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GROUNDWATER RESOURCES AND USE IN THE AL HAMRA PLAIN

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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 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 Hamra Plain represents one of the surveys that will contribute to the WMP 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 of the Al Hamra Plain were carried out during the month of December 1991. One team consisting of two engineers and a driver, was used; the drivers also assisted in carrying out the measurements at the well sites. A list of the persons that participated is presented in Appendix 4.

Before the start of the survey each team received training in the field, and various background information on subjects like the local hydrogeological situation, locating the well sites with a compass, the use of the water level measuring tape and EC-meter, and the measuring of well discharge. The basic field equipment was a stopwatch, a thermometer, binoculars, an EC-meter, an 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 38 wells were visited in the study area and the same number of questionnaires filled out, each containing up to 120 data. The information collected included data on the well location, well details, pump characteristics, measured well observations, water use, well costs, among others. A copy of the questionnaire is presented in Appendix 2. The most important topics are summarized and presented in Appendix 3.

2 PHYSICAL SETTING

2.1 LOCATION AND TOPOGRAPHY

The Al Hamra Plain is situated in the Central Highlands about midway between the towns of Amran and Sa'dah, some 14 km northeast of Huth. The alluvial plain covers an area of about 25 km^2 and has a large catchment area of 632 km^2 that extends from the plain up to the major water divide of the Central Highlands in the west and includes the catchment area of Wadi Adaf (also called Wadi Al Fayz) south of the plain.

It lies within UTM coordinates 1794 000 and 1804 000 north and 400 000 and 407 000 east (see Figs. 2.1 and 2.2), and has a length (northwest-southeast) of about 12 km. The width of the valley varies from 5.5 km in the centre to 3 km at either end.

The road from Sana'a to Sa'dah town in the north passes through the plain. The most important towns are Al Hamra at the eastern side of the plain and the mountain village Khaywan at the western margin.

One major wadi channel enters the plain near Khaywan in the west (wadi Khaywan) and traverses the entire plain to join Wadi Adaf at the southeast margin which enters the plain from the south. This latter wadi (the surface water outlet of the plain) in its turn debouches into Wadi Kharid in the southeast. Another smaller wadi, Wadi Mughdir, enters the plain in the southwest.

Topographic elevations in the plain range from 1560 m amsl (above mean sea level) in the southeast corner of the plain, where Wadi Adaf leaves the plain, up to 1600 m almost everywhere at the margins of the plain.

The surrounding mountain ranges are entirely composed of the limestones of the Amran Series, except in the north where Quaternary volcanics outcrop. These volcanic cones, called Al Jabal al Aswad reach an altitude of almost 1900 m and separate the Al Hamra Plain from the Al Harf Plain in the north. The heights of the limestone mountains range from 1620 m in the south to 1900 m east of the plain.

The 1986 Census gave a population estimate for the Khaywan/Al Harf Sufyan Target Area (approximately the Al Harf and Al Hamra Plains, taken together) of 9000.

2.2 CLIMATE

The climate in the Al Hamra Plain is classified (Koppen) as mountainous semi-arid. The natural vegetation is of the briar, succulent, savannah-type, represented by some trees on moist soils near wadi outlets in the southern part of the plain, shrubs, briar and grassland. Shrubs dominate in the limestone mountains. As a consequence of intensive grazing by sheep and goats little of the grassland is left in the plain, and the result is the desert-like aspect of the non-cultivated parts of the plain.

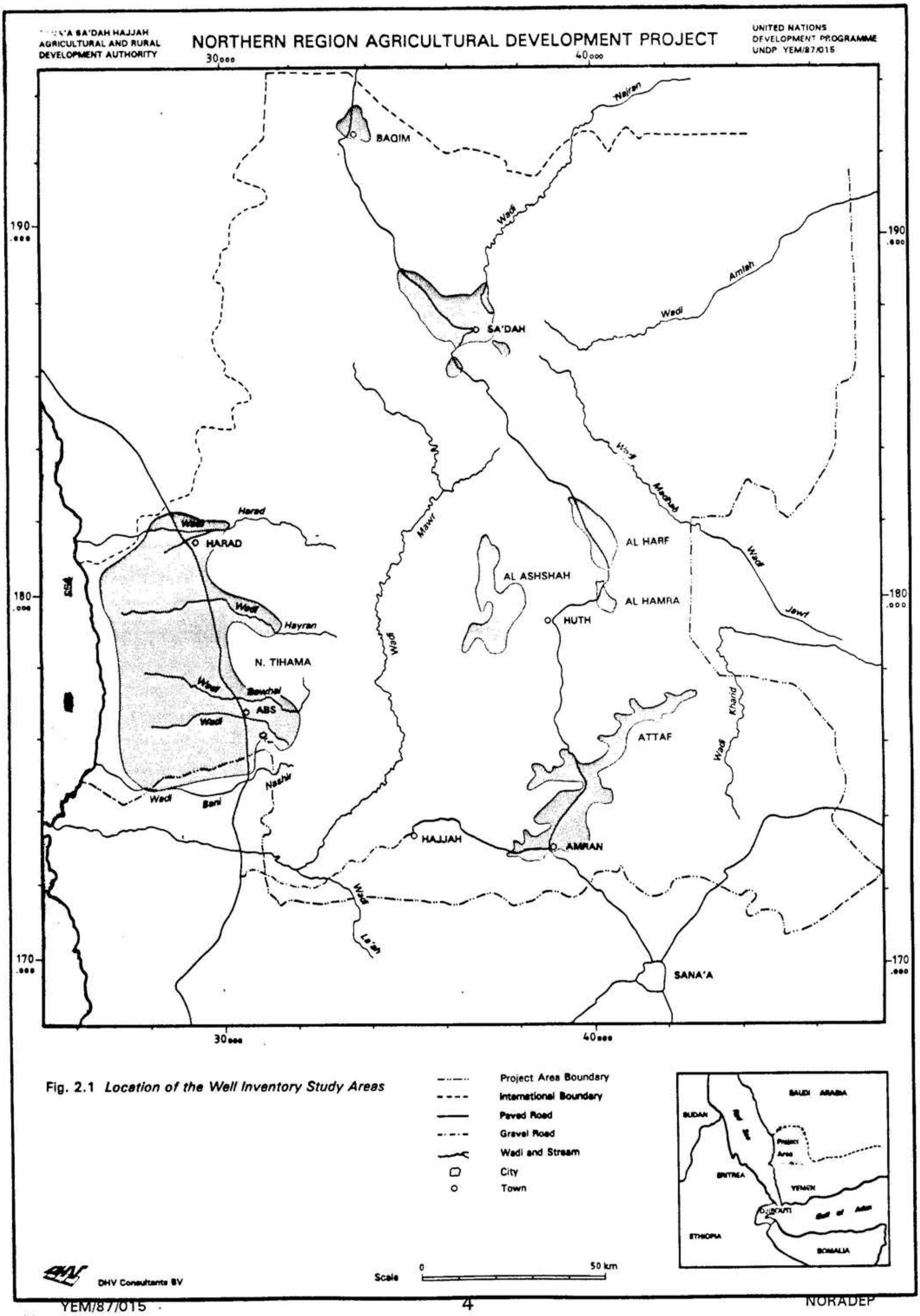


Fig. 2.1 *Location of the Well Inventory Study Areas*

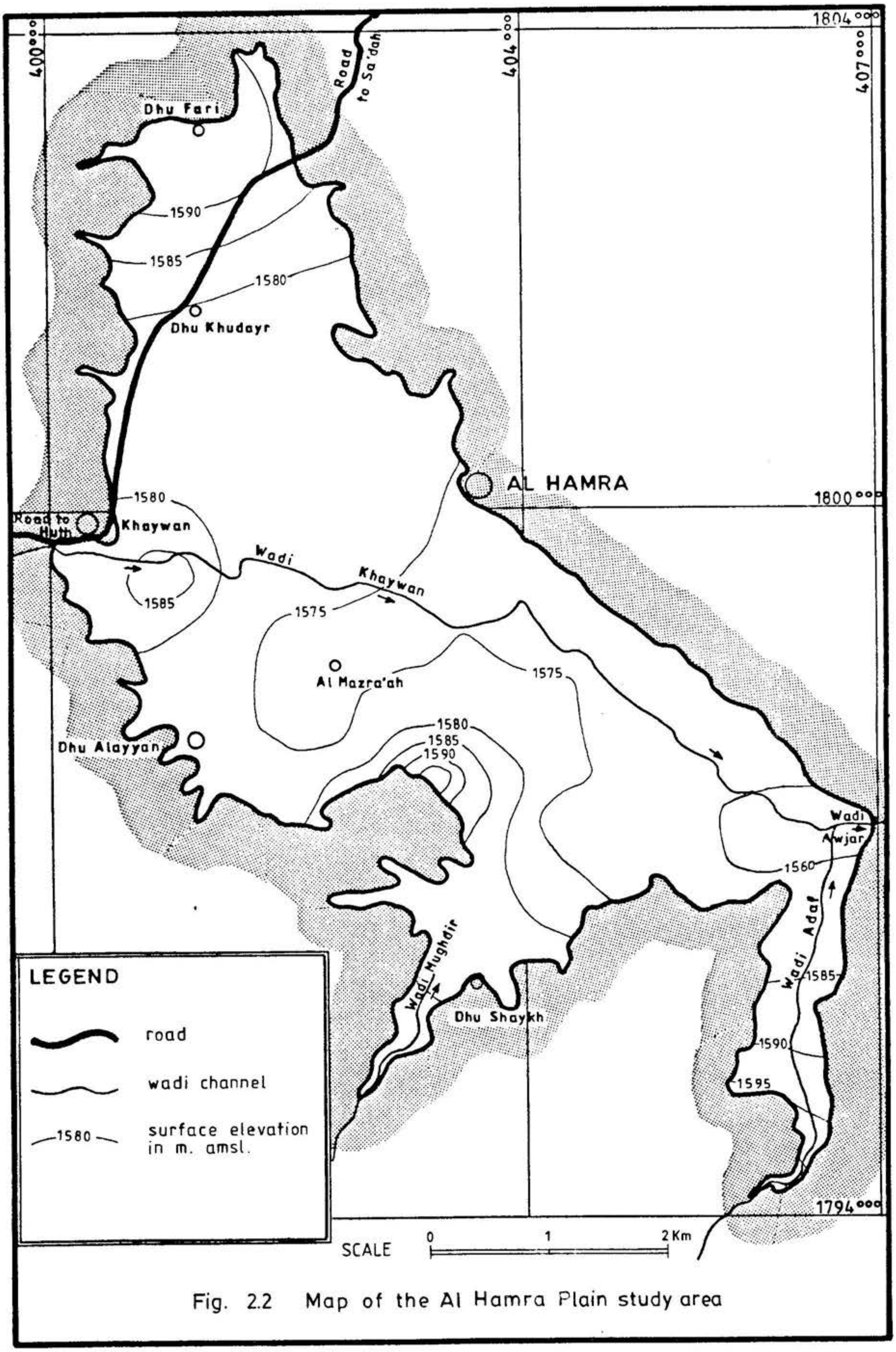


Fig. 2.2 Map of the Al Hamra Plain study area

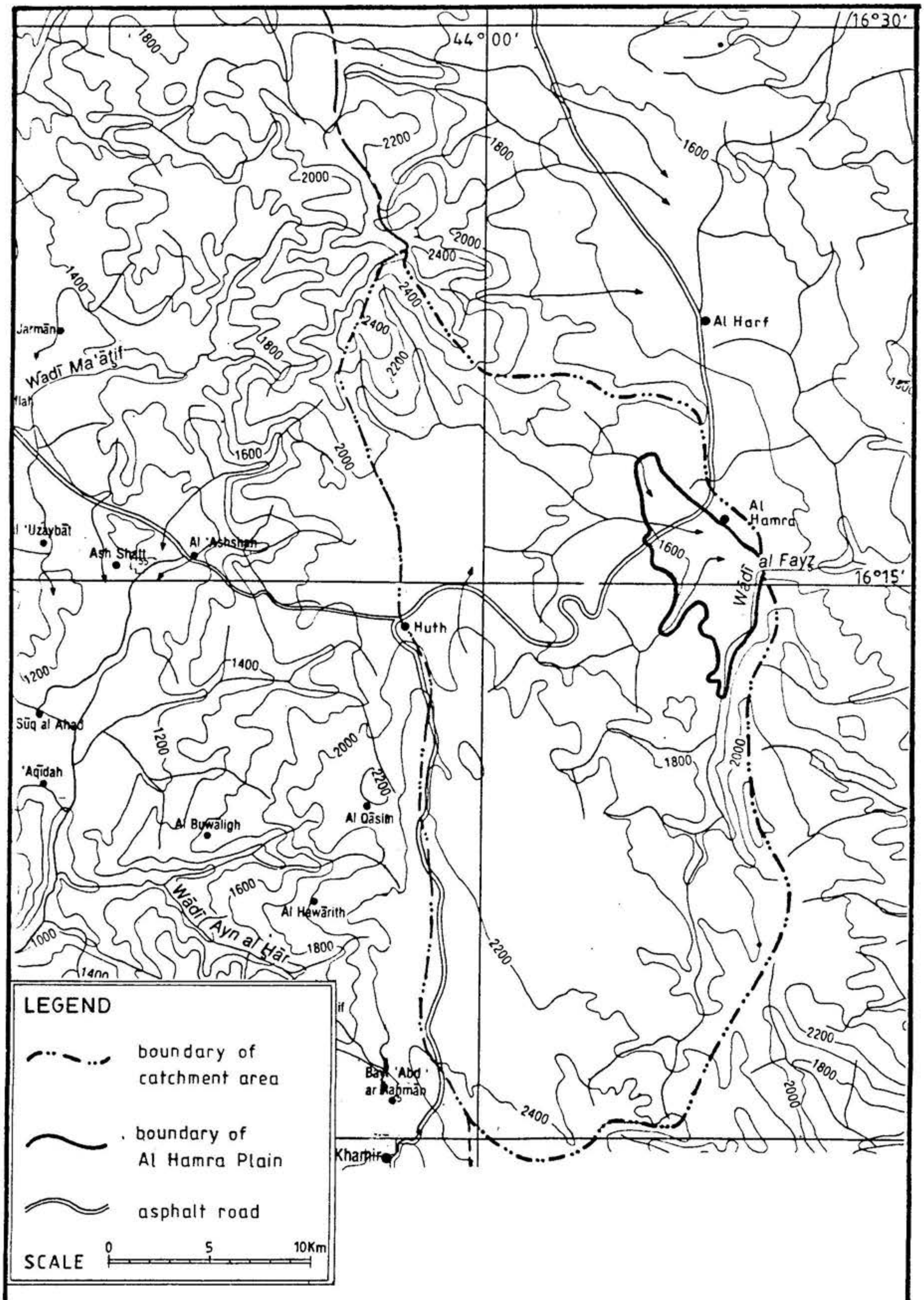


Fig. 2.3 Catchment area of Al Hamra Plain

Fig. 2.4 *Mean Monthly Precipitation Near Al Hamra Plain (1975-1989)*

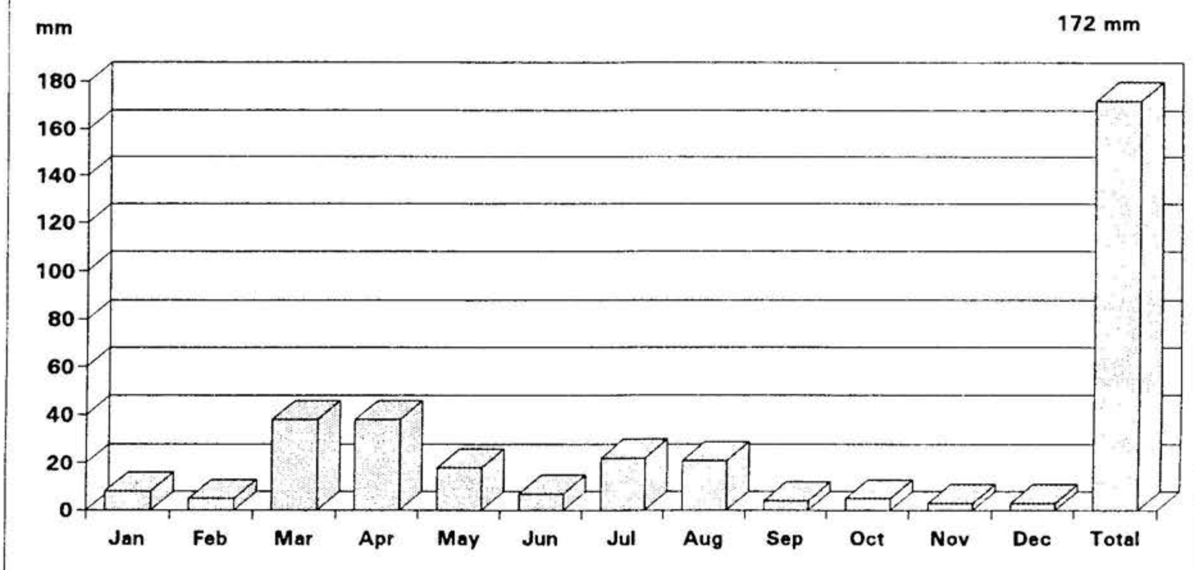
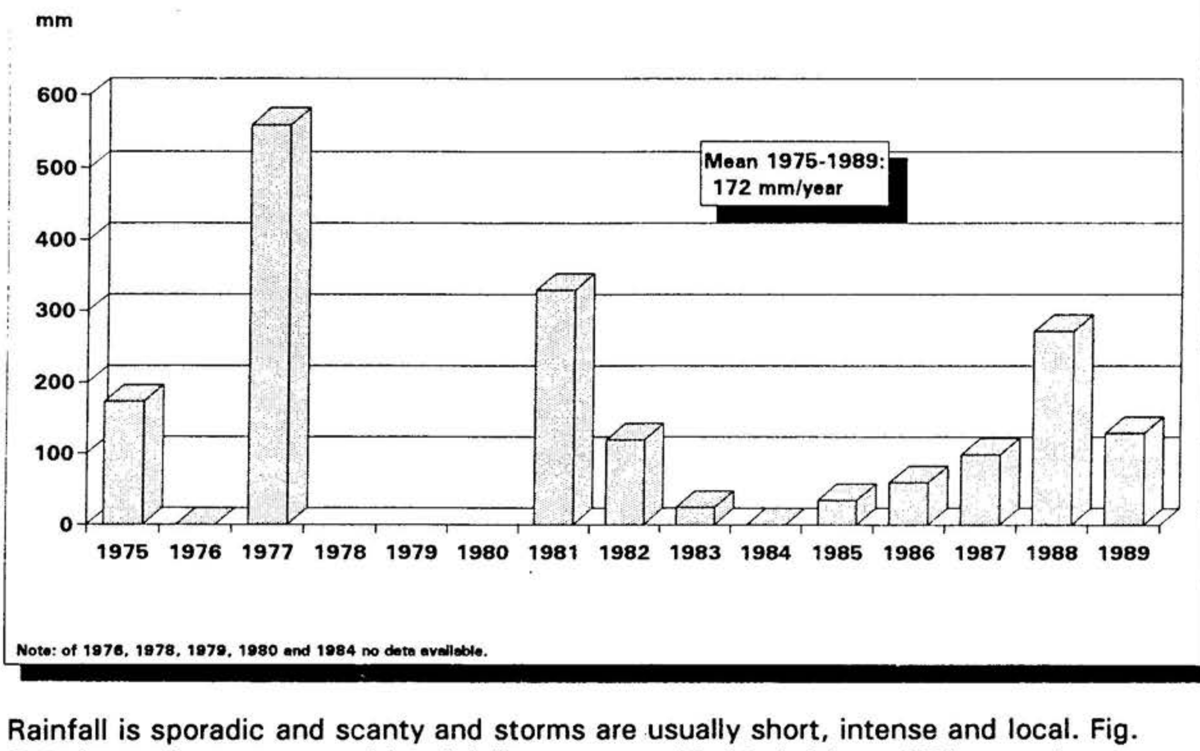


Fig. 2.5 *Total Annual Precipitation Near Al Hamra Plain*



Note: of 1976, 1978, 1979, 1980 and 1984 no data available.

Rainfall is sporadic and scanty and storms are usually short, intense and local. Fig. 2.4 shows the mean monthly rainfall as measured in Huth (about 15 km southwest of Al Hamra town) during the period 1975-1989, while Fig. 2.5 shows the total annual rainfall at the same station. Annual totals range from 34 to 559 mm. The monthly distribution of rainfall is variable; in general two peaks of rainfall occur during the year: March-May and July-August. The wettest months are generally March and April.

Temperatures range from 35°C in the summer to 4°C in the winter. The annual average temperature is 15.4°C. The mean monthly maximum temperature is 29.6°C, while temperatures in the winter can drop close to zero.

Evaporation far exceeds precipitation during most of the year. It was measured by the German-Yemeni Plant Protection Project in 1976 at about 2800 mm per year (Class A pan). Daily figures in the driest months were 10 mm and 5-6 mm in the wettest months.

3 GEOLOGY AND HYDROGEOLOGY

3.1 GEOLOGY

3.1.1 Tectonics

Probably during the Oligocene (Tertiary) major northwest-southeast faulting at the eastern margin of the plain caused a downthrow in the limestones of at least 60 m forming a *graben*. Like many of the alluvial plains in Yemen the Al Hamra Plain was created by filling up of the *graben* by alluvial deposits during late Tertiary and Quaternary times. During this deposition intermittent volcanic activity took place to the north and south of the plain, creating several basaltic cratons between the Al Hamra Plain and the Al Harf Plain: the Al Jabal al Aswad in the north and Jabal Ash Sha'fah in the south.

3.1.2 The Quaternary Volcanics

During the Quaternary volcanic activity resulted in the build-up of basaltic cones at the northern edge of the plain; also, to a lesser extent, to the south. The volcanic cones to the north side reach altitudes of almost 300 m above the plain.
Near the Amran and Attaf valley it has been determined that the Quaternary volcanic activity occurred between 100 000 and 2000 years ago. The thickness of the volcanic cover varies from zero to more than 200 metres. The basalts are dark grey to black coloured. Table 3.1 shows the geological formations and their hydraulic characteristics.

3.1.3 The Quaternary Alluvium

The *graben* formed during the Tertiary was filled during the Quaternary period by alluvial deposits, consisting of clay, loess, silt, sand, gravel and boulders. This material originated mainly from the surrounding Amran limestones, less from the volcanic outcrops in the north. The thickness of these unconsolidated sediments is limited. Fig. 4.17 shows the thickness of the alluvium above the underlying limestone; it ranges from 0 to more than 90 m. Fig. 4.18 is a north-south cross-section through the plain showing the thickness of the alluvium and the depth to the groundwater. It clearly shows that water is not pumped from the alluvium, but from the limestone below it. Nevertheless, the alluvium functions as a sponge, a surface and rain water collecting medium, from which the water can infiltrate into the underlying limestone.

