partnership by more than one farmer. The areas of land associate with individual wells will therefore be called for the purposes of this report *well areas*, not farms.

Extrapolating from this data, by assuming a total of 242 well areas (see Section 4.2) and the same population distribution for the additional data, resulted in a total well area of 4135 ha, of which 415 ha were commanded by irrigation and 3720 ha were fallow (see Table 5.1).

Table 5.1 *Breakdown of Land Area*

	Based on available well data	Extrapolating, assuming a total of 242 wells
Total area of land associated with wells (231 wells)	3947 ha	4135 ha
Area commanded by Groundwater (180 wells)	309 ha	415 ha
Fallow	3638 ha	3720 ha

It must be emphasized that these figures were based on farms where groundwater irrigation was applied, so rainfed farms are not included. The 415 ha command area translates to an average command area of about 1.7 ha per well.

Fig. 5.1 shows the distribution of the well areas. The smallest plot was only 10 libnas or 640 m^2, while the largest was 50 ha, an extensive farm near Jabal Shidhiba, in the north. However, there only 10% of the land was used for groundwater irrigated cultivation, while the remaining part was fallow. Dispersion of the data was high (coefficient of variation 2.15). About 68% of the wells had a total area less than 14 ha, with a mean of 17.1 ha and a median of 9.6 ha.

Groundwater irrigated plots were very small in the Al Ashshah Plain. From Fig. 5.2 the mean groundwater commanded area was 1.7 ha (median: 0.64 ha). The smallest irrigated plot was four libnas of 256 m^2 and the largest 5000 libnas or 32 ha. These data show a rather large dispersion (coefficient of variation 1.96). Most of the irrigated farms had a commanded area smaller than 1.5 ha.

Fig. 5.1 *Distribution of Well Areas (ha)*

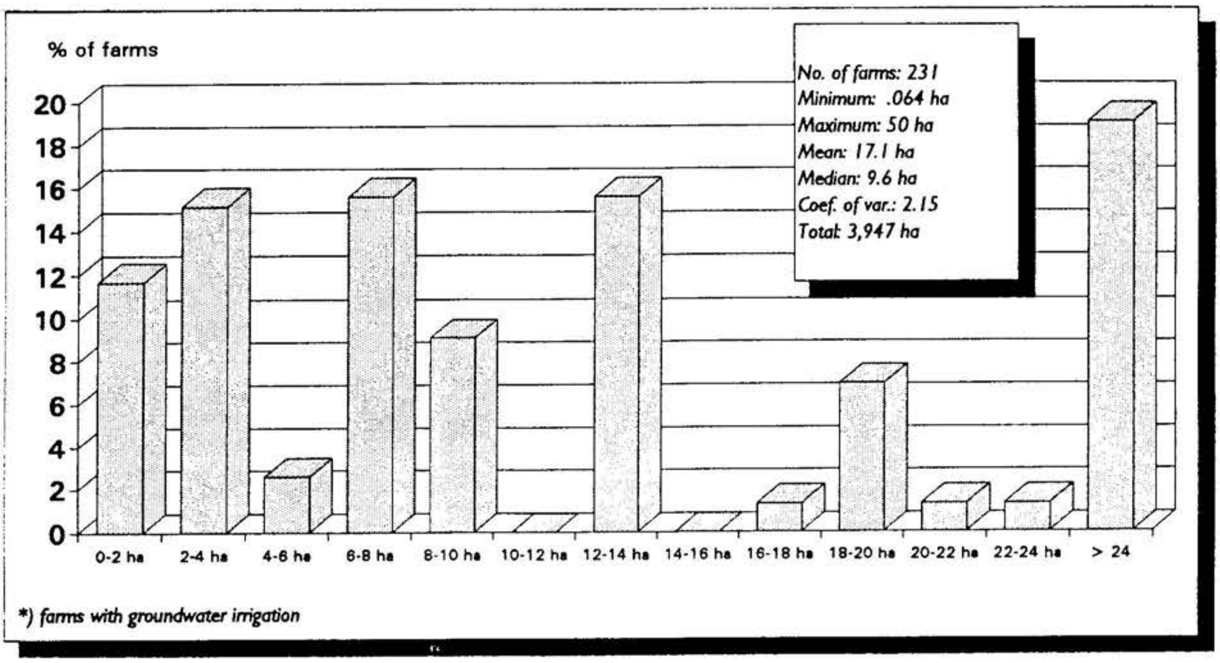
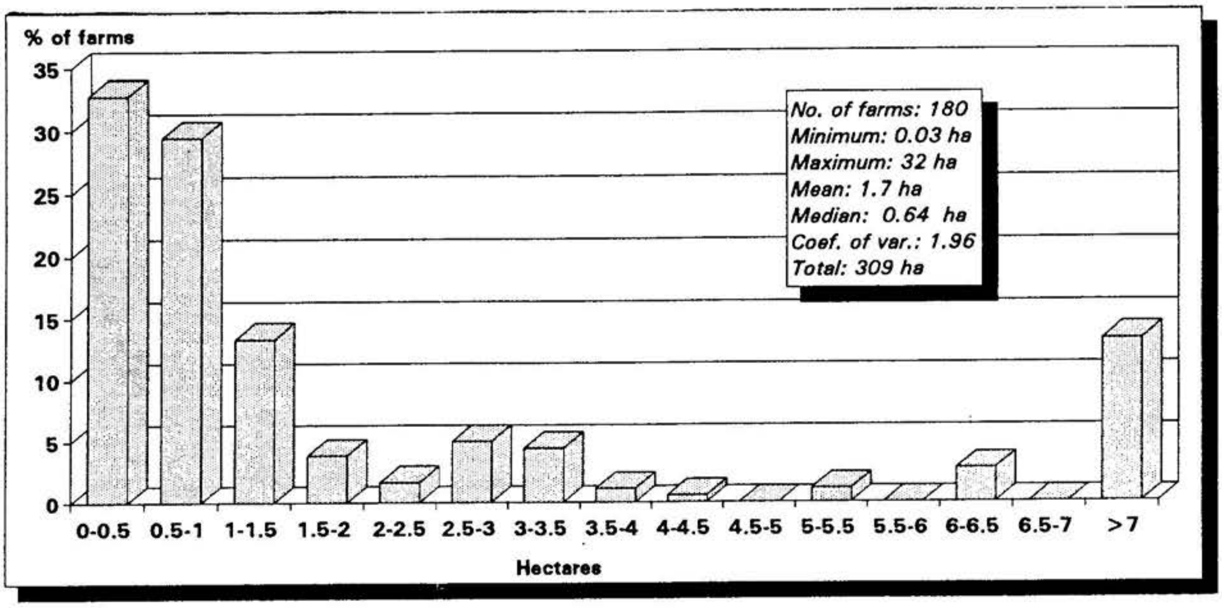


Fig. 5.2 *Distribution of Areas Commanded by Groundwater (ha).*



The state-owned extension centre and demonstration farm Al Batana is situated southeast of Al Qarfah. it comprises about 26 ha of land where research on new crop types and the combat of plant disease is carried out, and guidance is given to local farmers. Six wells had been drilled here, four of which had fallen dry. In the past, water levels here were only two to three metres bgl. In 1991 levels reached depths of more than 10 m. The farm was cultivated with seven ha of mango, banana, citrus and papaya trees and included a 0.7 ha nursery. On about three ha sorghum and maize was grown.

5.2 CROPS

In the well inventory questionnaire space was made to collect information on crop patterns during the seasons on groundwater irrigated farms. The year is subdivided into four seasons: Rabi'a, Sayf, Kharif and Shita, approximately corresponding with spring, summer, autumn and winter. The collected information deals with the major and secondary cultivated crop types and their total irrigated area during each season. All these data are summarized in Figs. 5.3 to 5.6. Qat and firewood (from the surrounding mountainous area) are the main cash crops. The figures show that of the perennial crops, qat was grown by most of the farmers (86%), followed by alfalfa and the fruits banana, papaya, mango and orange. These fruit trees were flourishing here, because of the warm climate.

Of the annual crops wheat was cultivated by 55% of the farmers during the seasons Shita and Rabi'a. During the same seasons, barley was grown on 54% of the farms. Sorghum was the major crop during Sayf and Kharif (73% of the farms). Maize, another important cereal, was grown on 21.4% of the farms during Shita and Rabi'a. Other observed cash crops were tomato and potato.

These crops patterns demonstrate the attractive nature of groundwater irrigation for the farmer. In contrast with the traditional untrustworthy practices of spate irrigated and rainfed cultivation, where at the most one harvest per year was possible, now most crops can be sown and harvested the whole year round. In the Al Ashshah Plain wheat and sorghum were cultivated by some farmers during the whole year. The high risk of failure of the harvest as a consequence of the absence of rainfall and spate water diminished significantly when pumped irrigation started. In the 1970s, on rainfed and spate water irrigated areas, the average loss of sorghum was 40% and of wheat and barley 50% (Rethwilm/Brandes, 1979).

Nowadays, for example, wheat can be sown two times per year. The cultivation of sorghum in the winter (Shita) was also mentioned by some of the farmers. This would be either the ratoon phase of the sorghum sown in May and April or a second planting. Commonly sorghum is sown during the months April and May. Many farmers, after harvesting the grain during the months of September to October, let the crop ratoon , solely for fodder.

Wheat and barley, the other two traditionally cultivated crops in the plain, were sown during November or December. Harvest of this cycle is in March and April. This was the most common practice in the Al Ashshah Plain. However, on some farms, another crop of wheat was started immediately after the previous one by sowing during June and July for harvest in October and November.

