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GROUNDWATER RESOURCES AND USE IN THE ATTAF 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 governorate and the governorate 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 Attaf Valley 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 Attaf Valley were carried out during December 1991. Two teams were used, each consisted of two engineers and a driver. The drivers also assisted with the several 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 background information on subjects such as the local hydrogeological conditions locating well sites with a compass, the use of the water level measuring tape, the EC-meter and measuring of well discharge. The basic field equipment of each team included 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 113 wells were visited in the study area and the same number of questionnaires were been filled out, each containing up to 120 data from each well site. Information collected included data on the well location, well details, pump characteristics, measured well observations, water use, and well costs, among others. The layout of the questionnaire is presented in Appendix 3. For convenience of processing and retrieval the most important topics of data are summarized and presented in Appendix 3.

2 PHYSICAL SETTING

2.1 LOCATION AND TOPOGRAPHY

The Attaf Valley is situated in the Central Highlands and can, geologically, be considered as a continuation of the Amran Valley in a north easterly direction. Like the Amran Valley it is a graben formed by tectonic movements along northeast/southwest major faults, filled with alluvial deposits interbedded with basalt flows and partly covered with basaltic pyro-clastics and fragmented volcanic detritus. Its location is within the UTM coordinates 1 755 000 and 1 775 000 north and 400 000 and 435 000 east (15° 52' to 16° 03' north and 44° 00' to 44° 24' east) and it is about 39 km long. The width of the valley varies from five km in the southwest to only 500 m in the northeast.

Topographic elevations in the plain range from 2150 m above mean sea level (amsl) in the southwest near Mahali Athar (see Fig. 2.2) to 1306 m at the eastern margin near Wadi Attaf, resulting in an average surface gradient of 850 m over a distance of about 39 km, or 2.2%. The bounding mountain ranges are composed of Quaternary basalt in the south and Amran limestones in the north, ranging in height from 2700 m in the southwest to 1400 m in the northeast.

The entire catchment area of the valley covers 2200 km^2 (see Fig. 2.3). The Attaf Valley forms part of the catchment area of Wadi Kharid, which is a major tributary of Wadi Jawf in the east.

There are no data available on the number of inhabitants of the study area. The two most important towns are Dhi Bin and Sinwan.

2.2 CLIMATE

Just as in the bordering Amran Valley a semi-arid climate prevails in the study area. The climate 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, shrubs, briar and grassland. As a consequence of intensive grazing by sheep and goats little of it is left and the result is the desert-like appearance of the non-cultivated parts of the valley.

Rainfall is sporadic and scanty and storms usually are short, intense and local. Fig. 2.4 shows the mean monthly rainfall measured at two locations near the Attaf Valley (Al Boun Farm 9 km south of Raydah, and Huth), while Fig. 2.5 gives the total annual rainfall within the Attaf Valley catchment area (Al Boun Farm and Raydah). Sources of these data are MAWR, TDA and Eger (1987). Totals range from an annual average of 150 to 425 mm within the valley. For example, the station in the centre of the Qa' Al Boun showed an average yearly precipitation of 250 mm during the period 1975-1991. The monthly distribution of rainfall is variable. In general two peaks of rainfall occur during the year: March-May and July-August. The wettest month in most locations is August. The rest of the year has little or no rainfall.