3.1.4 The Amran Limestones

The Al Hamra Plain is underlain and enclosed on all sides, except in the north, by limestones of the Amran Series, which outcrops over a vast area, roughly between the towns of Sana'a, Hajjah, Sa'dah and Marib. Its age has been determined by fossils (stromatoporoids, ostrea, brachiopodes) as middle to late Jurassic. During that period an important marine transgression (or land subsidence) extended over the entire country and shallow water marine calcareous deposits were formed.

Table 3.1 *Geological Formations and Their Hydrogeological Characteristics In and Near Al Hamra Plain*

Stratigraphic Age	Litho-stratigraphy	Lithology	Hydrogeology
Quaternary	Alluvial deposits, locally interbedded with basalt flows	Loam, silt, clay, loess, gravel, boulders. Basalts and tuffs	Alluvium does not act as an aquifer, because water level is situated below it in the limestone. Alluvium functions as surface and rain water collector, where after it infiltrates in the limestone below.
Tertiairy	Yemen Volcanics	Volcanic flows, sills, tuffs, basalts and intrusives.	Poor aquifer, unless fractured. Too far outside study area to be significant in water balance.
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.	Main aquifer of the area. In general poor hydraulic properties, except in or near fractured zones. No indications for the occurrence of karst. Moderate well yields in Al Hamra Plain (2-10 l/s).
Triassic	Kohlan Series	Fine grained. partly cemented quartz sandstones with conglomerate horizons.	Not significant for the water supply of the Al Hamra 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.

The lower horizons of the Amran Series are represented by the Shuqra Formation and consist mainly of white/yellow/black limestones. Its depositional environment was shallow reef marine.

Then a period of block faulting followed. During a new transgression the Maabi and Sabatain formations were deposited directly upon the eroded surface of the Shuqra formation in the graben extending from Amran to Thula. This consists of deposits of rock salt, marl, gypsum, some shales and limestones.

The late Jurassic was a relatively stable period and fluvio-marine sediments were laid down, comprising the Al-Ahjur formation, which consists mainly of marly, shaley and sandy mudstones. Towards the end of late Jurassic there was a regression resulting in a continental depositional environment. Continental fluviatile sands and conglomerates were then laid down (Tawilah Group).

The thickness of the Amran Series ranges from 400 to 600 m at the cliffs on the flanks of the Amran Valley, and exceeds 800 m in the Attaf Valley. It is calcareous throughout, although the facies change with location. Near the Amran Valley the formation shows yellow-white limestones containing shallow water fossils.

In the NORADEP Region the Amran Series rest upon the calcareous sandstones of the Kohlan Group and in some areas directly upon the Precambrian Basement.

3.2 AQUIFER SYSTEMS

3.2.1 Alluvium

Only in upstream wadi fills does the Quaternary alluvium sometimes function as a temporary perched aquifer and, where saturated, it is a relatively good one in which the highest permeabilities are in the interbedded gravel layers. However, in the Al Hamra Plain the alluvium is not saturated and only functions as a collecting medium for surface and rain water.

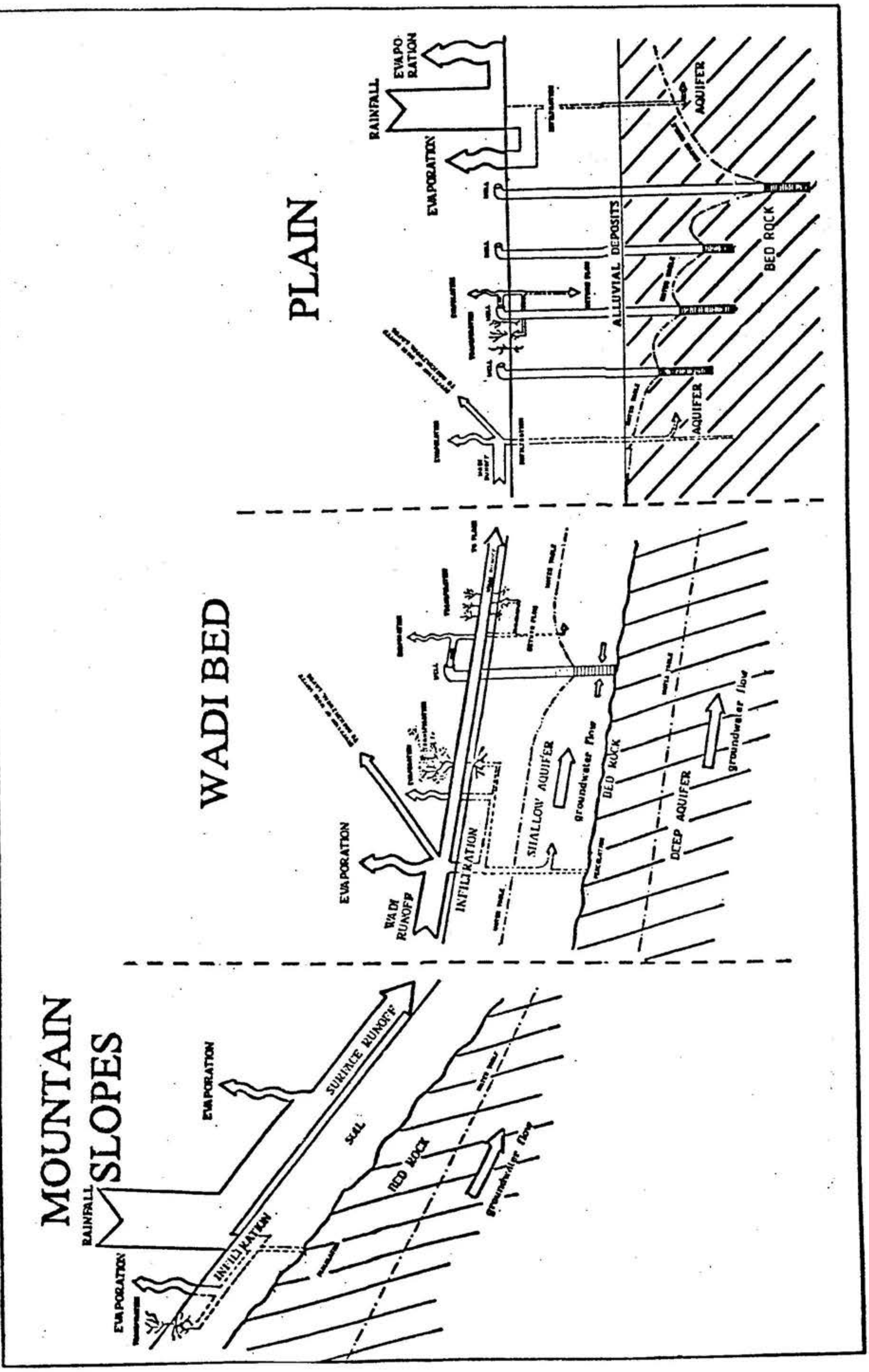
Fig. 3.1, the hydrological cycle, is a schematic model of the movement of water in the Al Hamra Plain and its catchment area.

The water table in the Al Hamra Plain is too undulating for the determination of a clear direction of groundwater movement.

3.2.2 Bedrock

Limestones
The Amran Series, principally composed of limestones, marls and some shales, is generally considered as a poor aquifer. Higher permeabilities are only (sometimes) encountered in fractured zones. Interbedded shales and marls act as aquicludes or aquitards. There exists no evidence of an extensive system of solution openings (karst). It can be expected that the frequency of fractures and faults, and thus permeability, decreases with depth.

Fig. 3.1 *Hydrological cycle*



Using the same pumping equipment, average well yields of wells tapping the limestone are generally much lower than when pumping from the alluvium. Some aquifer tests in the Amran Limestone Series were carried out in the Amran Plain. Here Tibbits and Aubel (1980) drilled six boreholes in the limestone. Only one well (near Menjidah) gave a high yield (14.5 l/s); the other five boreholes did not give substantial discharges.

Volcanics
Most of the test boreholes drilled in the volcanic deposits during the above-mentioned study proved to be dry. Water-bearing and water-transporting properties might only be expected in fractured zones, along dykes and bedding planes and in scoriaceous (tuff) intercalations.

Test holes drilled in the basaltic volcanics near Raydah (northeast of Amran) were dry, even at depths of 60 m below the local water level in the alluvium. The volcanics in the study area are all situated above the general water table and therefore do not function as aquifers.

4 GROUNDWATER - GENERAL

4.1 DISTRIBUTION OF WELLS

Fig. 4.1 shows the locations of the wells visited during the month of December 1991. A total of 38 wells were inventoried, the lowest number of wells found in all the target areas. It can be assumed that about 90% of all existing wells were surveyed and that the remaining 10% are evenly distributed over the total area. There are large areas with a low density of wells.

Several parts of the plain are not suited for agriculture, because the topography is irregular and/or inferior soil properties dominate, as in the area west and southwest of Dhu Darwan.

In a large area in the southeast part of the plain no wells were encountered. Near the borders of the plains and in the south, in the two tributary valleys of the Wadis Mughdir and Adaf/Awjar, spate irrigation dominates, in some places supported by pumped irrigation.

4.2 NUMBER OF WELLS

Of the 38 wells located, four (10.5%) were not in operation: one was dry and three did not have a pump and/or engine. On the assumption that about 90% of the wells were visited, the total number of wells has been estimated at 42, of which 89% or 40 would have been operational at the time of the well survey.

Most dug wells have fallen dry during the last ten years because of decreasing water levels. Since the introduction of drilled wells the water levels have fallen to such extent that manual digging and deepening of wells has been forced to stop, except in some areas with shallow (perched) groundwater tables such as in the borders of the plain and in the upper parts of the wadi channels. Only the richer farmers could afford to drill deeper wells to reach the lower water levels, but groups of farmers have started to cooperate to finance the drilling of a shared deep well.

In the past water was abstracted by buckets lifted by donkey power; now all these wells are pumped by means of turbine lineshaft pumps. Only manually dug wells with high water levels are fitted with low power centrifugal pumps. Figs. 4.2 and 4.3 show the total number and the cumulative number respectively of the wells that were still operational in 1991, and were drilled during the period from 1981 (the oldest well located was drilled in 1981) to 1991. It must be noted that these are net figures: the number of drilled wells minus the number of abandoned wells. Perhaps drilling started before 1981, but if so these wells have since been abandoned.

Serious groundwater development in the Al Hamra Plain started only in 1981, about 19 years later than in the Amran Valley. The main drilling activity occurred in the period from 1985 to 1991. A first impression is that the maximum yearly drilling rate has not yet past, as it has for example in the Amran Valley.

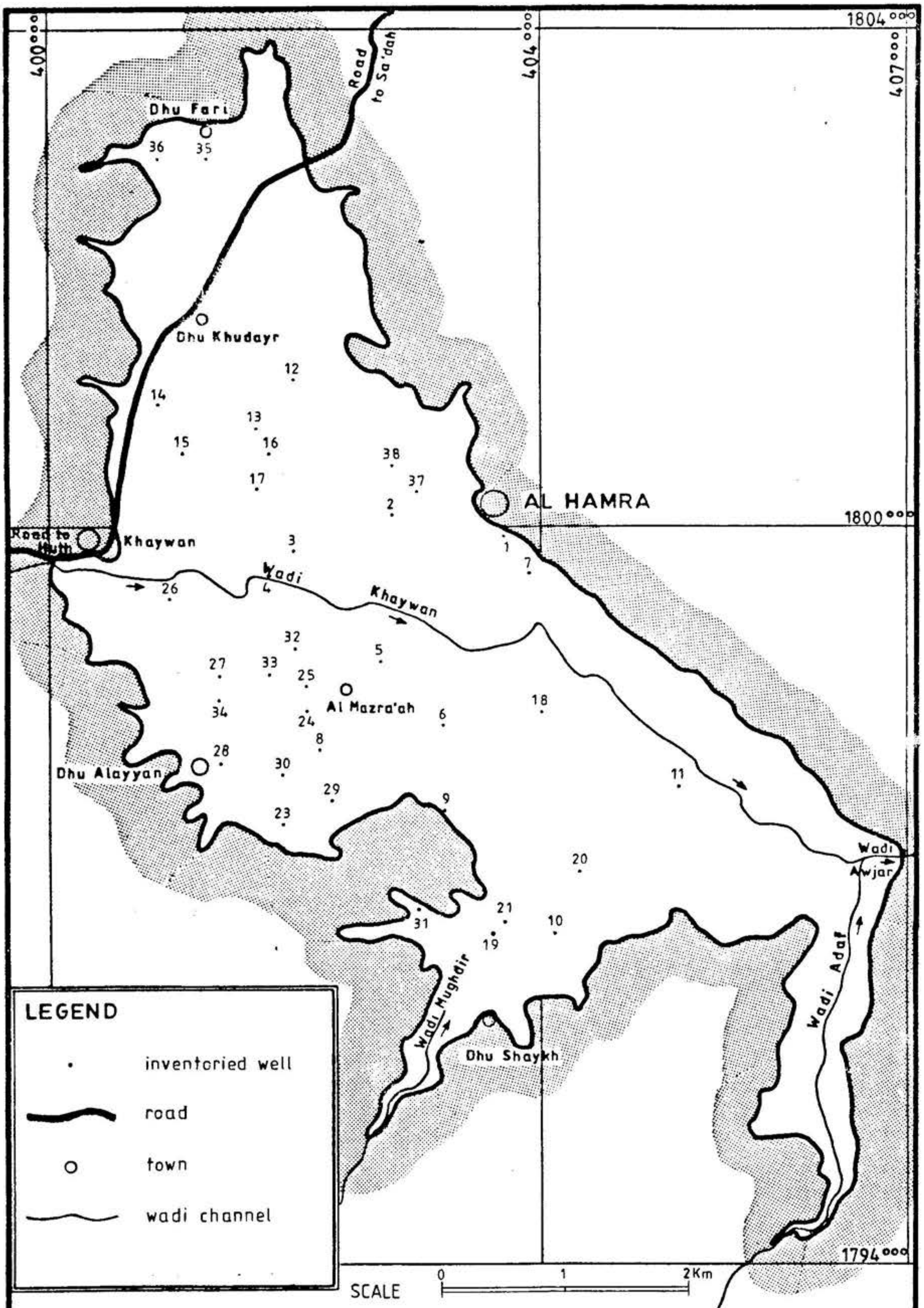
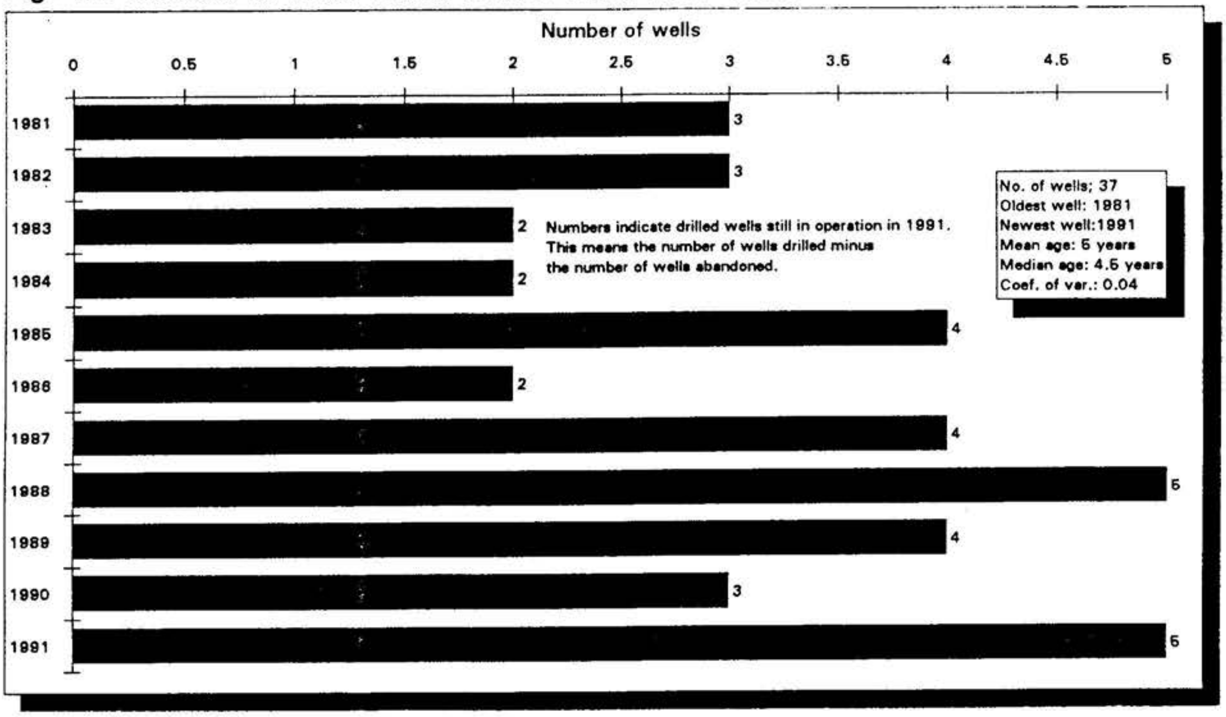


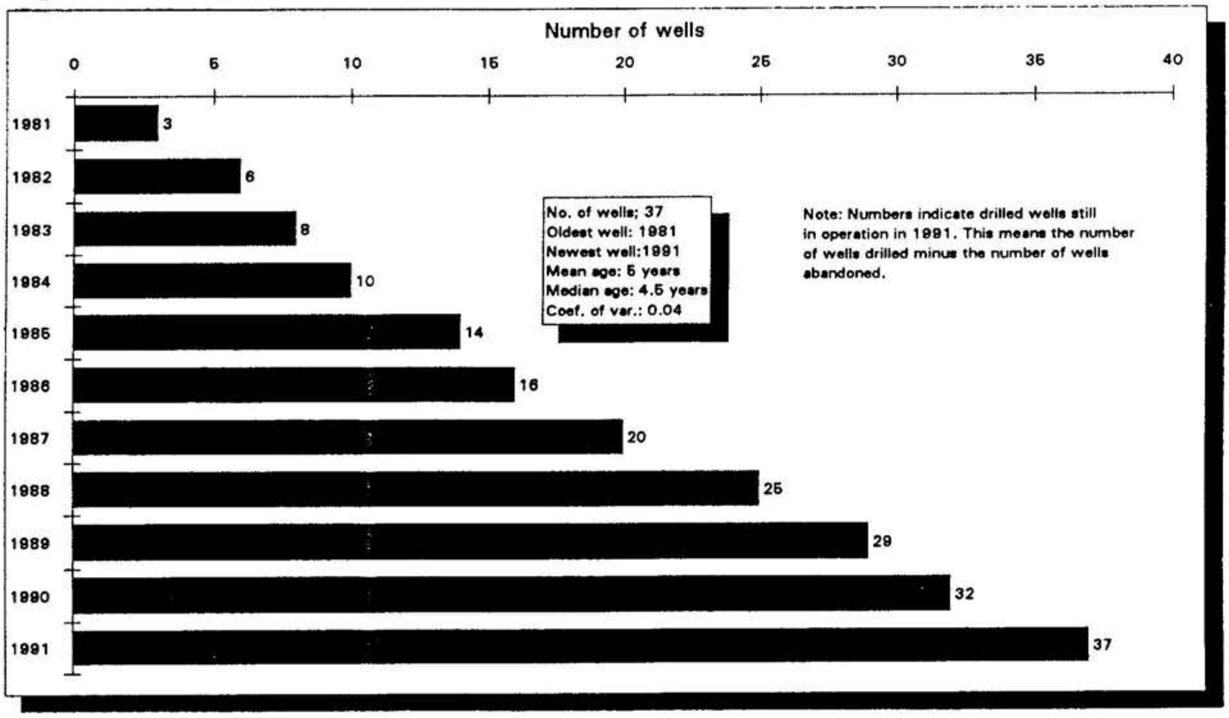
Fig. 4.1 Map of the locations of the inventoried wells

Fig. 4.2 *Number of Wells Drilled in the Period 1981-1991*



Statistical analysis of the cumulative distribution of the number of wells constructed during the years shows that 50% of all the existing wells were drilled after 1986, and the average well age is 5 years. During the last 10 years, only one well was reported to have been deepened.

Fig. 4.3 *The Cumulative Number of Wells Drilled in the Period 1981 - 1991*



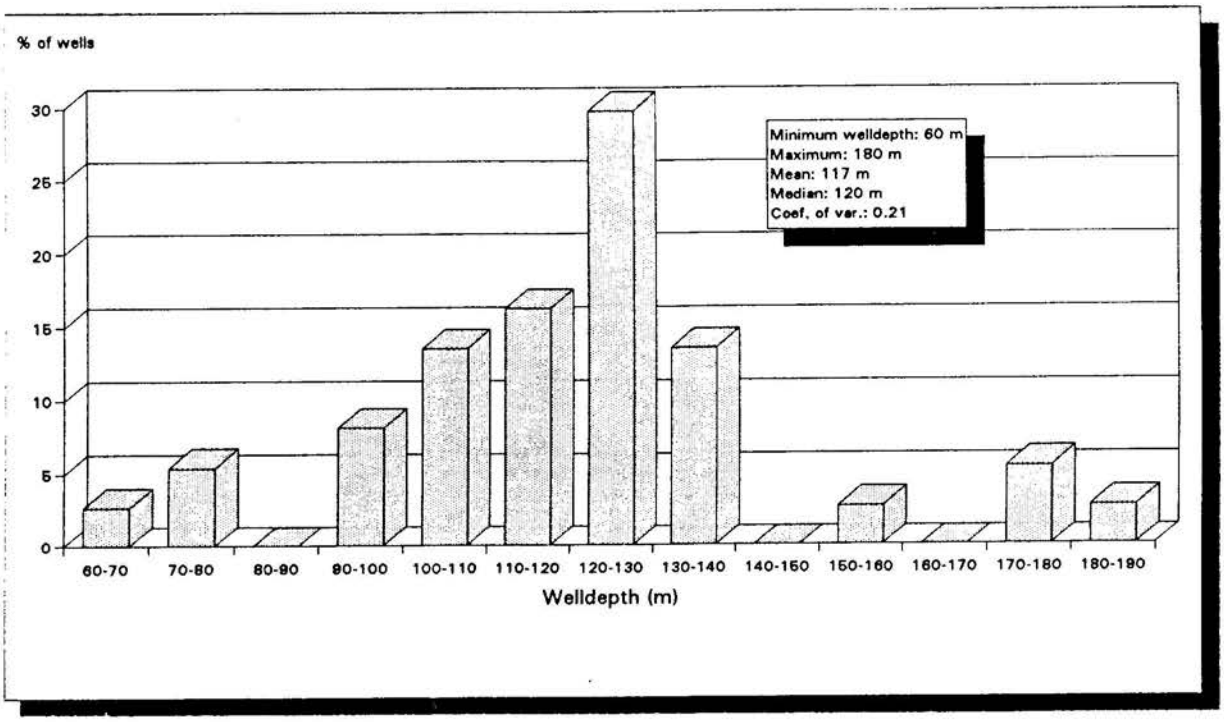
4.3 WELL CHARACTERISTICS

All the wells surveyed were drilled wells. As mentioned above, only one well was reported to have been deepened (once), relatively a very low figure when compared with the Amran Valley where about 23% of the wells have been deepened one or more times.