Fig. 5.3 *Crops Cultivated During Rabi'a (Spring)*

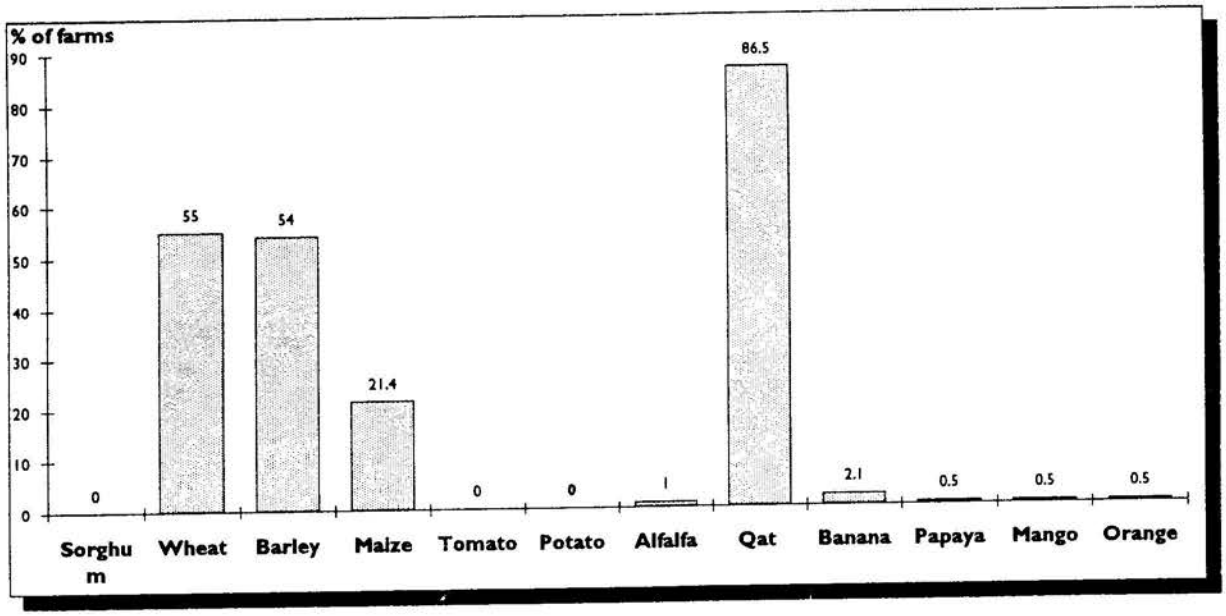


Fig. 5.4 *Crops Cultivated During Sayf (Summer)*

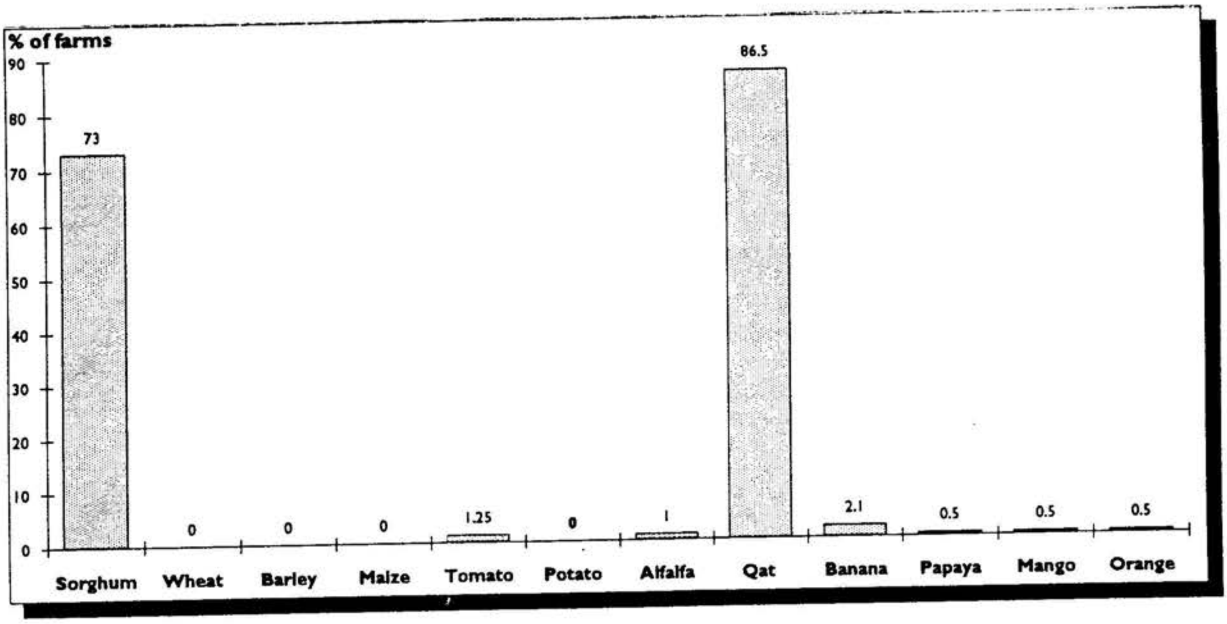


Fig. 5.5 *Crops Cultivated During Kharif (Autumn)*

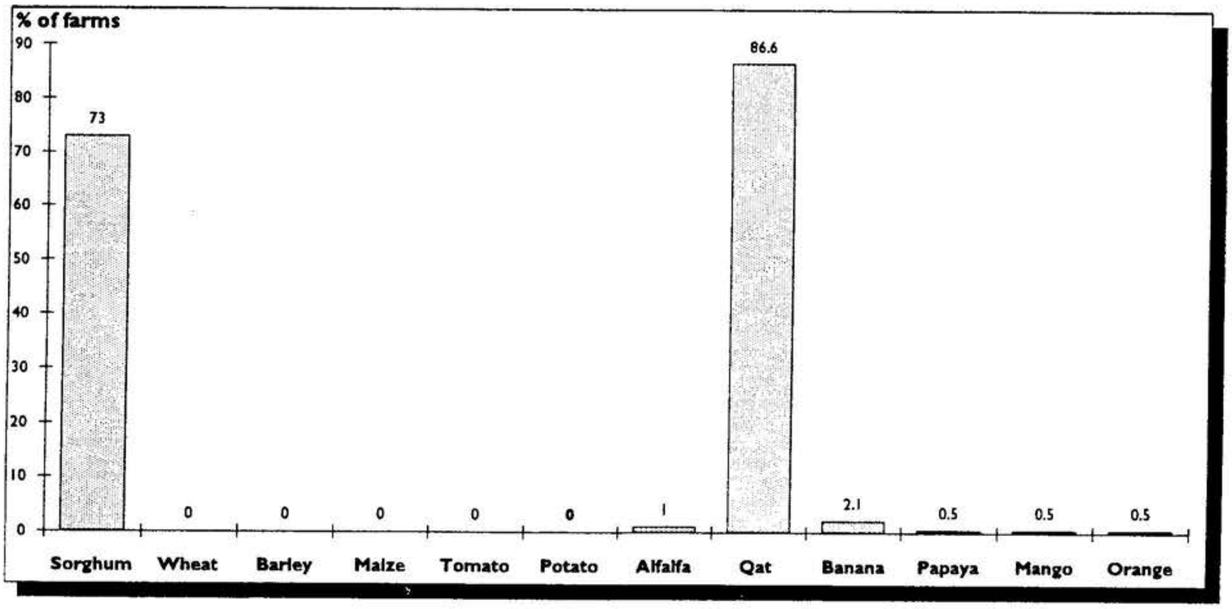
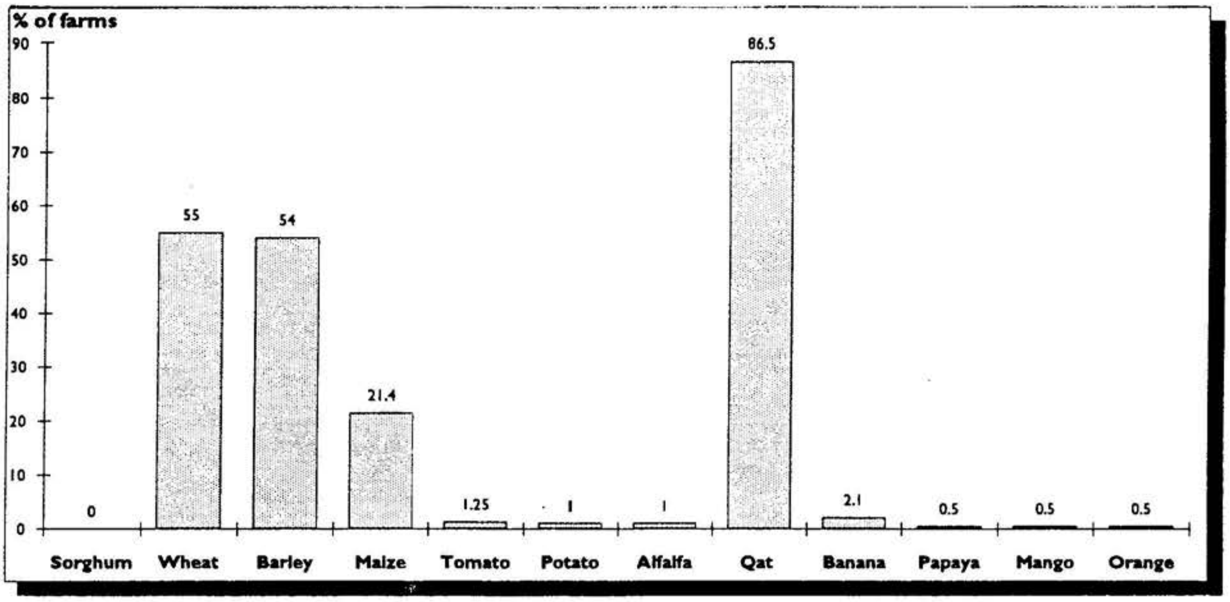


Fig. 5.6 *Crops Cultivated During Shita (Winter)*



Fruit crops like mango, papaya, orange and banana were introduced only recently by some progressive farmers. Both pure-stand and inter-cropping patterns were observed. Large plots tended to show more pure-stand cultivation, like sorghum, wheat and barley, than the smaller plots where, generally, a more mixed crop pattern was noticed.

5.3 IRRIGATION PRACTICE

Pumped water is conveyed through earthen channels or pipes to the fields. According to field tests carried out by GTZ in Qa' Al Boun in 1979, water losses during conveyance in the traditional open irrigation channels are usually about 50-65%, depending on the distance.

Other water losses can result from over-irrigation and/or inefficient irrigation schedules. The irrigation method generally used was border, furrow or basin. The border method was usually used for wheat and sorghum; furrow for potato, tomato and water melon; and basin for fruit crops like banana, orange, papaya and mango.

The highest frequency of irrigation application was utilized for the growing of tomato, alfalfa, banana, orange, papaya and mango. They are the crops with the highest total costs, and the greatest benefits, except for alfalfa. The lowest gross margin was for cereals like sorghum, wheat and barley (Amran Valley, Hossain/Nouman, 1991).

A high percentage of the non-irrigated area of the Al Ashshah Plain was used for rainfed and spate irrigated crops. Some remained permanently fallow because of shortage of water.