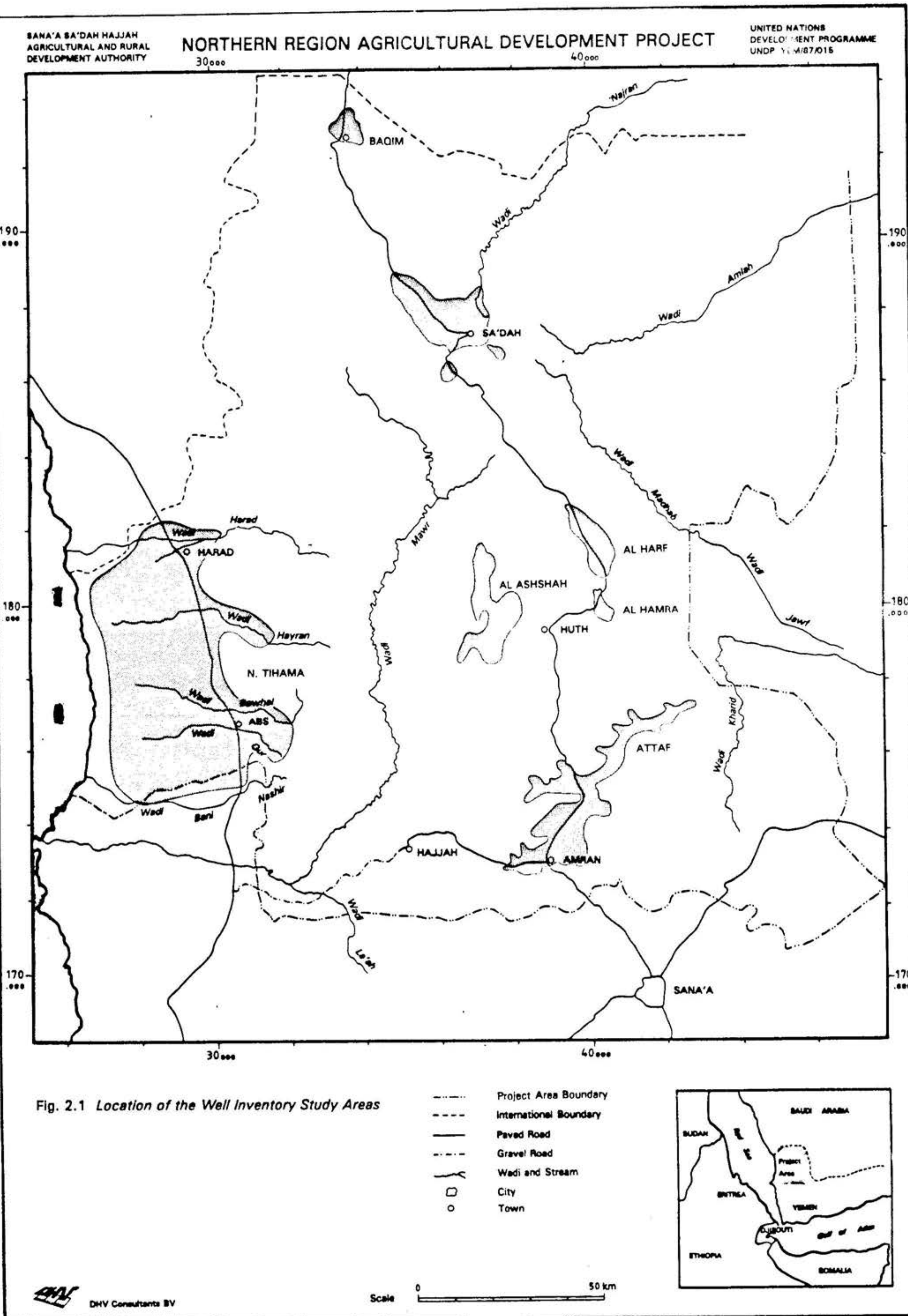


Fig. 2.1 *Location of the Well Inventory Study Areas*

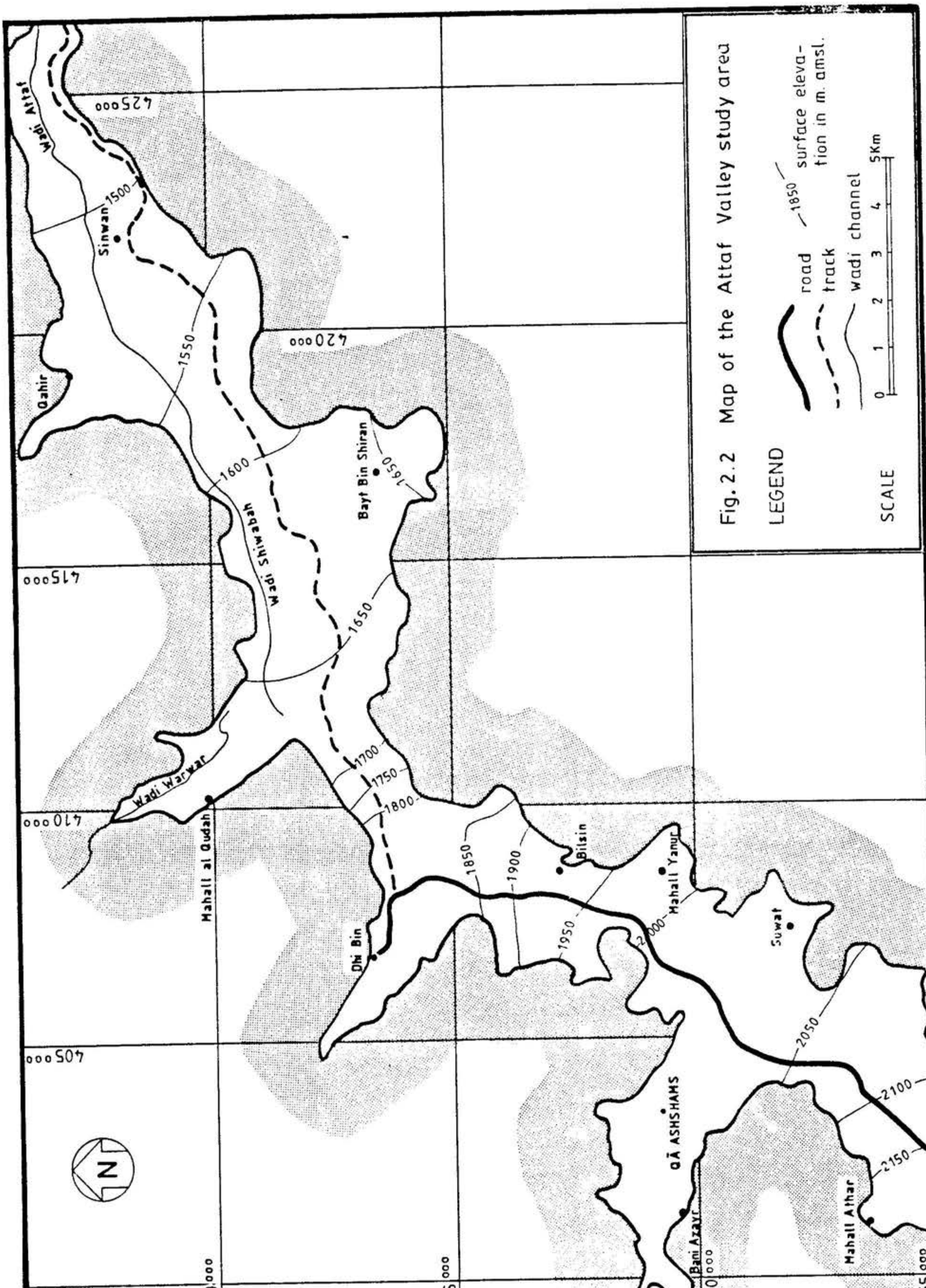


Fig. 2.2 Map of the Attaf Valley study area

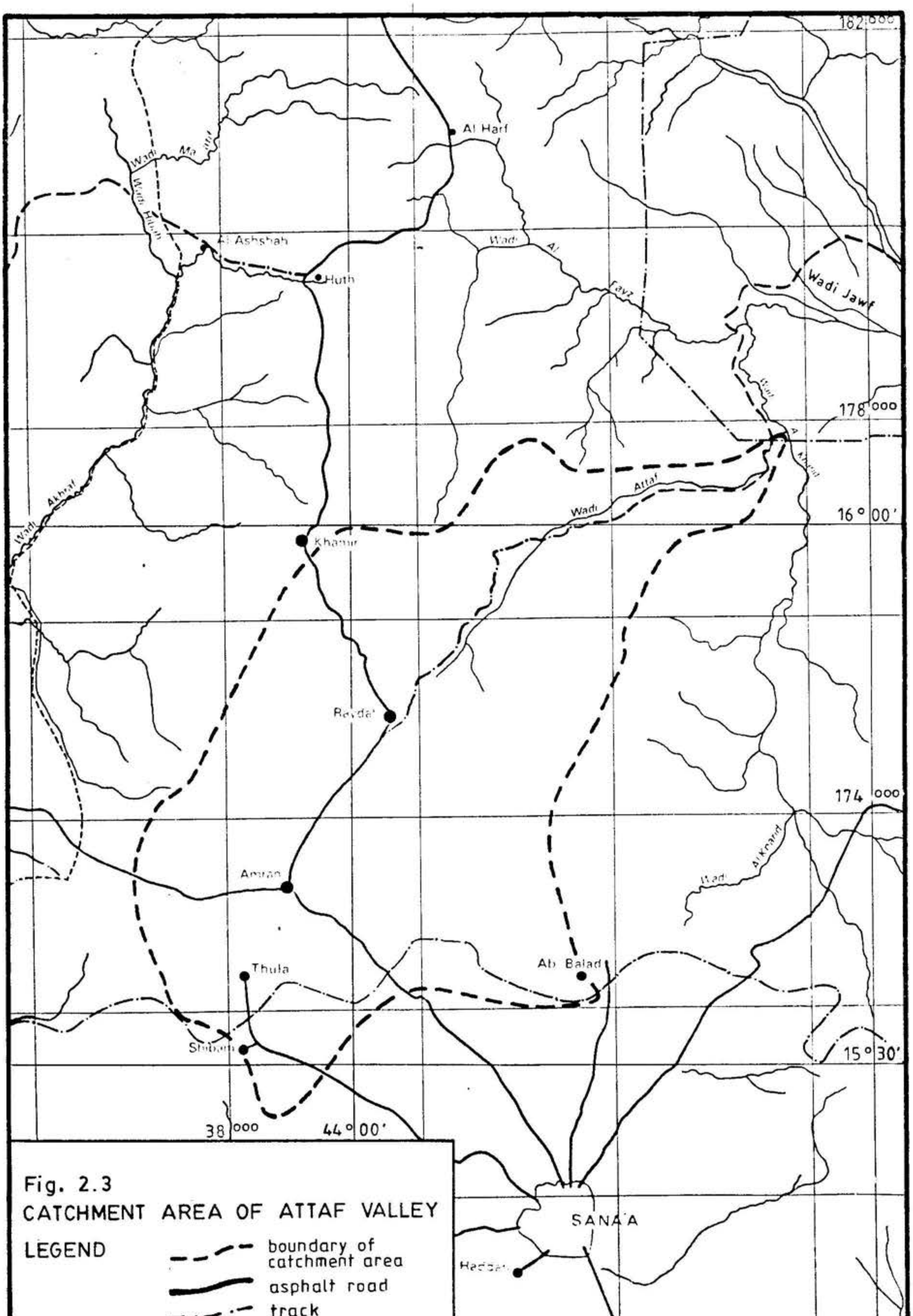


Fig. 2.3
CATCHMENT AREA OF ATTAF VALLEY

Fig.2.4 *Mean Monthly Precipitation Near Attaf Valley*

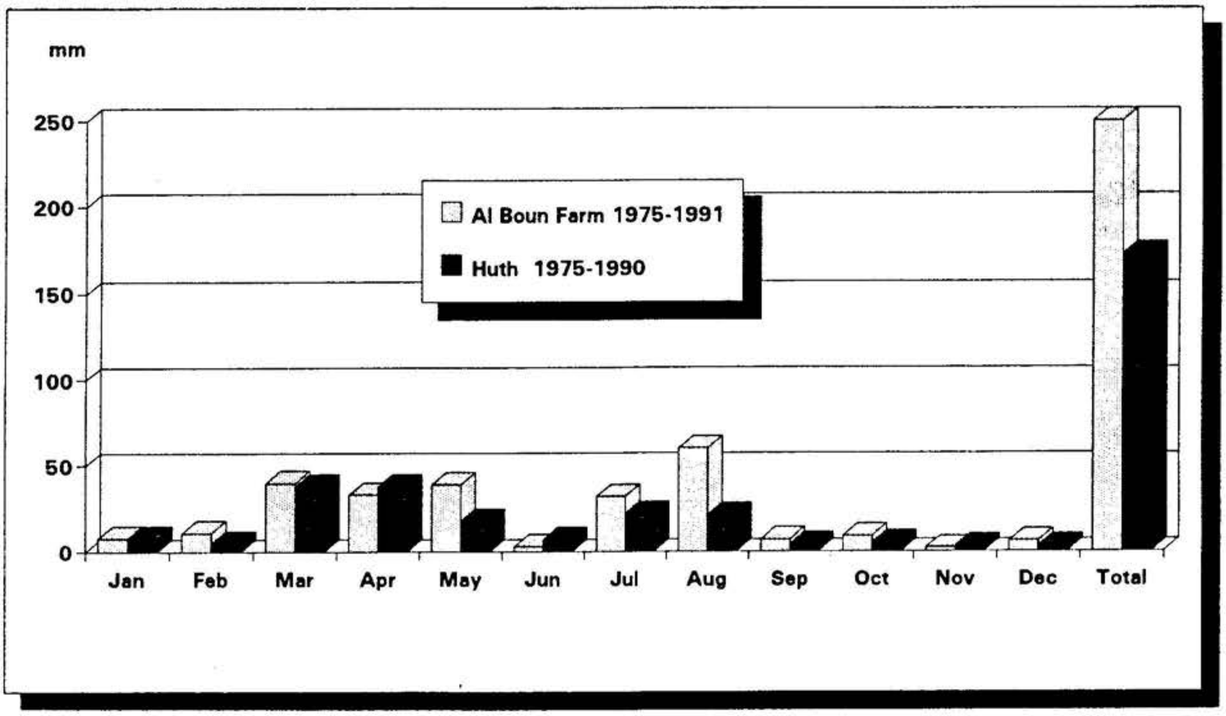
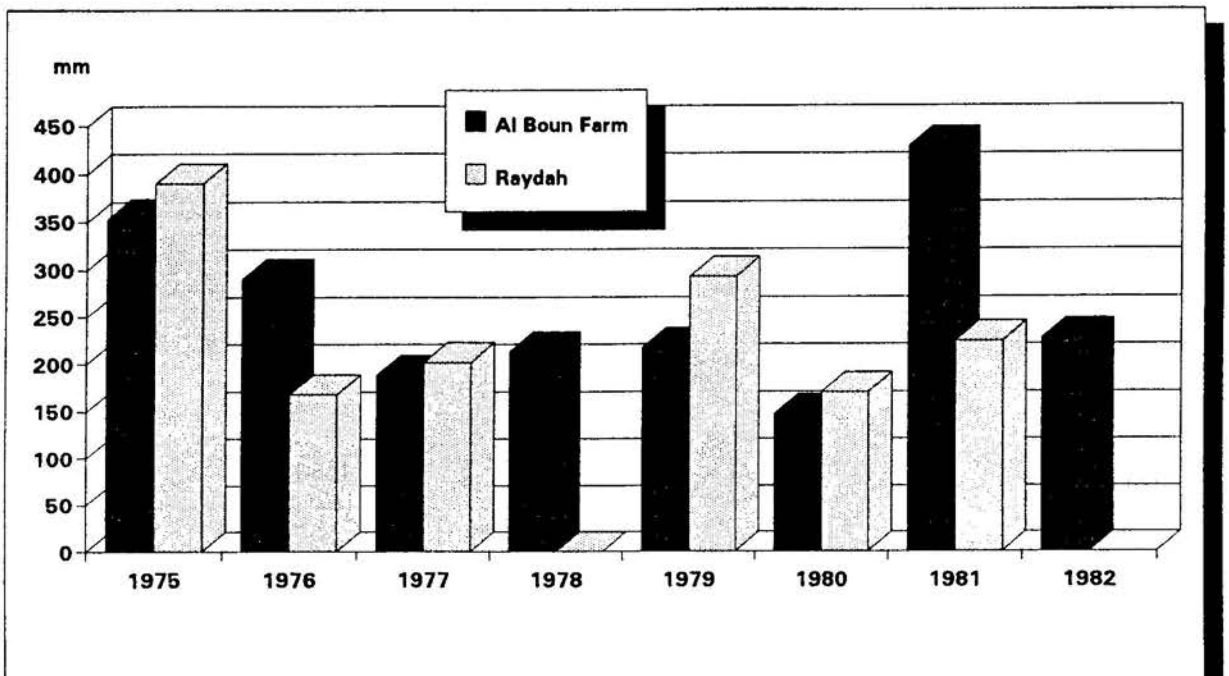


Fig. 2.5 *Total Annual Precipitation Near Attaf Valley*



Note: of 1978, 1981 and 1982 not all data available.

Temperatures range from 33 degrees Celsius in the summer to three degrees in the winter. The annual average temperature is 14.6 degrees. The mean monthly maximum temperature is 28.4 degrees, while temperatures in the winter can drop to below zero.

The relative humidity is usually very low: in dry periods monthly minima of only 10-20% are reached. Even during wet periods with maximum figures from 90 to 100%, minimum values of only 10% were still measured.

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

3 GEOLOGY AND HYDROGEOLOGY

3.1 GEOLOGY

3.1.1 Tectonics

The Attaf Valley gets its name from the wadi that drains the northwest part of the valley: Wadi Attaf. Geologically the Attaf Valley is a continuation of the Amran Valley. Like the Amran Valley it originated in the downthrow during the Oligocene (Tertiary) of the Amran limestone along major faults, causing a graben system that later during the late Tertiary (Pliocene and Miocene) and Quaternary filled with alluvial sediments. During this deposition intermittent volcanic activities at the southeast border of the valley were responsible for the deposition of the interbedded basalt layers (see Figs. 3.1 and 3.2).

3.1.2 The Quaternary Volcanics

To the south and the southeast of the graben a volcanic field, composed of some 100 cones and associated basaltic lava flows, extends over an area of about 26 km long and 2-5 km wide. The volcanic activity occurred between 100 000 and 1800 years ago. The thickness of the volcanic cover varies from zero to several hundreds of metres. The basalts here are dark grey to black coloured.

The satellite photos show most of the valley as a black colour. This is partly caused by basalt flows, but also in large areas by the existence of a thin layer of black basaltic detritus and pyro-clastics. Only in some areas, mainly near the main wadi outlets, this sheet of black stones has been covered by more recent alluvial wadi deposits. These are the areas with the main agricultural activity.
Table 3.1 shows the description of the geological formations and their hydraulic characteristics.

3.1.3 The Quaternary Alluvium

During the Quaternary period, the depression (graben) was filled up by alluvial deposits, consisting of clay, loess, silt, sand, gravel and boulders. This material originated from the surrounding outcropping Amran limestones, the Tawilah and Medj-Zir sandstone escarpment in the southwest near Shibam. These unconsolidated sediments are interbedded with Quaternary basaltic layers and form the principal aquifer of the area. Fig. 3.2 is a northwest-southeast geological cross-section through the Attaf Valley.

The thickness is greatest along the main axis of the valley where it probably reaches probably more than 300 m. It diminishes towards the limestone and basaltic flanks. The Quaternary alluvial deposits lie upon the block-faulted limestones of the Amran Series.

3.1.4 The Amran Limestones

The Amran Limestone Series outcrops over a vast area, roughly between the

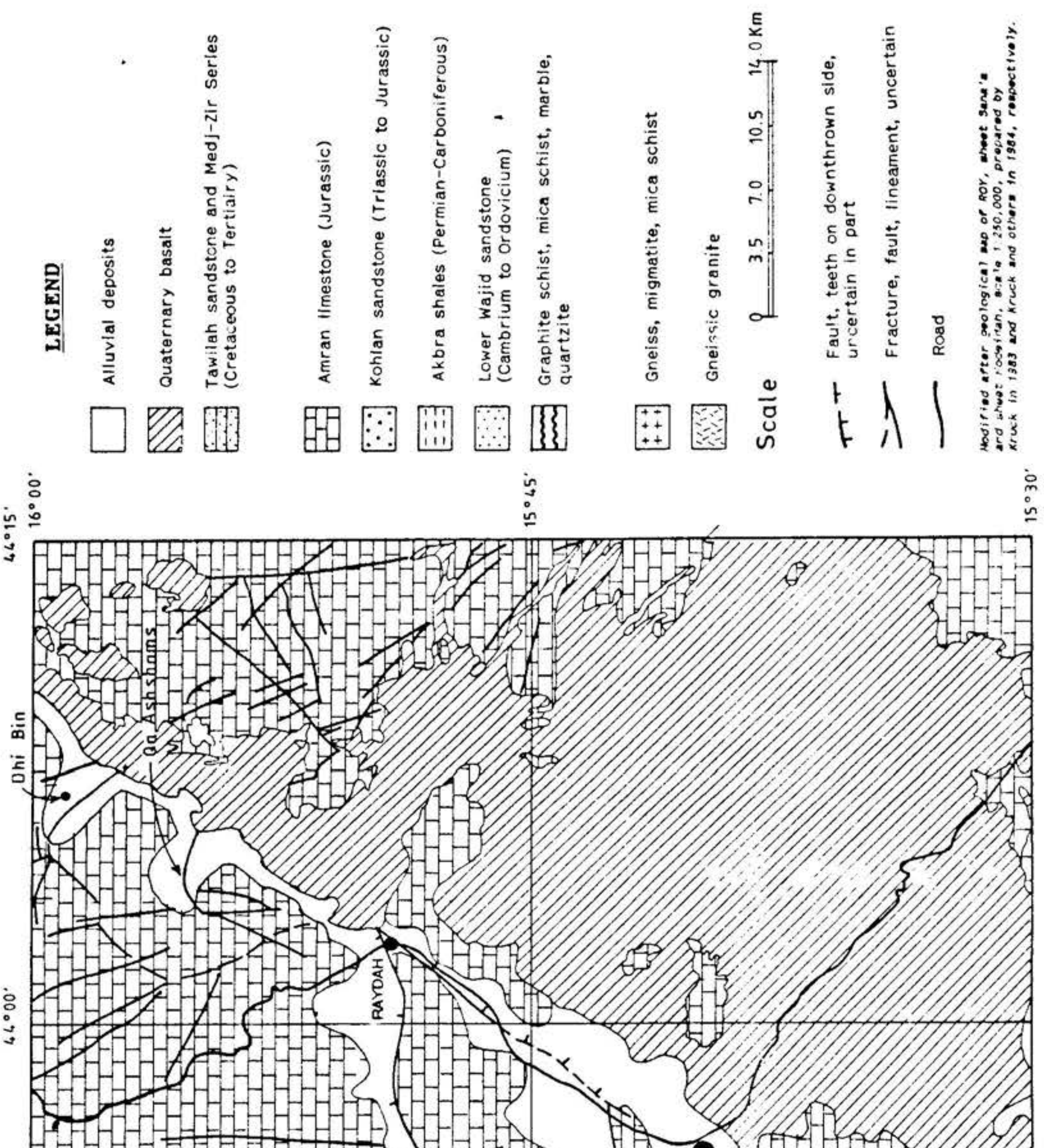


Figure 3.1 Geological map of the study area.

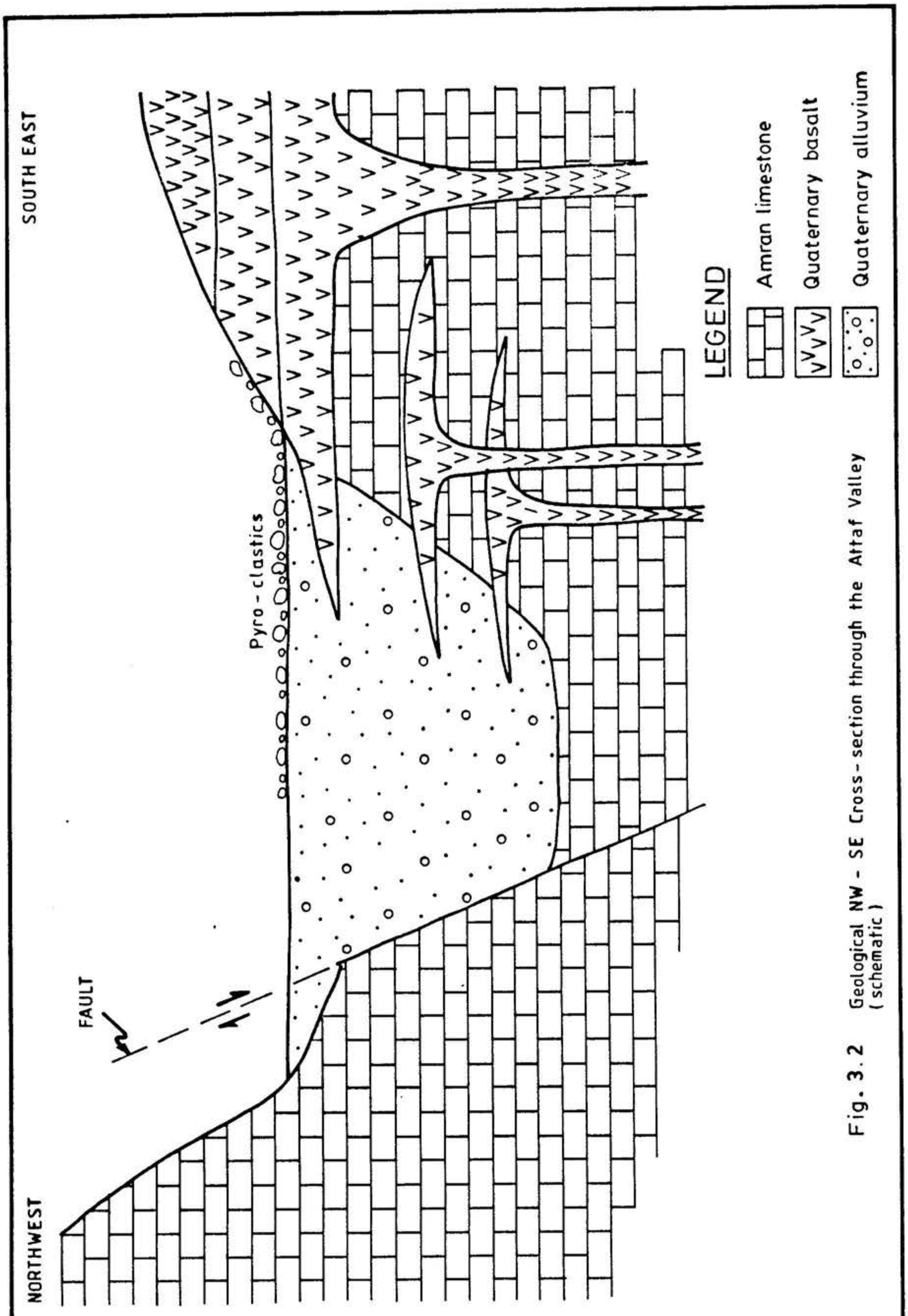


Fig. 3.2 Geological NW - SE Cross-section through the Attaf Valley (schematic)

Table 3.1 *Geological Formations and their Hydrogeological Characteristics*

Geological formations and their hydrogeological characteristics			
Stratigraphic age	**Litho-stratigraphy**	**Lithology**	**Hydrogeology**
Quaternary	Alluvial deposits, locally interbedded with basalt flows	Loam, silt, clay, loess, gravel, boulders. Basalts and tuffs	Main aquifer of Attaf Valley. Multi-semiconfined aquifer system of: a) Alluvium: moderate to good aquifer depending on grainsize and b) Basalt flows: poor aquifers, unless fractured. Basalt flows function as semi-confining layers at variable depth.
Tertiairy	Yemen Volcanics	Volcanic flows, sills, tuffs, basalts and intrusives.	Poor aquifer, unless fractured. Too far outside study area (20 km S) 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.	Potential aquifer due to its volume. Possibly important supplier of groundwater to the Amran Valley from SW (10 km)
Jurassic	Amran Series	Limestones, dolomites, marl, shale layers and Quaternary basalt dykes.	Poor aquifer, except in or near fractured fault zones, no indications for the occurrence of karst.
Triassic	Kohlan Series	Fine grained, partly cemented quartz sandstones with conglomerate horizons.	Not significant for the water supply of Attaf Valley. Outcropping 35 km W of study area. Probably underlies Amran Limestone Series.
Precambrian	Basement complex	Granite, gneiss and mica schists.	Practically impermeable and little water storage. Aquiclude and aquifuge, outcrops 25 km SW of Amran.

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

The lower member of the Amran Series is represented by the Shuqra Formation and consists mainly of white/yellow/black limestones. Its depositional environment was shallow reefal marine. Then a period of block faulting followed. During a new transgression, the Maabi and Sabatain formations (rock salt, marl, gypsum, some shales and limestones) were deposited directly upon the eroded top of the Shuqra formation in the graben extending from Amran to Thula. The late Jurassic was a relatively stable period and fluvio-marine sediments were laid down (the Al-Ahjur formation), consisting mainly of marly, shaly and sandy mudstones. Towards the end of late Jurassic, another regression resulted 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 edge of the Amran Valley and exceeds 800 m in the Attaf Valley. It is calcareous everywhere, although the facies change with location. Near the Amran Valley, the formation shows yellow-white limestones containing shallow water fossils. Here the limestone is faulted and heavily jointed, forming the eastern, western and northern flanks of the Amran Valley.

3.2 AQUIFER SYSTEMS

3.2.1 Alluvium

The Quaternary alluvium, where saturated, represents a relatively good aquifer. The highest permeabilities are in the interbedded gravel layers. The groundwater of the Quaternary alluvium of the plain is assumed to be replenished by the surrounding Amran limestones, Quaternary volcanics and the wadi-fills debouching in the valley. Fig. 3.3, the hydrological cycle, presents a schematic model of the movement of water in the Attaf Valley and its catchment area.