The drilling method used was predominantly rotary, although some older wells were drilled with the cable tool method. Practically all the wells are completely cased with steel pipes of six metres long. Casing diameters differ significantly from the diameters observed in the nearby Al Harf Plain. Here large (10") diameter casings dominate (62%), followed by 8" (27%), and 12" (27%)). The lower sections of casings are slotted.

Fig. 4.4 shows the distribution of the well depths in the plain. The depth to the water, in general, is not very large; it ranges from 45 to 60 m only (see also figure 4.15). As a consequence, well depths also are not very large. Well depths range from 60 m up to 180 m, although most wells have a depth between 90 and 140 m (the coefficient of variation amounts to a low 0.27). The average depth equals 117 m.

Fig. 4.4 *Distribution of Well Depths*

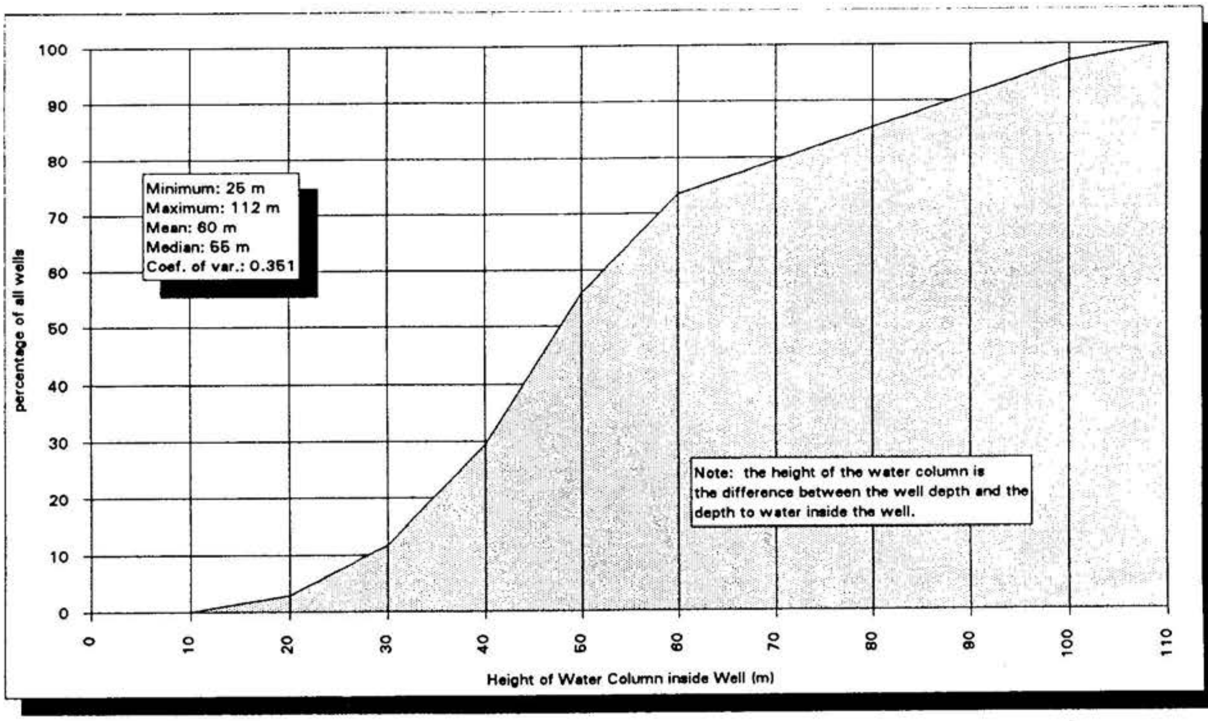


4.4 WATER COLUMN HEIGHTS

One way illustrate to indicate to what extent the wells have been prepared for falling water levels in the near future, in other words how much water column is available inside the wells, is to define and analyse the "water column height" of the well. This is the difference between the well depth and the depth to the static water level. By analysing the cumulative distribution plot of the water column heights of all the wells the percentage of wells that will fall dry when the water table drops by a certain amount can be deduced.

Fig. 4.5 shows that the depths of most wells in relation to water level are such that, should there be a substantial drop in water level, few wells will fall dry. The water column heights range from 25 to 112 m; the average aquifer penetration is 60 m. If the groundwater were to drop 30 m over the whole plain then about 11% (Amran Valley 9%) will fall dry. This percentage would increase to a minor extent when the drawdown brought about by pumping is also considered.

Fig. 4.5 *Cumulative Distribution of Heights of Water Columns*



4.5 PUMPING EQUIPMENT

Water is pumped typically by vertical turbine (lineshaft) pumps coupled via crossed webbing belts to diesel engines. No wells were found with electro-submersible pumps.

A high level of standardization in engine and pumping equipment was observed: 79% of the pumps were supplied by Caprari (model V16P/3L/20A with 20 bowls). The pump column diameter was mostly three and four inches (in 58% and 31%, respectively of all wells).

The same level of standardization was noticed among the engines that power the pumps: Japanese Yanmar (Yahama) engines, models NP22Y, NP28 and NP30 comprise 69% of the total and Kuboto 10%. The engines have, in most of cases, capacities ranging from 23 to 35 horsepower.

The wells and pumps in the Al Hamra Plain are new (the oldest well and pump date from 1981). Most wells are still equipped with the first pump set.

Fig. 4.6 *Number of Pumps Installed in Relation to the Number of Wells Constructed*

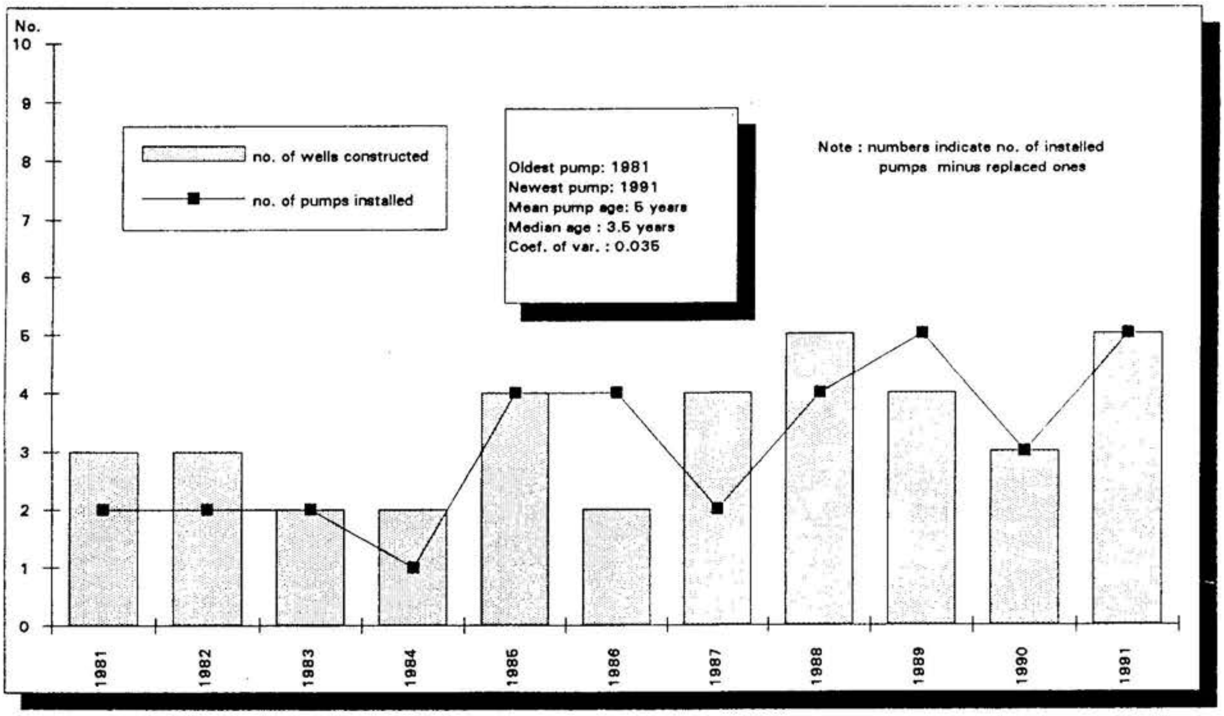
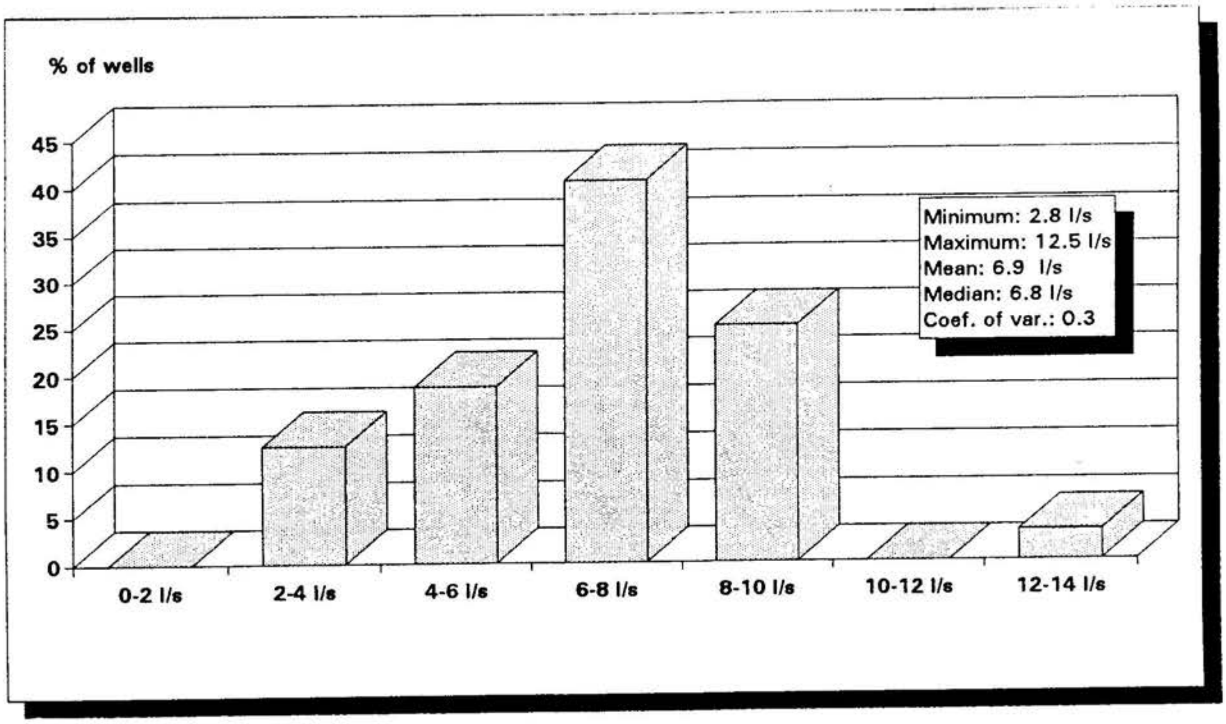


Fig. 4.7 *Distribution of the Well Discharge Rates (l/s)*



4.6 WELL YIELDS

Well yields are moderate: the mean (6.9 l/s) is about the same as in the Amran Valley (6.5 l/s). Well discharge rates vary from 2.8 l/s up to 12.5 l/s. The distribution of well yields observed in the Al Hamra Plain is presented in Fig. 4.7. All the wells are abstracting water from the limestone, which is of low permeability. The magnitude of the well yield is determined by several factors, ie. the capacity of the pump, well efficiency, screen length, depth to water, and aquifer parameters like transmissivity and storage coefficient. In the Al Harf Plain (north of Al Hamra Plain, in the same hydrogeological setting) well yields are much lower (average 3.5 l/s).

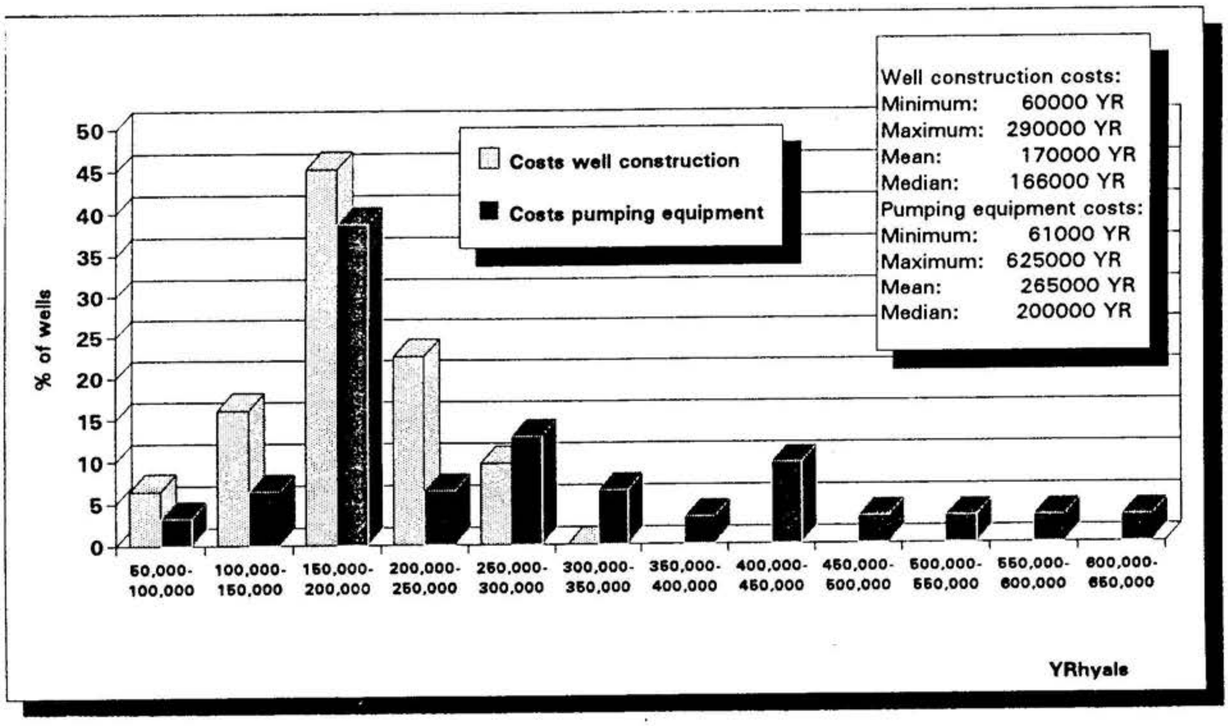
Drawdowns during pumping are moderate: in the order of 2 m at a discharge rate of about 3 l/s up to 8 m at a yield of 10 l/s.

The specific discharge, defined as the discharge divided by the well drawdown, 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, only a few measurements of the dynamic water level could be carried out.

4.7 COSTS OF WELL CONSTRUCTION AND PUMPING EQUIPMENT

Data on costs of well construction and for the purchase and installation of the pumping equipment are presented in Fig. 4.8. The costs of well construction include the drilling of the well, the installation of the casing, the screen (slotted pipes), the gravel pack and the development (air lift) of the well.

Fig. 4.8 *Distribution of Costs of Well Construction and Pumping Equipment*

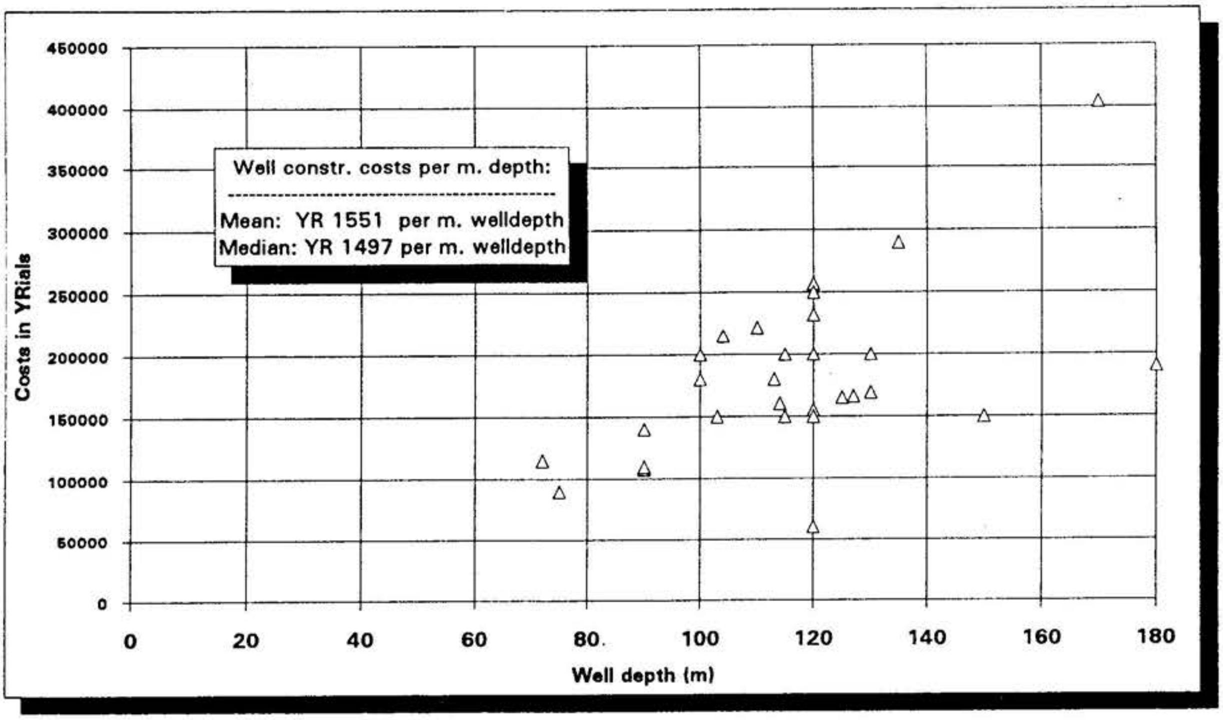


The pumping equipment costs involve a more variable package of items. In all cases the costs of the pump and the engine are included. In many cases a small stone house is constructed around the engine and well. Most farmers built a reservoir where the pumped water is collected and from where it is distributed to the field. The costs may also include for installation of pipes and tubes to convey the water.

The figure also shows the distribution of well construction and pumping equipment costs. Well construction costs range from YR 60 000 (a 120 m deep well, drilled in 1985) to YR 290 000 (a 135 m deep well, drilled in 1991), clearly indicating the increase of well construction costs over time. Median well construction costs were YR 166 000. Pumping equipment costs have a much larger variation: from YR 61 000 to YR 625 000, with a median of YR 200 000. Well construction costs are lower than in the Amran Valley (mean YR 228 000). As a consequence of the harder medium to be drilled (limestone instead of alluvium) the opposite might have been expected, although the more complicated arrangements for keeping an alluvial borehole open before the casing is installed could account for the difference.

However, pumping equipment costs are higher than in the Amran Valley. This can be partly explained by the younger age of the wells and pumps in the Al Hamra Plain (more recent prices).

Fig. 4.9 *Relation of Well Depths to Well Construction Costs*



In Fig. 4.9 the costs of well construction, excluding the costs of pumps and related equipment, are plotted against the well depth. It must be remembered that these costs are costs at the time of construction and that the data concern wells drilled during the period from about 1981 to 1991. As a consequence of inflation, the mean real costs (1991 YRials) would be somewhat higher. In general, the average price per metre drilled well for this period is YR 1550.

Fig. 4.10 *Seasonal Distribution of Daily Pumping Hours*

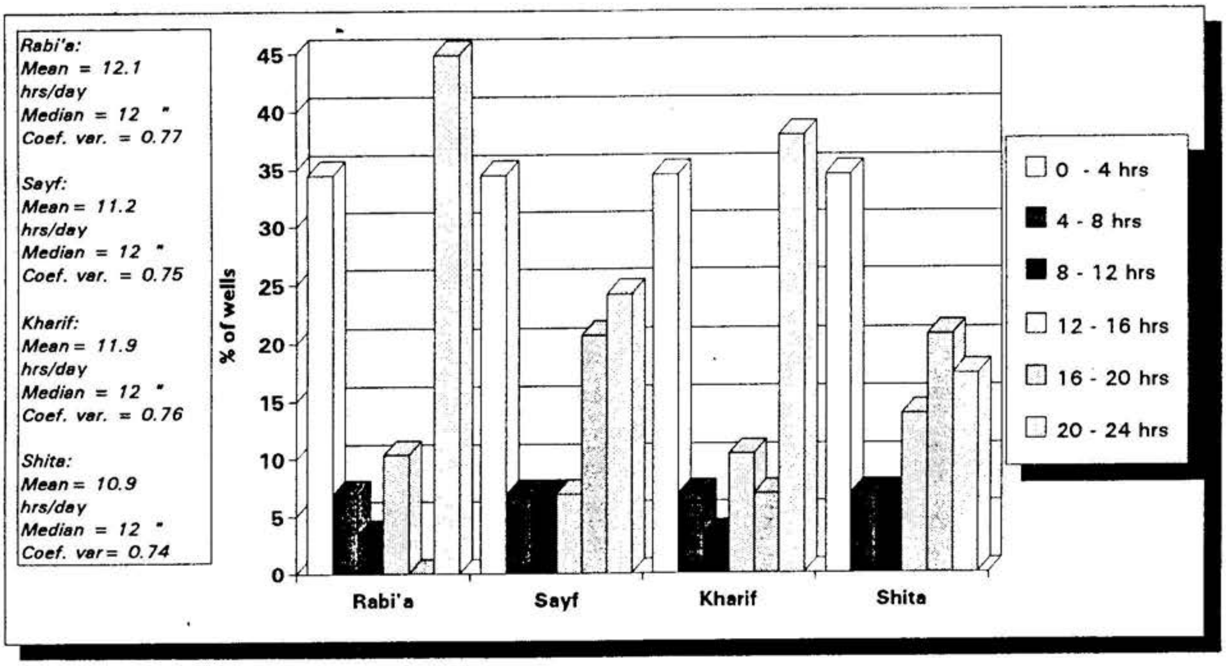
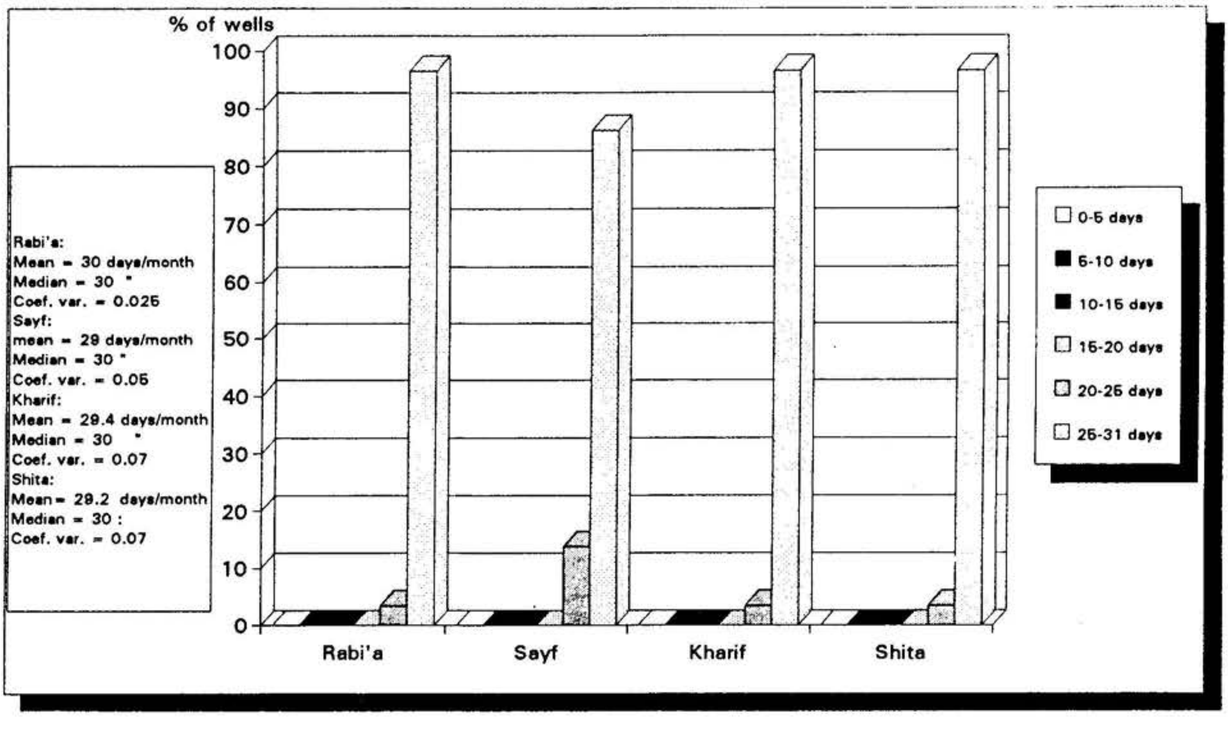