5.4 USE OF FERTILIZERS

Crop rotation including a fallow period was used for reasons of maintaining soil fertility and to economise on the usage of fertilizers. Both chemical fertilizers and manure were added, the first at regular intervals. on 94% of the farms fertilizers were applied, manure alone on 87%, and both chemical fertilizers and manure on 7%.

5.5 DOMESTIC WATER USE

Based on the projected 1991 population of the Target Area of 31 000 (Section 2.1) and a per capita consumption of 40 l/day, the annual domestic consumption would have been about 450 000 m^3. Many farmers sell the water from their well to consumers elsewhere in the plain. Transport usually is by tank-trucks. Livestock water consumption is low in relation to the domestic and agricultural water use (1.3 m^3/year per sheep or goat or 9% of the human water consumption) and has been neglected.

5.6 IRRIGATION WATER APPLIED

The present study is intended to deal with the water resources of the Al Ashshah Plain with emphasis on groundwater and its use. The reason for including in the inventory the collection of information concerning cultivated crops and agricultural practices was to permit a reasonable appraisal of the volume of return flow (or water loss) occurring during irrigation. The water loss would be a valuable component of the water balance, because it represents the feedback of the pumped groundwater to the aquifer. The return flow, or irrigation water losses, can be defined as the difference of the water needed for the evapotranspirational demand of the cultivated crops (ETc) and the pumped water volume.

A detailed description of the land use of each farmer would require comprehensive information on crop types, cropping calendar and cropping patterns. The collection of these data would be too elaborate and time consuming in the context of a well inventory. However, the restricted series of collected data allow a reasonable estimate of the yearly crop water requirements in the study area to be made.

An acceptable estimate of the total area commanded by groundwater has been made, groundwater abstraction data are available, and a clear general picture has been formed of the types of crops cultivated and the cropping pattern. However, data on the irrigated area are not complete enough to permit the calculation of the various crop water requirements on a decade or monthly basis.

Reference evapotranspiration (ETO) for the Amran Valley has been calculated using the Penman method as 2375 mm/year (Chaudry, 1992). The potential crop evapotranspiration or consumptive use of a particular crop at a certain time is defined as the product of its reference evapotranspiration and a crop coefficient (kc) typical for that crop at that time. The values of the crop factor depend on the type of crop, growth stage, growing season and weather conditions (FAO, 1977).

No data on potential evaporation are available for the Al Ashshah Plain. A tentative solution was found by applying already existing potential evapotranspiration data, valid for the nearby Amran Valley. Eger (1987) published values of crop water requirements for the main cultivated crop types. Most crops have a consistent average daily net crop evapotranspirational need of about 4.2 mm, when considering the whole growing period. Because calculations of applied water quantities are made on a yearly basis, these figures will be sufficient to arrive at an adequate estimate of the annual crop water requirements in the study area. Thus an annual ETc of 1533 mm was established for the groundwater irrigated part of the Al Ashshah Plain.

Rainfall data were measured in Huth (17 km east of Al Ashshah Town) during the period 1975-1989. Spate irrigation values were derived from farmers' information and the local rainfall data.

From the evidence gathered during the SONDEO survey, backed up by the experience of agricultural extension staff, it is clear that:

- Not all of the area commanded by groundwater is irrigated at any one time, because not enough water is pumped to meet crop water requirements.
- Farmers' irrigation scheduling is not optimum.
- Water conveyance and application is not efficient: there is seepage from unlined conveyance canals (little of the water is conveyed in pipes from pump to field-edge); land levelling is poor; the layout of basins, borders and furrows is not

always ideal; and farmers tend to apply more water than the crop actually requires, leading to excessive deep percolation.

All the matters discussed above have been taken into account in the compilation to Table 5.2, in which the volume of water abstracted in 1991 is balanced with domestic and irrigation usage, and the return flow to the aquifer through deep percolation.

Table 5.2 *Al Ashshah Plain - Groundwater Use 1991*

Total Groundwater Abstracted (Mcm)	5.94
Domestic Water Use (Mcm)	0.45
Irrigation Water Use (Mcm)	4.93
Commands Area (ha) (1)	415
Average Area Irrigated (ha) (2)	128
Gross Irrigation Application (mm)	3843
Total Efficiency (%) (3)	35.8
Irrigation Water Losses (mm)	2469
Aquifer Recharge (Mcm	3.17
Net Irrigation Application (mm)	1374
Effective Rain (mm) (4)	138
Effective Spate (mm)	21
Total Effective Water (mm)	1533
Annual Crop ET (ETc-mm)	1533

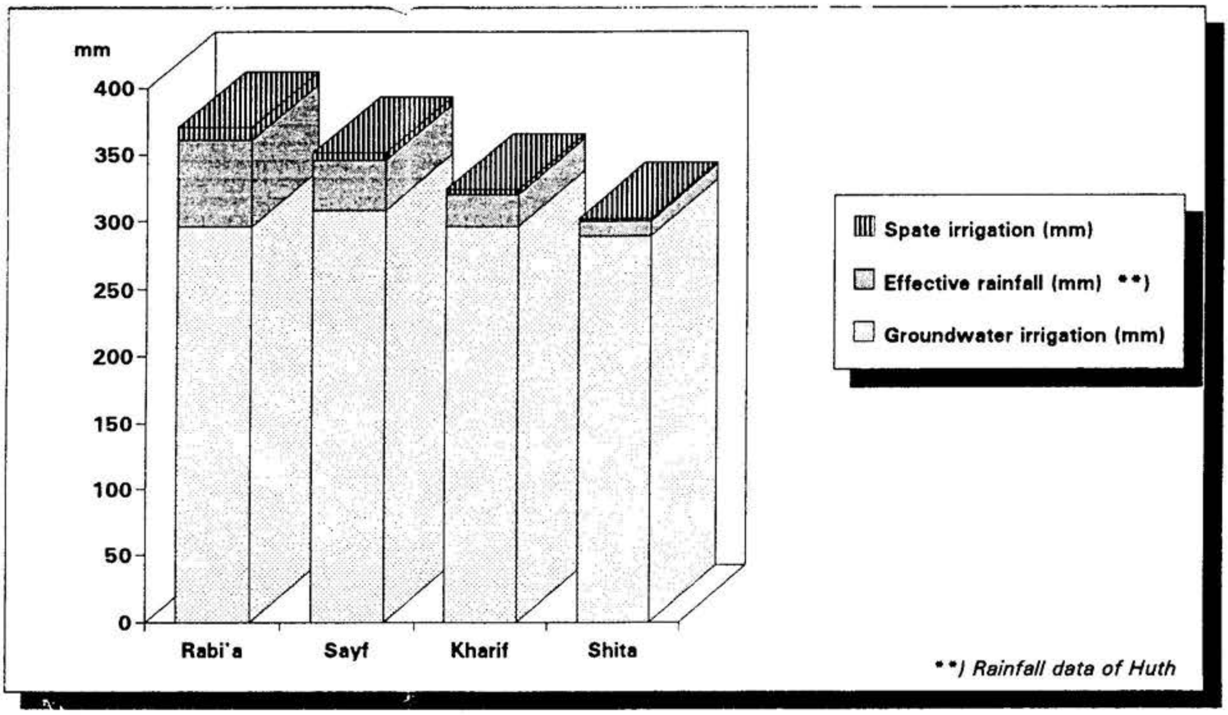
NOTES

(1) Table 5.1
(2) Adjusted to achieve balance between ETc and Total effective water
(3) Conveyance efficiency 65 % (30 % piped conveyance)
Application efficiency 55 % (Uneven levelling and slopes)
Total efficiency 35.8 %
(4) Based on data from Huth (USBR method)

It should be noted that surface runoff from irrigated areas due to inefficient water application is not specifically accounted for. In comparison with seepage losses, runoff is likely to be insignificant at the level of accuracy of the estimates presented in the table.

Fig. 5.7 shows the distribution of contributions from the several water sources used for irrigation and demonstrates that on groundwater irrigated farms, spate irrigation and rainfall make only a minor contribution.

Fig. 5.7 *Irrigation Water Application*



6 SUMMARY AND CONCLUSION

The total number of wells located in the Al Ashshah Plain during the well inventory was 271. Of these 53 (or about 20%) were not operational for the following reasons: 47 wells were dry, four wells were not in use because they were being deepened, and at two wells the pump was broken. The objective was to visit all the wells and it was assumed that about 90% of the wells were surveyed. The total number of operational wells in 1991 was estimated at 242.

Although not noticeable from the rainfall data of the nearby stations Huth and Shahara, the period 1986 to 1991 was characterized, according to the local farmers, by a severe drought. Despite the water table decline as a result of this drought, water levels, in absolute terms, were still very shallow. Their depths ranged from five to 30 m over most of the plain. This also explains why most wells (92%) were still hand dug shallow wells and only 8% were drilled wells. Another explanation is that the tribal head of the Al Ashshah Plain has restricted access for drilling rigs.

Only four of the total of 271 surveyed wells were constructed during the period 1930-1970. This means that real groundwater development only started in the early 1970s.

Statistical analysis of the well construction data revealed that most of the wells (65%) were dug or drilled during the period of 1983 to 1991 and the average age of the wells was 7.5 years. The oldest well encountered was dug in 1930.

In the past, water was abstracted by buckets lifted by donkey power. However, now, most of these wells are pumped by centrifugal pumps, some by turbine (lineshaft) pumps.

Statistical analysis of the cumulative distribution of the number of well constructed during the years, showed that 50% of the existing wells were drilled after 1985. During the last five years, any wells were reported to have been deepened.

Many wells (17% of all the wells) fell dry during the period of drought that afflicted the area from 1986 to 1991. Most of these wells run dry during 1991 (68% of all the dry wells) and 1990 (19% of the dry wells). The drought caused a decline of several metres in the water table over most of the plain. Therefore, many farmers had to deepen their wells. A large percentage (38%) of the dug wells had been deepened one to four times during this period (26% were deepened four times, 2% three times, 4% two times and 6%: only once).

The shallow dug wells were lined with masonry. Casing diameters differed significantly from those in the nearby Al Harf Plain. Here, large (10") diameter casings dominated (57%), followed by 8" diameter casings (24%) and 12" casings (14%). The lower section contained a series of six m long slotted pipes for the screen.

The depth to the water, in general, was rather shallow. As a consequence, well depths also were not very great. Depths of dug wells ranged from 5 m to 50 m and were on average 18 m deep. Drilled wells were much deeper and varied from 110 m to 360 m, with a mean of 199 m. The diameter of the shallow hand dug wells ranged from 1.2 to 7 m (mean and median: 3 m).