The (natural) water table gradients in the Amran Valley indicated a groundwater flow directed to the northeast, bending eastward into the Attaf Valley. In this wadi, east of Shuarba, groundwater discharges through springs (perched aquifer?).

3.2.2 Bedrock

Limestones
The Amran Series, principally composed of limestones, marls and some shales, are generally considered as a poor aquifer. Higher permeabilities are only 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, faults and thus permeability

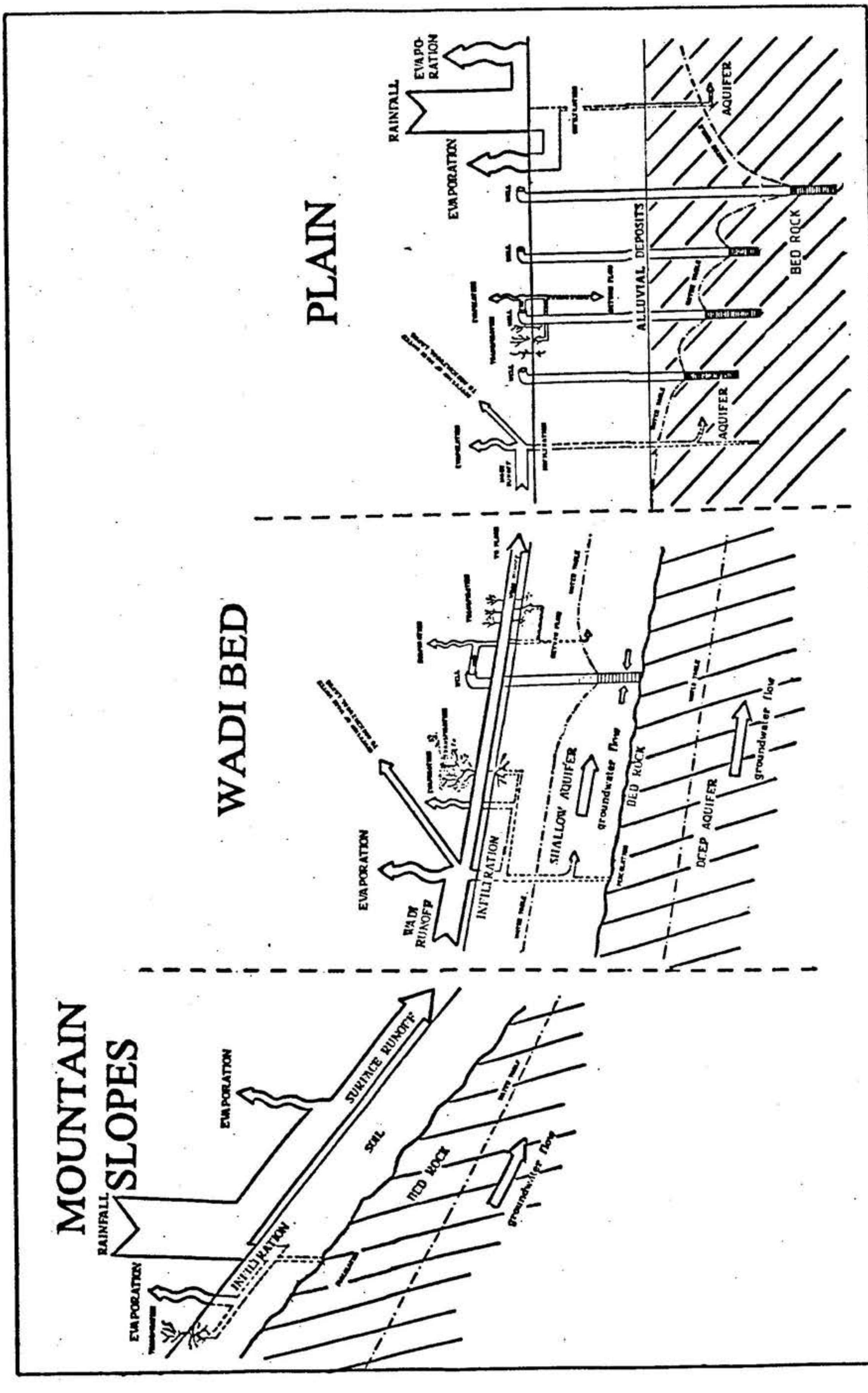


Fig. 3.3 Hydrological cycle

decreases with the depth. Only at the edges of the Attaf Valley is exploitable groundwater found in fracture zones.

Tibbits and Aubel (1980) drilled six boreholes in the limestone in the nearby Amran Valley. Only one well (near Menjidah) gave a reasonable yield: 14.5 l/s; the remaining five boreholes did not yield much water.

Volcanics
Most of the test boreholes drilled during the same study in the volcanic deposits proved to be dry. Water-bearing and water-transporting capacities would only be expected in fractured zones and dykes, along 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 table in the alluvium (Tibbits/Aubel, 1980).

Test drilling by the same consultants in the Amran Valley near the Attaf Valley revealed that the Quaternary volcanics are underlain by the Amran limestones. Locally, small groundwater occurrences were indicated at shallow depths in dykes crossing the adjacent mountainous area.

3.3 AQUIFER PARAMETERS

Aquifer tests executed by Tibbits/Aubel (1980) in the period 1975-1977 clearly showed groundwater occurrence under semi-confined (leaky) conditions in the Amran Valley. Because of the similar depositional environment in the Attaf Valley, the same can be assumed for the study area. The semi-confinement is caused by semi-permeable basalt beds that are interbedded with alluvial sediments. Wells penetrating these beds may show some higher water tables than the general water table (artesian groundwater). The aquifer tests indicated that, in general, aquifers here have good capacities, are leaky and that transmissivity values increase towards the axis of the valley.

4 GROUNDWATER - GENERAL

4.1 DISTRIBUTION OF WELLS

Fig. 4.1 shows the locations of the wells visited during December 1991. A total of 113 wells were inventoried. It can be assumed that at least 90% of all existing wells were surveyed and that the remaining 10% are evenly distributed over the total area. Nevertheless large areas with a lower well density show up.

Several parts of the plain are not suited for agriculture because of irregular topography and soil properties, but mainly because large areas of the valley are covered with a carpet of basalt layers and/or basalt stones (pyro-clastics and clastic basalt). Near the borders of the plains spate irrigation dominates, in some places supported by pumped irrigation.

4.2 NUMBER OF WELLS

The total number of wells was estimated at about 125, of which 113 were operational.

Most dug wells have fallen dry over the last ten years because of the reducing water table. Since the introduction of drilled wells water levels have fallen to such an extent that the manual digging and deepening of wells has been forced to stop, except in some areas with shallow (perched) groundwater tables at the borders of the plain, in the valley tributaries and in wadi courses. Only the richer farmers could afford to drill deeper wells to reach the water, although 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. However, all the wells are now equipped with turbine pumps. Only a few wells in the upper wadi regions with shallow water levels use low power centrifugal pumps.

Fig. 4.2 and 4.3 show the total number and the cumulative number respectively of wells that were still operational in 1991 and were drilled during the period of 1971 to 1991. It should be noted that these are net figures, ie. the number of drilled wells minus the number of abandoned wells. Serious groundwater development in the Attaf Valley started about 10 years (1971) later than in the Amran Valley (1962). Most drilling activity occurred in the period from 1981 to 1987. Since 1987 the rate of drilling has dropped from 15 wells in 1987 to three in the following years. 1990 and 1991 also show relatively very low numbers.

A preliminary conclusion is that farmers started to recognise the high costs involved in pumping from great depths. Statistical analysis of the cumulative distribution of construction over the years shows that 50% of all existing wells were drilled after 1984, and the average well age is 7.5 years. The oldest well dates from 1971. Because of the falling groundwater table some wells have been deepened during the last 20 years.

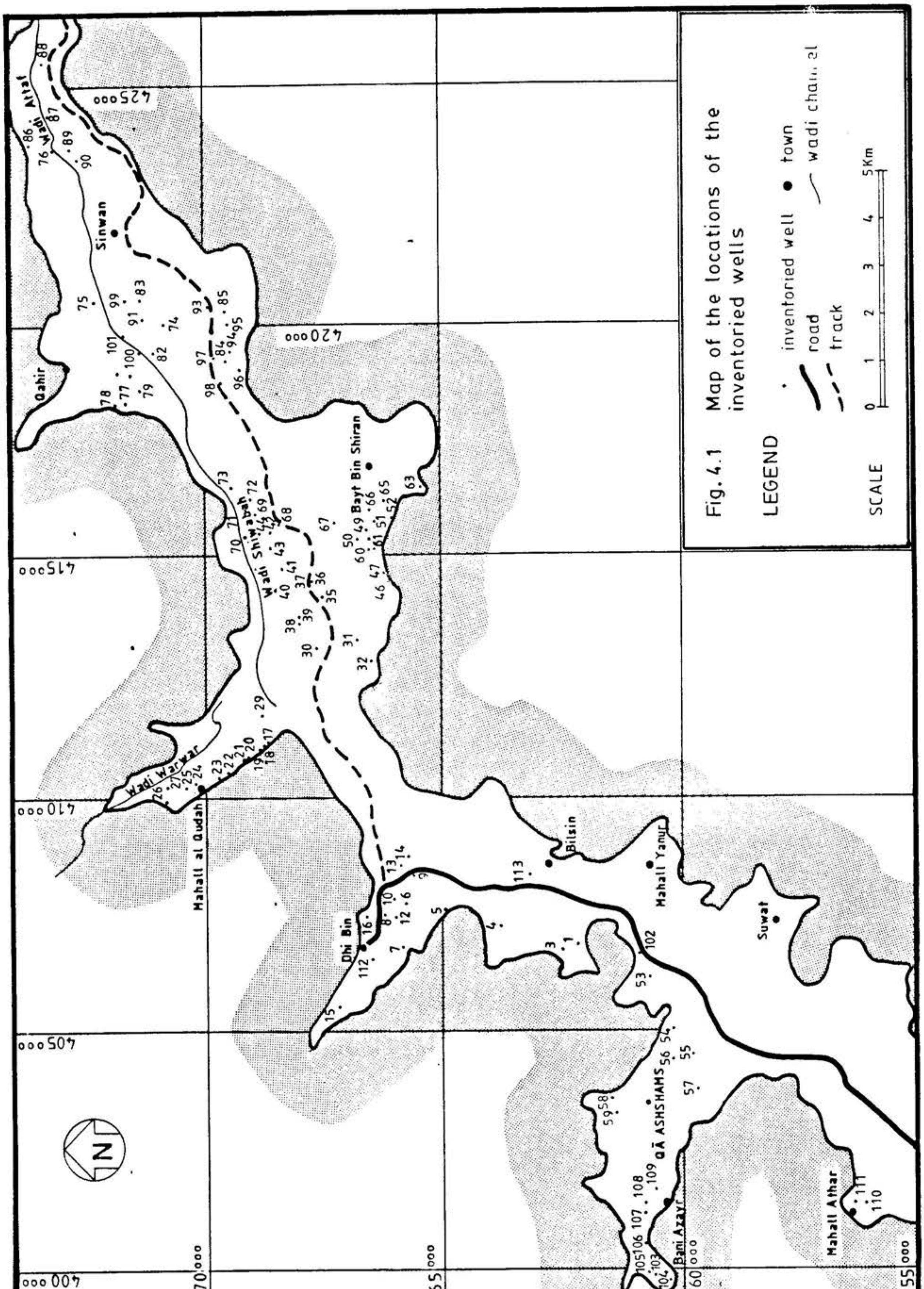


Fig. 4.1 Map of the locations of the inventoried wells
LEGEND
inventoried well
town
road
track
wadi channel
SCALE
0 1 2 3 4 5Km
Wadi Attaf
Sinwan
Qahir
Wadi Shiwabah
Bayt Bin Shiran
Wadi Warwar
Mahall al Qudah
Dhi Bin
Bilsin
Mahall Yanur
Suwat
QĀ ASHSHAMS
Bani Azayr
Mahall Athar
425000
420000
415000
410000
405000
400000
1770000
1765000
1760000
1755000
N

Fig. 4.2 *Number of Wells Drilled in the Period 1971 - 1991*

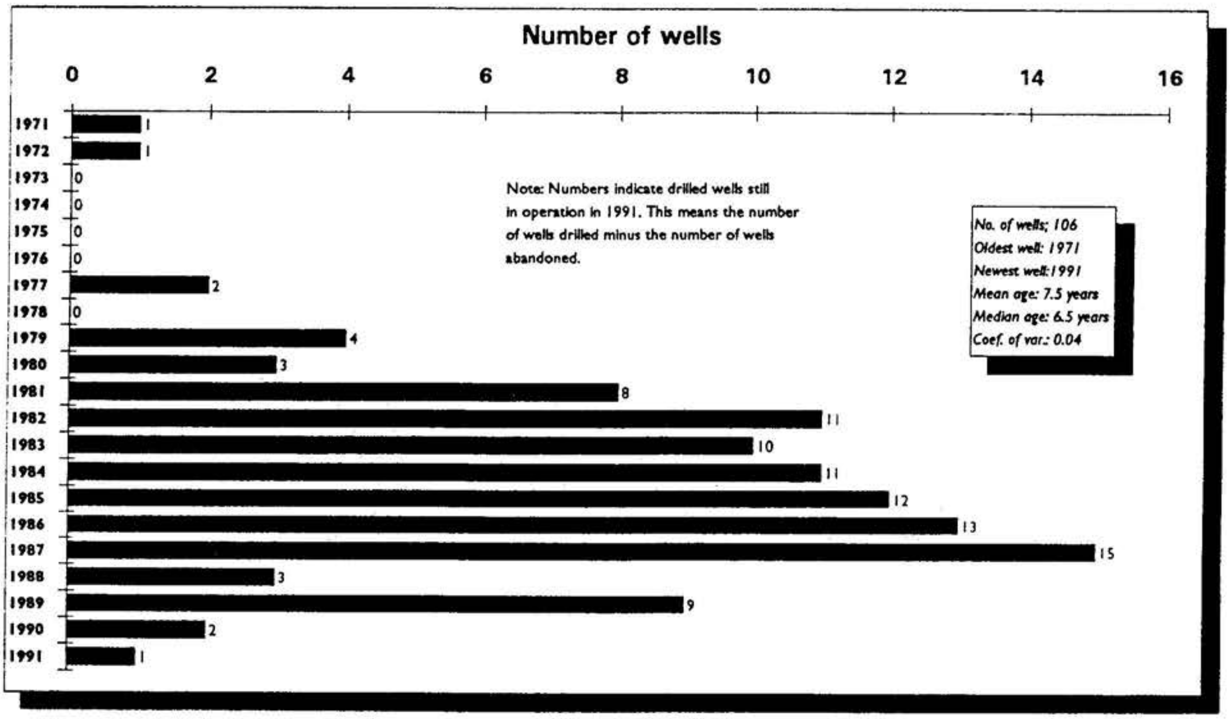
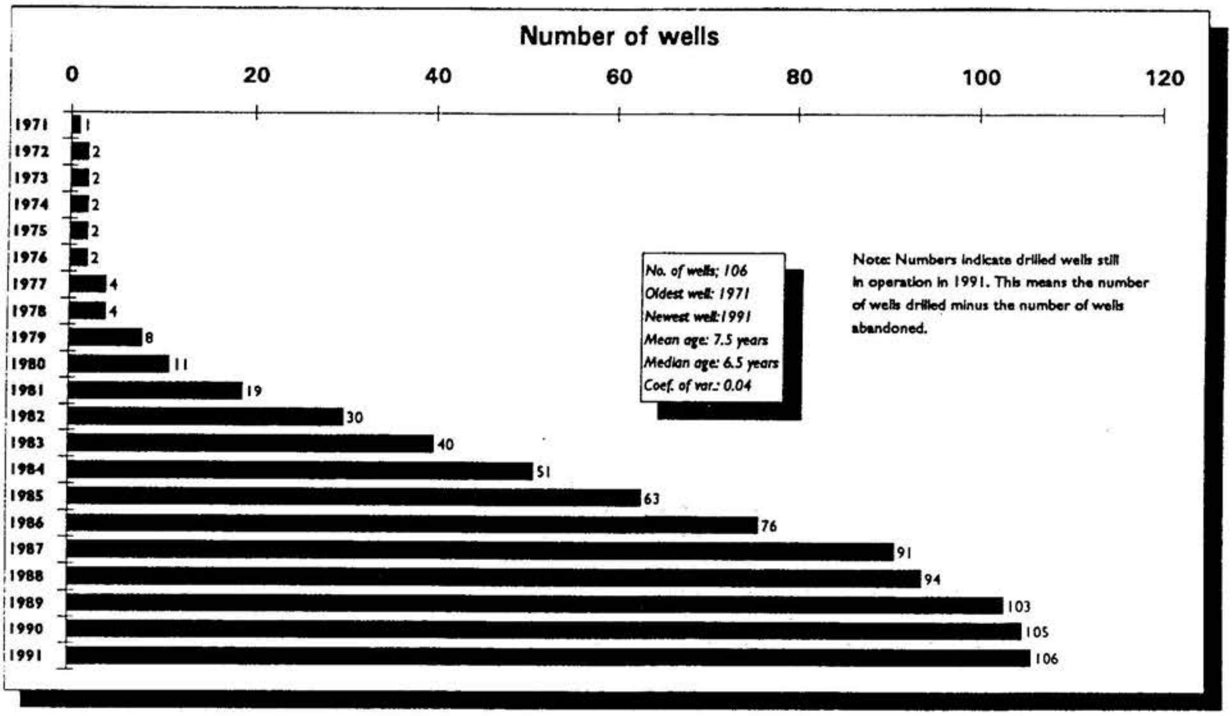