Fig. 4.11 *Monthly Number of Pumping Days*



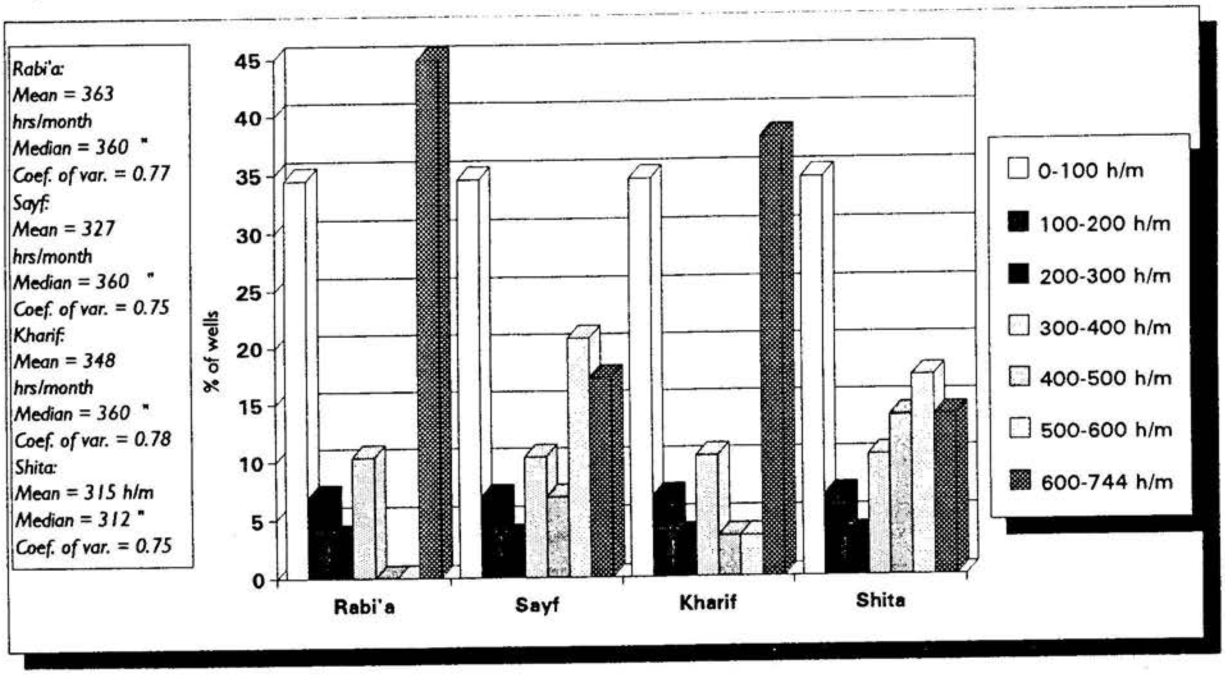
4.8 PUMPING SCHEDULES

The average farmer in the Al Hamra Plain pumps groundwater for 11 to 12 hours per day, throughout the seasons; the mean yearly number of pumping hours per day is

11.5. Pumping activities are highest during Rabi'a[1] (mean 12.1 hrs/day), followed by Kharif (mean 11.9 hrs/day), Sayf (mean 11.2 hrs/day) and Shita (mean 10.9 hrs/day). Fig. 4.10 shows the seasonal distribution of daily pumping hours. About 4% of the farmers operate the pump 24 hours per day.

Over the whole year, the average number of pumping days per month was 29.4 days (see Fig. 4.11); and pumping hours, 338 per month (see Fig. 4.12).

Fig. 4.12 *Monthly Number of Pumping Hours*



4.9 GROUNDWATER ABSTRACTION

To allow assessment of total groundwater abstraction in the Al Hamra Plain a fair estimate had first to be made of the total number of operational wells. At 27 wells (of the total of 38 wells visited) the discharge could be measured and data collected on the pumping schedule. For the remaining 11 wells these data could not be collected, because the well was dry, there was: no pump and/or engine no diesel, no oil, a broken pump/engine; or just because nobody was there to switch on the pump and/or to give information on pumping activities.

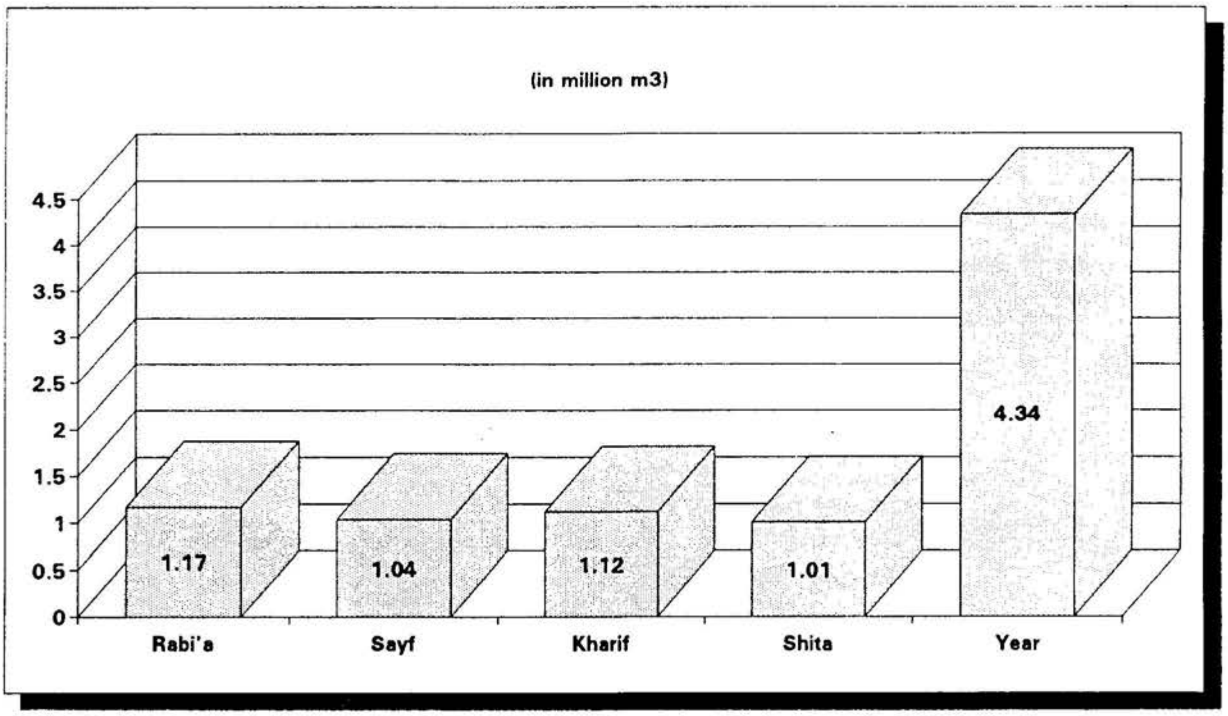
For the calculation of the yearly total discharge in the plain, the 10.5 % of the wells permanently out of order were not taken into consideration. Assuming the real total wells to be 42, and applying the same percentage of fall out, then about 40 wells would have been operational.

[1] The seasons in Yemen are Rabi'a, Sayf, Kharif and Shita, corresponding approximately with Spring, Summer, Autumn and Winter.

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 5.5% of the time. This percentage was taken into account when calculating the seasonal and total yearly abstracted groundwater volumes.

In Table 4.1 and Fig. 4.13 are calculated and presented the seasonal groundwater abstractions. A yearly total of approximately 4.34 million m^3(Mcm) of groundwater was abstracted in the Al Hamra Plain during 1991.

Fig. 4.13 *Volumes of Groundwater Abstraction in 1991 (Mcm)*



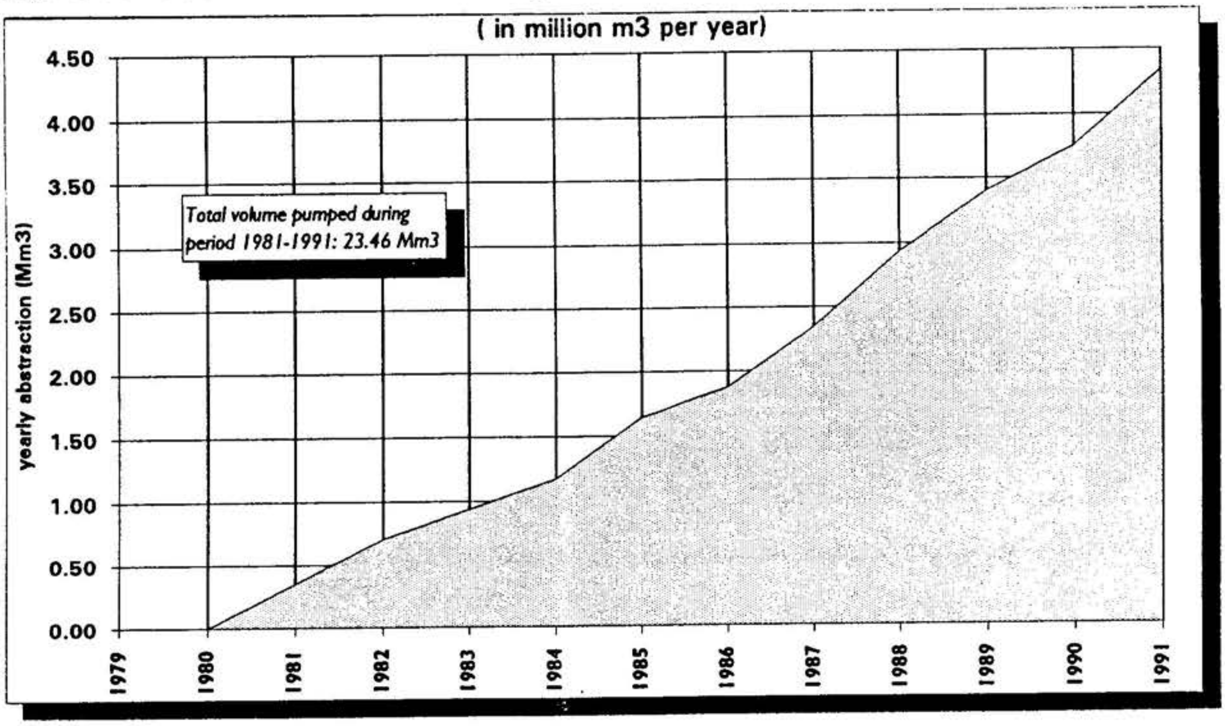
The volumes abstracted are 1.17, 1.04, 1.12 and 1.01 Mcm for Rabi'a, Sayf, Kharif and Shita, respectively.

Fig. 4.14 displays the yearly increase in groundwater abstraction during the period 1980 to 1991. In contrast with most other plains in the NORADEP Project Region the rate of increase in the yearly abstracted volume has not diminished during the last five years. A (very rough) estimate of all the groundwater pumped in the Al Hamra Plain, using figures from 1981 (when abstraction became significant) to 1991, is about 23 million Mcm which represents a water layer 0.92 m deep over the whole Al Hamra Plain (25 km^2). Expressed in terms of lost aquifer, assuming an average effective porosity (specific yield) for the limestone aquifer of 3%, the volume pumped during the 10 years corresponds to a lost saturated aquifer thickness of 100/3 * 0.92 = 31 metres over the whole plain.

Table 4.1 *Volumes of Groundwater Abstracted in 1991*

	Rabi'a	Sayf	Kharif	Shita	Year
Groundwater abstracted per well (in 1000 m³)					
Mean	29.2	26.1	28.1	25.2	108.5
Median	25.1	23.0	25.1	20.9	91.9
Minimum	15.3	15.3	15.3	15.3	61.2
Maximum	63.1	63.1	63.1	63.1	252.6
coef.of variance	0.82	0.80	0.83	0.80	0.81
Total volume of groundwater abstracted in Mcm	0.79	0.7	0.76	0.68	2.93
Based on no. of wells	27	27	27	27	27
Total volume of groundwater abstracted in Mcm *(extrapolated, assuming a total of 40 operational wells*	1.17	1.04	1.12	1.01	4.34

Fig. 4.14 *Estimated Increase in Yearly Groundwater Abstraction 1981 to 1991*



4.10 DEPTH TO GROUNDWATER

Data on groundwater levels were collected, either by measuring with a sounding tape, or by speaking to the well owner. In many cases it proved to be rather difficult to measure the groundwater level, because some of the wells are completely sealed with masonry, or because the space between the pump column and the casing is so small that the sounding probe could hardly pass through it.

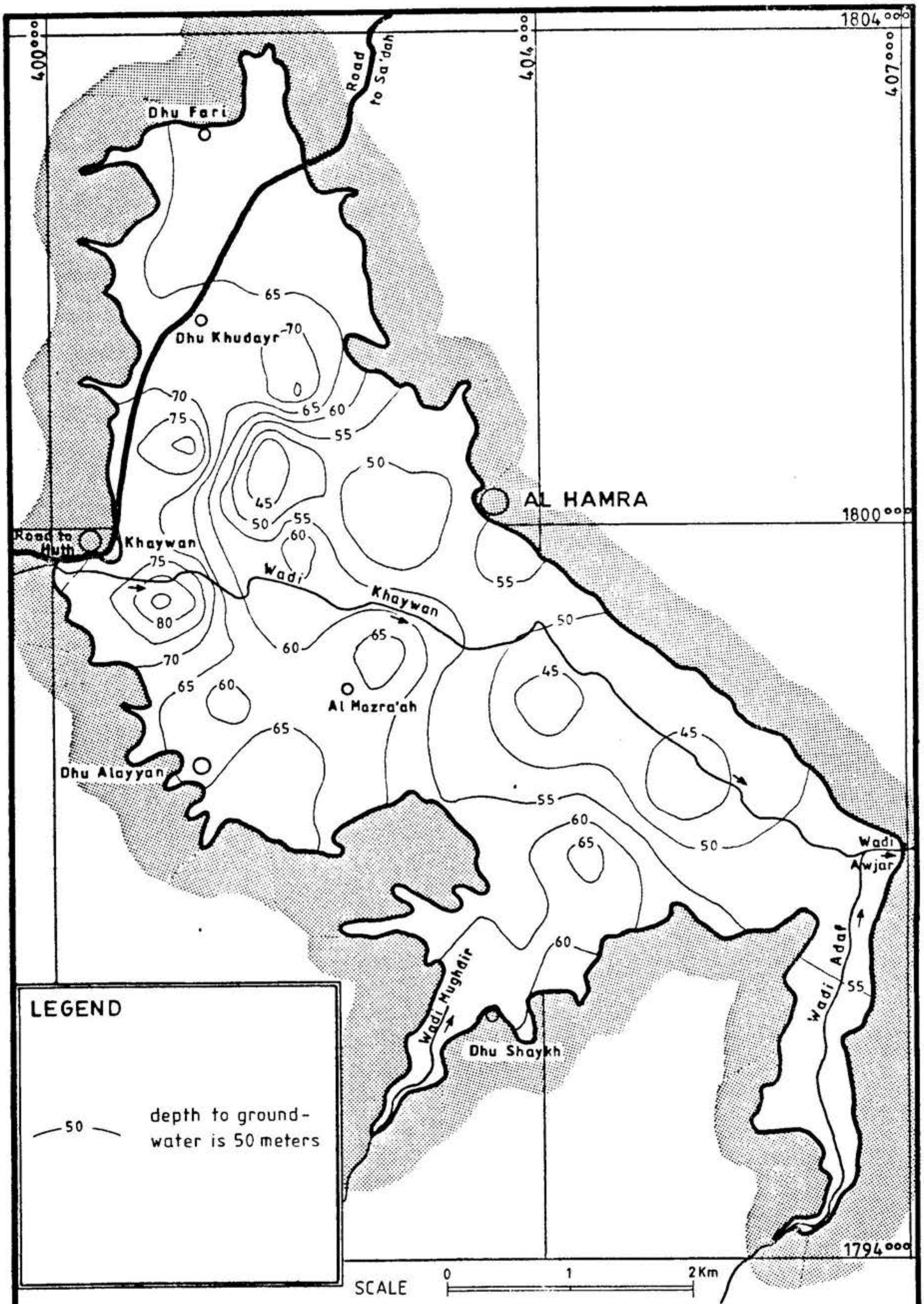


Fig. 4.15 Map of the depth to groundwater

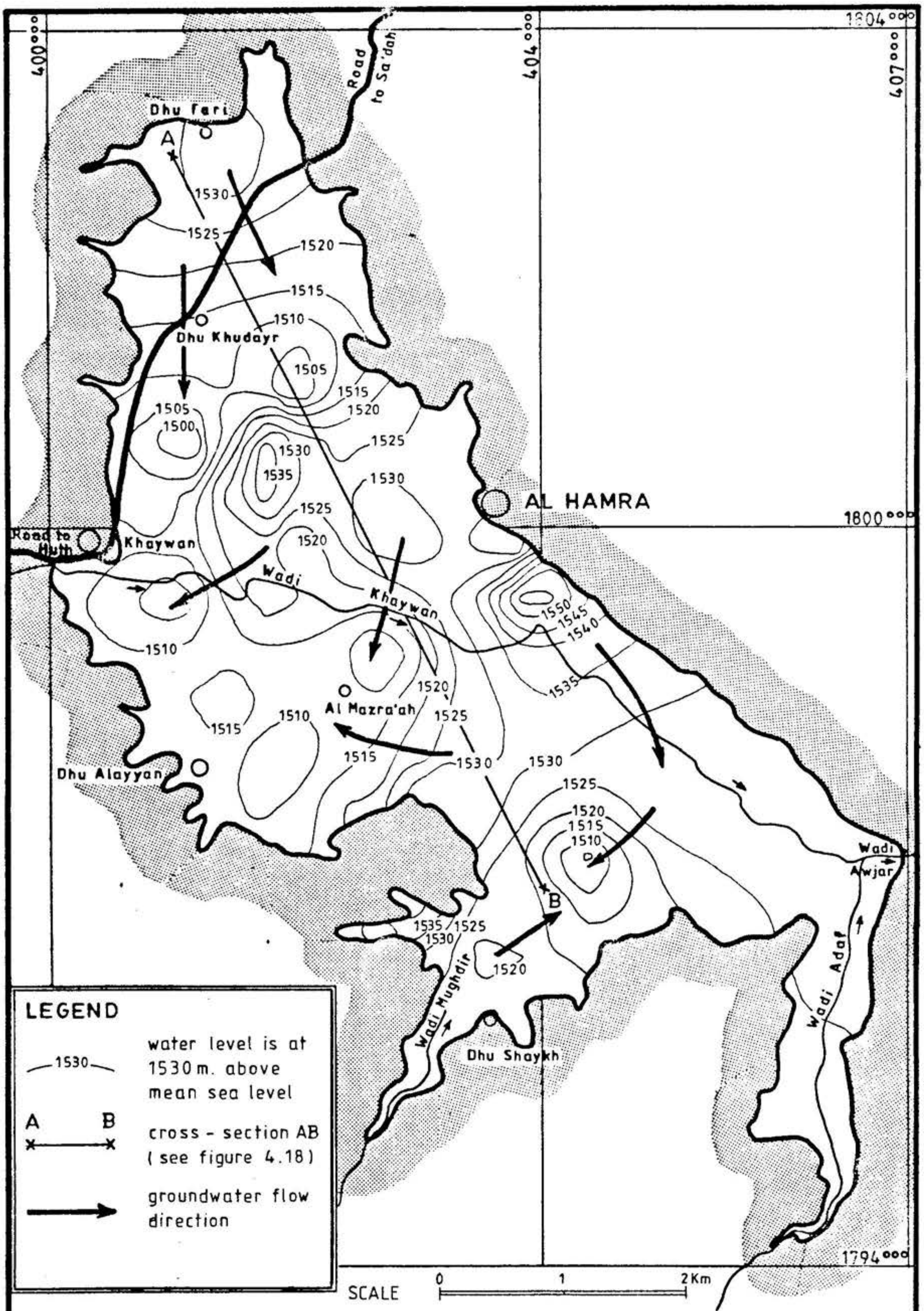


Fig. 4.16 Map of the piezometric groundwater level

During the well inventory several tapes were lost, stuck in the annular space between the two pipes. This was why, in many cases, the farmer had to be questioned about the water depth. The depth to the water table was usually approximately known to him (expressed in the number of three metre long pump column pipes). Many farmers also measured the water level regularly with a marked cord. However, practically all farmers knew the depth of the pump (expressed in the number of pump column pipes above the pump). Because this figure appeared to be a more reliable depth indicator than the depth to water given by the farmers, a contour map of the depth to the pump has been composed, as a quality control. The pattern of depths to groundwater almost completely corresponded with the pump depth contour map.

Depths to groundwater, in general, have small range: from 25 m (a well between Al Hamra and Khaywan) to 90 m (a well 500 m southeast of Khaywan). From Fig. 4.15 it can be seen that, in general, the larger water depths occur in the north and northwest of the plain, where they range from 60 to 90 m. Around Khaywan in particular water depths are large; but are lower in the central and southeast part of the plain, where they vary between 40 and 60 m.

4.11 GROUNDWATER PIEZOMETRIC LEVEL

A piezometric map (Fig. 4.16) was composed by contouring the piezometric levels, being the difference between the depth to of groundwater and ground surface elevation above mean sea level at each well site. Thus, the piezometric contour lines indicate the groundwater level, expressed in metres amsl.

Piezometric levels show very little variation over the Al Hamra Plain. Their range is between 1510 and 1530 m. The natural groundwater flow was judged to be directed to the southeast. However, several cones in the water level caused by large abstractions disturb the general groundwater flow pattern. Several depressions in the groundwater table were apparent around Khaywan town.