The drought had caused a severe groundwater problem. A drop in groundwater level of only 1.5 m would cause 65% of the dug wells to fall dry. A decline of 4 m would result in the drying up of 90% of the wells.

The water column height ranged from 10 cm to 32 m and the mean was 2 m, As a consequence, the typical pumping schedule was to pump for a short period until the well was empty (say 0.5 hour), followed by several hours of recovery, when pumping could start against for a short duration.

Groundwater was abstracted by centrifugal pumps (62% of the wells) and lineshaft turbine pumps (35% of the wells). In 3% of the wells the water was still taken out manually. In the shallow dug wells the most common pump type was the centrifugal, but lineshaft pumps were installed in 26% of the well's.

The mean pump age was 6.2 years; the oldest pump observed was installed in 1970.

A moderate level of standardization in engine and pumping equipment was observed: 33% of the lineshaft pumps were supplied by Caprari and 18% by Porcelli. Because water levels were shallow, the capacity of the pump was restricted to an average of seven bowls (median 4).

Most centrifugal pumps were made by Basan (67%), followed by Honda (19%) and Robin (11%). These pumps usually had a capacity of 3.5 to 4 HP and were mostly running on petrol. The average diameter of the hose or pipe was 2.15" (minimum diameter was 1" and the maximum 3") pump column diameter was mostly three and four inch (58% and 31%).

A higher level of standardization was noticed among the engines that power the turbine pumps: the Japanese Yanmar (Yamaha) engines, models NP22Y, NP28 and NP30 accounted for about 52% and Mitsubishi for 18%. The engines had, in most cases, a capacity ranging from 21 to 35 horsepower.

Yields from centrifugal pumps were restricted, ranging from 1.5 to 4 l/s, with a mean of 2.6 l/s. Lineshaft pumps had higher capacity and produced on average 4.5 l/s (from 1.9 to 12.5 l/s).

Over most of the plain, the groundwater table was below the alluvium, so that the majority of the wells abstracted water from the Tertiary Yemen Volcanics below the alluvial top layer. It is clear that this rock possesses low hydraulic capacities, because groundwater here only circulates through fissures and fractures.

Costs for well construction ranged from YR 2200 (a shallow dug well) to an extreme high value of YR 600 000 (a drilled well). Average well construction costs were close to YR 115 000.

The pumping equipment costs for wells with centrifugal pumps varied from YR 3000 (a simple pump and hose) to YR 150 000 (a centrifugal pumps with a network of pipes). Average costs were about YR 13 000. Costs for wells equipped with turbine lineshaft pumps were much higher: from YR 20 000 to YR 700 000, with an average of about YR 144 000.

A median of YR 3800 per meter well depth clearly indicated that relatively high costs were involved with the labour-intensive digging of a well by manual and/or animal power. These costs were more than double the (rotary) drilling costs.

The capacity of most of the wells was very limited and the majority of the farmers could only pump for a very short time. The median of only two hours pumping per day illustrates the pumping schedule of the average farmer. Pumping activity is lowest during Shita (winter). Over the whole year, the average number of pumping days per month was 27; the number of pumping hours per month from Rabi'a to kharif was about 126, and during Shita 116 hours.

19.6% of the wells were permanently out of order, and in average 6% of the time the wells were not pumping for reasons of maintenance and repair. These data were taken into account when calculating the seasonal and total yearly abstracted groundwater volumes.

A yearly total of approximately 6 Mcm of groundwater abstraction was estimated for the Al Ashshah Plain in 1991. The abstracted volumes during the individual seasons were 1.48, 1.53, 1.48 and 1.45 Mcm for Rabi'a, Sayf, Kharif and Shita, respectively.

A (very rough) estimate of all the groundwater pumped in the Al Ashshah Plain, using figures from 1970 (when abstraction became significant) up to 1991, gave about 44 Mcm. This represents a water layer of 0.24 m depth covering the whole Al Ashshah Plain) (180 km^2). Expressed in terms of lost aquifer: the volume pumped during 21 years corresponded to a lost saturated aquifer thickness of 12 metres over the whole Al Ashshah Plain.

The groundwater table in the Al Ashshah Plain, in general, was rather shallow, ranging from five to 35 m. Deeper water levels, up to 35 m. were observed in the eastern part, near Dhu Muflin. North of Kharab Bur a deep well of 300 m had caused a large cone of depression in the water table around it. Water depth here was the greatest in the plain: 80 m.

Total area associated with wells was 4135 ha, of which 90% or 3720 ha was fallow. The 415 ha as the area commanded by groundwater translated to a small average command area of about 1.7 ha per well.

The smallest plot was only 10 libnas or 640 m^2, while the largest was 50 ha, an extensive farm near Jabal Shidhiba, in the north. However, there only 10% of the land was used for groundwater irrigated cultivation, while the remaining part was fallow. About 68% of the farms had a total farm size less than 14 ha. The mean total farm size was 17.1 ha and the median 9.6 ha.

The mean groundwater commanded area was 1.7 ha (median: 0.64 ha). The smallest irrigated plot was four libnas or 256 m^2 and the largest 5000 libnas or 32 ha. Most of the irrigated farm has an irrigated areas smaller than 1.5 ha.

Qat and firewood (from the surrounding mountainous area) were the main cash crops. Qat was grown by most of the farmers (86%), followed by alfa!fa and the fruit trees banana, papaya, mango and orange. These fruit trees flourished here, because of the warm climate.

Of the annual crops, wheat was cultivated by 55% of the farmers during the seasons Shita and Rabi'a. During the same seasons, barley was grown on 54% of the farms. Sorghum was the major seasonal crop during Sayf and Kharif (73% of the farms). Maize, another important cereal, was found on 21.4% of the farms during Shita and Rabi'a. Other observed cash crops were tomato and potato.

The irrigation methods generally used were border, furrow and basin. The border method was usually used for wheat and sorghum; furrow for potato, tomato and water melon; and basin for fruit crops like banana, orange, papaya and mango.

A high percentage of the non-irrigated area was used for rainfed and spate irrigated crops. Another part remained permanently fallow because of shortage of water.

The southern area had the most shallow groundwater levels. Here, depths to water were less than eight m, and 4.5 m near Kharab Bur.

The general groundwater flow was from north to south. The groundwater level dropped from about 1400 m (above mean sea level) in the north to about 1100 m in the south. This translates to an average hydraulic gradient, measured in the flow direction, of about 1%.

Hardly any large scale depressions in the groundwater level, caused by excessive pumping, were observed in the plain.

The electrical conductivity of the groundwater was measured in 234 wells. The minimum value was 420, the maximum 2610 and the mean 1179 microSiemens/cm. These figures indicated a relatively highly mineralized groundwater that is about twice as saline as the groundwater in the Amran Valley. Most of the groundwater was abstracted from the bedrock, mainly consisting of Tertiary volcanic deposits. As a consequence of its low permeability, the groundwater has a low flow rate and therefore long travel times, probably resulting in the high mineralization of the water.

The more saline groundwater was in the southwest of the valley, near Al Hadabah, where salinity was more than 1700 microS/cm. In the extreme north, north of Az Zali, values were above 1600 microS/cm. Low groundwater salinity (less than 800 microS/cm) was observed in the area around Al Ashshah town in the east of the plain.

Water temperatures showed a wide range, from 17 to 36 °C, with a mean and a median of about 24 °C. Dispersion was moderate: the coefficient of variation was 0.12 and most values ranged from 22 to 26 °C.

The water temperature is relatively low compared to the other inventoried areas. This could be explained by the relatively shallow depths from which the water is abstracted. There were no areas with extreme groundwater temperatures.

In 94% of the farm fertilizers were applied, manure alone on 87% of the farms and both chemical fertilizers and manure on 7%.

On the basis of a 1991 population of 31 000 (projected from the 1986 census) and a consumption of 40 l/head/day the annual domestic water consumption was estimated as about 450 000 m^3.

The gross irrigation water applied was estimated at 5.5 Mcm in 1991 of which, at the low overall irrigation efficiency assumed (36%), about 4.1 Mcm would return to the aquifer as deep percolation.

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APPENDIX 1

PROCESSING OF THE

WELL INVENTORY DATA

APPENDIX 1 PROCESSING OF THE WELL INVENTORY DATA

A tailor-made database computer program was composed for the entry of the NORADEP well inventory results. To minimise errors during data entry the layout of the pages on the screen were made the same as the pages of the questionnaire. Each record in the database corresponded with a complete well inventory sheet and had space for the 123 fields necessary. A total of 271 wells were surveyed in the Al Ashshah Plain., Thus 271 times 123 (33 333) data had to be entered and subsequently processed and analysed.

The entry of data was carried out by two SSHARDA engineers. The entry of these data did not cause any holdup in the reporting activities. However, the verifying and correcting of data copied from the questionnaires caused a substantial delay. Also it turned out that altitudes measured with the altimeter had errors up to 10%. Therefore most of the well site altitudes had to be determined all over again by interpolating from contour lines on the 50 000 scale topographic maps. In addition many errors were made in expressing the well locations in UTM coordinates.

Analysis and interpretation of all the stored data were carried out with the help of several application computer, such as statistical, spreadsheet, contouring and graphics software. The reporting was done with a word processing and a desktop publishing program.

APPENDIX 2

WELL INVENTORY

QUESTIONNAIRE

SSHARDA

WELL INVENTORY
QUESTIONNAIRE
NORADEP

- First, plot the well location and its number on the map.
- Then, make sketch of the well location on the next page.
- In case of multiple-choice: select number
- Large letters: fill out in the field.
- Small letters: fill out after fieldwork.

A. WELL LOCATION

1. WELL NUMBER ..../..........
(number topo map + serial number)
for example: *1643B1/31*
2. ALTITUDE ....m
3. NAME of NEAREST VILLAGE ....
4. NAME of WADI NEARBY ....
5. WELL OWNER ....
6. LOCATION DESCRIPTION ....
(refer to location ....
sketch on next page) ....
....

Fill out after fieldwork:

7. COORDINATES (UTM), NORTHING .... m. EASTING .... m.
8. SUBREGION NUMBER (see subregion map) ....
9. DISTRICT NUMBER (see district map) ....
10. GOVERNORATE ... 1. Sana'a 2. Hajjah 3. Sa'dah
11. OLD WELL CODE ....
12. TEAM NUMBER ...