Fig. 4.3 *Cumulative Number of Wells Drilled in the period 1971 - 1991*

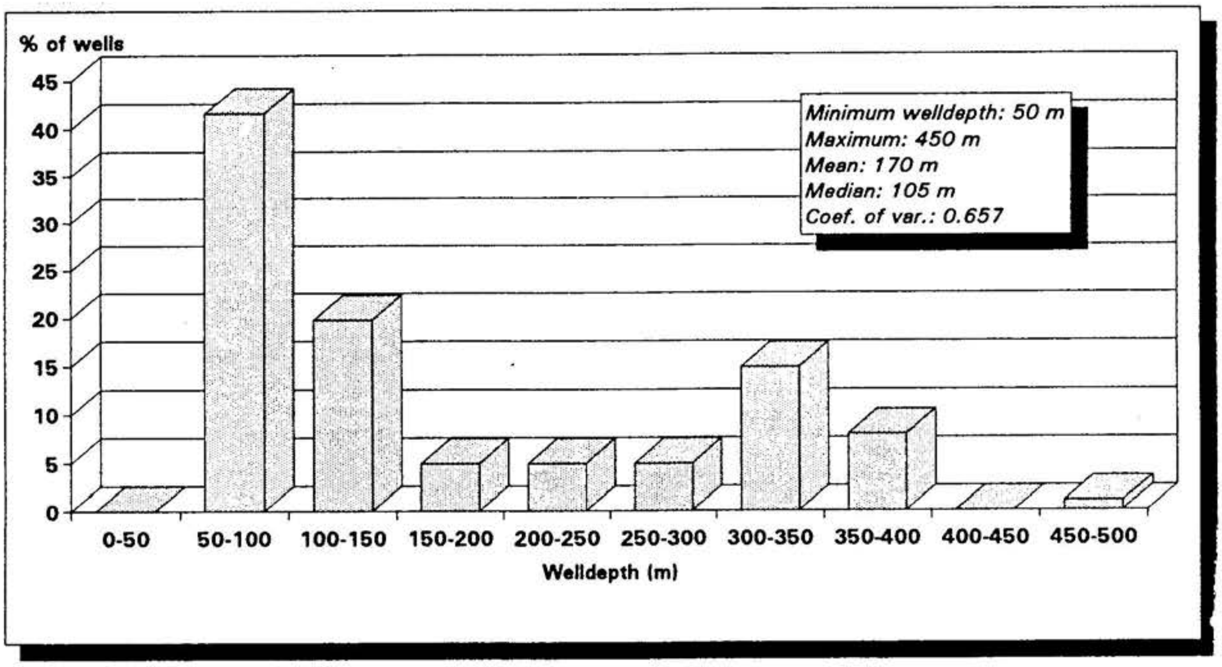


4.3 WELL CHARACTERISTICS

Almost all the wells inventoried are drilled wells. Only one dug well was encountered. Only two wells were reported to have been deepened once, a very low figure when compared with the Amran Valley, where 23% of the wells were deepened one or more times.

The drilling method used was predominantly rotary although some older wells were drilled with the cable tool method. Except for a few wells drilled in limestone and basalt, all wells were completely cased.

Fig. 4.4 *Distribution of Well Depths*



All the wells, except the dug well, had steel casings. Casing diameters differ significantly from those observed in the neighbouring Amran Valley: small diameters (8") dominate. They range from 8" to 12" (8" diameter: 58%, 10": 26% and 12": 14%). The lower section is screened with a series of 6 m long slotted pipes.

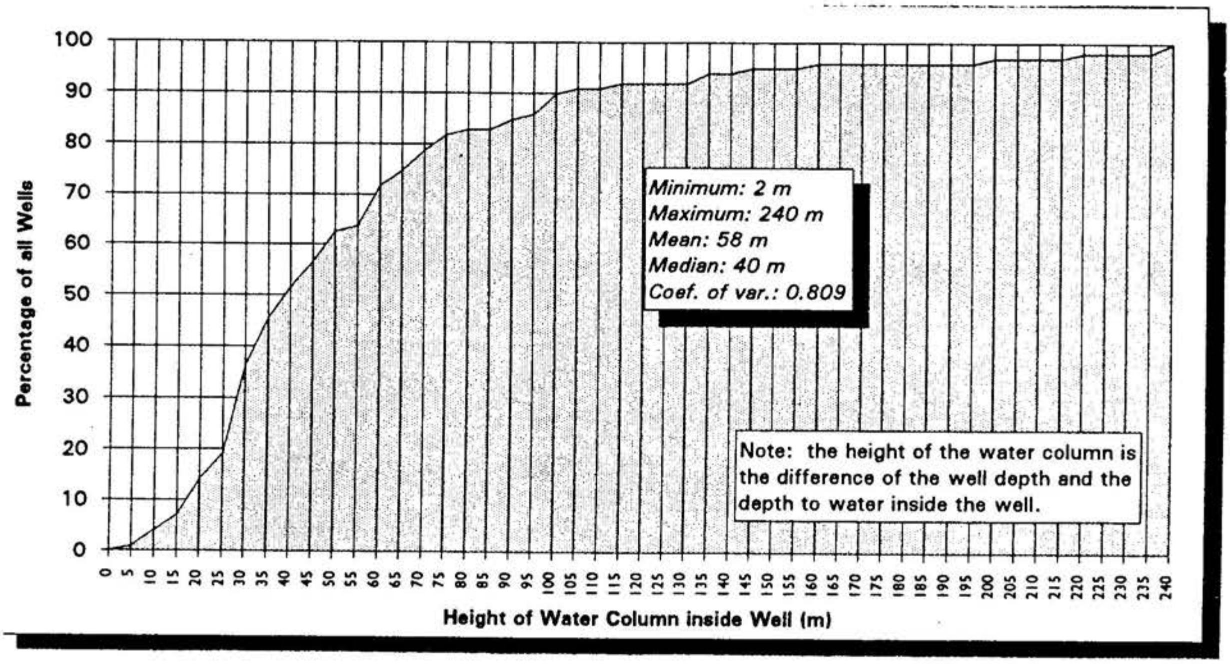
Well depths range from 50 m to 450 m. The average depth is 170 m. A relatively high concentration of deep wells exist in the southwest part of the valley. Here, groundwater levels are very deep: from 200 to more than 350 m. (see Fig. 4.15). Fig. 4.4 shows the distribution of depth over all the wells. It indicates that there are two dominant groups of well depths, one of 50 to 150 m (mostly wells in the northeast with shallow water depths) and one of 300 to 400 m (wells in the southwest with deep water levels).

4.4 WATER COLUMN HEIGHTS

One way to indicate how the wells would withstand falling water levels, or in other words how much water column is available inside the wells, is to define and analyze the water column height of the well. The water column height is the difference between the well depth and the depth to the local static water level. By analysing the cumulative distribution plot of the water column heights of all the wells the percentage of wells that would 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 the water level depths are such that before long a significant percentage of the wells are likely to fall dry. The average aquifer penetration is 58 m. The figure shows that, if the groundwater drops 30 m over the whole plain, then 35% of the wells (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 Height of Water Column*



4.5 PUMPING EQUIPMENT

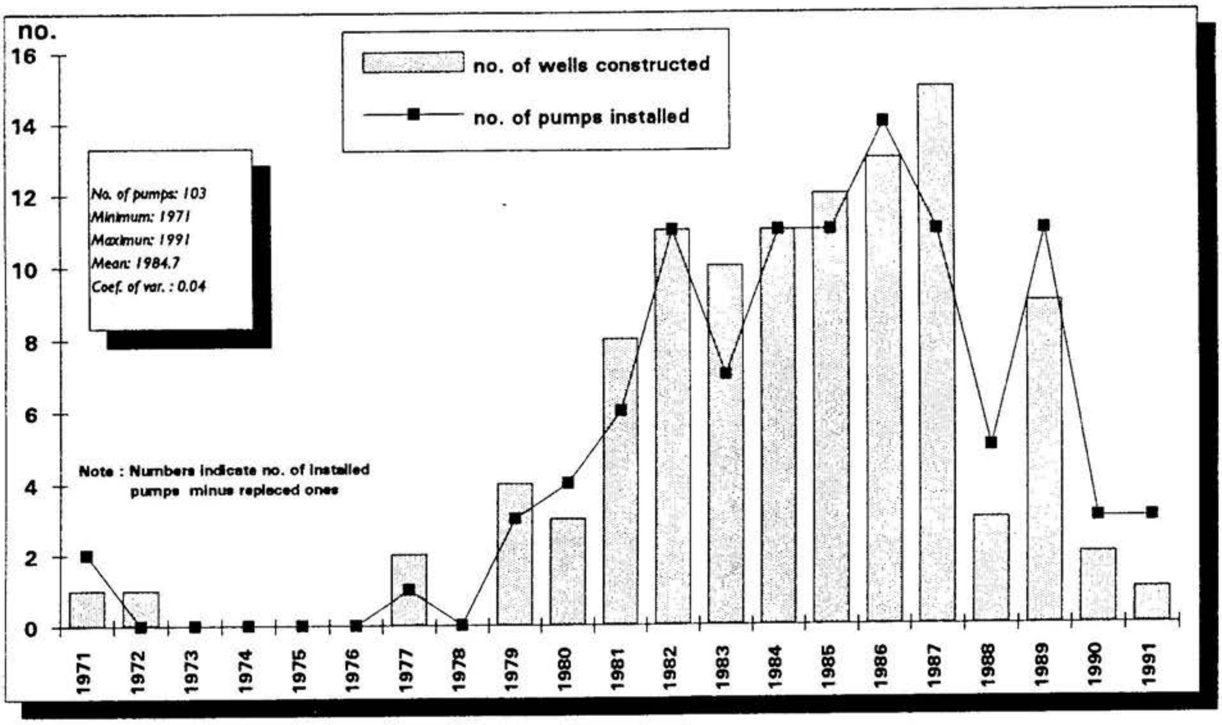
Water is pumped in 73% of the wells by vertical turbine (lineshaft) pumps coupled via crossed webbing belts to diesel engines. However, a relatively high percentage (27%) of the wells are equipped with electro-submersible pumps, driven by electrical power generated by high capacity engines, particularly in the southwest part of the valley where water levels are very deep.

The level of standardization in engine and pumping equipment is lower than in the Amran Valley: 72% of the pumps were supplied by two manufacturers, Caprari (68%) and Iperson (8.5%), while the remaining 28% were fabricated by nine different manufacturers. The pump column diameter was mostly three inch (71% of wells) or four inch (19%).

The same level of standardization was noticed among the engines that power the pumps. Japanese engines are used for about 60% (Yanmar 46% and Mitsubishi 14%). The remaining 40% was divided between 17 other makes. The engines had capacities ranging from 20 to 35 horsepower for the lineshaft pumps and 74 to 250 kiloWatt for the electro-submersible pumps.

The average age of the wells is about the same as that of the pumps (7.5 years in 1991). During the period 1988-1991 more pumps were installed than wells constructed, replacing pumps installed before this period (see Fig. 4.6).

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



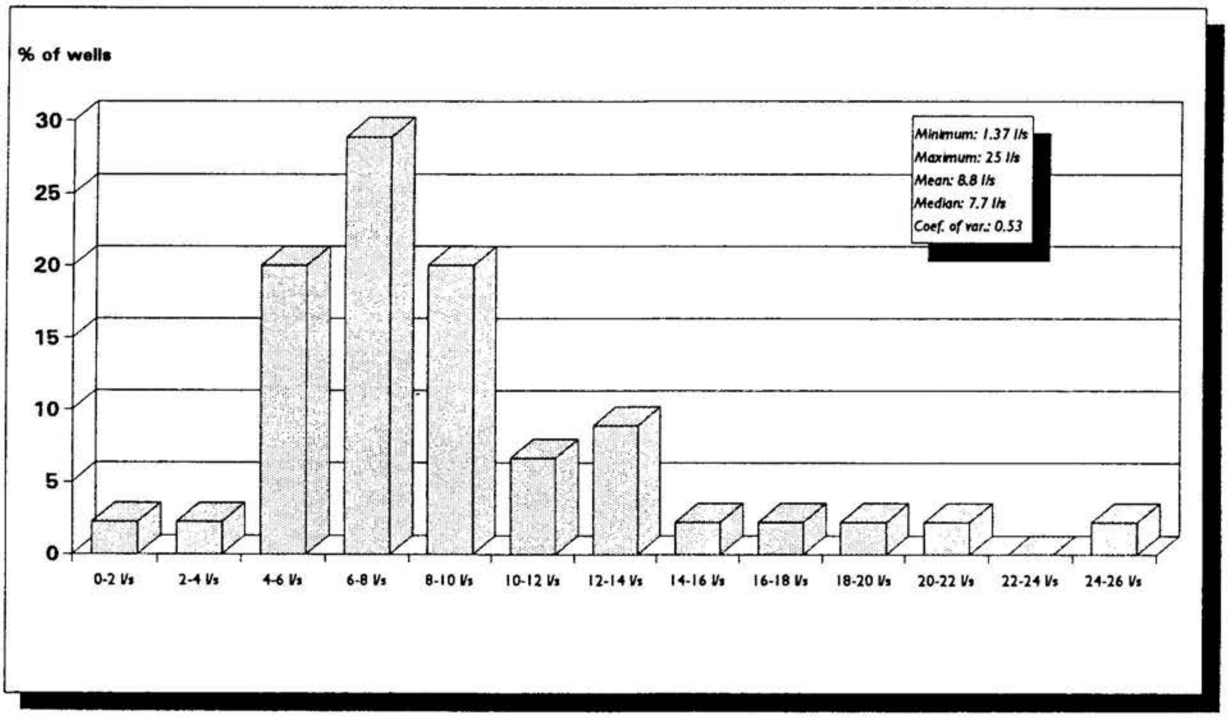
4.6 WELL YIELDS

Well discharge rates vary from about 1.4 l/s to 25 l/s. The mean is 8.8 l/s. The distribution of well yields is presented in Fig. 4.7. Well yields are determined by several parameters: the capacity of the pump, the well efficiency, the screen length, the depth to water, and aquifer parameters like transmissivity and storage coefficient.

Drawdowns during pumping are in general low: in the order of only a few metres at a discharge rate of about 10 l/s.

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. Only a few measurements of the dynamic water level could be carried out.

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



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 installing of the casing, the screen (slotted pipes), the gravel pack and the development (air lift) of the well.

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 have built a reservoir where the pumped water is collected and from where it is distributed to the fields. The costs may also include the installation of pipes and tubes to convey the water.

The same figure shows the distribution of costs. Well construction costs range from YR 66 000 (a 66 m deep well) to YR 500 000 (a 350 m deep well). Median well cost is YR 254 000, while pumping equipment costs have a much larger variation - from YR 30 000 to a YR 1 000 000 (a 340 m deep well), and a median of YR 238 000.