Fig. 4.18 shows a north-south cross-section, the location of which is given in Fig. 4.16. Included in this section are the surface elevation, the groundwater level and the alluvium-limestone contact (see also Fig. 4.17); all three units are plotted in m amsl. The groundwater table is situated in the limestone. This is true for the whole Al Hamra Plain and means that all the groundwater is being abstracted from the limestone aquifer.

It was not possible to measure the hydraulic gradient in the plain because of the undulating nature of the piezometric surface. Considering the levels in the extreme northwest and southwest of the plain then there is a drop of only five meters over a distance of eight km.

The groundwater table (or piezometric surface) can be considered as an undulating surface, characterized by several peaks and depressions. However, the pattern of this surface is not fixed in time: in some places water levels are lowered by pumping, elsewhere water levels rise as a result of switching off pumps, resulting in a continuously undulating water table 24 hours per day.

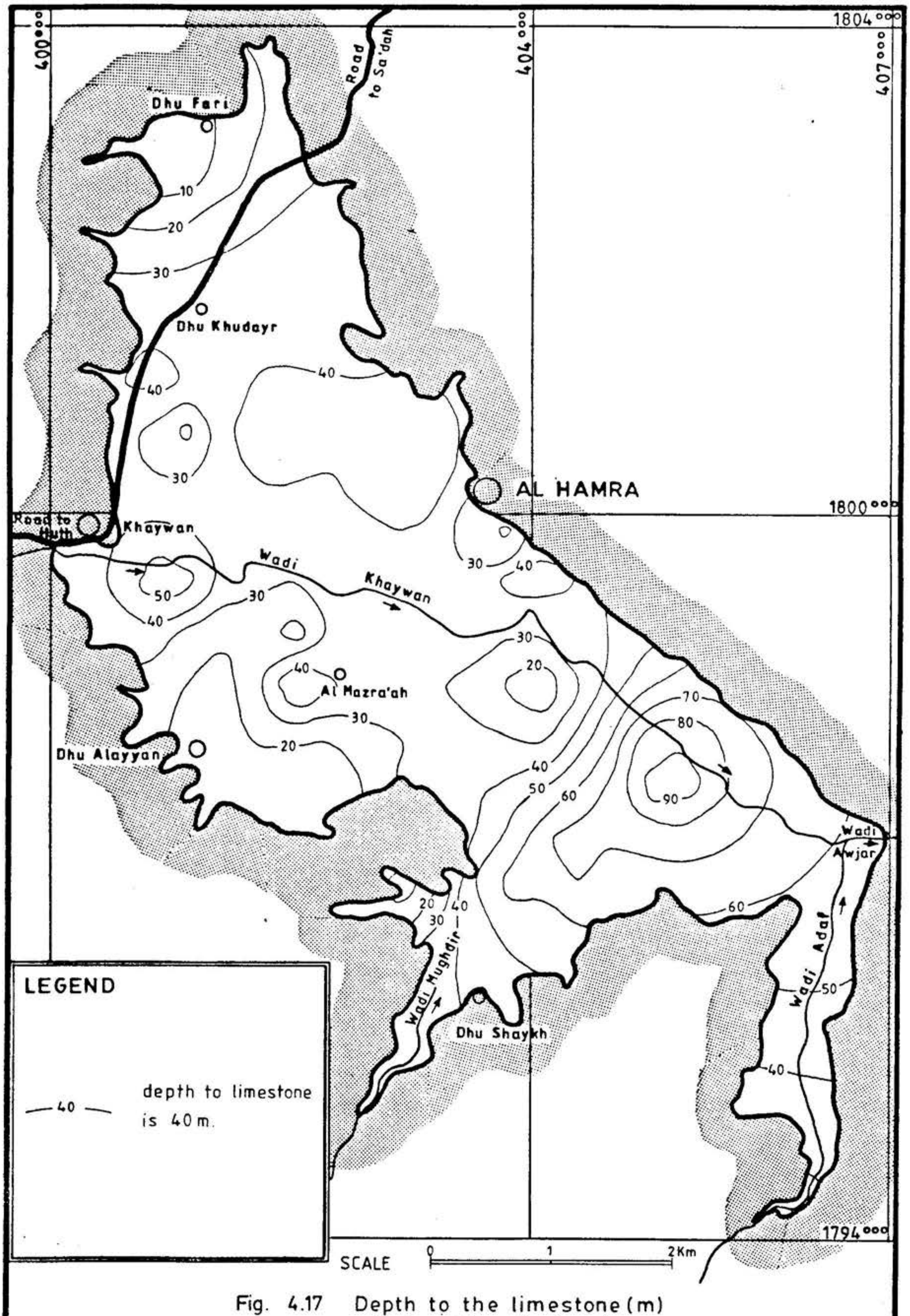


Fig. 4.17 Depth to the limestone (m) (below the alluvium)

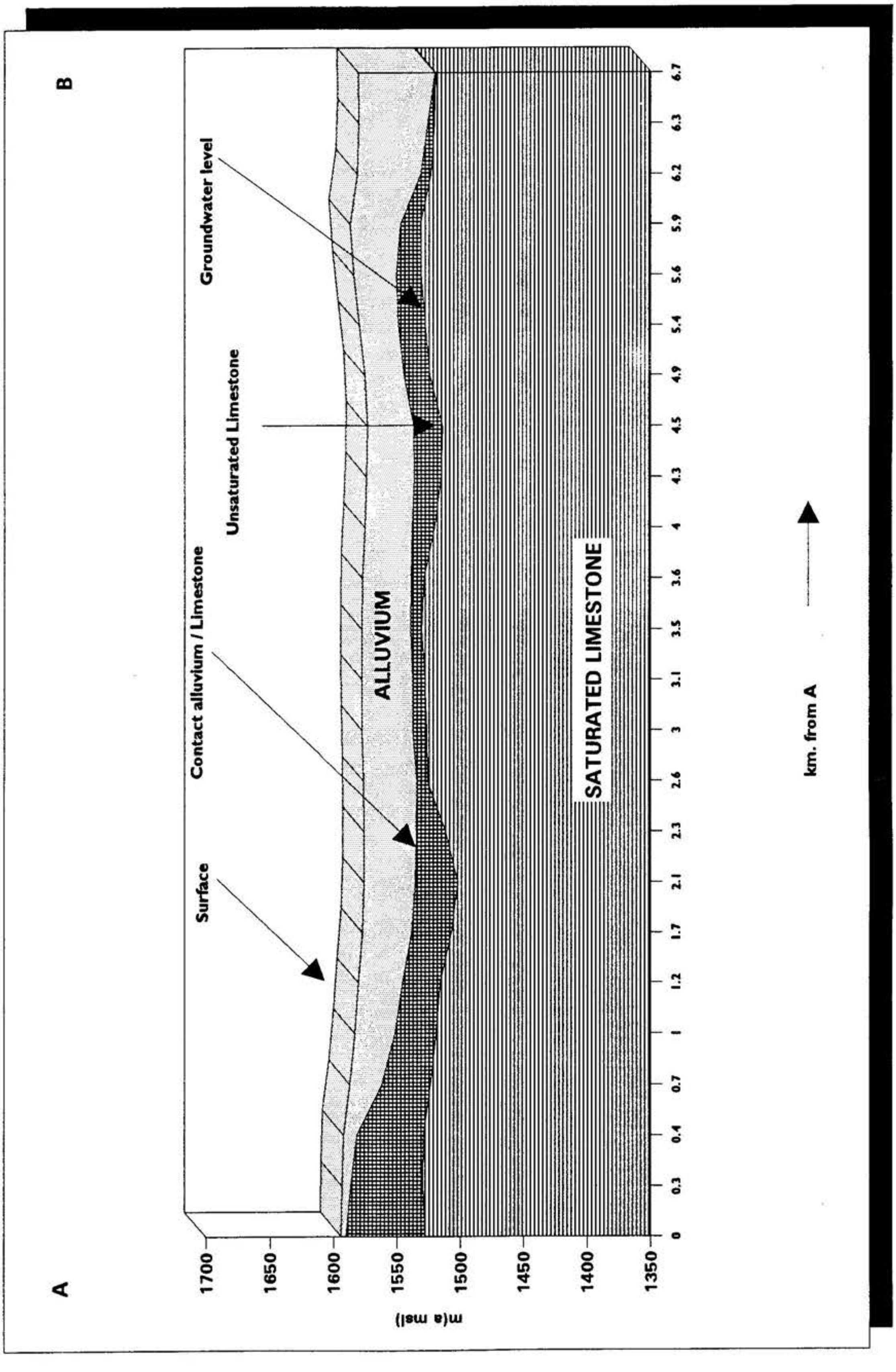


Figure 4.18 Cross-section A-B (for location, see fig. 4.16)

4.12 LOWERING OF GROUNDWATER LEVELS

To enable an analysis to be carried of the trends of groundwater levels over time, time series of groundwater depths are needed. However, no long term data on water levels were available. Serious pumping from drilled wells started here only at the beginning of the 1980s, about 20 years later than in the Amran Valley; also, the density of well does not give as much cause for alarm as in the Amran Valley. However, the hydrogeological situation here is not promising: just as in the Al Harf Plain water is being tapped from a limestone 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, which signifies that a relatively large drop in groundwater level can be expected in this area as a consequence of 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 wells the EC of the pumped water was measured in microS/cm at 25°C microS/cm. The measurements not only gave an indication of the areal distribution of water quality, but could also indicate its variation with water depth, because the measured value is often related to the depth from where the water is pumped.

Fig. 4. 19 *Distribution of Electrical Conductivity*

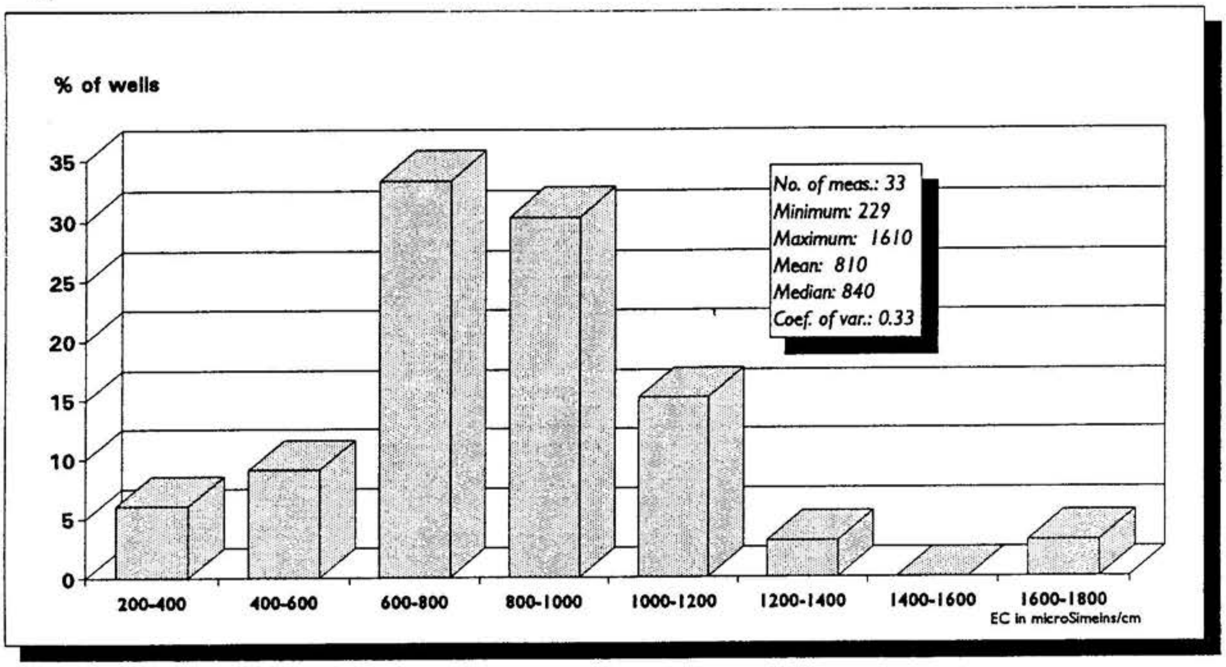


Fig. 4.19 shows the distribution of the electrical conductivity values for all the measurements carried out in the Al Hamra Plain. The minimum value was 229 microS/cm, the maximum 1610 and the mean amounted to 810. Thus the

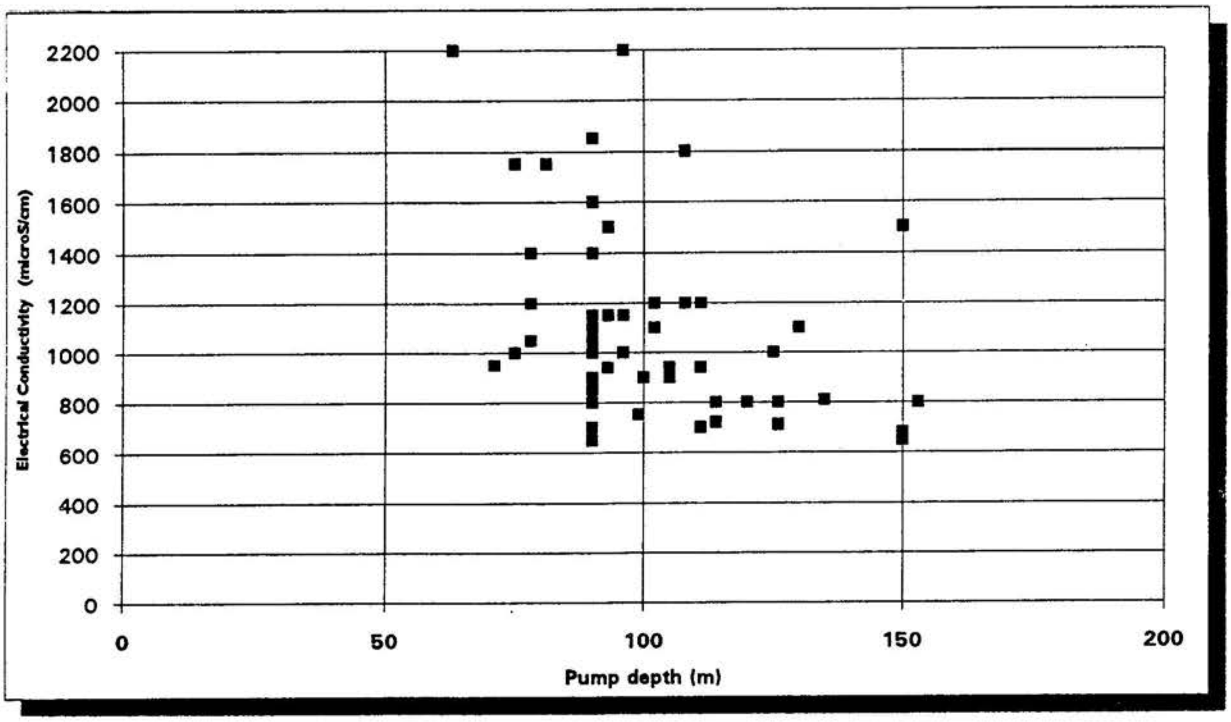
groundwater is moderately mineralized. The mean EC-value of all the measurements is significantly higher than the mean calculated for the Amran Valley (571). This may be because the water originates from the limestone, where low flow rates and thus long travel times could have caused the rather high degree of mineralization.

The coefficient of variation of the measured EC-values was 0.33. This represents a measure of deviation from the mean (standard deviation/mean), and implies, when assuming a normal distribution of all the values, that 67% of the EC-values are within the range (1-0.33) * mean and (1+0.33) * mean or 67% of the measurements have EC values ranging from 543 to 1077 microS/cm.

The measured values have been contoured and presented in Fig. 4.20. The most saline groundwater is present in the northwest and southeast part of the plain (above 900 microS/cm). Probably in these localities water is being tapped from saline shaley layers in the Amran Limestone Series. In the central plain more moderate values were found between 400 and 700 microS/cm.

Fig. 4.21 shows the relation (or, rather, the absence of relation) between the measured EC and the depth to groundwater. There is no indication that salinity increases with depth. High salinity seems to be caused only by the presence of shaley layers in the limestone aquifer.

Fig. 4.21 *Relation of Electrical Conductivity to Pump Depth*



4.14 GROUNDWATER TEMPERATURE

At most of the wells that were visited, the temperature of the water was measured during pumping. The distribution of the temperature values is presented in Fig. 4.22.

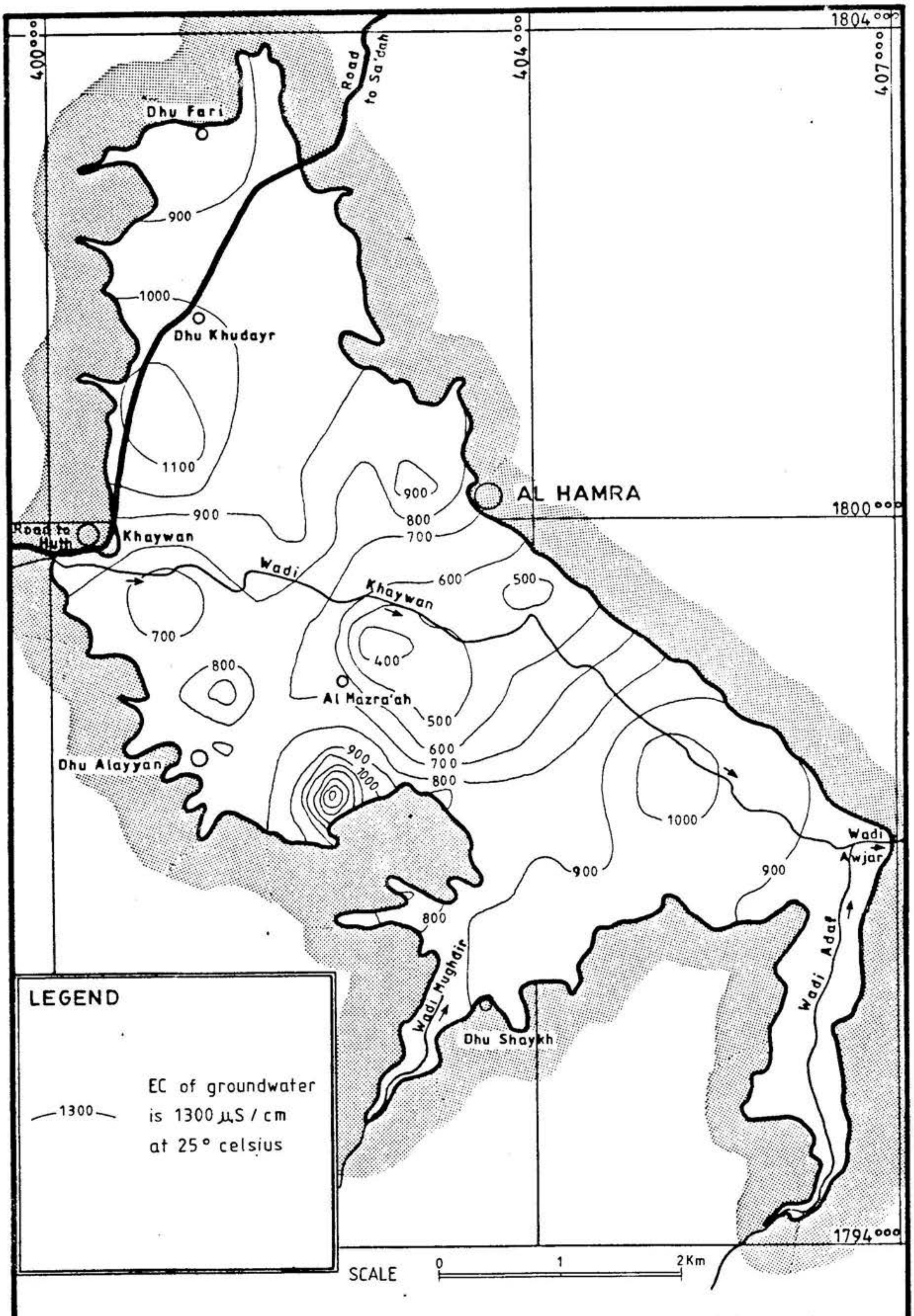


Fig. 4.20 Map of the groundwater electrical conductivity (EC)

Temperatures range from 23 to 29°C, with a mean and a median of about 26°C. Dispersion is low: the coefficient of variation is only 0.05 and most measurements show values that range from 24 to 28°C .