SKETCH OF WELL LOCATION

(Location of well with reference to
landmarks such as school, mosque, village, road, etc.)

↑
NORTH

B. WELL DETAILS

1. YEAR of CONSTRUCTION 19.......

2. TYPE of WELL ...
   1= hand-dug
   2= machine-dug
   3= hand-dug + deepened by machine-dug

3. DIAMETER of WELL .... m

4. DIAMETER of CASING .... inch

5. WELL DEPTH .... m

6. NUMBER of TIMES DEEPENED 0 / 1 / 2 / 3 / 4

7. MATERIAL of CASING or LINING ...
   1= steel 2= pvc
   3= cement 4= bricks
   5= rock 6= other

8. SCREEN or OPEN INTERVAL from ...... m to ....m.

9. DESCRIPTION of UNDERGROUND:

TYPE of LITHOLOGY	FROM (m)	UP TO (m)
....	....	....
....	....	....
....	....	....
....	....	....

10. COMMENTS ....
....
....
....

C. PUMP DETAILS

1. PUMP INSTALLED yes/no

2. YEAR of INSTALLATION PUMP 19....

3. PUMP TYPE ... 1= lineshaft
   2= electro-submersible
   3= centrifugal

4. PUMP NAME ....

5. PUMP MODEL ....

6. NUMBER of STAGES (bowls) ....

7. Only in case of ELECTRO-SUBMERSIBLE and CENTRIFUGAL PUMP:
   PUMP CAPACITY ...... bhp/...... rotations

8. DIAMETER of PUMP COLUMN .... inch

9. ENGINE NAME ....

10. ENGINE MODEL ....

11. ENGINE CAPACITY ...... bhp/...... rotations

12. DEPTH of PUMP .... m

13. HOW MUCH DIESEL or PETROL IS USED PER DAY ...... litres/day

14. COMMENTS
    ....
    ....
    ....

D. OBSERVATIONS AT WELL

1.	DATE of OBSERVATION	day month year ...../....../19....
2.	TIME of OBSERVATION	.....hours......min
3.	DEPTH to STATIC WATER LEVEL	..................m
	...	1= measured 2= communicated
4.	DEPTH to DYNAMIC WATER LEVEL	..................m
	...	1= measured 2= communicated
5.	HOW MANY HOURS WELL IS PUMPING NOW	.... hours
6.	TIME SINCE PUMPING STOPPED	.... hours
7.	SEASONAL VARIATION of WATER LEVEL	.... m
8.	TIME TO FILL .... LITRE BARREL	.... sec
9.	TEMPERATURE of WATER	.... ^{0} Celsius
10.	EC or ELECTRICAL CONDUCTIVITY	.... microS/cm
11.	IS WATER SAMPLE TAKEN (if yes, put well number and date on bottle)	.............yes/no

12. COMMENTS ....
....
....
....

E. WATER USE

1. WATER IS **PRINCIPALLY** USED FOR WHAT? ...
   1= irrigation 2= live-stock
   3= domestic 4= industry
   5= dry

2. WHAT IS THE **TOTAL** FARM AREA ? .... libnas or ma'ads

3. WHAT IS THE **IRRIGATED** FARM AREA ? .... libnas or ma'ads

4. HOW MANY M^2 IS 1 LIBNA (MA'AD) IN THIS AREA ?
   1 libna (ma'ad) = ... m^2

5. MAIN TYPE OF IRRIGATION APPLIED ...
   1= border 2= basin
   3= furrow 4= drip
   5= sprinkler

		RABI'A	SAYF	KHARIF	SHITA
6.	MAJOR CROP TYPE:	....	......	....	......
	irrigated area for this crop:	......	......	....	......
7.	CROP TYPE NO. 2	....	......	....	......
	CROP TYPE NO. 3	....	......	....	......
	CROP TYPE NO. 4	....	......	....	......
	irrigated area for crops 2/3/4	......	......	....	......

8. IS ALSO SPATE WATER IRRIGATION APPLIED ....yes/no

ONLY IN CASE OF DOMESTIC USE OF WATER:

9. DOMESTIC WATER SUPPLY FOR: ...
   1= some houses
   2= village
   3= town

10. HOW MANY HOUSES DRINK OF THE WELL ....houses

11. HOW MANY PERSONS DRINK OF THE WELL ....persons

12. NAMES of VILLAGE(S) SUPPLIED BY THE WELL:
    1 ....
    2 ....

13. NUMBER of WELLS in the VILLAGE(S) ....wells

E. WATER USE (continued)

14. IS WELL SOMETIMES DRY ? yes/no

15. IF YES, AFTER HOW MANY HOURS of PUMPING ? ...... hours

16. WELL IS DRY in WHICH SEASON ? ... 1= Rabi'a 2= Sayf 3= Kharif 4= Shita

		RABI'A	SAYF	KHARIF	SHITA
17.	HOW MANY HOURS of PUMPING per DAY	......	......	......	......
18.	HOW MANY DAYS of PUMPING PER MONTH	......	......	......	......

19. HOW MANY DAYS A YEAR ARE LOST FOR MAINTENANCE AND REPAIR OF WELL ..... days

20. COMMENTS ....
....
....
....

F. COSTS

1. COSTS of WELL CONSTRUCTION YRial..............

2. COSTS of WELL EQUIPMENT (pump, engine, pipelines, reservoir, etc.) YRial..............

3. COSTS OF 1 LITRE OF FUEL YRial..............

G. MISCELLANEOUS

1. IS FERTILIZER APPLIED? .... yes/no

2. IF YES, TYPE OF FERTILIZER ....

3. COMMENTS ....
....
....

APPENDIX 3

WELL INVENTORY

SUMMARIES

Data of well inventory of Al Ashshah Plain (selection of data)

Well no.	Village (nearest)	Coordinates (UTM) N	E	Altitude m. above msl	Year of constr.	Well type *)	Well diam. (m)	Well depth (m)	Thickness alluvium (m)	Year install pump	Type of pump **)	Depth water (m)	Well yield (l/s)	Total farm size (ha)	Water use Irrigtd (ha)	Domest. (persons)	Temp. (o C)	EC micro-S (25 o C)
	*) 1=dug well 2=drilled 3=dug+drilled				**) 1=lineshaft pump 2=electro 3=centrifugal													
1	SHA'AB JAHHAF	1809800	371500	1310	76	1	3.0	27	20	76	1	25	3.9	50.0			25	720
2	GARMAN	1809780	371600	1300	88	1	3.0	22						32.0				
3	GARMAN	1809700	371150	1315	87	1	3.0	23		87	1	20	3.1	4.5			24	808
4	GARMAN	1809750	371050	1320	90	1	3.0	20		90	1	19						
5	GARMAN	1809500	371100	1310	80	1	3.0	27	20		1	25	3.8	19.2			24	810
6	GARMAN	1809480	371050	1310	86	1	3.0	18		86	1	17		1.3				
7	GARMAN	1809890	371850	1315	80	1	3.0	27	25			21		1.3				
8	GARMAN	1809500	371830	1315	75	1	4.0	22		75	1	20	5.8	2.6	2.6		25	922
9	MAHAL ALWASI	1810900	372000	1335	30	1	5.0	45				26					25	768
10	ALWASI VELIGE	1810890	372100	1340	91	1	4.0	36				26					25	768
11	MAHIL ALWASI	1810470	373450	1380	90	1	2.0	18				14		3.8	0.3		23	574
12	MAHAL ALWASI	1811100	372990	1355	91	1	5.0	18						6.4				
13	MAHIL ALWASI	1811150	371800	1338	79	1	6.0	32						12.8				
14	MAHAL ALWASI	1811400	371400	1338	83	1	3.0	18						3.8				
15	MAHAL ALWASI	1810650	372500	1320	85	1	3.0	25				21		2.6				
16	DHOR WA'AI	1810500	372650	1325	40	1	2.0	27				25		12.8			27	696
17	DHO RAWA'AI	1810500	372600	1330	89	1	3.0	18										
18	MAHAL GARWAY	1810450	372200	1325	90	1	4.0	25		90	1	22	4.7	6.4			28	613
19	MAHAL GARWAY	1810500	372180	1322	91	1	3.0	18										
20	GARMAN ALGALA'A	1810350	371650	1322	80	2		40	5	80	1	30		3.2	0.3		29	1362
21	GARMAN	1810100	371700	1320	86	1	4.0	27		86	1	23	5.0	12.8	0.3	500	27	1420
22	GARMAN	1810000	371870	1320	76	1	3.0	27		76	1	24	3.4	22.4	0.3	1400	24	1221
23	GARMAN	1810050	371700	1320	86	1	3.0	25				12		22.4				
24	ALKOLAH	1809300	371800	1322	84	1	5.0	23		84	1	21	5.4	19.2	0.6	2000	28	879
25	ALKOLAH	1809400	371600	1320	91	1	5.0	20						3.2				
26	ALKAWLAT	1809200	371800	1320	91	1	5.0	25			3	19		38.4	6.4	1000	29	950
27	ALKAWLAH	1809220	371890	1320	81		4.0	22				19		6.4			21	880
28	GARMAN	1809900	371200	1320	79	1		42		79	1	20		9.6	0.3	20	22	970
29	MALAH ALTAFISH	1808970	373450	1330	86	1	3.0	20	5			19		25.6				
30	MAHLAH	1809200	372230	1325	87	1	5.0	23	5	87	1	21		12.8	0.6	50	23	1862
31	MAHLAH	1809100	372100	1327	86	1	5.0	20				19		9.6				
32	MIDAH	1808010	372010	1310	87	1	7.0	25	15					25.6				
33	DHO MYDAH	1808050	371860	1300	89	1	5.0	22	10					9.6				
34	ALMIALLA	1794900	376100	1170	76	2		16	6			11					29	636
35	ALMIALLA	1794730	376050	1170	76	2		17	7	76	2	8		20.1	2.0	840	28	643
36	ALMIALA	1794700	376200	1170	76	2		35	10	71	2	9		20.1	2.2		28	642
37	ALMIALLA	1794600	376470	1170	76	2		14	10	76	2							
38	ALMIALLA	1794900	376200	1172	77	1	2.0	10		77	2			20.1				