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

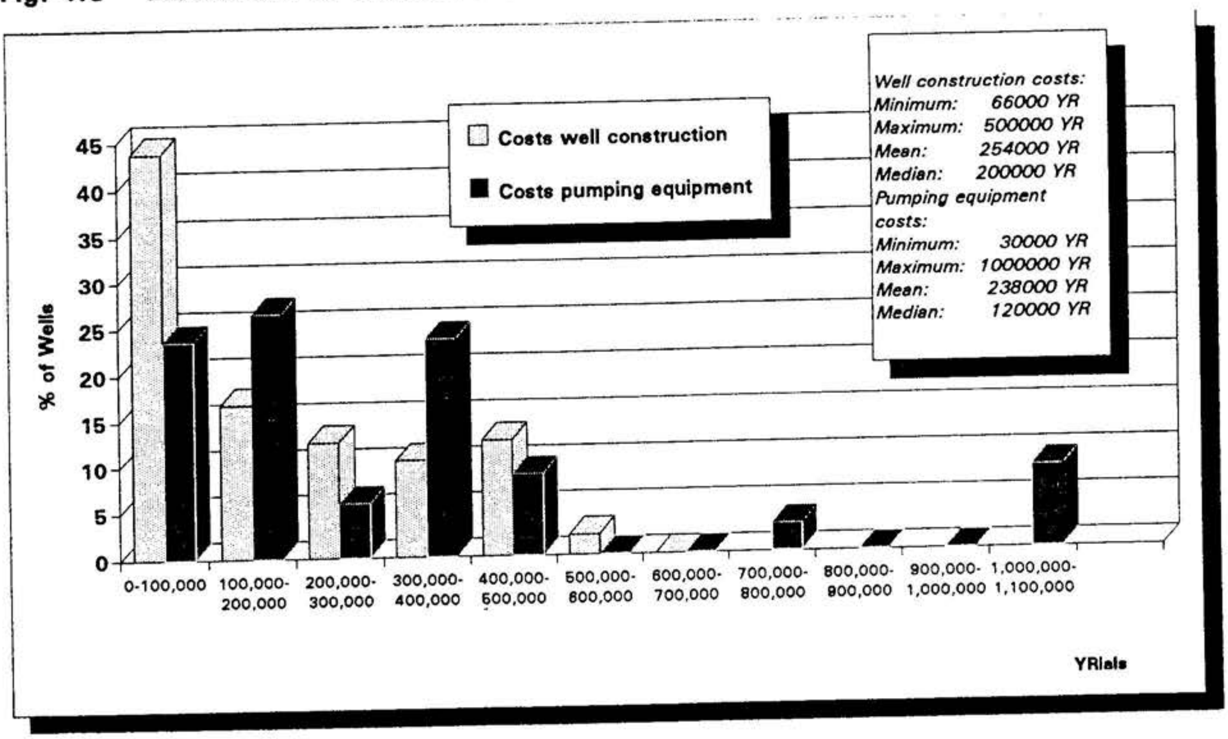
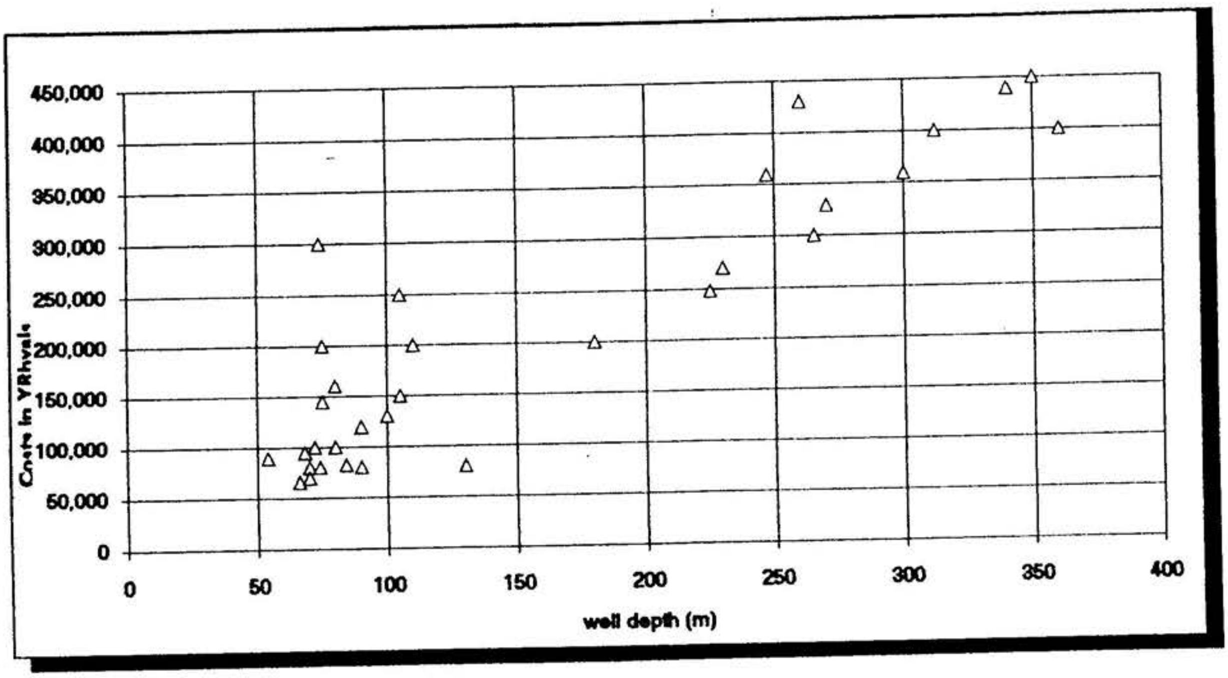


Fig. 4.9 *Relation of Well Depths to Well Construction Costs*



Both well construction and pumping equipment costs are higher than in the Amran Valley. This can be partly explained by the lower age of the wells and pumps in the Attaf Valley (more recent prices) and the expensive engines for the electro-submersible pumps.

In Fig. 4.9 the costs of well construction, excluding the costs for pumping and related equipment are plotted against the well depth. It must be remembered that these costs are costs at the time of construction or purchase and that the data concerns wells drilled during the period of about 1971 to 1991. As a consequence of currency inflation, the mean real costs (1991 YR) are somewhat higher. The average price per metre over this period was about YR 1250.

4.8 PUMPING SCHEDULES

The average farmer switches the pump on at sunrise and switches the pump off at sunset, throughout the seasons. This is reflected in the mean yearly number of pumping hours per day - 12. Pumping activities are highest during Sayf[1] (mean 13.7 hrs/day), followed by Kharif (mean 13.6 hrs/day), Rabi'a (mean 11.9 hrs/day) and Shita (mean 10.5 hrs/day).

Fig. 4.10 *Distribution of Daily Pumping Hours*

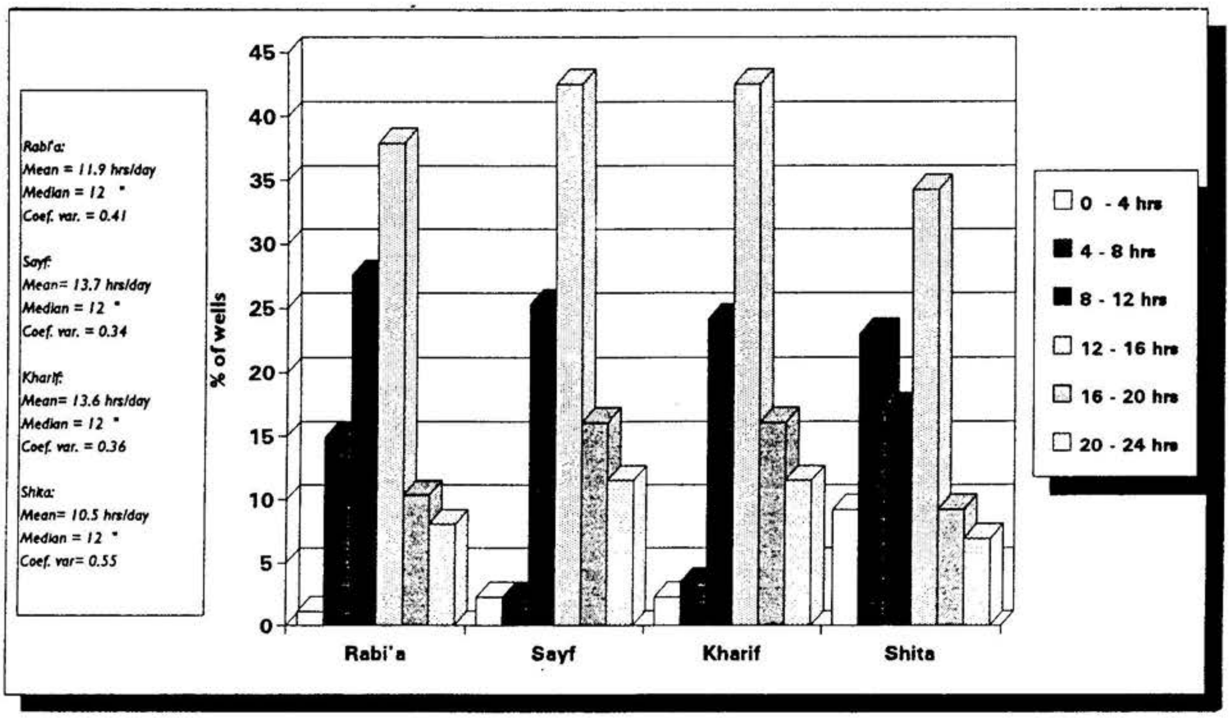


Fig. 4.10 shows the distribution of daily pumping hours throughout the seasons. On about 60-65% of the irrigated land grape is cultivated (see Section 5.2), and so during Sayf much water is needed as the grapes are then in their mature phase.

[1] The seasons in Yemen are Rabi'a, Sayf, Kharif and Shita. They correspond approximately with spring, summer, autumn and winter.

About 4% of the farmers let the pump operate 24 hours per day.

Fig. 4.11 *Distribution of Monthly Pumping Days*

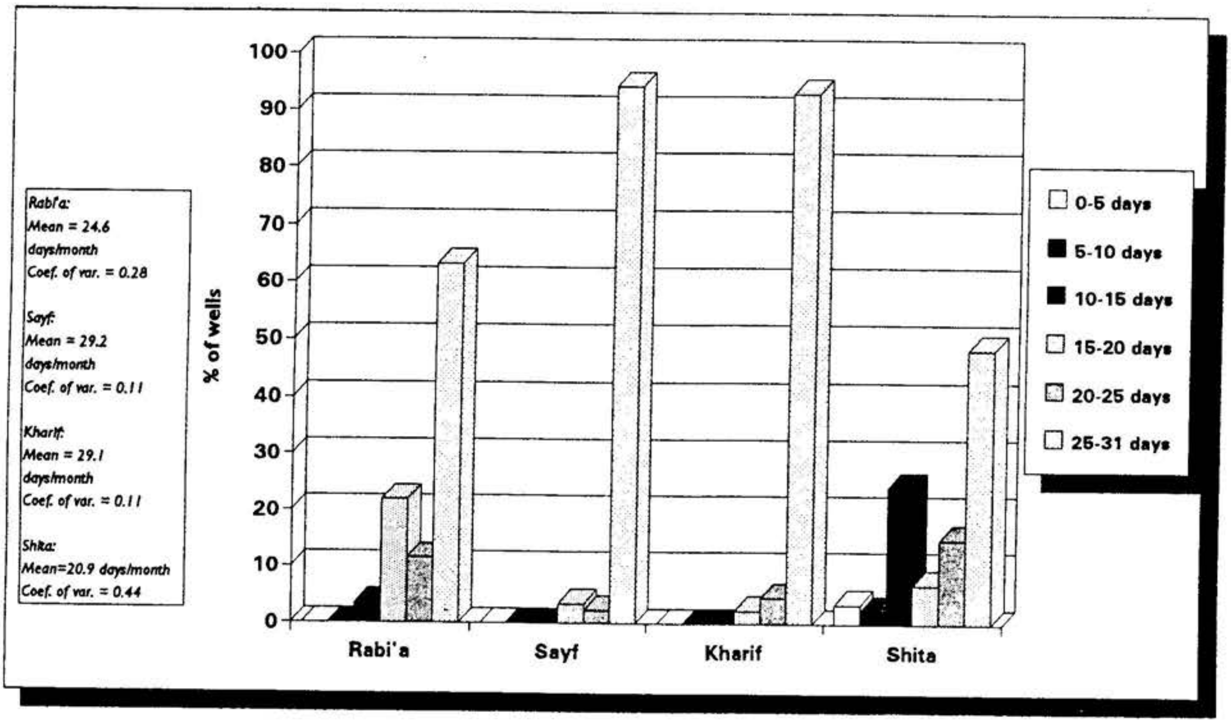
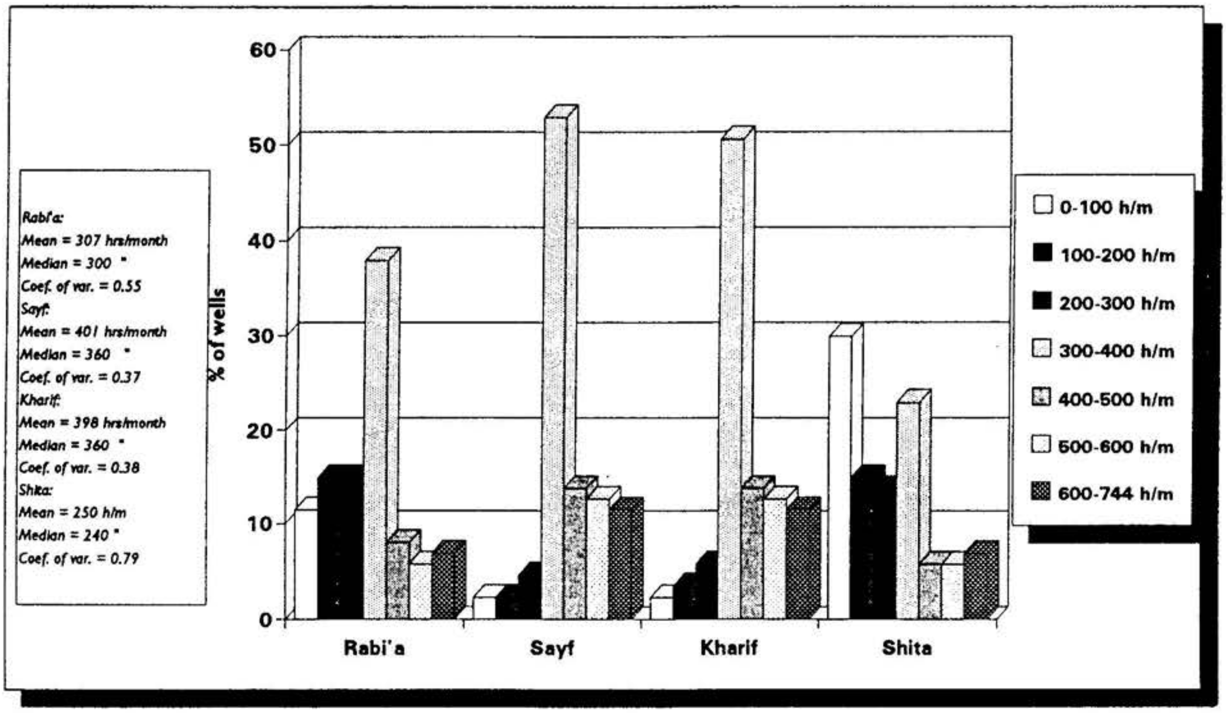


Fig. 4.12 *Distribution of Monthly Pumping Hours*



Over the whole year the average number of pumping days per month was 26 (see Fig. 4.11); the number of pumping hours per month 339, an average of 11.3 hours per day (see Fig. 4.12).

4.9 GROUNDWATER ABSTRACTION

To enable an assessment to be made of the total groundwater abstraction a fair estimate has to be made of the total number of operational wells. At 45 wells (of the total of 113 wells visited) the discharge could be measured, but at the remaining 68 wells no discharge measurements could be carried out for the following reasons: the well was dry, there was no pump and/or engine, no diesel, no oil, because of a broken pump/engine, or just because there was nobody to switch on the pump.

10.6% of the wells appeared to be permanently out of order. For the calculation of the yearly total discharge in the plains, these wells were not taken into consideration. Assuming the total number of wells to be about 125 and applying the same percentage of fall out, then about 112 wells would have been operational.

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 6% of the time the wells were not pumping on these grounds. This percentage was also taken into account when calculating the seasonal and total yearly abstracted groundwater volumes.

Table 4.1 *Volumes of Groundwater Abstracted During the Seasons*

	Rabi'a	Sayf	Kharif	Shita	Year
Groundwater Abstracted per well (in 1000 m^3)					
Mean	30.4	38.8	38.8	24.4	132.4
Median	25.7	35.0	35.0	22.4	10.9
Minimum	4.8	8.9	9.9	0.9	37.7
Maximum	114.2	114.2	114.2	81.2	365.5
Coef. of variance	0.67	0.56	0.56	0.72	0.52
Total volume of groundwater abstracted in Mcm	1.37	1.75	1.75	1.1	5.96
Based on no. of wells	45	45	45	45	
Total volume of groundwater abstracted in Mcm *(extrapolated, assuming a total of 112 operational wells)*	3.4	4.35	4.35	2.73	14.83

In Table 4.1 and Fig. 4.13 are calculated and presented the seasonal groundwater abstractions. A yearly total of approximately 15 million m^3 (Mcm) of groundwater abstraction was determined for the Attaf Valley in 1991. The volumes during the individual seasons were 3.4, 4.3, 4.3 and 2.7 Mcm for Rabi'a, Sayf, Kharif and Shita, respectively.