Fig. 4.22 *Distribution of Groundwater Temperature*

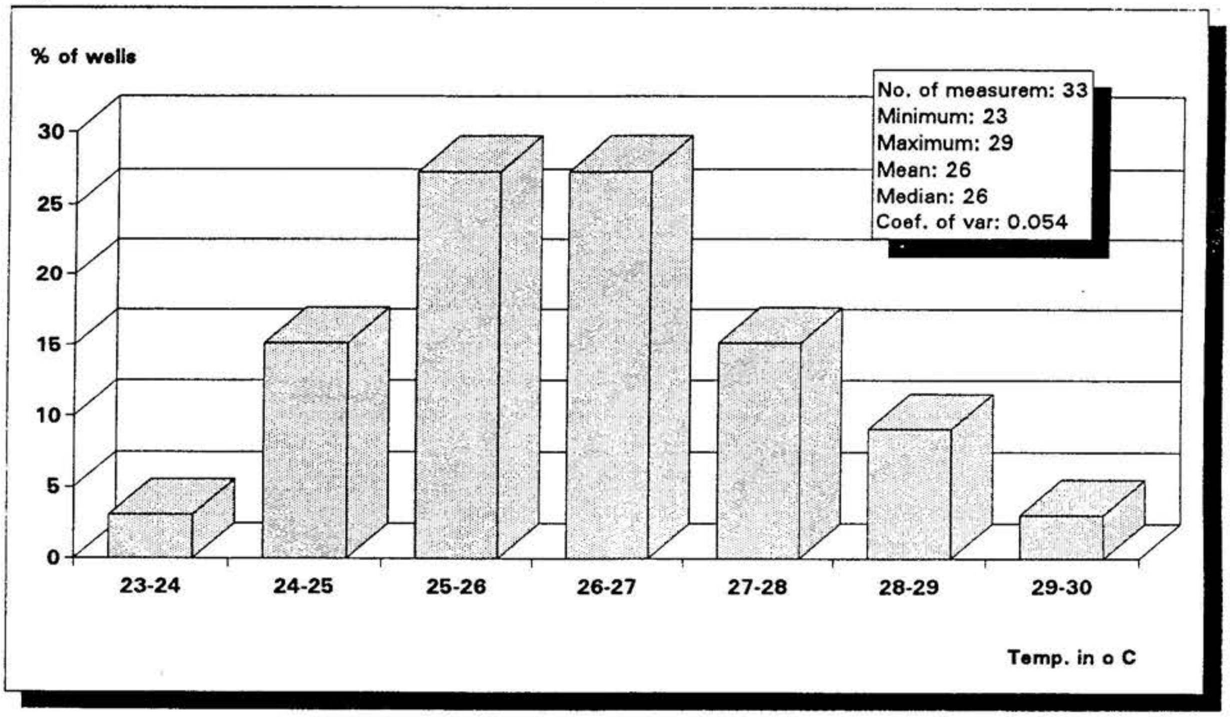
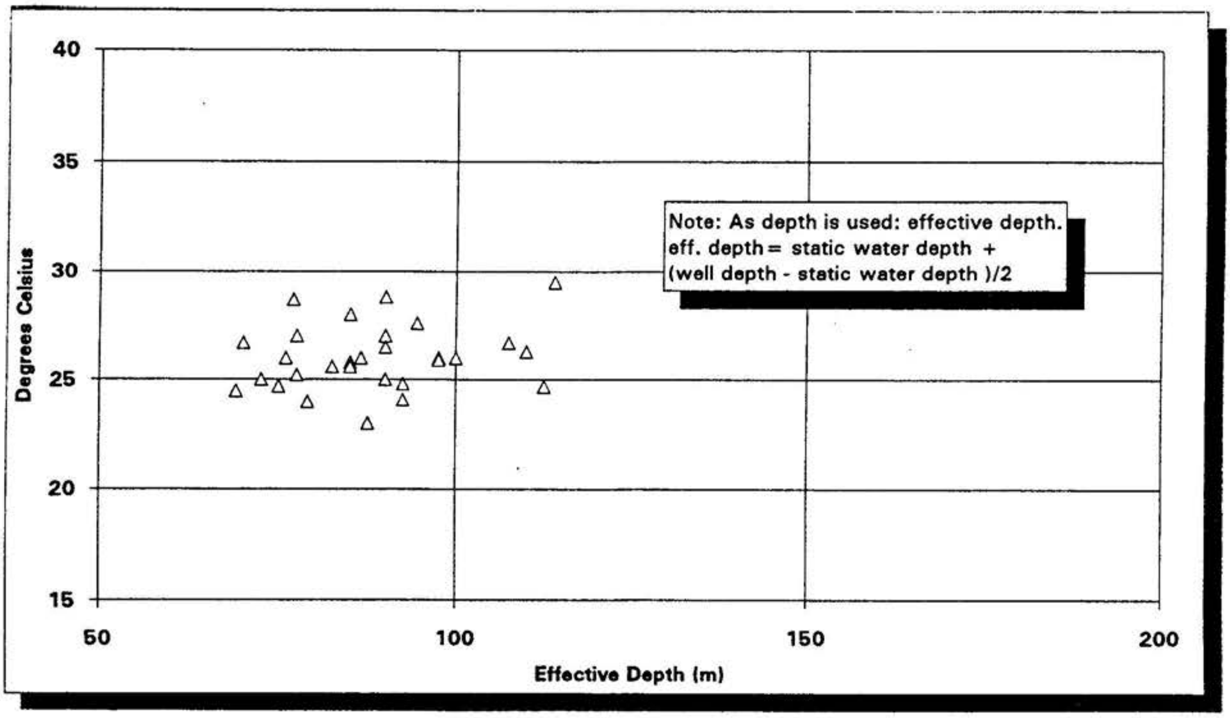


Fig. 4.24 *Relation of Water Temperature to Water Depth*



The mean groundwater temperature in the Al Hamra Plain is almost two degrees

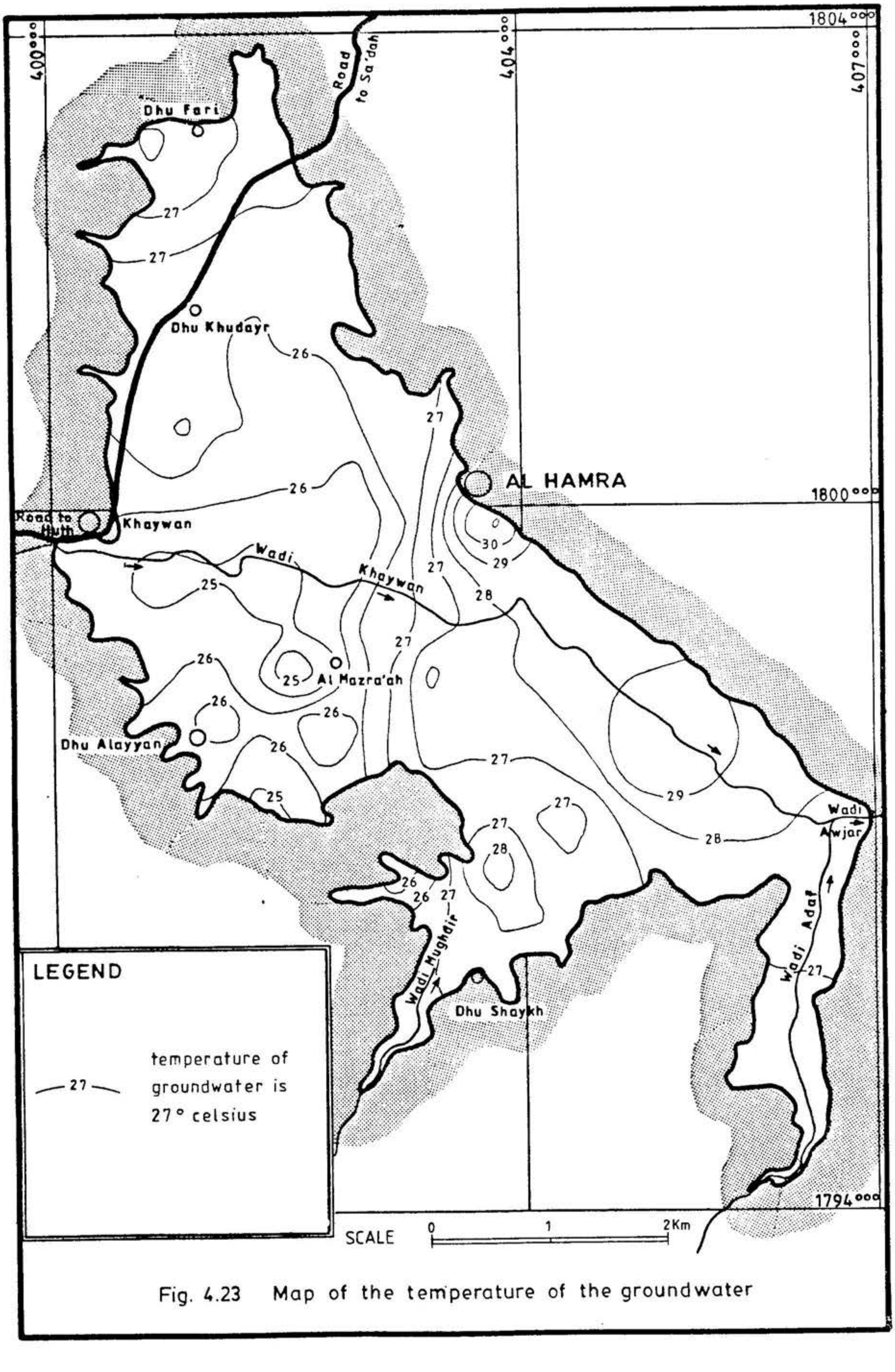


Fig. 4.23 Map of the temperature of the groundwater

higher than in the Amran Valley. There are no areas with extreme groundwater temperatures (see Fig. 4.23).

To find out if a relation exists between water depth and water temperature, values of the temperature were plotted against the effective depth of the well. The effective depth has been introduced to get a better indication of from what depth water originates during pumping, and is defined as the depth to a point midway between the static water level and the bottom of the well.

There is a slight positive correlation between water depth and water temperature (see Fig. 4.24), probably as a result of the geo-thermal gradient, that shows a temperature increase of about 0.5 °C per 100 m of depth.

5 GROUNDWATER USE

5.1 LAND AREAS

The total area of land associated with the 31 wells visited in December 1991 was 390 ha, of which 218 ha were cultivated and under irrigation command, and 172 ha were fallow (assumed local measure 1 libna = 64 m^2). It must be emphasised that this land would have been divided into more than 31 individual holdings, since wells are often owned in partnership by more than one farmer. The areas of land associated with individual wells will therefore be called for purposes of this report *well areas*, not farms.

Extrapolating from this data, by assuming a total of 40 wells areas (see Section 4.2) and the same population distribution for the additional data, resulted in a total well area of 503 ha, of which 281 ha were commanded by irrigation and 222 ha were fallow (see Table 5.1).

Table 5.1 *Breakdown of Land Areas*

	Based on data from 31 visited wells	Extrapolating,assuming a total of 40 wells
Total area of land associated with wells	390 ha	503 ha
Area commanded by groundwater	218 ha	281 ha
Fallow	172 ha	222 ha

It must be emphasized that these figures are based on areas where groundwater irrigation is applied, so rainfed cultivated farms are not included. The 281 ha as the area commanded by groundwater translates to an average command area of about 7 ha per well.

Fig. 5.1 shows the distribution of the well areas. The smallest plot was 1.9 ha, while the largest was 64 ha, an extensive farm near Dhu Darwan where only 6.4 ha were used for groundwater irrigated cultivation - the remainder was fallow.

Most well areas had an area between 2 and 14 ha. The mean well area size was 12.6 ha and the median 9.6 ha.

From Fig. 5.2 it can be seen that the area under groundwater command was much smaller: the mean was 7.6 ha (median: 6.4 ha). The smallest irrigated plot was 1.3 ha and the largest 7.6 ha. The dispersion, expressed as coefficient of variation, was high (0.75). Most commanded areas had a total area ranging from 1.3 to 8 ha.

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

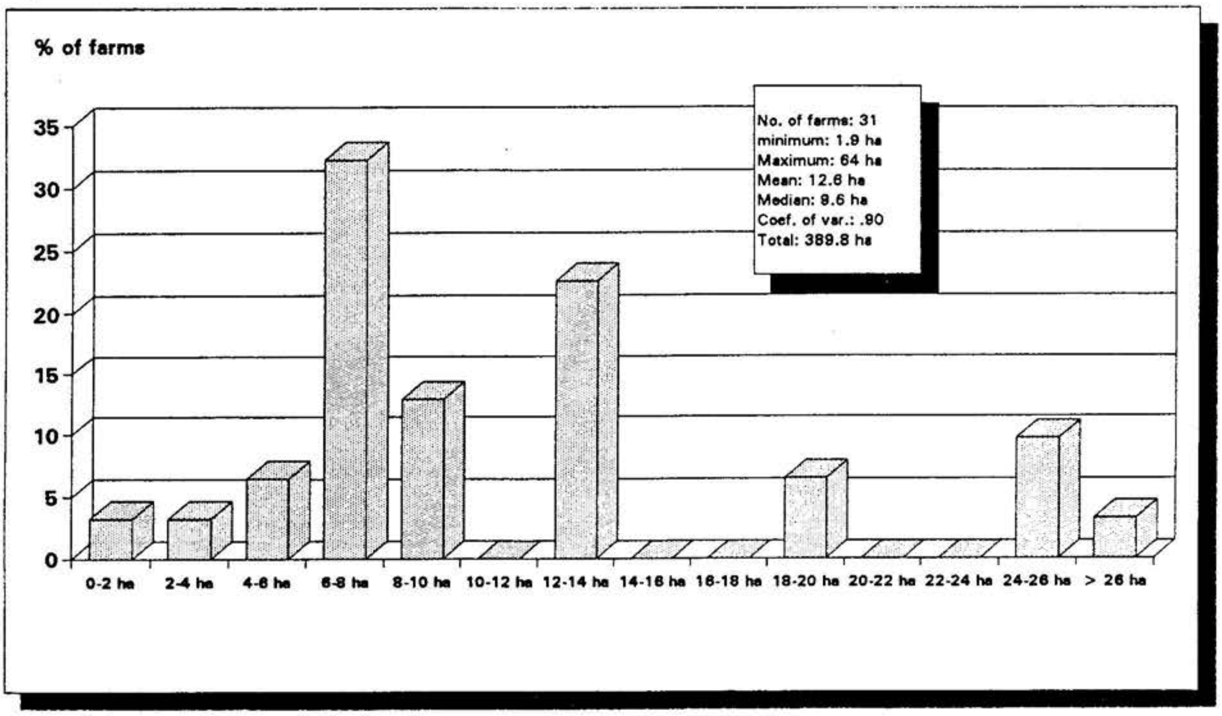
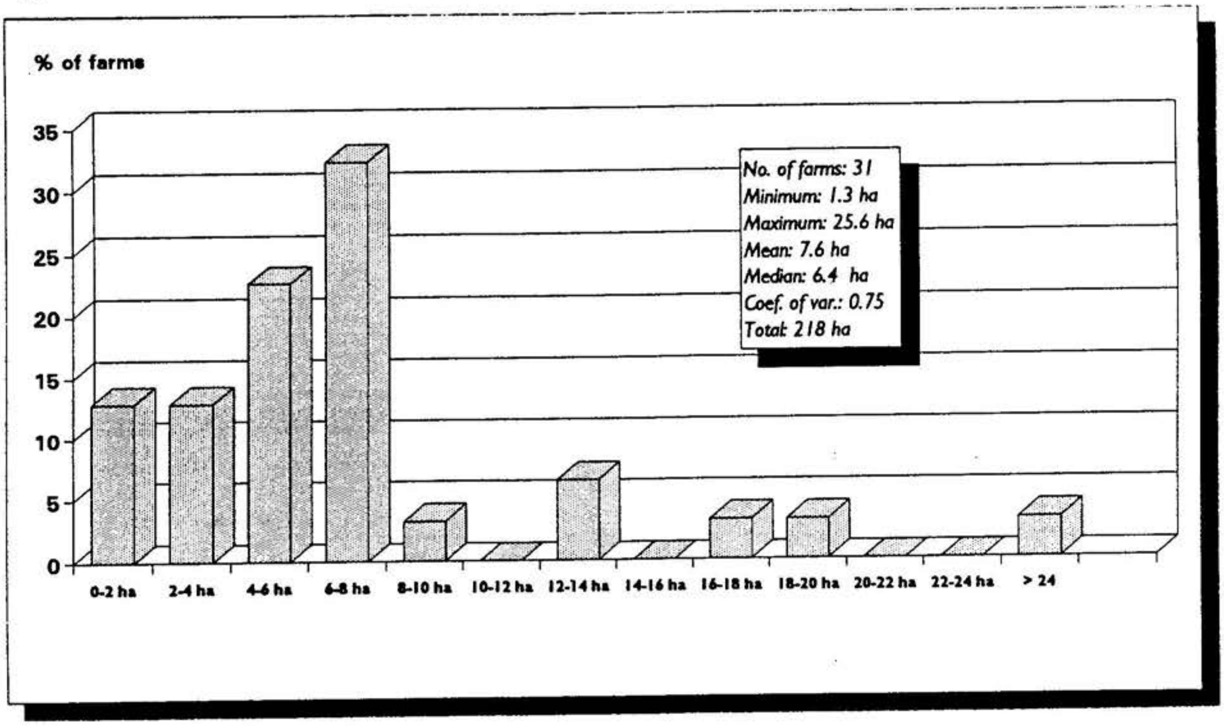


Fig. 5.2 *Distribution of Areas Under Groundwater Command (ha)*

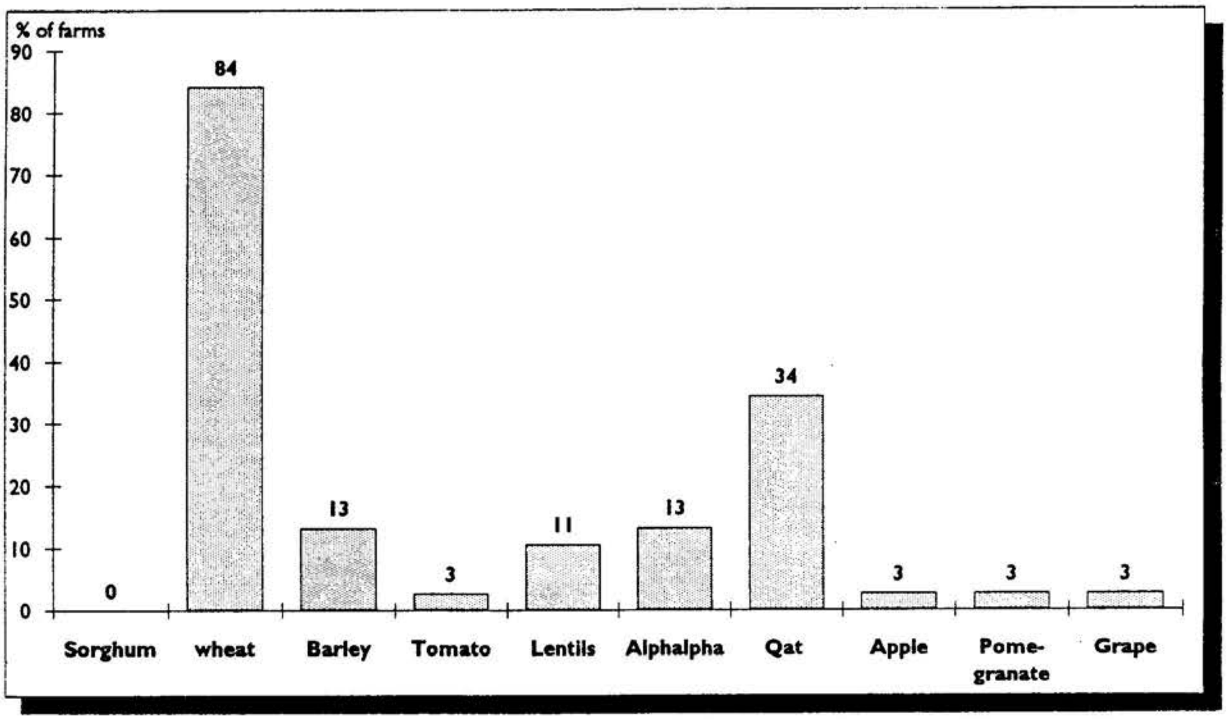


5.2 CROPS

As part of the well inventory questionnaire some information on crops was collected, concerning crop patterns during the seasons, and covering the major and secondary crop types and their total irrigated areas.

These data are summarized in Figs. 5.3 to 5.6, which show that of the perennial crops qat was grown by 34% of the farmers, followed by alfalfa (13%), apple, pomegranate and grape (each 3%).

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



Of the annual crops wheat was cultivated by 84% of the farmers during the seasons Shita and Rabi'a. Barley was grown during Shita on 42% and during Rabi'a on 13% of the farms. Sorghum was the major annual crop during Sayf and Kharif (87% of the farms). Cash crops observed other than fruit were tomato and lentils.

These crop patterns demonstrate the attractive aspects of groundwater irrigation for the farmer, since in contrast to the traditional unreliable practice of spate irrigated cultivation and the even less reliable rainfed cultivation, where at the most one harvest per year was possible, most crops can now be sown and harvested the whole year round. In the Al Hamra Plain, wheat and sorghum were cultivated by some farmers throughout the year. Moreover the high risk of crop failure as a consequence of a lack of rainfall and spate water diminished significantly when pumped irrigation started. In the 1970s on rainfed and spate water irrigated land the average loss of sorghum was 40%, of wheat and barley 50% (Rethwilm/Brandes, 1979).

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

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

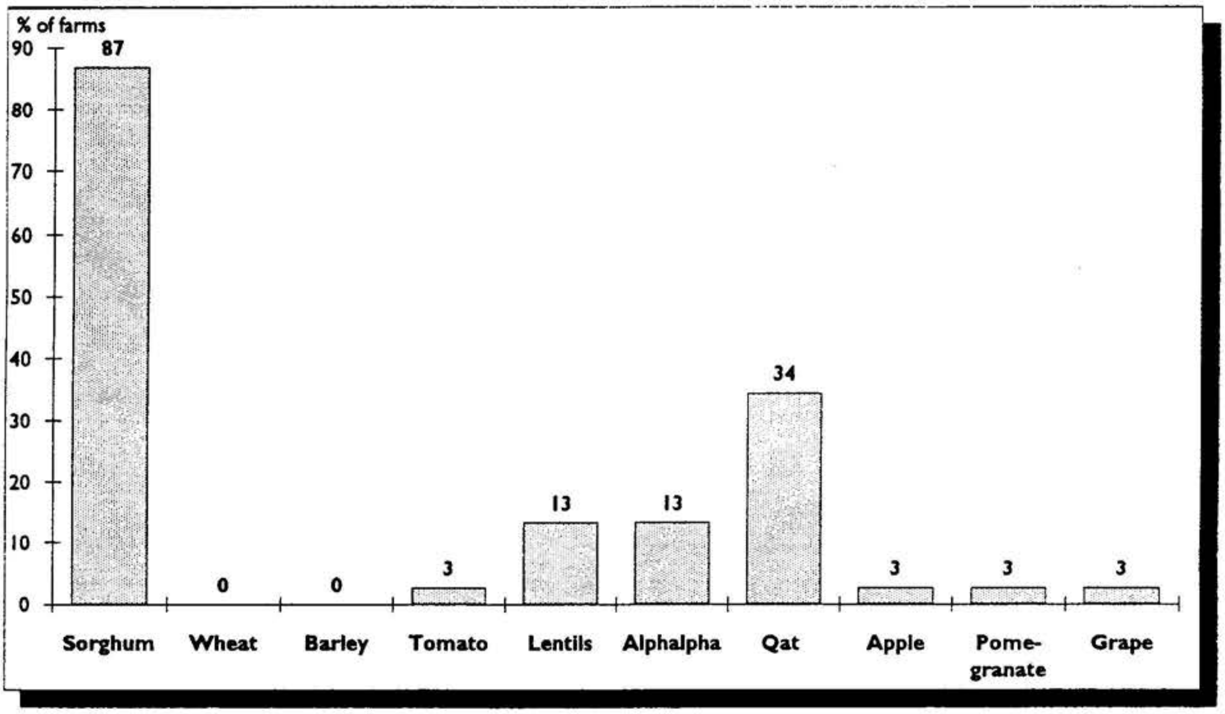
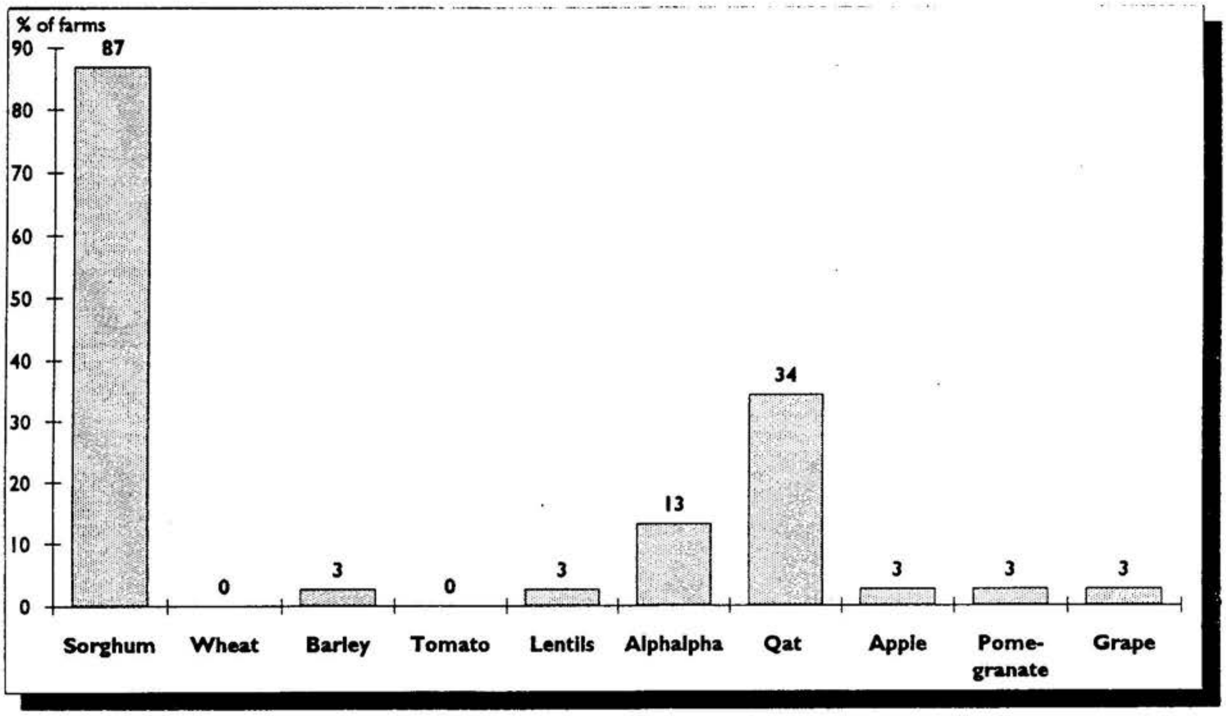