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Well no.	Village (nearest)	Coordinates (UTM) N	E	Altitude m above msl	Year of constr.	Well type *)	Well diam. (m)	Well depth (m)	Thickness alluvium (m)	Year install pump	Type of pump **)	Depth water (m)	Well yield (l/s)	Total farm size (ha)	Water use Irrigtd (ha)	Domest. (persons)	Temp. (o C)	EC micro-S (25 o C)
	*) 1=dug well 2=drilled 3=dug+drilled				**) 1=lineshoft pump 2=electro 3=centrifugal													
39	KAWLAT BIN AKKAM	1809000	372500	1320	90	1	3.0	18	17			9		12.8			18	488
40	KAWLAT BIN AKKAM	1808750	372750	1320	91	1	3.0	18	15			9		6.4		10	32	868
41	ALGARIP AND NAGD	1808300	372200	1298	91	1	2.0	29		91	1	28		19.2	4.5	560	25	511
42	ALKAFLAH	1804700	368120	1310	50	1	1.5	25	18			21					28	1198
43	ALKAFLAH	1804740	368820	1290	80	1	3.0	28				26		1.9	0.6	800	23	1258
44	ALKAFLAH	1804900	369070	1290	78	1	3.0	31	12	78	1	29		3.8			25	1142
45	ALKAFLAH	1804730	368550	1300	70	2		110	35	70	1	45	3.1		6.4	800	25	1960
46	ALMUAIRIJAH	1798900	373100	1180	86	1	1.2	11				10		3.2	0.6	25	25	1280
47	ALGAMRA	1802400	370700	1170	88	1	2.0	20		86		18	2.8				25	701
48	DANAN	1802750	371100	1165	90	1	3.0	20		90	1	16	5.8	25.6	0.6		25	834
49	ALHADABAH	1802500	371200	1190	85	1	3.0	20				20		3.2			25	543
50	ALHADABAH	1802480	371700	1190	87	1	2.0	20				20					25	545
51	ALHADABAH	1802700	371800	1240	86	1	3.0	20				20		6.4			25	670
52	AS SAFARIYAH	1801920	371800	1160	74	1	2.0	26	24	85				44.8				
53	AS SAFARIYAH	1802700	372400	1380	76	1	2.0	34	5					5.1				
54	ARASOFAH/ASSAFA	1803300	371600	1240	78	1	2.0	25	24			24	5.8	12.8	1.0	700	25	635
55	AS SAFARIYAH	1803000	371880	1220	87	1	2.0	23	15					9.6				
56	ALMA'ANAG	1804000	369800	1250	91	1	2.0	25		91	1	23	3.0	9.6	32.0		25	620
57	ALMA'ANAG	1803900	370900	1240	83	1	3.0	25		83	1	23	3.0	32.0	19.2		25	580
58	ALMA'ANAG	1803600	371200	1230	84	1	2.0	15	13					32.0				
59	DANAN	1803600	370700	1260	83	1	3.0	26	16	83	1	24		1.3	1.9		25	1213
60	DANAN	1804400	370300	1220		1	2.0	29		76	1	23	3.9				20	1886
61	AZZAWNI	1806750	368400	1380	80	1	2.0	18	8			17					23	1117
62	HADABAT ADHARI	1809900	368900	1230	90	1	2.0	21	18			20		12.8			25	1422
63	ASHBAN	1808600	369400	1230	80	1	3.0	27	20			26		12.8			25	1860
64	ASHBAN	1808980	369480	1300	89	1	3.0	20				19		12.8			25	1314
65	ALHANAKAH	1808000	368870	1320	76	1		32	10	76	1	28	3.9	32.0	0.6		25	1990
66	RAYSHAN	1795880	377780	1090	86	2		140		86		18	5.8	96.0	6.4		25	888
67	RAYSHAN	1795700	376850	1190	80	1	3.0	21			2	20	2.3	96.0	1.9		25	758
68	RAYSHAN	1796010	376990	1190	89	1	3.0	23	17			20		51.2	0.6		25	630
69	ZAWGAR	1796300	377680	1195	83		2.0	24	10			21		9.6	5.1		25	800
70	ALASSHAH	1797500	377700	1195	84	2	3.0	170		84		30	3.1		0.6		25	1114
71	ALMARZAMIAH	1798890	377600	1190	87	1	3.0	23	6			22		2.6	0.3		25	516
72	ALHIJAH RYSHAN	1795160	377100	1175		1	3.0	23	15		2	18		25.6			25	690
73	ALHAIJAH RAYSHAN	1795300	376450	1175	80	1	3.0	23	19		2	19		9.6			25	700
74	ALSHATY ABO KAHL	1804100	367700	1320	89	1	3.0	17	16			16		6.4	0.1	500	21	1200
75	ALSHATY	1803850	367700	1300	89	1	4.0	16	15			14		12.8	0.3	500	21	740
76	ALSHATY	1803700	367300	1320	89		3.0	15	12			12		12.8	0.3		22	580
77	ALSHATY	1803700	367010	1300	89	1	6.0	12	6			11		12.8	0.3		19	580
78	ALSHATY	1803700	366870	1380	89	1	3.0	14	13			13		12.8	0.3		25	645

Data of well inventory of Al Ashshah Plain (selection of data)

Well no.	Village (nearest)	Coordinates (UTM) N	Coordinates (UTM) E	Altitude m above msl	Year of constr.	Well type *)	Well diam. (m)	Well depth (m)	Thickness alluvium (m)	Year install pump	Type of pump **)	Depth water (m)	Well yield (l/s)	Total farm size (ha)	Water use Irrigtd (ha)	Water use Domest. (persons)	Temp. (o C)	EC micro-S (25 o C)
	*) 1=dug well 2=drilled 3=dug+drilled			**) 1=lineshoft pump 2=electro 3=centrifugal														
79	ALSHATY	1803900	366500	1380	80	1	3.0	5				4				600	21	755
80	ALSHATY	1804400	367850	1340	89	1	3.0	16	12			16		6.4	0.6		20	905
81	ALMAHADADAH	1803150	370300	1240	87	1	3.0	19	12			18		12.8	2.6		23	953
82	ALMAHADADAH	1801900	370750	1250	90	1	2.0	18				18		1.3	0.1		25	500
83	ALMASAHR	1810600	368400	1320	85	1	3.0	24	20			24		3.2	0.3		21	1988
84	ALMASAHIR	1810400	368100	1320	79	1	2.0	26	20	79	1	25		32.0	0.3		20	1640
85	ALMASAHR	1810010	368300	1310	86	1	3.0	23	22			23		6.4	1.3		19	1650
86	ALMASAHR	1810280	368550	1300	79	1	3.0	23	22			22		6.4			20	1685
87	ALMASAHR	1810200	368950	1310			3.0	19	17		3	18		6.4	0.3		32	1180
88	ALMASAHAR	1809920	368720	1305	86	1	2.0	21	14	86	3	19		25.6	0.6	90	32	1180
89	KARIAT ALIRG	1809910	368050	1320	81	1	3.0	21	10			22		6.4	0.3		20	1048
90	JAYR	1810630	368000	1338	79	1	3.0	21	5	79	3	19		2.6	0.6	25	22	1140
91	JAYR	1811000	368850	1322	80	1	3.0	24	13	90	3	23		12.8	1.3		25	1530
92	ALHANAKAH	1809100	367350	1360	80	1	2.0	23	6			22		6.4	1.9		21	1585
93	ALHANAKAH	1808750	367500	1340	80	1	3.0	21	4			20		3.8	0.6		24	1465
94	ALHANAKAH	1808700	367320	1340	80	1	3.0	17	4			17		4.5	0.1		21	1988
95	JAYR	1810550	368880	1318		1	3.0	25				24				1000	22	1955
96	JAYR	1810600	369180	1321	84	1	4.0	20		84	3	19	3.0	12.8	0.6		21	1165
97	ALQABIL	1810190	369620	1320	80	1	3.0	15		80	3	13		12.8	1.3	90	22	1393
98	ALHOSILAH	1811650	369500	1342	79	1	4.0	21	1			20		25.6		12	23	1500
99	ALHOSILAH	1811700	369120	1335	90	1	3.0	23	22	90	3	22	3.0	25.6	2.6	6	25	865
100	JAYR	1811130	368550	1330	87	1	3.0	20		87	3	20	3.0	4.5	0.6	60	22	885
101	JAYR	1811140	368900	1330	87	1	3.0	20	18	87	3	20	3.0	19.2	0.3	40	23	820
102	ASSHIB	1811120	367400	1345	78	1	3.0	29	15	78	1	27		0.6	0.6	80	24	840
102	SHEAB NASSER	1814900	368500	1345	88	1	3.0	18	15	90	3	18		12.8	0.3		21	1370
103	ALAZIMAH	1812900	368200	1345	88	1	4.0	22	7	88	3	21	3.0	9.0	0.6	500	26	1720
104	MAHFINAH	1813600	368400	1355		1	2.0	18		91	3	18		32.0	0.6	1000	30	1785
105	MAHFINAH	1813370	368300	1350	88	2		360		88			4.2			3000	23	1800
106	ALWAGADEN	1814600	368180	1375	89	1	4.0	16				15				50	21	1270
107	ALHANW	1815750	368080	1380	90	1	3.0	12	2			12		19.2			27	1480
108	SHA'AB NASSER	1814900	368500	1380	88	1	3.0	18	15	90	3	18		12.8	0.3		21	1370
109	JAYR	1810880	369080	1322	90	1	3.0	13	7			13		2.6	0.6		20	1530
110	JAYR	1811000	369490	1330	90	1	4.0	22	15	90	3	21		1.3	0.6		20	1530
111	ALASHAH	1798380	378190	1210	87	2		150		87	1		3.8	25.6	1.3		29	1040
112	ALASHAH	1798700	378350	1210	87	2		150		87			12.5	32.0	12.8		29	560
113	ALKHAWSH	1798720	377850	1200	80	1	6.0	22		80	1	21		19.2	3.2		23	563
114	ALKHAWSH	1798370	377540	1200	70	1	3.0	18		70	1	17	3.8	19.2	2.6	100	22	550
115	HADAD	1799400	377770	1218	70	1	2.0	21	15			20				1000	25	520
116	AZZAHWAF	1800320	377550	1223	70	1	3.0	31	7	85	1	29		32.0	9.6	500	25	1295
117	ALKHAWSH	1797750	377680	1195		1	2.0	21	10			20		64.0	3.2		26	700

Data of well inventory of Al Ashshah Plain (selection of data)