Fig. 4.13 *Volumes of Groundwater Abstraction in 1991*

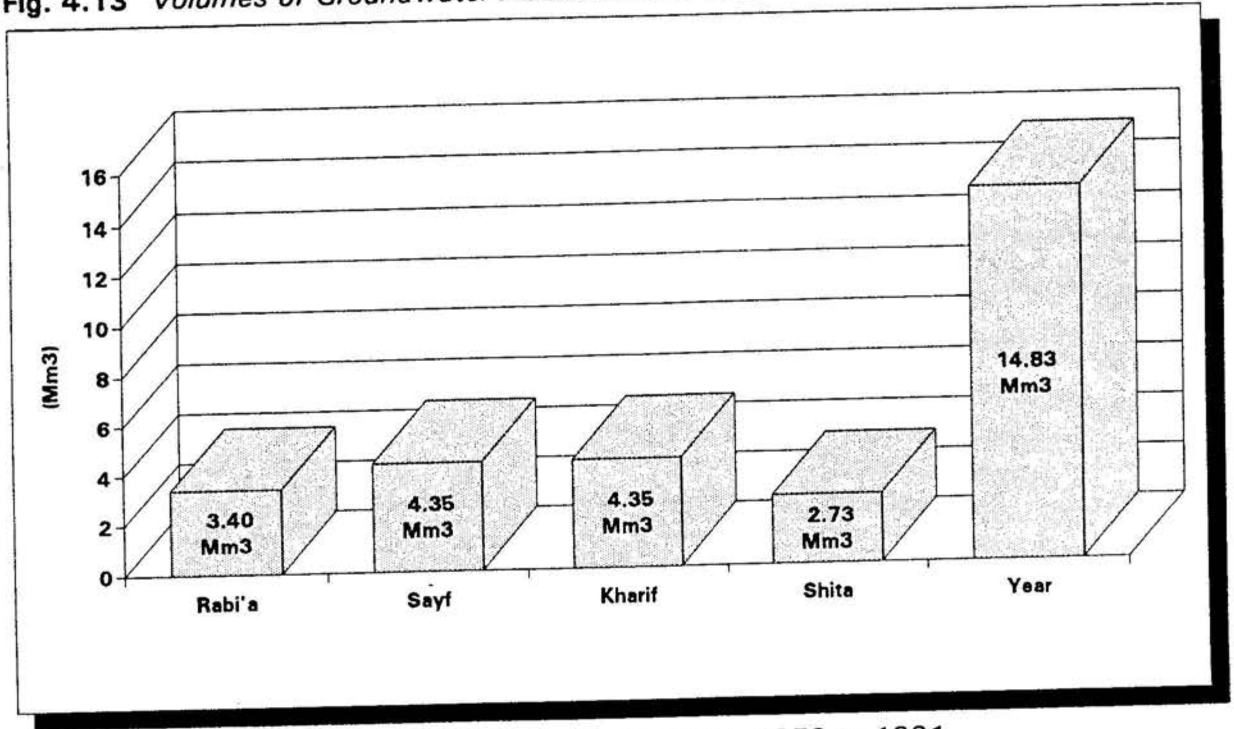


Fig. 4.14 *Estimated Increase of Yearly Abstractions, 1970 to 1991*

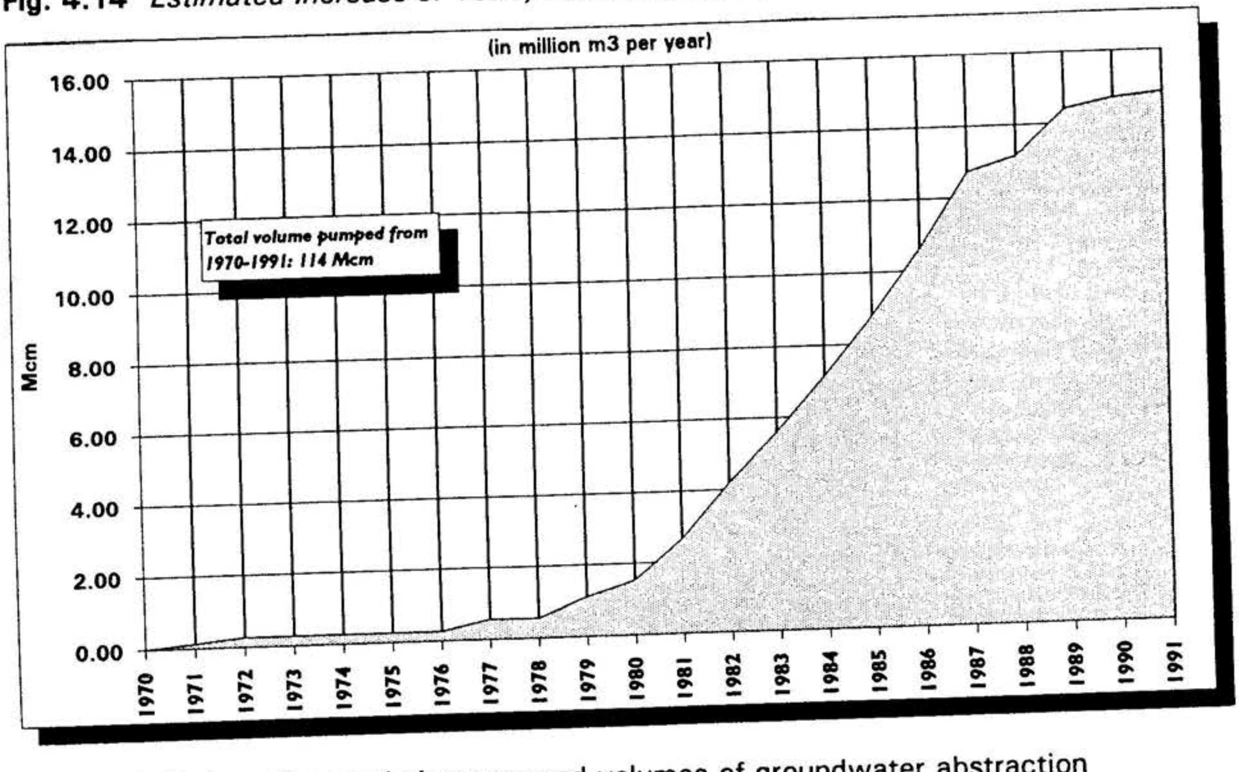


Fig. 4.14 displays the yearly increase and volumes of groundwater abstraction during the period 1971 to 1991. The highest growth occurred from 1981 to

1987. From 1987 to 1991 this increase diminished. A (very rough) estimate of all the groundwater pumped in the Attaf Valley, using figures from 1971 (when abstraction became significant) to 1991 is about 114 million m^3. This represents a water layer of 0.8 m depth covering the whole Attaf Valley. Expressed in terms of lost aquifer, assuming an average effective porosity (specific yield) of 5%, then the volume pumped during the 20 years corresponds to a lost saturated aquifer thickness of 100/5 * 0.8 = 16 metres, over the whole Attaf Valley.

4.10 DEPTH TO GROUNDWATER

Data on groundwater levels were collected either by measuring with a sounding tape or by asking the well owner. In many cases it proved to be rather difficult to measure the groundwater level, 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. Thus it was that in many cases the farmer had to be questioned on the water depth. Usually 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, practically all farmers know the depth of the pump setting (expressed in the number of pump column pipes above the pump). Because this figure seemed to be a more reliable depth indicator than an estimated water depth, a contour map of the depth to the pump setting has also been composed, as a quality control. The pattern of groundwater depths almost completely corresponds with the pump depth contour map.

There is a wide range of groundwater depths in the Attaf Valley, from 25 m (4 km southwest of Sinwan) to 320 m (4 km southeast of Dhi Bin), and up to 370 m 1 km northwest of Bilsin). When analysing Fig. 4.15 it can be observed that the southwest part of the valley (west of UTM 411 000) has extremely deep groundwater levels (ranging from 160 to 370 m). The northeast part of the valley (east of UTM 411 000) shows much lower water depths, varying from only 25 to 85 m. This sudden change in the groundwater depth is caused by a very high topographic gradient of 100 m over a distance of 1 km (10%) to the east-north-east of Dhi Bin, resulting from the downthrow along a large southeast-northwest fault (see Fig. 2.2 and 4.17).

Excessive pumping takes place in the area southeast of Dhi Bin, for irrigation but also for the water supply to Dhi Bin village. There is a large elongated cone in the water table that can be observed both on the piezometric map (Fig. 4.16) and the cross-section ABC (Fig. 4.17).

4.11 GROUNDWATER PIEZOMETRIC LEVEL

A piezometric map (Fig. 4.16) has been composed by contouring the piezometric levels, the difference between groundwater depth and ground surface elevation