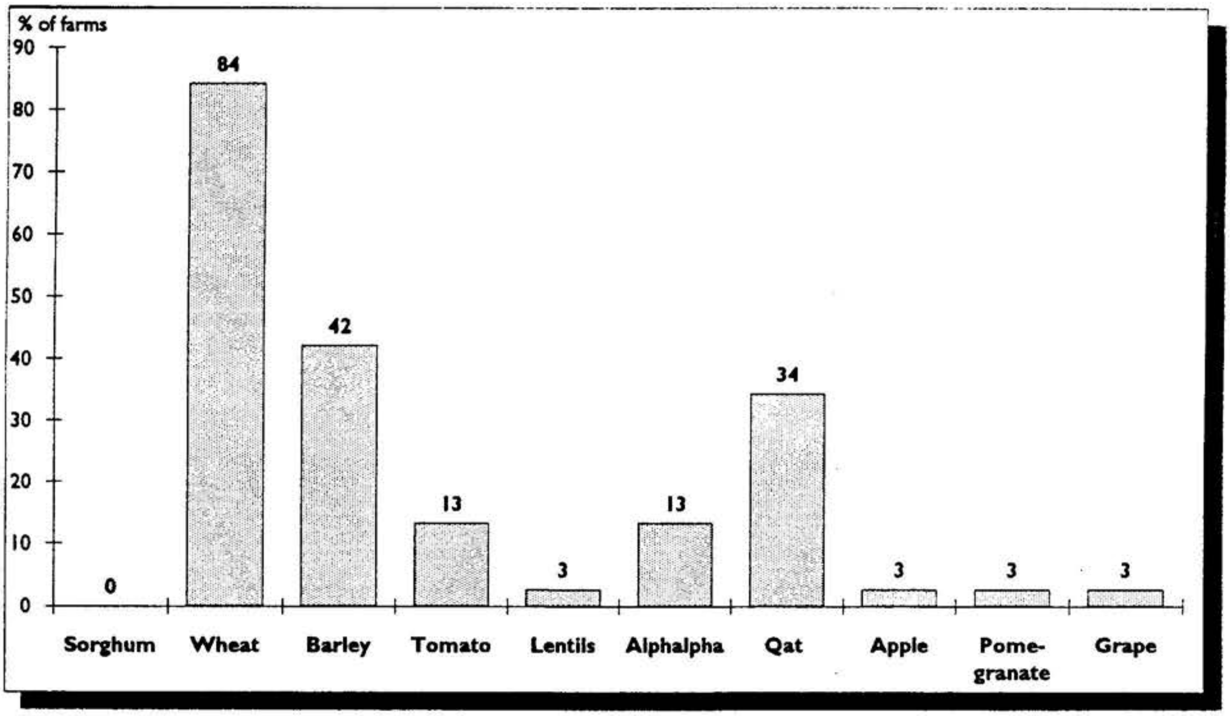
Fig. 5.5 *Crops Cultivated During Kharif (Autumn)*



Wheat and barley, the other two traditionally cultivated crops on the plain, were sown during November or December. Harvest of this crop was in March and April.

This was the most common practice, but on some farms another crop of wheat was planted immediately after the previous one, during June and July, to be harvested in October and November.

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



Fruit crops like apple, pomegranate and grape were introduced only recently by some progressive farmers. Both pure stand and inter-cropping patterns were observed. Large plots tend to show more pure stand cultivation (sorghum, wheat and barley) than the smaller plots, where, generally, a more mixed crop pattern was noticed.

5.3 IRRIGATION PRACTICE

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

Other water losses were incurred as a result of over-irrigation and/or in-efficient irrigation schedules (see Section 5.6). The irrigation method generally applied was one of the surface spreading systems: border, furrow and basin. The border method was usually applied for the irrigation of wheat and sorghum, furrow irrigation for potato, tomato and water melon and basin irrigation for fruit crops like apple, grape and pomegranate.

Time intervals between irrigation applications of 50-100 mm ranged from 10 to 15 days, depending on the crop type.

The highest frequency of irrigation applications was for the growing of grape, apple, tomato and alfalfa. These were the crops with the highest total costs per hectare; also with the greatest benefits - except for alfalfa. The lowest gross margin was for the growing of cereals: (sorghum, wheat and barley (Amran Valley, Hossain/Nouman, 1991).

A high percentage (76%) of the total cultivatable area of the Al Hamra Plain remained permanently fallow for the lack of water.

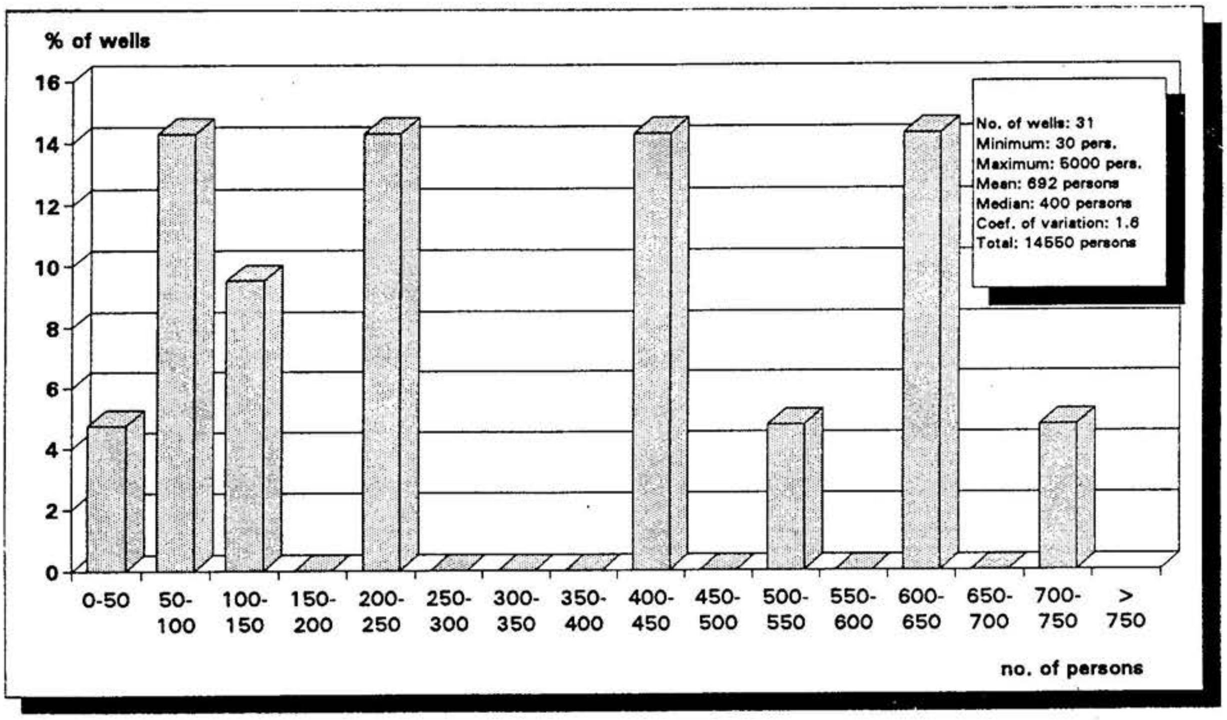
5.4. USE OF FERTILISERS

Crop rotation including a fallow was used to maintain soil fertility and to economize on the use of fertilisers. However, both chemical fertilizers and organic matter were added, the first at regular intervals. On 63% of the farms fertilizers were applied: urea alone on 24% of the farms, organic matter only on 34%, and both urea and organic matter on 5%. Livestock waste usually was not used as fertiliser, but was dried for fuel.

5.5 DOMESTIC WATER USE

The distribution of the number of persons that depended on one well is presented in Fig. 5.7.

Fig. 5.7 *Distribution of Number of Persons Consuming Water from One Well*



A wide dispersion was noticed and the number of dependent persons ranged from 30 to 5000 (a well that supplies the community Al Mazra'ah). The percentage of the pumped groundwater that is used for domestic purposes was about 6%. (compare Amran Valley:4%). The mean number of persons that used water from one well was 692, a value that was probably distorted by the high extreme values. However, the median was also high at 400 persons (compare Amran Valley - 100 persons).

A total number of 14 550 persons proved to be dependent on 31 wells, being the number of wells for which the collected domestic water consumption data were complete. When extrapolated, assuming a total number of 40 wells in the Al Hamra Plain and the same statistical distribution for the missing data, then a total number of 18 774 people could have consumed well water in 1991. This number might also be an indication of the number of inhabitants in the valley (see Table 5.2). This is a very high number in relation to the 1986 census return for the Al Hamra and Al Harf valleys together of 9000 persons.

However, it must be remembered that many farmers sell the water from their well to consumers elsewhere in the plain for domestic and farm use. Transport is usually by tank-trucks.

The average number of persons per house or per family was high: in the Al Hamra Plain the mean number of persons supplied by one well (692) appeared to correspond with an average of 40 houses, ie. 17.3 persons per house. Like the total population estimated above from recorded water consumption this number looks high; the actual number of persons per household is more likely to be of the order of 10. Assuming an average daily water consumption of 40 l per capita, the mean yearly domestic water use per well was estimated as 10 103 m^3 (Amran Valley 4132) and the total domestic water consumption from all wells as 274 100 m^3 per year (see Table 5.2). Livestock water consumption, 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), has been neglected.

Table 5.2 *Domestic Water Use*

	No. of persons using water from the well	Domestic water use per well (assuming 40l/day/capita)
Per well:		
mean	692	10 103 m^3/year
minimum	30	438 m^3/year
maximum	5000	73 000 m^3/year
Total: (based on 31 well data)	14 550	212 430 m^3/year
Grand total: (Extrapolated, assuming a total of 40 operational wells)	18 774	274 100 m^3/year

5.6 IRRIGATION WATER APPLIED

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

As has been explained in the section on crops, a detailed description of the land use of each farmer would need information on crop types, cropping calendar and cropping patterns throughout the seasons. The collection of these data would be too elaborate and time consuming in the context of a well inventory. However, the restricted series of data collected concerning crops and land-use, combined with the qualitative data obtained in the SONDEO study, allow a reasonable estimate to be made of the yearly crop water requirements in the study area.

Firstly, an acceptable estimate of the total area commanded by groundwater has been determined (Table 5.1). Secondly, groundwater abstraction data are available for each season, and a clear general picture has been formed of the types of crops cultivated and the cropping pattern during the four seasons. However, collected field data on the irrigated area of each crop are not complete enough to permit the calculation of the various crop water requirements on a decade or monthly base.

A solution has been found by applying existing potential evapotranspiration data, valid for the nearby Amran Valley. Eger (1987) published values of crop water requirements for the main cultivated crop types. From this it appeared that most crops have a consistent average daily net crop evapotranspirational need of about 4.0 mm, when considering the whole growing period. These figures have been used to arrive at a total yearly crop water demand. 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 crop evaporational demand (ETc) of 1460 mm has been established for the groundwater irrigated part of the Al Hamra Plain.

Rainfall data were measured in Huth (12 km southwest of Al Hamra town for the period 1975-1989. Spate irrigation values were derived from farmers' information and the 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 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 (no more than 50% of water is conveyed in pipes from pump to field-edge), and some of the canals are silted; 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 compilation of Table 5.3, 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.

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.

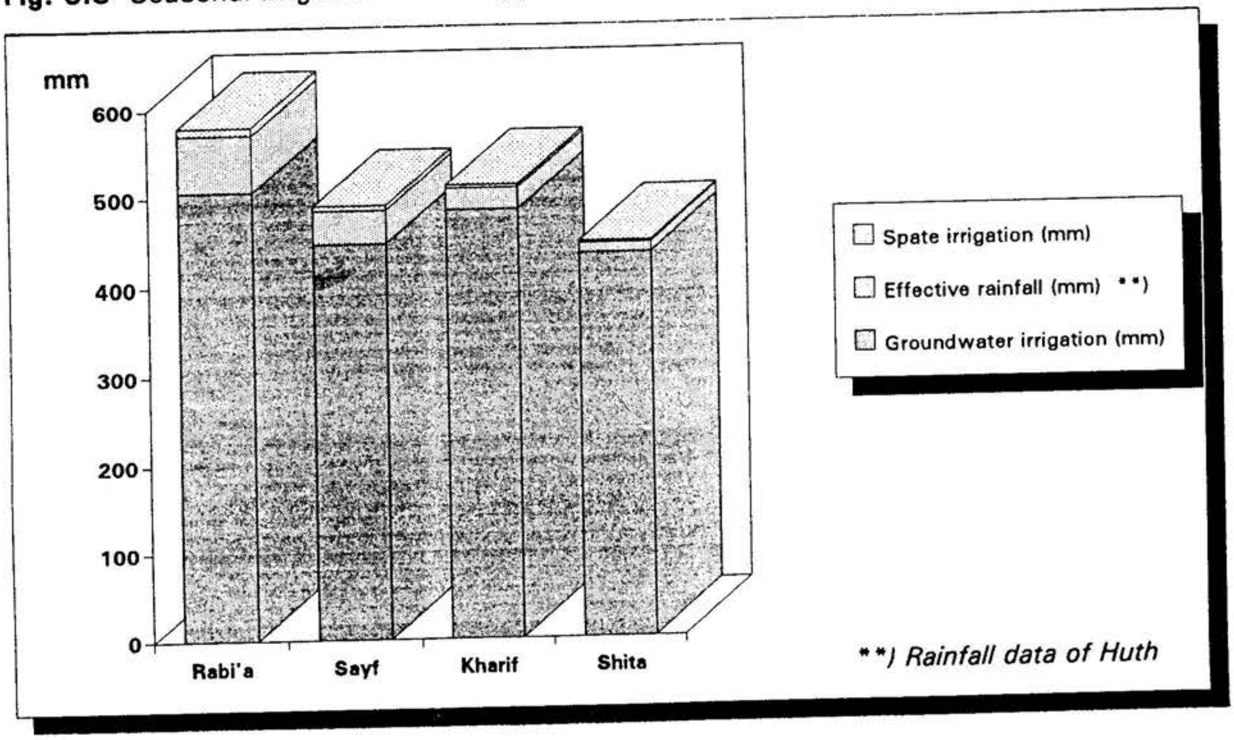
Fig. 5.8 shows the distribution of contributions from the several water sources used for irrigation during the seasons, and demonstrates that spate irrigation and rainfall represent only a minor contribution to the total irrigation water volumes.

Table 5.3 *Al Hamra Plain - Annual Groundwater Use in 1991*

Total Groundwater Abstracted (Mcm)	4.34
Domestic Water Use (Mcm)	0.28
Irrigation Water Use (Mcm)	4.06
Commanded Area (ha)[1]	281
Average Area Irrigated (ha)[2]	129
Gross Irrigation Application (mm)	3151
Total Efficiency (%)[3]	41.3
Irrigation Water Losses (mm)	1851
Aquifer Recharge (Mcm)	2.39
Net Irrigation Application (mm)	1300
Effective Rain (mm)[4]	138
Effective Spate (mm)	22
Total Effective Water (mm)	1460
Annual Crop ET (ETc - mm)	1460

1 Table 5.1
2 Adjusted to achieve balance between ETc and Total Effective Water
3 Conveyance Efficiency 75 % (50% piped/silted canals)
Application Efficiency 55 % (Poor levelling)
Total Efficiency 41.3 %
4 Based on data from Huth (USBR Method)

Fig. 5.8 *Seasonal Irrigation Water Application*



6 THE COST OF PUMPING GROUNDWATER

A model has been made for the calculation of the cost of both one hour of groundwater pumping, and of one m^3 of pumped groundwater. Various cost items were taken into account in the calculation procedure. Costs were subdivided into investment costs and O&M (Operation and Maintenance). All costs, including the investment costs, were treated as variable costs, that is, they are expressed per operation hour and not fixed for a certain number of years. The reason is that the lifetime of the most valuable components of the well and pumping equipment is not a fixed period, but depends on the farmer's pumping schedule, or the intensity of their use. For example, the pump and the engine have a lifetime of a certain number of operation hours, and so a higher pumping intensity would result in a shorter lifetime, when expressed in years, and the reverse. The O&M costs were also defined per operation hour.

The following assumptions were made:

- The lifetime of the well is 80 000 operation hours.
- The lifetimes of pump and engine are 40 000 operation hours.
- The lifetimes of reservoir and pumphouse are longer than the lifetime of the well.
- The higher cost of pumping from greater depths is fully covered by the deeper and more costly wells, the more powerful and thus more expensive pumps and engines and, the higher diesel consumption rates.
- Interest costs were not considered in the calculation model because the majority of the farmers in the Al Hamra Plain invest in wells from their own savings or by getting interest-free credit from private sources (friends or family). A negligible number of credits have been requested from the Agriculture Credit bank or government, because the farmer is against paying interest (Islamic principle), and because of the complex procedures (Hossain/Noman, 1991). When borrowed from friends or neighbours, the only credit costs are food and qat to please the lender. In many cases investments in a well were made by several shareholders who will benefit from the well in accordance to their share.
- Opportunity costs were not accounted for in the model because the farmer, in general, only invests in his farm and does not realise that his capital (saved or borrowed) could yield a profit elsewhere.
- Discharge rate and diesel consumption are constant during the entire lifetime of the well and pumping equipment.
- Costs for deepening wells were not included, because the majority of the wells are drilled to such a depth in relation to the local water table that deepening is not likely to be necessary during the 80 000 hour operating lifetime.

In the calculation model a (variable) period is taken for defining the costs per operation hour and the cost of one m^3 of pumped water. This period was set equal to 80 000 operation hours, the assumed lifetime of the most valuable components of the well, the casing and the screen. In the Al Hamra Plain, where the average farmer pumps 4176 hours per year, this corresponds to a well lifetime of about 19 years.

Table 6.1 *Calculation Model for Pumped Groundwater Costs*

A. INVESTMENT COSTS	**(1991 YR)**		
1. Well construction			
Cost	WC YR		
Lifetime well	LW hr *)		
Well depreciation	WC/LW YR/hr		
2. Pumping equipment			
Cost first set	PC1 YR		
Lifetime first equipment	LW/2 hr		
Equipment depreciation	2PC1/LW YR/hr		
Cost second set	PC2 YR		
Lifetime second equipment	LW/2 hr		
Equipment depreciation	2PC2/LW YR/hr	+	
Total depreciation costs	(WC + 2PC1 + 2PC2)/LW YR/hr		
B. OPERATION AND MAINTENANCE COSTS	**(1991 YR)**		
1. Maintenance/repair	M YR/hr		
2. Diesel consumption	DC YR/hr		
3. Diesel delivery costs	0.1 DC YR/hr		
4. Lubrificants (oil & grease)	0.2 DC YR/hr	+	
Total O & M costs	(M + 1.3 DC) YR/hr		
Total costs per hour of pumping (A + B)	(WC + 2PC1 + 2PC2)/LW + M + 1.3DC YR/hr		
Well discharge	Q m3/hr		
Cost per 1m3 of pumped groundwater	((WC + 2PC1 + 2PC2)/LW + M + 1.3DC) /Q YR		
Example:		**Depreciation**	
Well construction costs (WC)	300000 YR	3.95 YR/hr	
Cost first pumping equipment set (PC1)	200000 YR	5.00 YR/hr	
Cost second pumping equipment set (PC2)	350000 YR	8.75 YR/hr	
Lifetime well (LW)	80000 hr		
Lifetime pumping equipment (LW/2)	40000 hr		
Maintenance (M)	4 YR/hr		
Diesel consumption (DC) (5 l/hr x 3.3 YR/l)	16.5 YR/hr		
Well discharge (Q) 10 l/s	36 m3/hr		
	Investment costs	**O&M costs**	**Total costs**
Then, 1) cost per hour of pumping =	17.50 YR/hr	25.45 YR/hr	**42.95 YR/hr**
and 2) cost per 1m3 of pumped water =	0.49 YR	0.71 YR	**1.20 YR**

**) hr=operation hour*

The pumping equipment, when considering its most costly components, the pump and the engine, has a much lower lifetime, set here at half the lifetime of the well or 40 000 operation hours, which approximately corresponds with the lifetime given by the manufacturers. When operated at an average of 4176 pumping hours per year, the lifetime would be about 9.5 years Thus, during the lifetime of the well, two sets of pumping equipment would be needed.

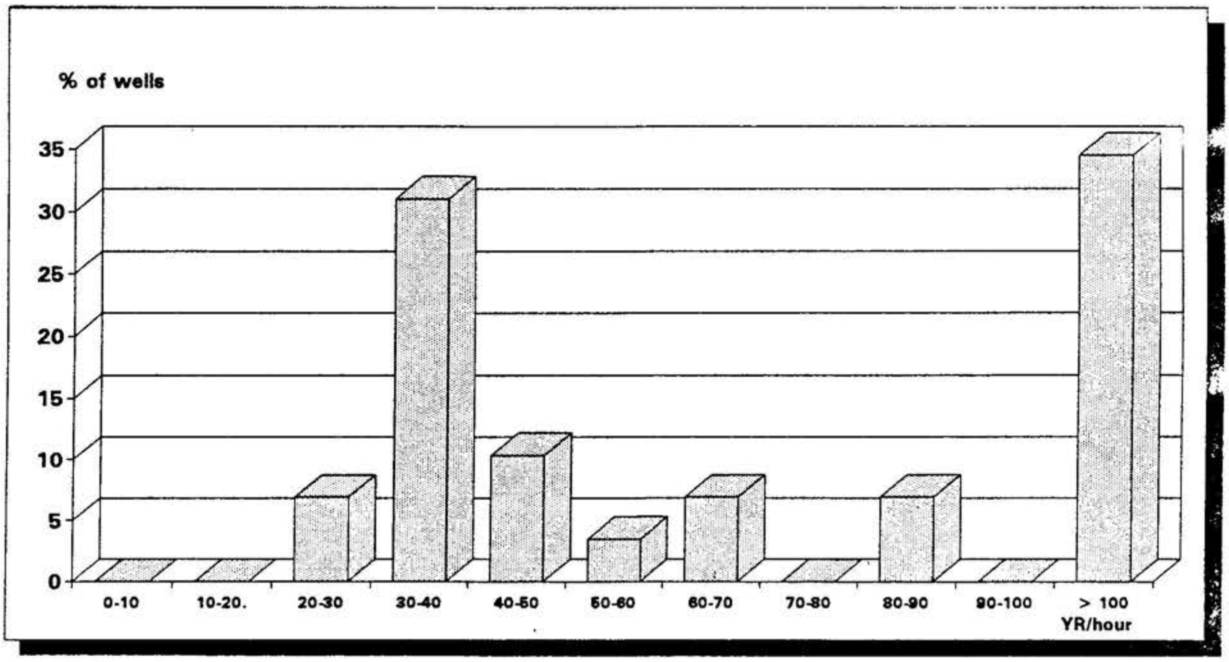
The cost item pumping equipment, collected as field data during the well inventory, generally embraces not only the pump and the engine but also the costs of reservoir, pump house and conveyance pipes (1991: 100 YR/metre length). However, these components have a lifetime longer than 80 000 hours and as a result do not need to be renewed when a second set of pumping equipment is installed.