Well no.	Village (nearest)	Coordinates (UTM) N	Coordinates (UTM) E	Altitude m above msl	Year of constr.	Well type *)	Well diam. (m)	Well depth (m)	Thickness alluvium (m)	Year install pump	Type of pump **)	Depth water (m)	Well yield (l/s)	Total farm size (ha)	Water use Irrigtd (ha)	Water use Domest. (persons)	Temp. (o C)	EC micro-S (25 o C)
	*) 1=dug well 2=drilled 3=dug+drilled			**) 1=lineshoft pump 2=electro 3=centrifugal														
118	ALMARJAM	1815800	368500	1390	80	1	3.0	20	10			18	3.0	12.8	3.2		27	720
119	ALMARJAM	1815810	368950	1380	83	1	3.0	19	13			18	3.0	5.1	3.2		23	1470
120	ALMARGAM	1816140	368950	1390		1	3.0	15	10			13					25	1774
121	ALMARJAM	1816500	368800	1395	87	1	5.0	19	6			18		12.8	0.1		25	1866
122	ALMARJAM	1815600	368880	1390	87	1	3.0	17	10			16	3.0	32.0	0.6		29	1870
123	ALMAJRAM	1815600	369200	1365	85	1	3.0	20	12			18		6.4	0.6		36	1830
124	ALMARJAM	1815480	369100	1370	88	1	3.0	19	14			17		3.2	0.6		21	1904
125	ALMARJAM	1815300	369100	1410	87	1	3.0	17	15			16		1.9	0.6		23	1871
126	ALMAJRAM	1815230	369340	1390	87	1	3.0	18	13			18	3.0	2.6	0.6		29	1870
127	ALMAJRAM	1815100	369350	1380	80	1	3.0	21				19					23	1880
128	ALHAJILAH	1815000	369110	1390	80	1	3.0	24	7			23		2.6	0.1		22	1950
129	ALHAJILAH	1814780	369250	1390	90	1	3.0	18	5			18		16.0	0.3		20	1740
130	ALHAJILAH	1814610	369500	1375		1	2.0	22				21					23	1307
131	ALHAJILAH	1814300	369690	1370	70	1	3.0	26	8			25		16.0	0.3		23	1373
132	ALHAJILAH	1813990	370000	1260	88	1	4.0	20	7			20		9.6	0.3		21	1554
133	SHAKHIT	1816650	369750	1400	85	1	2.0	18	9			18		6.4	0.1		30	1396
134	SHAKHIT	1817000	369750	1550		1	1.5	8				7					22	1380
135	SHOKHIT	1816010	369750	1395	83	1	2.0	19	11			19		6.4			23	1427
136	QARAH	1813600	371300	1395	88	1	3.0	32		91	3	32	3.8	12.8	1.9		24	544
137	QARAH	1813600	371470	1400	80	1	3.0	31		80		31		64.0	1.9		23	514
138	QARAH	1813850	371700	1430	86	1	2.0	18	9			16		6.4	0.6		22	420
139	QARAH	1813800	371080	1390	83	1	3.0	33	16			33		3.2	1.0		21	550
140	QARAH	1813870	370800	1390	87	2		270		87							24	
141	HAMIDAT	1814800	370100	1380	84	1	2.0	24	9			23		6.4	0.3		21	802
142	HAMIDAT	1814500	370000	1380	85	1	2.0	22	14			21		19.2			21	805
143	HAMIDAT	1814400	370100	1265	85	1	3.0	19	13			18		9.6	0.1		22	876
144	QARAH	1813850	370100	1260	76	1	2.0	21	9			20		9.6			23	557
145	QARAH	1813400	370360	1265	88	1	3.0	21	12			21		9.6			24	432
146	QA'AN	1813520	370500	1360	76	1	2.0	26	15			25		25.6	0.6		23	1180
147	DAMIKHIN	1814500	370400	1380	85	1	5.0	21	17			20		12.8	0.3		24	567
148	QA'AH	1813000	369850	1385	88	1	3.0	25		89		23	5.0	12.8			26	540
149	DAMIGHIN	1813120	369750	1250	90	1	3.0	24				22		12.8	1.3		26	557
150	DIMIGHIM	1813300	369730	1240	81	1	2.0	27		84	1	25	5.0	12.8	0.6		22	1420
151	DAMIGHIM	1813600	369880	1245	79	1	3.0	28	15	79	1	25	5.4	22.4			21	870
152	ALKHAWSH	1812000	370200	1340	91	1	2.0	22				20		6.4	0.6		27	527
153	ALKHAWSH	1812100	370100	1320	88	1	2.5	23	20	88	1	21	5.8	12.8	1.3		27	810
154	ALKHAWSH	1812570	369800	1320	81	1	3.0	15				14		19.2	0.6		23	831
155	HADABAT ADHAR	1809500	368880	1280	90	1	3.0	20	13			19		19.2	0.6		28	1213
156	ALDARJAH	1797600	373550	1285	85	1	3.0	24	15			24		19.2	0.1		23	1180
157	SURBAN	1800900	370550	1220	86	1	2.5	21	10			19	3.3	12.8	0.6		27	1090

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Well no.	Village (nearest)	Coordinates (UTM) N	Coordinates (UTM) E	Altitude m above msl	Year of constr.	Well type *)	Well diam. (m)	Well depth (m)	Thickness alluvium (m)	Year install pump	Type of pump **)	Depth water (m)	Well yield (l/s)	Total farm size (ha)	Water use Irrigtd (ha)	Water use Domest. (persons)	Temp. (o C)	EC micro-S (25 o C)
	*) 1=dug well 2=drilled 3=dug+drilled			**) 1=lineshaft pump 2=electro 3=centrifugal														
158	SURBAN	1801180	370750	1220	85	1	2.0	21	13			20		6.4	1.3		22	1222
159	SURBAN	1801000	371200	1220	86	1	3.0	21	16			20	3.0	19.2	1.3		22	990
160	SURBAN	1800730	371180	1220	83	1	2.0	18	7			17		16.0	0.6		21	
161	SURBAN	1800720	370850	1210	80	1	2.0	23	4			22		9.6	0.6		24	928
162	ALHALLAH	1799800	371400	1220	88	1	3.0	16				16	3.0	19.2	1.3		29	1270
163	DHO SAWLAN	1798500	371000	1220	86	1	2.0	12	5		1	10	3.8	32.0	3.2		27	997
164	DHU SAWLAN	1798100	371480	1210	84	1	1.5	10	4			8	3.8	32.0	3.8		27	960
165		1797100	374110	1170	82	1	2.0	12			3	11		6.4	2.6	12	23	1140
166	ALSHATT	1796700	374000	1170	84		2.3	13		84	3	11		9.6	1.3	600	24	1200
167	ALSHATT	1797100	373700	1176	86	1	3.0	14		81	3	13		38.4	9.6	80	23	1720
168	UMM HAZAH	1796300	373600	1175	87	1	2.5	13		89	3	12		51.2	1.3	50	24	1420
169	UMM HAZAH	1795900	373900	1570	86	1	2.5	13		86	3	12		96.0	0.1	150	24	1820
170	HAZAH	1795900	374000	1170	84	1	2.0	12		84	3	12		0.5	0.3	150	24	1400
171	UMM HAZAH	1795300	374100	1170	84	1	2.5	12			3	12		25.6	0.8	70		1334
172	ARAD	1795100	373900	1160	87	1	3.0	12		87	3	11		3.2		200	24	1270
173	AROD	1795500	373700	1160	91	1	2.5	9			3	9		6.4	0.1	80	23	1520
174	AROD	1795200	374600	1168	90	1	2.5	13			3	12		12.8	9.6	300	24	1230
175	ARAD	1794900	374400	1168	90	1	2.5	11			3	11					23	1320
176	ARAD	1795100	374800	1168	89	1	2.5	12			3	11		38.4	12.8	150	24	1620
177	ARAD	1795400	374300	1169	84	1	2.0	11			3	10		32.0	0.6	40	24	1660
178	QAHBASH	1796300	375600	1175	86	1	2.0	22		85	1	21		64.0		700	24	1010
179	HADOBAL QAHBASH	1796400	376200	1180	86	1	4.0	17			3	16		64.0			24	1200
180	ASSUWAYDAH	1793700	373600	1167	85	1	3.0	11				11		8.3	0.2	70		
181	ASSUWADAH	1793800	373900	1160	86	1	2.5	16			3	15		1.3	0.6	60	25	
182	ASSUWAIDAH	1793900	373900	1166	85	1	3.0	15			3	14			1.3	30	24	1860
183	UMM AFARAH	1794400	374600	1167	86	1	2.0	10			3	9		1.3		400	24	1160
184	UM ASSUWAIDAH	1794500	373800	1169	91	1	2.5	12			3			6.4	0.8	30	24	1210
185	ASSUWAIDAH	1794700	373800	1168	90	1	2.5	10			3	9		6.4	0.6	60	25	1510
186	ASSUWAIDAH	1794800	373400	1168	91	1	2.5	11			3	10		3.8	0.6		24	1260
187	ASSUWAIDAH	1794500	373400	1169	90	1	3.0	11			3	9		1.9	0.6	25	24	1300
188	ASSUWAIDAH	1794100	373700	1164	91	1	2.5	8		91	3	7		3.8	1.3	40	25	1360
189	BIN GHOROB	1793500	374500	1167	89	1	2.5	13		90	3	13		6.4	0.4	80	24	1800
190	BIN GHORAH	1793400	374200	1160	91	1	2.5	12			3	11			1.3	50	25	1400
191	BIN GHORAH	1793400	374400	1162	85	1	2.5	13		85	3	13		6.4	2.4	300	24	1260
192	BIUY GHORAB	1793100	374300	1175	90	1	4.0	10			3	9		12.8	6.4	40	23	1360
193	ALQSSRO	1792100	374300	1190	91	1	2.0					5		12.8			24	1320
194	ALISHASH	1791700	373800	1150	91	1	2.5	6				5		96.0	1.3	400	24	1330
195	ALASHASH	1791400	374000	1140	87	1	3.0	6			3	6		6.4	0.6		24	1320
196	ALISHESH	1791900	373100	1150	83	1	3.0			83	3	17		6.4	0.3	300	23	1190
197	ALBUQAYBIQ	1792700	373300	1150	76	2		300	25	76	1	80	1.9	2.6	0.5	100	25	802

Data of well inventory of Al Ashshah Plain (selection of data)