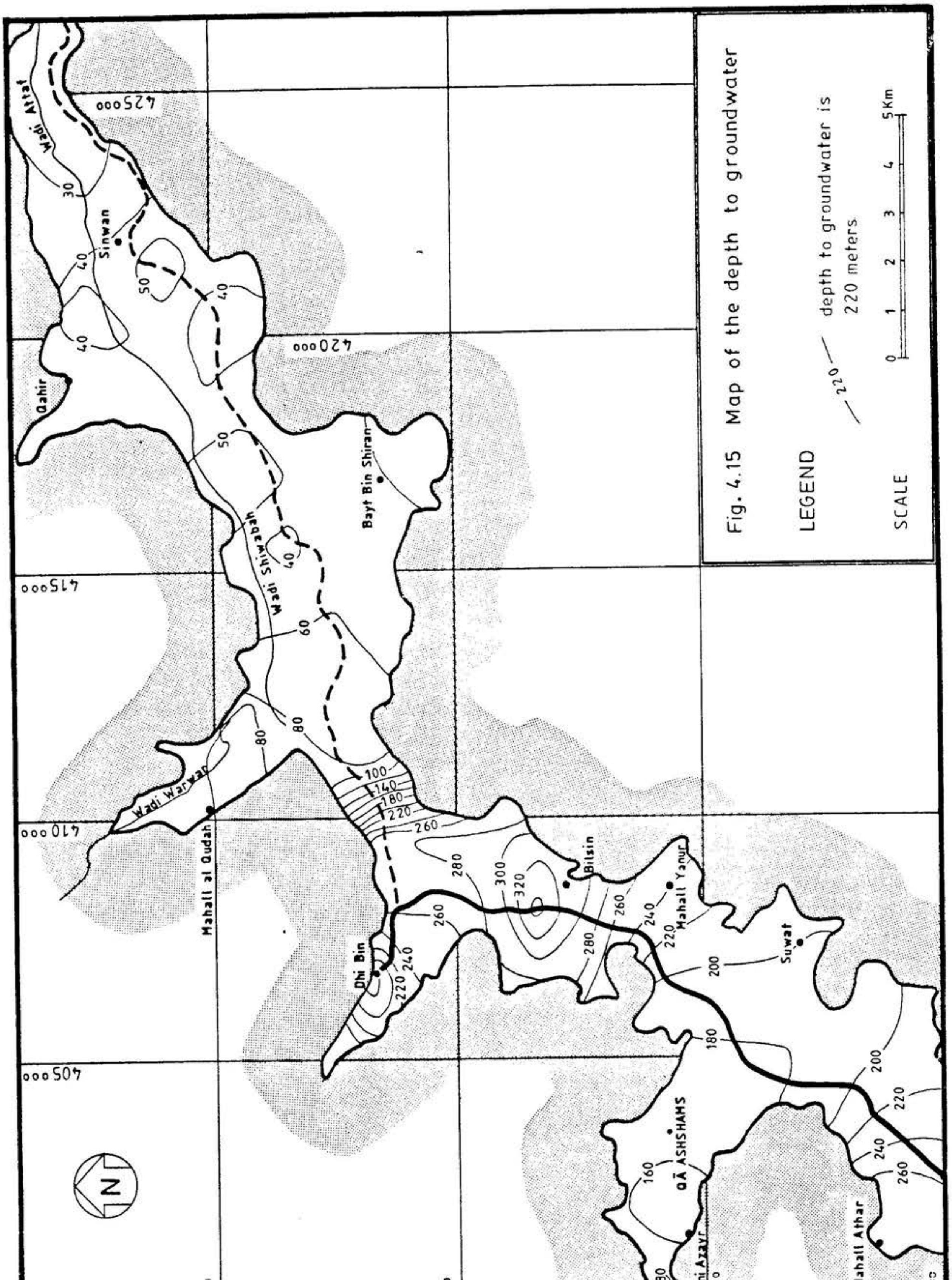


Fig. 4.15 Map of the depth to groundwater

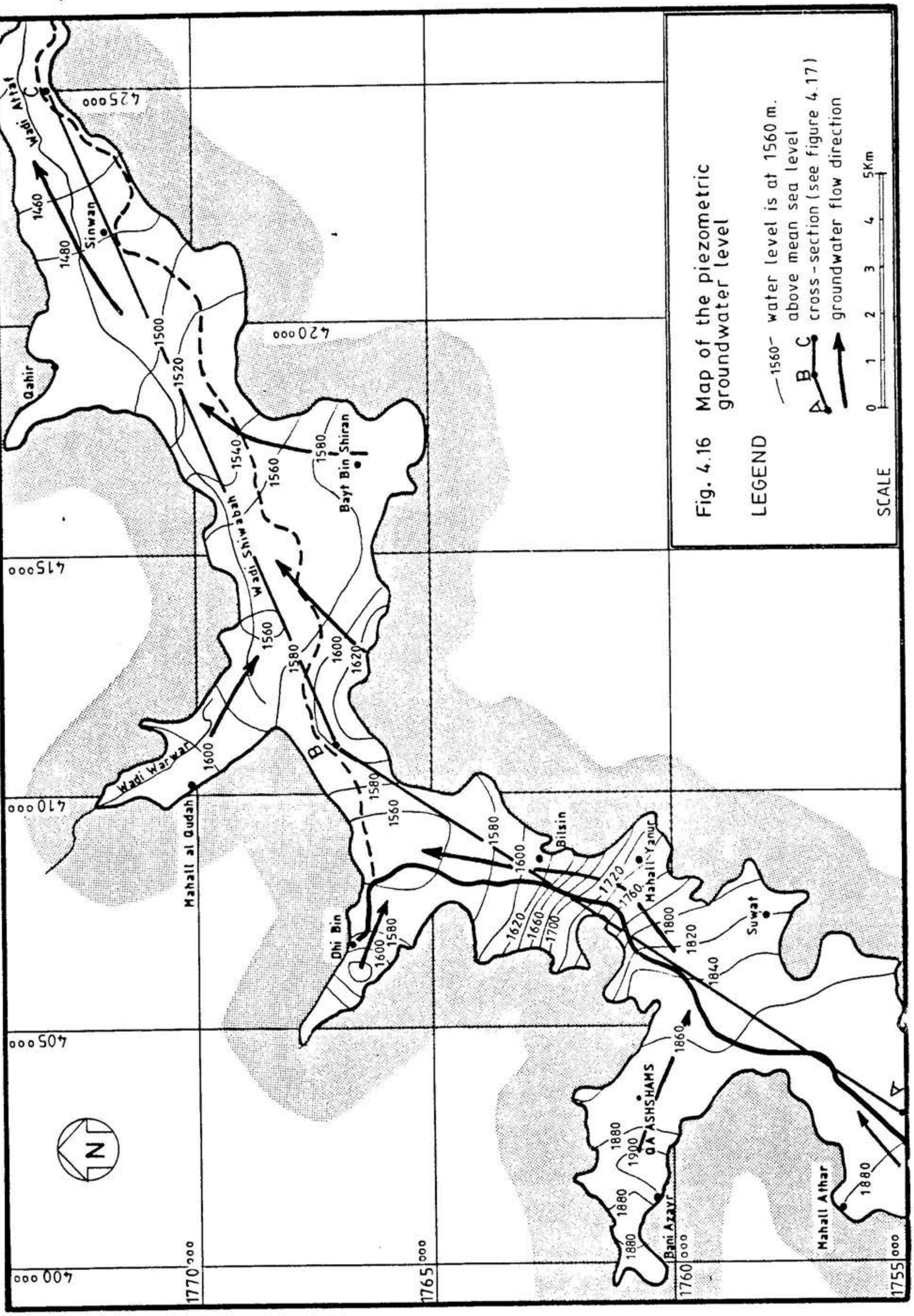


Fig. 4.16 Map of the piezometric groundwater level

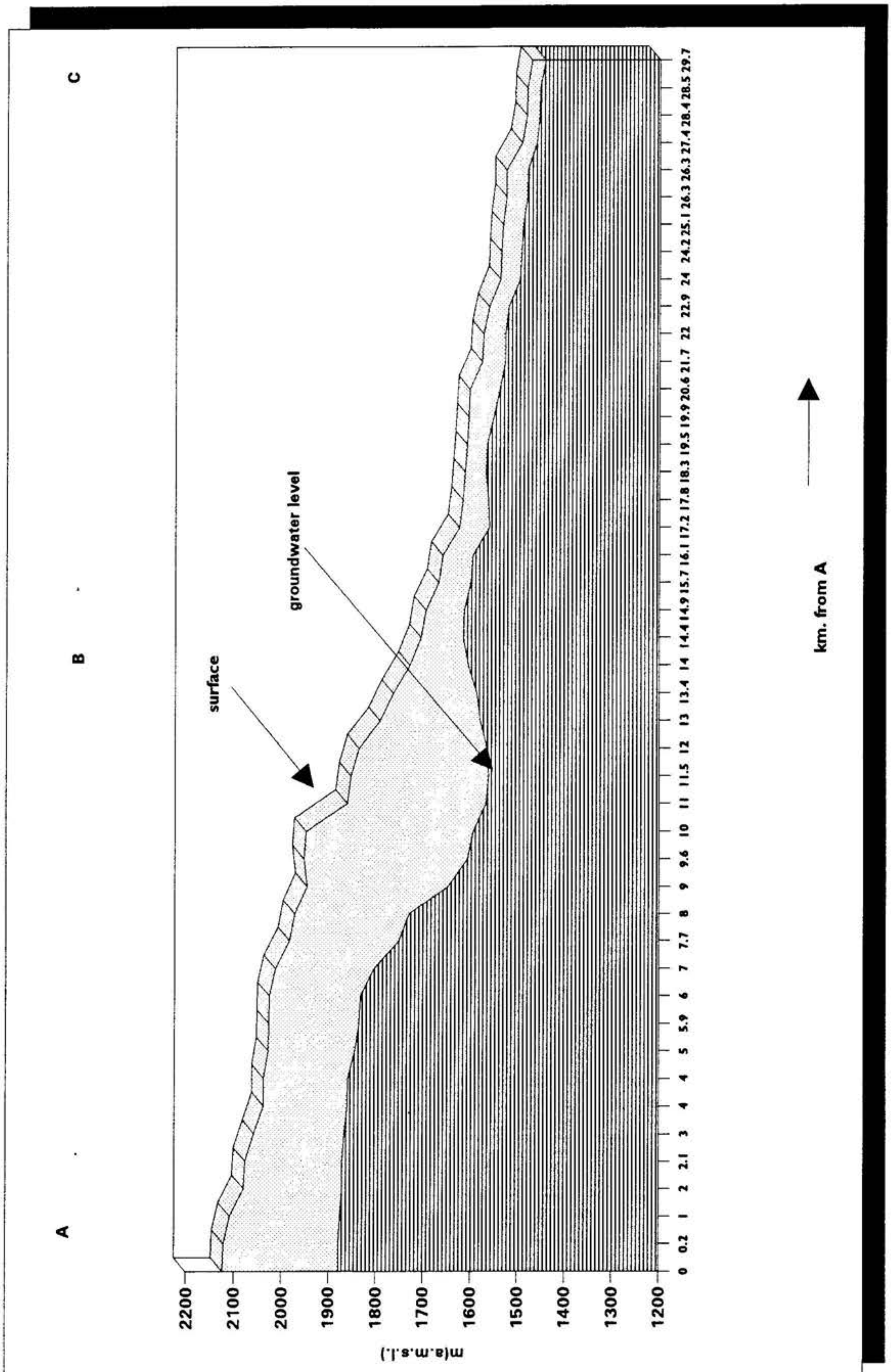


Figure 4.17 Cross-section A-B-C (for location, see fig. 4.16)

above mean sea level, at each well site. Thus, the piezometric contour lines indicate the groundwater level, expressed in meters above mean sea level.

Groundwater levels vary between 1880 m in the southwest near Mahall Athar and 1440 m near Wadi Attaf in the northeast, representing an average hydraulic gradient of 440 m over a distance of about 39 km (= 1.13 %). However, the main drop in groundwater level is from west of Suwat to Bilsin where, over a stretch of 4 km, the water level falls 240 m (see also cross-section ABC in Fig. 4.17). Here the hydraulic gradient is 6%. The remaining part of the Attaf Valley has a gradient of only 0.7%.

In the valley, east of Dhi Bin, the natural northeastly groundwater flow has been reversed as a consequence of excessive pumping.

It is clear that 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, not even over a small time unit such as a day. 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.

4.12 LOWERING OF GROUNDWATER LEVELS

For an analysis over time of trends in groundwater levels a time series of groundwater depths is needed. However, no long term data on monitored water levels are available. It is known that at the boundary of the Amran Valley and the Attaf Valley the groundwater level dropped 50 m from 2130 m in 1977 to 2080 m amsl in 1991. It would seem that groundwater depletion in the Attaf Valley is not as serious as in the Amran Valley. It is true that depths to groundwater in the southwest are very large, but the relatively small drop in water level during the period 1977-1991 suggests that water levels here have always been rather deep.

4.13 GROUNDWATER QUALITY

The electrical conductivity (EC) of water is a measure of its salinity. The more salts dissolved in the water, the higher the EC will be. In almost all the wells visited, the EC of the pumped water was measured (in micro S/cm at 25° C). 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. 4.18 shows the distribution of the electrical conductivity values over the Attaf Valley. The minimum value was 350, the maximum 1600, and the mean 676 microS/cm.

The coefficient of variation was calculated as 0.35. This represents a measure of deviation from the mean (standard deviation/mean), which implies, assuming a normal distribution of all values, that 67% of the EC-values were within the range (1-0.35) * mean and (1+0.35) * mean or 67% of the measurements had EC-values ranging from 439 to 913 microS/cm. The measured values were contoured and presented in Fig. 4.19.

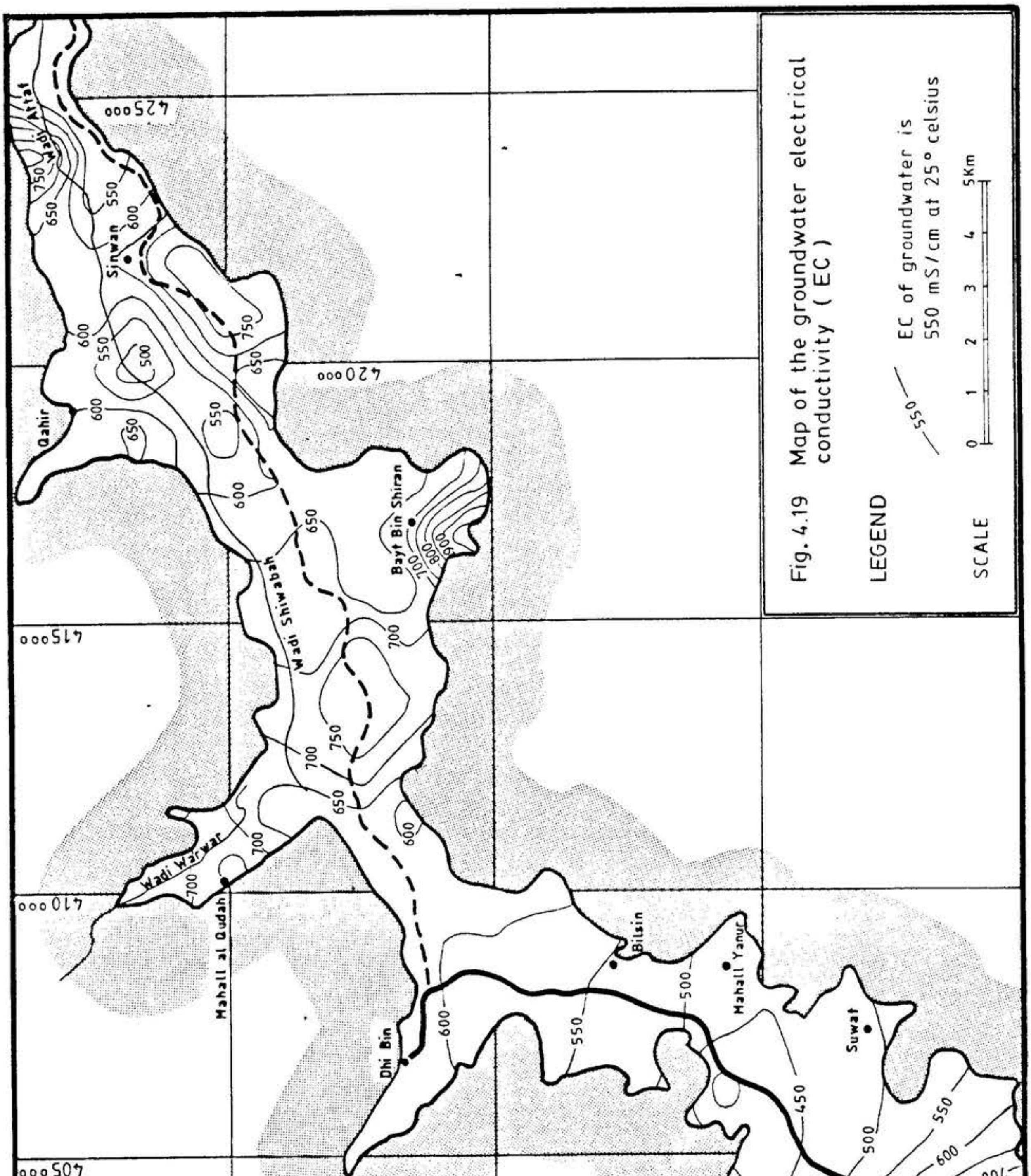


Fig. 4.19 Map of the groundwater electrical conductivity (EC)

Fig. 4.18 *Distribution of Electrical Conductivity*

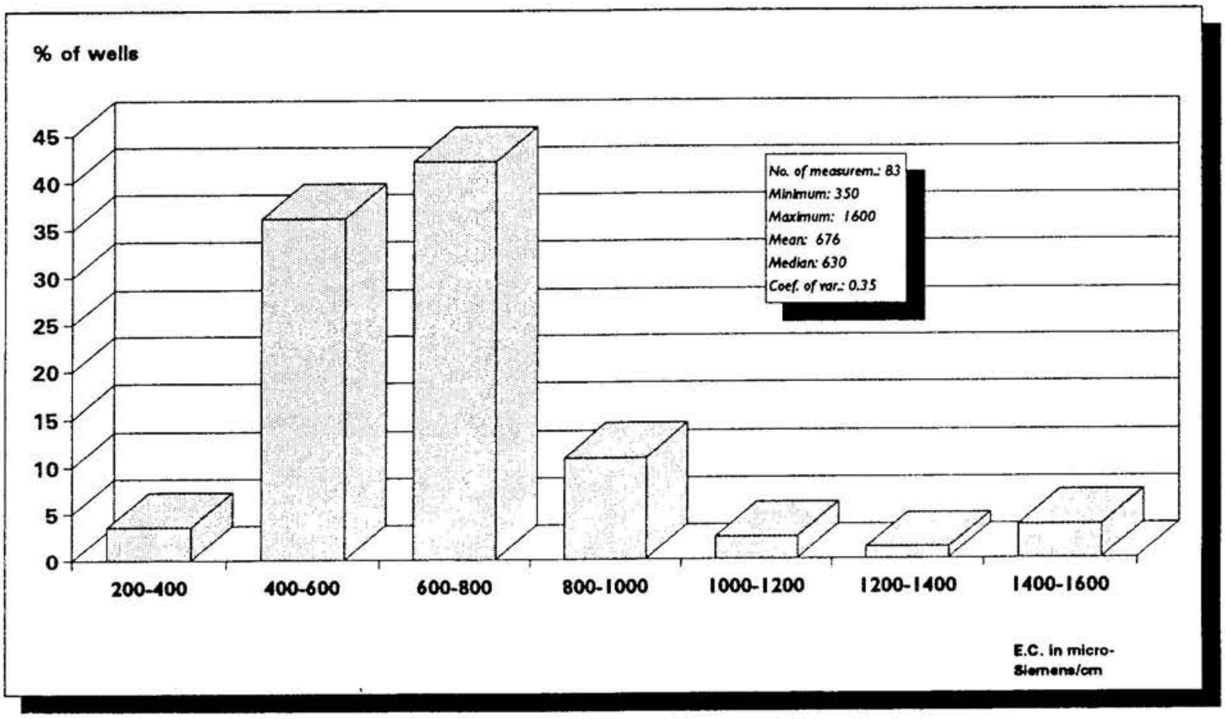
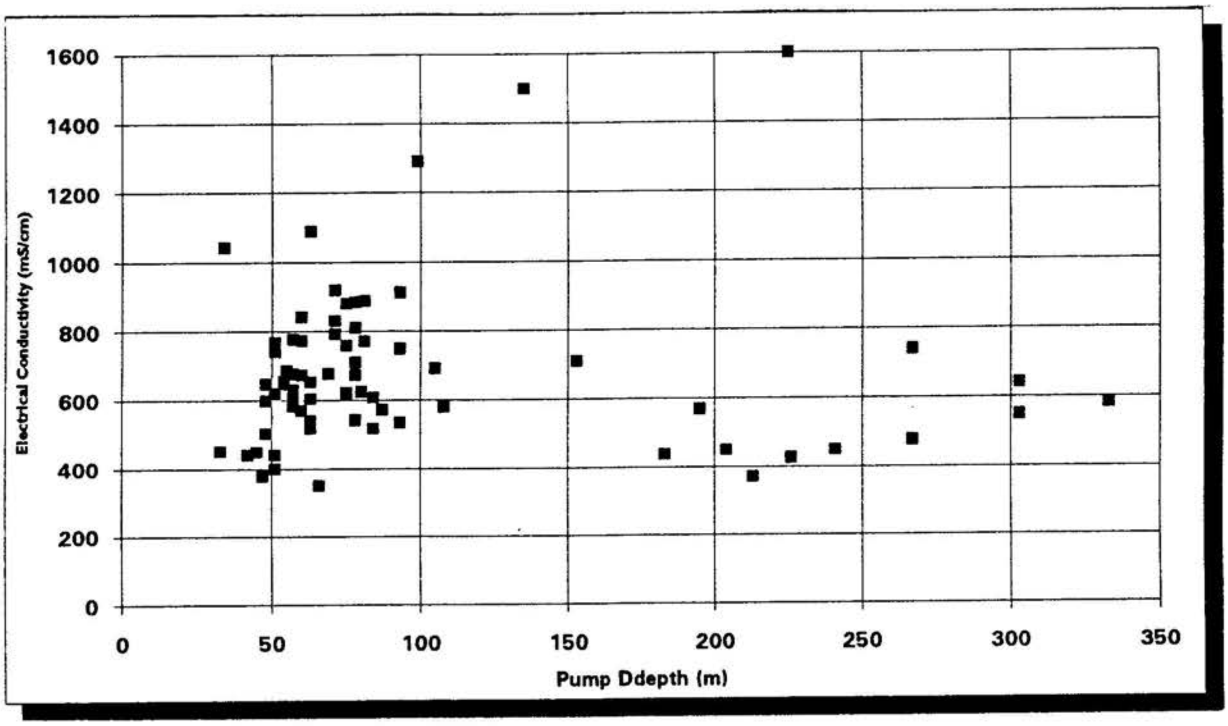


Fig. 4.20 *Relationship of Electrical Conductivity to Water Depth*



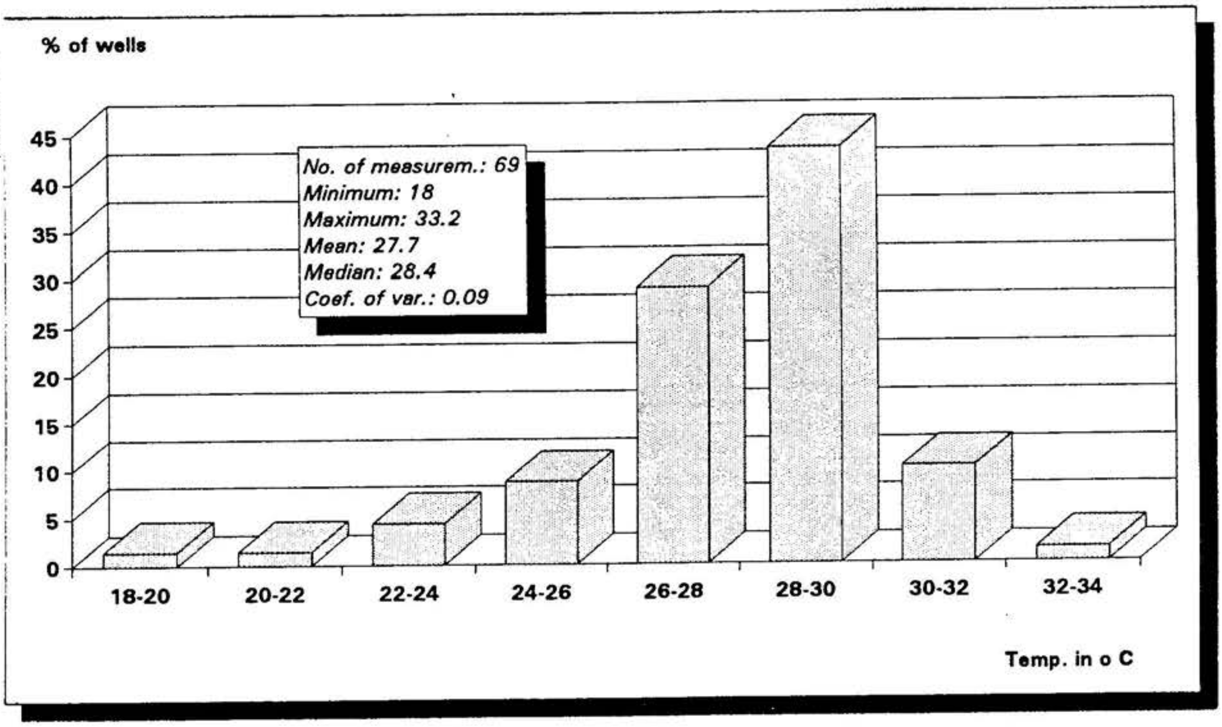
There is an area with high groundwater salinity (up to 1400 micro S/cm) in the southwest of the valley, near Amran Valley. In the higher part of the tributary valleys of Qa' Ashshams and Bayt Bin Shiran values of above 1000 microS/cm were also recorded. In general, the water quality, expressed in terms of EC, is good in the major part of the valley, ranging from 400-800 microS/cm. However, it is higher (20% of mean) than in the Amran Valley.