Table 6.1 shows the calculation model. The formula set out in this table has been applied to the data from the 38 inventoried wells in the Al Hamra Plain, which were as follows, for most of the wells:

- The costs of well construction.
- The costs of pumping equipment.
- Well yields.
- Number of pumping hours per day.
- Daily engine diesel consumption.
- The price of diesel.

The results are presented in Figs. 6.1 and 6.2. The average cost of one hour of pumping was YR 39.0, that of one m^3 of pumped groundwater YR 1.8 of which 45% was capital cost, 32% for diesel and 23% operation and maintenance.

Fig. 6.1 *Costs of One Hour of Groundwater Pumping*

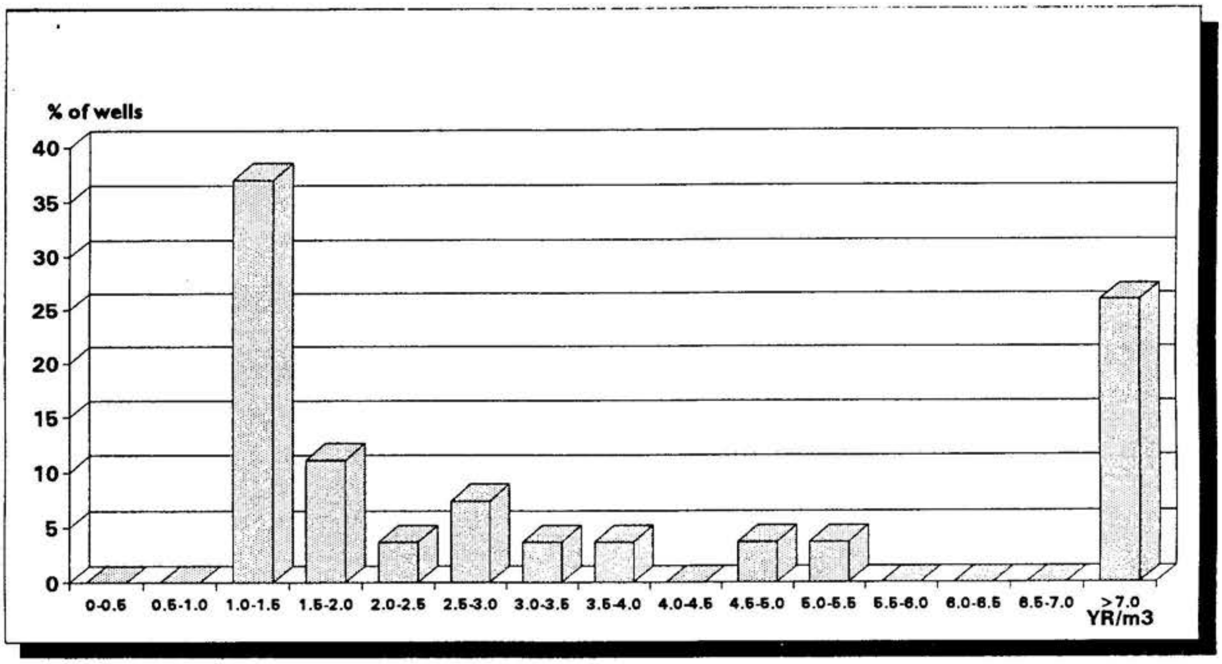


Assuming an average price of 1.8 YR/m^3 for pumped groundwater, then a total of YR 7.3 million was spent during 1991 in pumping about 4.1 Mcm for irrigation purposes.

The cost of one m^3 of pumped water was calculated at the level of the pump.

However, due to conveyance, application and scheduling water losses, not all the pumped water reaches the crops. This means that the price of water at the crop level is higher. Assuming the estimated overall irrigation efficiency of 41% (see Table 5.3), the average cost of the water at crop level would be YR 4.4/m^3 and the average yearly water costs per irrigated hectare of YR 57 200 (for a net application of 1300 mm).

Fig. 6.2 *Costs of One Cubic Meter of Pumped Groundwater*



7 SUMMARY AND CONCLUSION

The total number of wells located in the Al Hamra Plain during the well inventory was 38. Four of these wells (or 10.5%) were not in operation: one was dry and three others were not operational because of the absence of a pump and/or engine. The objective was to visit all the existing wells and it can be assumed that about 90% of the wells were visited. Therefore, the total number of wells was estimated at about 42, of which 40 would have been operational at the time of the well survey.

Serious groundwater development in the Al Hamra Plain started only in 1981, about 19 years later than in the Amran Valley. The main drilling activity occurred in the period from 1985 to 1991. The first impression is that the yearly drilling rate peak has not past yet, as it has for example in the Amran Valley.

Statistical analysis of the cumulative distribution of the number of wells constructed shows that 50% of all existing wells were drilled after 1986. The average well age is 5 years; the oldest dates from 1981. During the last 10 years only one well was reported to have been deepened. All the surveyed wells were drilled wells.

The drilling method used was predominantly rotary although some older wells were drilled with the cable tool method. Practically all the wells were fully cased with pipes of six metres in length.

All the wells have steel casings. Casing diameters differ significantly from those in the nearby Al Harf Plain. Here, large (10") diameter casings dominate (62%), followed by 8" (27%) and 12" (27%). The lower section is slotted.

The depth to water, in general, is not very great, ranging from 45 to 60 m. As a consequence well depths also are not very great, ranging from 60 m to 180 m, although most were between 90 and 140 m (the coefficient of variation is 0.27). The average depth is 117 m.

The water column heights range from 25 to 112 m; the average aquifer penetration is 60 m. If the groundwater were to drop 30 m over the whole plain then about 11% of the wells (Amran Valley 9%) would fall dry. This percentage would increase to a minor extent if the drawdown brought about by pumping is also considered.

Water is pumped typically by vertical turbine (lineshaft) pumps coupled via crossed webbing belts to diesel engines. No wells were found with electro-submersible pumps. A high level of standardization in engine and pumping equipment was observed: 79% of the pumps were supplied by Caprari, model V16P/3L/20A with 20 bowls (stages). The pump column diameter is mostly three and four inches (58% and 31% of all wells). The same level of standardization was noticed among the engines: Japanese Yanmar (Yahama) engines, models NP22Y, NP28 and NP30 comprise 69% and Kuboto 10%. The engines have, in most of the cases, a capacity ranging from 23 to 35 horsepower.

Well yields are moderate in the Al Hamra Plain. The mean well yield (6.9 l/s) is about the same as in the Amran Valley (6.5 l/s). Well discharge rates vary from 2.8 l/s to 12.5 l/s. The top layer, consisting of alluvium, is underlain by the limestone of the Amran Series. The groundwater table is below the alluvium-limestone contact. This means that all the wells are abstracting water from the limestone, which is not very permeable. In the Al Harf Plain (north of Al Hamra Plain, where the same hydrogeological conditions exist) well yields are much lower (average 3.5 l/s).

Well construction costs ranged from YR 60 000 (a 120 m deep well, drilled in 1985) to YR 290 000 (a 135 m deep well, drilled in 1991), clearly indicating the increase of well construction costs over time. Median well costs were YR 166 000. The average price per metre drilled for the period 1981-1991 was YR 1550.

Pumping equipment costs had a much larger variation: from YR 61 000 to YR 625 000, with a median of YR 200 000. Well construction costs are lower than in the Amran Valley (mean YR 228 000). However, pumping equipment costs are higher than in the Amran Valley. This can be partly explained by the younger age of the wells and pumps in the Al Hamra Plain (more recent prices).

The average farmer in the Al Hamra Plain pumps groundwater for 11 to 12 hours per day, throughout the seasons. This is reflected by the mean yearly number of pumping hours per day (11.5). Pumping activities are highest during Rabi'a[1] (mean 12.1 hrs/day), followed by Kharif (mean 11.9 hrs/day), Sayf (mean 11.2 hrs/day) and Shita (mean 10.9 hrs/day). About 4% of the farmers operate the pump 24 hours per day.

When considering the whole year the average number of pumping days per was 29.4. The average farmer pumps 338 hours per month, over the whole year.

At 27 wells (of the total of 38 wells visited) the discharge could be measured and data collected on the pumping schedule. At the remaining 11 wells these data could not be collected for the following reasons: the well was dry, no pump and/or engine was present, no diesel or oil available, or because of a broken pump/engine; or there was just nobody to switch on the pump and/or to give information on pumping activities. This resulted in a sample of 27 wells from which the seasonal and yearly discharge were calculated.

On average the wells were not pumping for reasons of maintenance and repair for 5.5% of the time. This percentage was also taken into account when calculating the seasonal and total yearly abstracted groundwater volumes.

A yearly total of approximately 4.34 Mcm of groundwater abstraction was calculated for the Al Hamra Plain in 1991. The abstracted volumes during the individual seasons were 1.17, 1.04, 1.12 and 1.01 Mcm for Rabi'a, Sayf, Kharif and Shita, respectively.

In contrast to most other plains in the NORADEP Project region the rate of increase of yearly abstracted volume has not diminished during the last five years. A (very rough) estimate of all the groundwater pumped in the Al Hamra Plain, using figures

1 The seasons in Yemen are Rabi'a, Sayf, Kharif and Shita, corresponding approximately with Spring, Summer, Autumn and Winter.

from 1981 (when abstraction became significant) up to 1991, is about 23 Mcm. This represents a water layer 0.92 m deep covering the whole Al Hamra Plain (25 km^2). Expressed in terms of lost aquifer on the assumption of an average effective porosity (specific yield) of 3%, the volume pumped during the 10 years corresponds to a lost saturated aquifer thickness of 100/3 * 0.92 = 31 meter, covering the whole Al Hamra Plain.

Depths to groundwater in general, show a small range in the Al Hamra Plain: from 25 m (a well between Al Hamra and Khaywan) to 90 m (a well 500 m southeast of Khaywan). In general, the larger water depths occurred in the north and northwest of the plain, where they ranged from 60 to 90 m. Around Khaywan water depths are particularly large. Water depths are lower in the central and southeast part of the plain, where they vary between 40 and 60 m.

The piezometric levels also show very little variation in the Al Hamra Plain. Their range is between 1510 and 1530 m. The natural groundwater flow is assumed to be directed to the southeast, but several cones in the water table caused by large abstractions disturb the general groundwater flow pattern. Several depressions in the groundwater level can be observed around Khaywan town.

It was not possible to measure the hydraulic gradient in the plain because of the undulating piezometric surface. Taking the levels in the extreme northwest and southwest of the plain, then there is a drop of only five metres over a distance of eight km.

No long term data on water levels were available in the Al Hamra Plain. Serious pumping from drilled wells started only at the beginning of the 1980s, about 20 years later than in the Amran Valley. The density of well sites does not give as much cause for alarm as in the Amran Valley. However, the hydrogeological situation here is not promising: just as in the Al Harf Plain water is tapped from a limestone aquifer that has, in general, rather low water bearing and water transporting capacities. This also signifies that a relatively large groundwater level drop could be expected in this area as a consequence of pumping.

The measured electrical conductivity (EC) values of the groundwater showed a minimum value of 229 microS/cm, a maximum of 1610 and a mean of 810. This means that the groundwater of the Al Hamra Plain is moderately mineralized. The mean EC-value of all the measurements was significantly higher than the mean for the Amran Valley (571). One justification might be that the water here originates from the limestone where low flow rates and thus long travel times might have caused the rather high degree of mineralization.

The more saline groundwater was present in the northwest and southeast part of the plain (above 900 microS/cm). Probably in these localities water was being tapped from saline shaley layers in the Amran Limestone Series. In the central plain more moderate values were observed: between 400 and 700 microS/cm.

There is no evidence that salinity increases with depth. High salinity seems to be determined only by the presence of shaley layers in the limestone aquifer.

Groundwater temperatures ranged from 23 to 29°C, with a mean and a median of about 26°C. Dispersion was low: the coefficient of variation was only 0.05 and most measurements showed values that ranged from 24 to 28°C. The mean groundwater temperature in the Al Hamra Plain was almost two degrees higher than in the Amran Valley. There were no areas with extreme groundwater temperatures. The plotting of measured temperature values against groundwater depths indicated a slight positive correlation between both variables, probably as a result of the geo-thermal gradient, that can introduce a temperature increase of about 0.5°C per 100 m depth.

The total farm size of the 31 farms visited amounted to 390 ha of which 218 ha were commanded by groundwater irrigation while 172 ha were fallow. Extrapolating, assuming the existence of a total of 40 farms, a total farm area of 503 ha where groundwater irrigation was derived of which 222 ha was fallow. The 281 ha commanded by groundwater translates to an average command area of about 7 ha per well.

The smallest plot was 1.9 ha, the largest 64 ha, an extensive farm near Dhu Darwan, where only 6.4 ha were used for groundwater irrigated cultivation, remaining part being fallow. Most farms had an area ranging from 2 to 14 ha. The mean total farm size was 12.6 ha and the median 9.6 ha.

The part of the total farm size that is irrigated by groundwater, is much smaller. The mean area commanded by groundwater was 7.6 ha (median: 6.4 ha). The smallest irrigated plot was 1.3 ha and the largest 7.6 ha. The dispersion, expressed as coefficient of variation, was rather high (0.75). Most irrigated farms had a total area ranging from 1.3 to 8 ha.

Of the perennial crops, qat was grown by 34% of the farmers, followed by alfalfa (13%), apple, pomegranate and grape (each 3%). Of the annual crops, wheat was cultivated by 84% of the farmers during the seasons Shita and Rabi'a. Barley was grown during Shita on 42% and during Rabi'a on 13% of the farms. Sorghum was the major seasonal crop during Sayf and Kharif (87% of the farms). Cash crops observed other than fruit were tomato and lentils.

A high percentage of about 76% of the total cultivatable area of the Al Hamra Plain remains permanently fallow because of shortage of water.

Both chemical fertilizers and organic matter were used, the first at regular intervals. On 63% of the farms fertilizers were applied. Solely urea on 24%, organic matter on 34%, and both urea and organic matter on 5% of the farms visited. Livestock waste was usually not used as fertilizer, but instead dried for fuel.

The number of persons depending on one well for domestic use ranged from 30 to 5000 (a well that supplied the community Al Mazra'ah). The percentage of the pumped groundwater used for domestic purposes is about 6%. (Amran Valley 4%). The mean number of persons using water from one well was 692, the median 400. (Amran Valley 100 persons).

A total of 14 550 persons proved to be dependent on 31 wells. When extrapolated a total number of 18 774 people could have consumed well water in 1991. The mean number of persons supplied by one well (692) corresponded with an average of 40 houses, ie. 17.3 persons per house. Assuming an average daily water consumption of 40 l per capita, the mean yearly domestic water use per well was 10 103 m^3 (Amran Valley 4132 m^3), and total domestic water consumption from all wells in the Al Hamra Plain 274 100 m^3 per year.

(**N.B.** The 1986 census showed the population of the Al Harf and Al Hamra Valleys together as about 9000. Thus the numbers for total population and for household occupancy derived from the well inventory look high).

The gross irrigation water applied was estimated at 4.06 Mcm annually. At the low overall efficiency assumed (41%), about 2.4 Mcm of this would return to the aquifer as deep percolation.

A model was made for the calculation of the cost of one hour of groundwater pumping and of one m^3 of pumped groundwater. Various cost items were taken into account in the calculation procedure.

The costs of one hour of pumping averaged YR 39.0, that of one m^3 of pumped groundwater YR 1.8.

Assuming an average price of 1.8 YR/m^3 of pumped groundwater, then a total of YR 7.3 million has been spent during 1991 by pumping about 4.1 Mcm for irrigation purposes.

Applying the estimated overall irrigation efficiency of 41%, the average cost of the water at the crop level would be YR 4.4/m^3 and the average yearly water costs per irrigated hectare YR 57 200 (for a net application of 1300 mm).

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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 prepared for the analysis of the NORADEP well inventory results. To minimise errors during data entry the layout of the pages on the screen is the same as the pages of the questionnaire. Each record in the database corresponds with a complete well inventory sheet and has space for the 123 fields necessary. A total of 38 wells were surveyed in the Al Hamra Plain, and so 38 times 123 (4674) data had to be entered and subsequently processed and interpreted.

The entry of data was carried out by two SSHARDA engineers. The entry of these data did not cause any holdup in 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 also made in expressing the well locations in UTM coordinates.

Analysis and interpretation of all the stored data was 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

WELL INVENTORY
QUESTIONNAIRE
NORADEP

SSHARDA

- 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 Hamra Plain (selection)

Well no.	Village (nearest)	Coordinates (UTM) N	E	Altitude m.abv msl	Year of constr.	Well depth (m)	Diameter casing (inch)	Screen/open from (m)	to (m)	Year inst. pump	Depth of pump (m)	Depth to water (m)	Well yield (l/s)	Total farm size (ha)	Water use Irriged (ha)	Domest. (persons)
1	DHU SHAHWAN	1799900	403700	1570	81	170.0	10.0				81	58.0				2000
2	ALSHAATAH	1800100	402800	1580	88	103.0	10.0	67	103	88	75	35.0	6.82	12.8	5.12	200
3	ALQAF	1799800	402000	1578	82	90.0	8.0	54	90	82	69	65.0	5.77	9.6	6.4	200
4	JAYRAH	1799600	401800	1580	90	100.0	8.0	52	100	90	72	50.0	5.00	3.2	3.2	
5	JAIRAH	1798900	402700	1573	85	150.0	8.0	120	150	85	81	70.0	7.50	12.8	5.12	
6	JAIRAH	1798400	403200	1575	91	120.0	8.0	60	120	91	75	30.0	12.50	25.6	19.2	5000
7	JAYRAH	1799600	403900	1570	85	120.0	10.0	90	120	85	66		5.00	19.2	12.8	500
8	JAYRAH	1798200	402200	1570	84	72.0	10.0	54	72	84	66		9.38	9.6	5.12	50
9	ALQAHIRAH	1797700	403200	1600	87	100.0	10.0	76	100	87	66	55.0	9.38	9.6	3.84	
10	ALKAWLAH	1796700	404100	1580	84	120.0	8.0	96	120	86		60.0	5.77	5.12	1.92	1500
11	ALMAYAN	1797900	405100	1570	82	114.0	12.0	72	90	86	75	40.0	7.50	6.4	6.4	
12	RAYK	1801200	402000	1576	88	180.0	8.0			89	150	80.0		6.4	6.4	200
13	ALSORPAH	1800800	401700	1576	88	170.0	12.0					80.0				
14	ALSORPAH	1801000	400900	1576	81	60.0	10.0			81	54					800
15	ALMAHJAR (ALWAQBAH)	1800600	401100	1578	89	130.0	10.0	102	130	89	99	85.0	6.25	4.48	1.28	
16	ALMAHJAR	1800600	401800	1576	90	127.0	10.0	67	127	90	99	25.0	6.25	7.68	1.92	
17	AS SURRAH(AL AORANI)	1800300	401700	1578	90	130.0	10.0	94	130	90	90	40.0	5.00	19.2	6.4	
18	AS SURRAH	1798500	404000	1575	89	75.0	10.0	45	75	89	54	40.0	9.38	25.6	16	600
19	ASSURRAH(ALGOLSOM)	1796700	403600	1580	81	130.0	10.0	100	130	81	99	70.0				700
20	ALWAGBAH	1797200	404300	1570	85	125.0	10.0	95	125	85	84	70.0	5.77	64	6.4	
21	ALMODAYYAR	1796800	403700	1580	89	130.0	12.0	100	130	89	70	50.0	8.33	9.6	6.4	60
22	ALMODAYYAR	1794000	404800	1630	85		10.0			85			6.25			600
23	SAHBAL	1797600	401900	1580	83	115.0	10.0	100	130	83	78	70.0	7.50	6.4	5.12	30
24	HAJARAN	1798500	402100	1570	86	115.0	12.0	75	115	86	87	60.0	6.82	7.68	7.68	60
25	ALWAQBAH	1798700	402100	1577	91	120.0	8.0	60	120	91	81	65.0	9.38	6.4	5.12	
26	SALIL HAGRAN	1799400	401000	1590	91	135.0	8.0	100	135	91	105	90.0	9.38	12.8	9.6	120
27	AYYAN	1798800	401400	1580	88	100.0	10.0	65	100	88	81	70.0	9.38	25.6	25.6	400
28	SHPAREJ	1798100	401400	1577	83	115.0	10.0	85	115	83	78	65.0	7.50	7.68	7.68	400
29	AL-ANAB	1797800	402300	1580	88	113.0	10.0	57	115	88	81	60.0	6.25	1.92	1.92	400
30	ALZAFG	1798000	401900	1575	82	120.0	10.0	90	120	82	84	75.0	2.88			600
31	AL HAYRAH	1796900	403000	1600	87	90.0	10.0	60	90	87	72	55.0	6.82	6.4	5.12	130
32	AL HAYRAH	1799000	402000	1574	89	120.0	10.0	80	120	89	90	60.0	8.33	12.8	6.4	
33	AL HUSHIN	1798800	401800	1574	91	120.0	10.0	80	120	91	75	60.0	7.50	12.8	12.8	500
34	ALHAWL	1798600	401400	1576	91	110.0	8.0	70	110	91	75	55.0	7.50	6.4	5.12	
35	AL ALAWL	1803000	401300	1595	87	120.0	10.0	102	120	88	105	60.0	3.00	6.4	3.2	150
36	AL UGLAH	1803000	400900	1595	87	120.0						69.0				
37	ALHAJAR	1800300	403000	1577	86	90.0	10.0	60	90	86	72	50.0	2.78	12.8	7.04	1000
38	OMCAN	1800500	402800	1577	87	104.0	8.0	77	104		60	54.0	3.00	12.8	2.56	

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 Hamra Plain

The following SSHARDA engineers were involved in the well inventory:

Wasfi Mohd Abdo Alezzi (team leader)
Faisal Ahmed Taher
Abdul Halim Hazza

Drivers

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

W.J. Honijk (hydrogeologist)