Well no.	Village (nearest)	Coordinates (UTM) N	E	Altitude m. above msl	Year of constr.	Well type *)	Well diam. (m)	Well depth (m)	Thickness alluvium (m)	Year install pump	Type of pump **)	Depth water (m)	Well yield (l/s)	Total farm size (ha)	Water use irrigtd (ha)	Domest. (persons)	Temp. (o C)	EC micro-S (25 o C)
.	*) 1=dug well 2=drilled 3=dug+drilled			**) 1=lineshaft pump 2=electro 3=centrifugal														
199	ASSAHFA	1794400	376100	1170	90	1	3.0	6				5		3.2	1.3	60	24	1180
200	ALSAHFA	1794300	376300	1170		1	3.0	6			3	6		3.8	1.3	70	25	1180
201	ASSAHFA	1794700	376800	1172	86	1	3.0	7			3	6		6.4	1.3	180	25	1208
202	ALMIALLO	1794800	377100	1180	83	1	3.0	8			3	8		6.4	1.9	80	25	1108
203	ASSAHFA	1794800	376500	1160	76	1	2.5	7			3	6		6.4	0.0	60	25	1260
204	RAYSHAN	1795100	376200	1170	76	1	2.0	9			3	9		6.4	0.2	100	25	1100
205	ASSHAHLA	1794200	377500	1190	81	1	2.0	17	17		3	16		6.4	1.3	30	25	1090
206	RAYSHAN	1795700	377200	1183	87	1	3.0	8			3	8		6.4	0.8	150	25	1180
207	SHAAYF	1801800	369880	1250	88	1	3.0	20	14	88	3	19	2.0	6.4	1.0		24	1474
209	SAWKAN	1802300	369550	1260	76	1	2.0	23	13			22					20	990
210	KAWALIH	1801250	369400	1240	84	1	3.0	20	10	84	3	20	2.8	5.1	1.3		22	2510
211	ALMASHRAJ	1802750	369450	1240	84	1	2.0	15	10			15		19.2			19	1575
212	ALMASHRAJ	1802600	369000	1280	88	2		220		88	1		2.5	9.6	0.6		33	2610
213	ALMASHRAG	1802780	369100	1280	84	3	2.0	50	12			18		2.6			19	1520
214	ALMASHRAG	1802800	369600	1250	84	2		240	18					9.6				
215	SURBAN	1801200	370010	1240	85	1	2.0	22	14	85	3	21					20	1075
216	ANNABAJAH	1798000	372350	1200	86	1	3.0	12	11	91	3	11	2.5	3.2	0.3		26	1160
217	ANNABAJAH	1798000	372000	1210	84	1	3.0	9				8		3.2			19	
218	ANNABAJAH	1798300	371900	1200	84	1	2.0	14	2			10		9.6			20	1600
219	ANNABAJAH	1798420	372400	1200	82	1	2.0	13				8		9.6			19	
220	SHAT RAMAM	1797700	372000	1140	92	1	2.0	5		92	3	5	2.1	32.0	1.3		23	1120
221	SHAT RAMAM	1797550	372200	1150	77	1	1.5	9	8	91	3	9	2.0	19.2	1.9		28	1090
222	GARAB HOMRAN	1797760	371770	1130	86	1	2.0	8	6	80	3	8	2.8	12.8	0.3		21	1042
223	ALSSED DHU SAWL/	1799450	371180	1180	84	1	2.0	14	5	89	3	13		12.8	3.2		19	1120
224	ALSEED DHU SAWL/	1799200	371180	1180	85	1	3.0	13	6		3	12	2.1	9.6	0.3		28	1085
225	ALSEED DHU SAWL/	1798900	371360	1190	88	1	3.0	9	4			9		9.6			17	1785
226	DHU MUFLEH	1801300	379300	1250	84	2		130		84	1	50		128.0	3.2	400	22	530
227	KHOSH ALARJA	1801400	376800	1240	85	1	3.0	21	13	85	1	20				600	28	1316
228	ALMAHGER	1799900	376100	1215	80	1	2.0	30		80	1						28	860
228	ALMAHGER	1799900	376100	1215	80	1	2.0	30		80	1						28	860
229	ALMUHARAG	1799200	372100	1225	91	2		50		91	1	20		0.5	0.1	100		863
230	ALMUAYRIJAH	1797350	373300	1180	82	1	3.0	22	10			21				100	25	1280
231	ATOR	1797200	372800	1180	82	1	3.0	19				18				160	28	1216
232	ALSSORAR	1791980	369100	1170	86	1	3.0	12	6		3			19.2	0.3	100	24	1270
233	DISHUILOT	1791800	369200	1200	87	1	2.5	9	6		3			1.3	0.2	70	25	970
234	DISHOYLOT	1791600	369100	1200	90	1	3.0	11	7		3			1.3	0.2			
235	DISHOYLOT	1791580	369200	1200	80	1	1.5	12			3				5.1	70	25	970
236	DISHAYLOT	1791600	369200	1180	83	1	2.0	16	8		3			1.3	0.3	180	24	938
237	DISHOYLOT	1791500	369300	1180	87	1	2.5	10	7		3			0.6	0.1		24	990
238	DISHAYLOT	1791300	369200	1200	88	1	3.0	14	9		3			0.3	0.1	50	24	980

Data of well inventory of Al Ashshah Plain (selection of data)

Well no.	Village (nearest)	Coordinates (UTM) N	E	Altitude m above msl	Year of constr.	Well type *)	Well diam. (m)	Well depth (m)	Thickness alluvium (m)	Year install pump	Type of pump **)	Depth water (m)	Well yield (l/s)	Total farm size (ha)	Water use Irrigtd (ha)	Domest. (persons)	Temp. (o C)	EC micro-S (25 o C)
	*) 1=dug well 2=drilled 3=dug+drilled			**) 1=lineshoft pump 2=electro 3=centrifugal														
239	MAGRABAH	1791400	369600	1180	88	1	3.5	14			3			1.9	0.1	30	24	1070
240	MAGRABAH	1791100	369400	1200	81	1	2.5	11			3			0.6	0.3		24	1100
241	MAGRABAH	1790900	369500	1159	81	1	3.0	15			3			3.2	1.3	90	24	1890
242	MAGRABAH	1791200	369800	1190	88	1	3.5	12	7		3			3.2	0.8		24	1090
243	MAGRABAH	1790800	369800	1175	87	1	3.0	12			3			0.6	0.3		24	1100
244	MAGRABAH	1791000	369900	1190	81	1	2.0	15	9		3			6.4	2.6	400	24	980
245	MAGRABAH	1790900	369800	1156	81	1	3.0	14	11		3			25.6	0.3	300	25	930
246	MAGRABAH	1790900	369700	1180	86	2		175	10	86	1					1200		
247	MAGRABAH	1790600	369500	1200	88	1	2.0	13	10		3			25.6	0.3	70	24	870
248	MAGRABAH	1790480	369300	1200	85	1	4.0	15	10		3			3.2	1.3	100	24	1320
249	MAGRABAH	1789900	369600	1154	85	1	3.5	13	9		3			38.4	0.6	70	23	930
250	DHU JAMAN	1789950	370200	1156	80	1	1.5	11	6		3			12.8	0.5	60	24	1280
251	DHU JAMAN	1789900	370300	1156	86	1	4.0	15	9		3			1.0	0.5	70	24	1227
252	DHU GAMAN	1789400	371000	1150	91	1	4.0	9	6		3			32.0	0.5	60	24	1220
253	DHU GAMAN	1789300	371200	1150	86	1	4.0	7	5		3			38.4	0.4	70	24	1360
254	DHU GAMAN	1789860	371500	1160	91	1	4.0	6	4		3			12.8		30	24	1217
255	DHU GAMAN	1790000	372000	1160	91	1	3.0	7	5		3				0.3	150	23	1400
256	KHORAB BURI	1798200	372200	1142	83	1	2.5	18	10		3			1.9	0.4	60	24	1200
257	DHU GAMAN	1789600	371500	1148	86	2		175	10	86	1					500		
258	AQIDAH	1786200	370800	1120	90	1	1.5	8		90	3	7		0.1	0.1	150	26	1200
258	AQIDAH	1786100	371100	1120	91	1	1.5	6		90	3	5	3.0	0.2	0.1	30	24	950
260	KHARAB AT TABISHI	1785800	371800	1114	91	1	2.0	8		91	3	8		1.3	0.8	70	26	1600
261	QARIAT ALHAMRA	1784800	372000	1112	91	1	2.0	7		91	3	6		3.8	2.6	200	25	1600
262	QARIATV ALHAMRA	1784800	371900	1112	91	1	1.5	7			1	7	1.9	3.8	1.3	30	24	1600
263	AL ISHASH	1791000	372700	1120	89	1	2.0	9	3			10				400	24	810
264	SHATI SHIFARI	1790300	372900	1122	84	1	1.5	8	6			9						
265	SHATI SHIFARI	1789900	373000	1120	91	1	2.0	6				6		6.4	3.2		18	2500
266	KHARAB BURI	1789700	373000	1120	91	1	1.5	7		91	3	6	2.5	3.8	2.6		30	1200
267	SHATI SHIFARI	1789800	373200	1120	90	1	1.5	8		82	3	7		1.0	0.6		23	1700
268	SHATI SHIFARI	1790000	373300	1120	91	1	2.0	7		89	3	6		3.8	2.6		34	2600
269	KHARAB BURI	1790000	372300	1150	89	1	2.5	8		90	3	7		3.8	0.4	50	25	1250
270	KHARAB BURI	1789200	373300	1140	90	1	1.5	9		90	3	6	1.5	12.8	3.8	80	26	1950
271	KHARAB BURI	1789400	373300	1140	91	1	1.5	8		90	3	7	2.5	38.4	6.4		26	1950

APPENDIX 4

STAFF PARTICIPATING IN THE WELL INVENTORY

APPENDIX 4 STAFF PARTICIPATING IN THE WELL INVENTORY

Staff that participated in the well inventory of the Al Ashshah Plain

The following SSHARDA engineers were involved in the well inventory:

Wasfi Mohd Abdo Alezzi (team leader)
Faisal Ahmed Taher
Mohamed Abu Talep
Yahya Yahya Abdul Khader
Sultan Hassan Al Barakani

Drivers

Ali Khorap
Abdullah Alyazidi
Ali Ahmed Al Montassar

Database entry was carried out by the SSHARDA engineers:

Samir Al Shamiri
Abdul Al Shamiri

Planning, supervision and reporting

WJ Honijk (hydrogeologist)