Fig. 4.20 shows the relationship (or rather the absence of relationship) between the measured EC and the depth of groundwater. Salinity does not seem to increase with depth. High salinity appears to be determined only by the presence of clayey (alluvium) or shaly (limestones) in the aquifer.

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. 4.21. Temperatures range from 18 to 33 °C, with a mean and a median of about 28 °C. Dispersion is low: the coefficient of variation is only 0.09 and most measurements show values that range from 26 to 30 °C.

Fig. 4.21 *Distribution of Groundwater Temperature*



It should be noted that the mean groundwater temperature in the Attaf Valley is about 3 degrees higher than in the Amran Valley. The contoured measurement results in Fig. 4.22 show that higher temperatures occur on the volcanic side of the valley. Here temperatures rise above 29 °C. It seems reasonable to conclude that the geo-thermal gradient here is higher than in the limestones. On the opposite side of the valley the low temperature groundwater influxs from the wadi alluvium aquifers are clearly visible from the tributary valleys of Qa' Ashshams, Dhi Bin and Wadi Warwar, where water temperatures range from 21-27 °C.

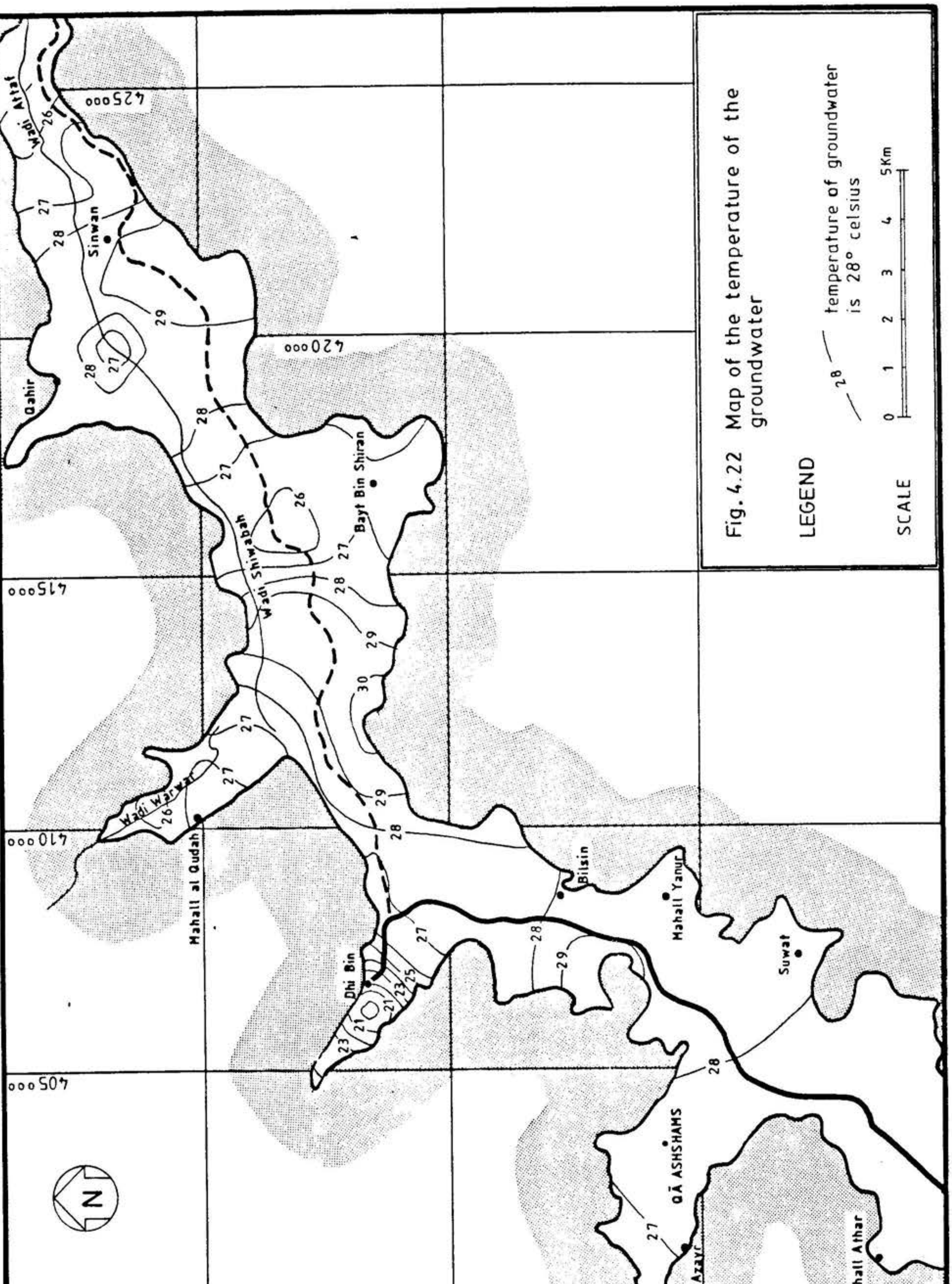
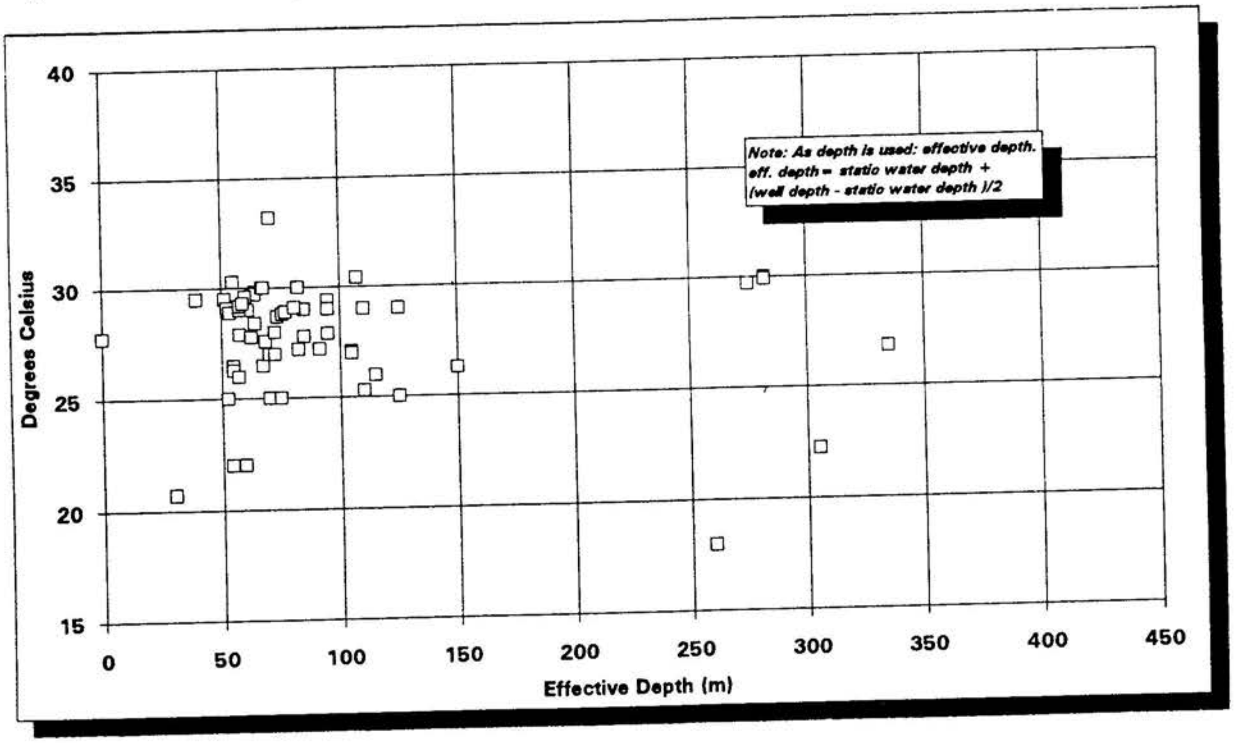


Fig. 4.22 Map of the temperature of the groundwater

To find out if a relationship exists between water depth and water temperature, values of temperature were plotted against the effective depth of the well. The effective depth was introduced to get a better indication of from what depth the water originates during pumping. It is defined as the depth to the static water level inside the well plus the difference of well depth and the static water level depth. In other words, the effective depth is the depth to midway between the static water level and the bottom of the well. No correlation between water depth and water temperature is indicated (see Fig. 4.23), probably as a result of the mix of data from the 'colder' and 'warmer' areas. Nevertheless, the main factor that probably determines the water temperature here is the geo-thermal gradient, which can show a temperature increase in volcanic areas of about 0.6° per 100 m depth.

Fig. 4.23 *Relationship of Water Temperature to Water Depth*



5 GROUNDWATER USE

5.1 LAND AREAS

The total area of land associated with the 94 wells visited in December 1991 was 1254 ha, of which 849 ha were cultivated and under irrigation command, and 405 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 94 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 the purpose of this report *well areas*, not farms.

Extrapolating from this data, by assuming a total of 113 well areas (see Section 4.2) and the same population distribution for the additional data, resulted in a total well area of 1494 ha, of which 1012 ha were commanded by irrigation and 482 ha were fallow (see Table 5.1).

Table 5.1 *Breakdown of Land Area*

	Based on data of 94 visited wells	Extrapolating, assuming a total of 113 wells
Total area of land associated with wells	1254 ha	1494 ha
Area Commanded by groundwater	849 ha	1012 ha
Fallow	405 ha	482 ha

It must be emphasized that these figures are based on areas where groundwater irrigation is applied, so rainfed farms are not included. This figure translates to an average command area of almost 9 ha per well.

Fig. 5.1 shows the distribution of the well areas. The smallest parcel was 2 ha, the largest 58 ha, an extensive farm in Qa' Ashshams where only 10 ha is used for groundwater irrigated cultivation, while the remaining part is fallow. Most areas range from 2 to 14 ha. The mean well area is 13.4 ha and the median 10 ha.

From Fig. 5.2 it can be seen that the area under groundwater command was much smaller: the mean was 9 ha (median 6 ha). The smallest plot was 1 ha and the largest 32 ha, a farm two km south of Dhi Bin and a farm three km southwest of Sinwan. The dispersion, expressed as coefficient of variation, was rather high (0.76). Most commanded areas had an area ranging from 2 to 8 ha.

Fig. 5.1 *Distribution of Total Well Areas*

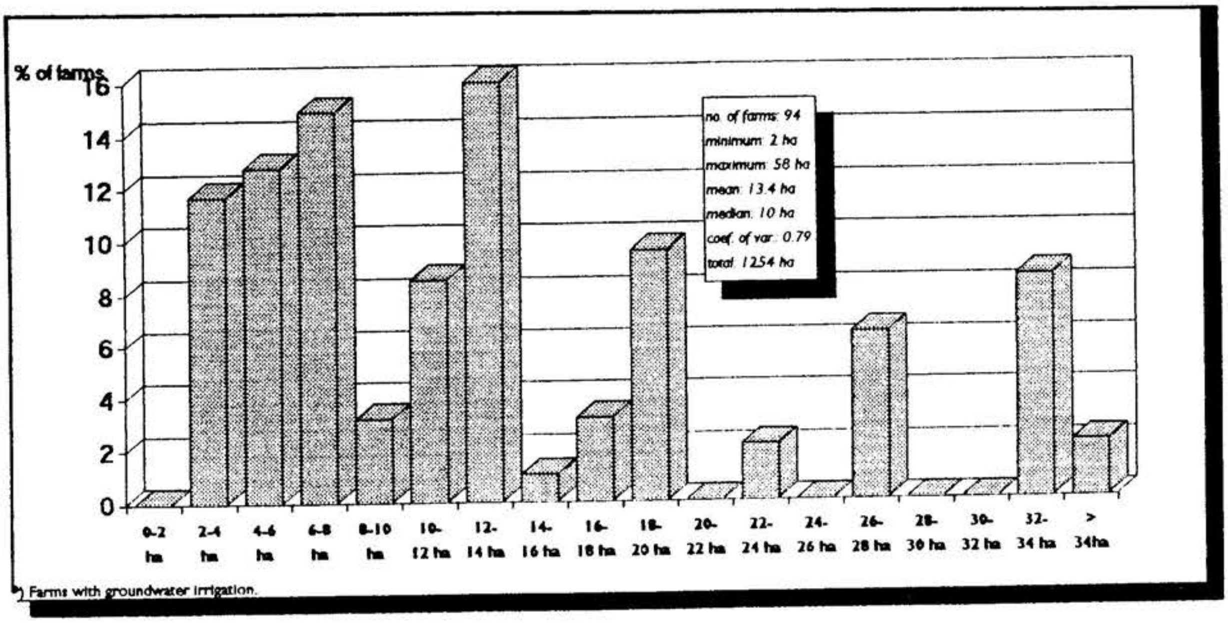
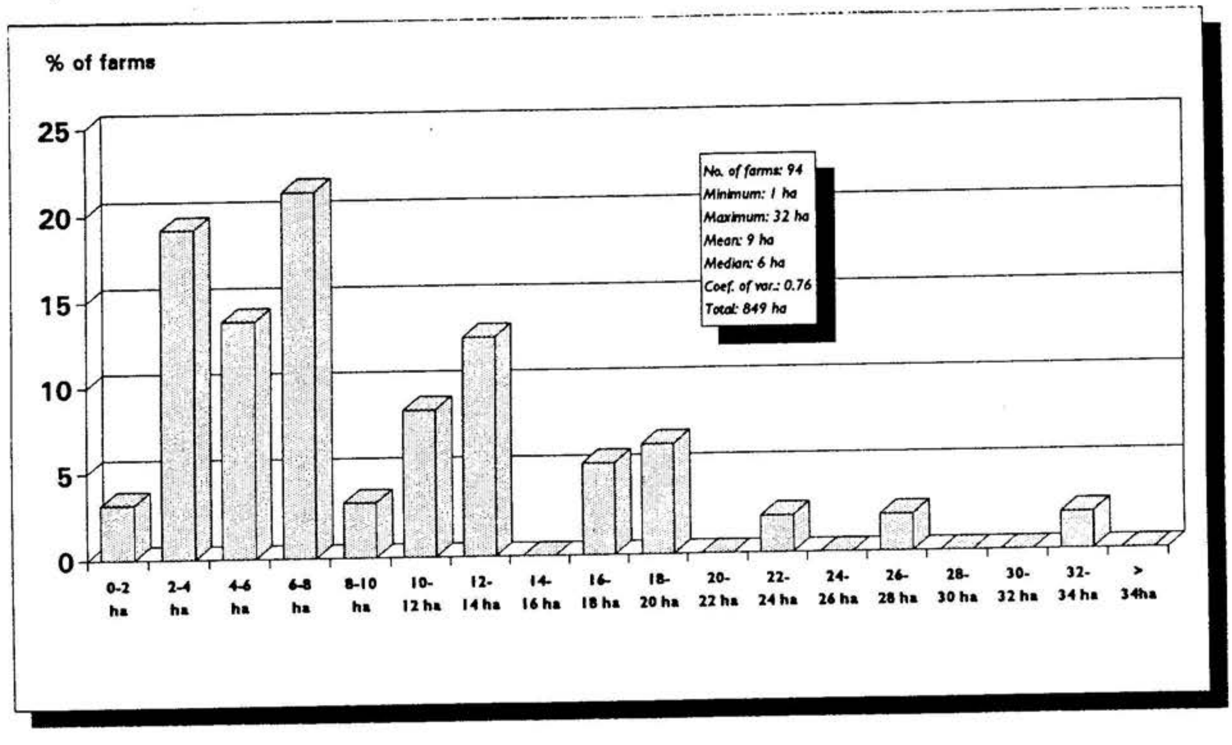


Fig. 5.2 *Distribution of Areas Commanded by Groundwater (ha)*



5.2 CROPS

As part of the well inventory questionnaire some information was collected on crops, concerning data on crop patterns during the seasons. The collected information covered the major and secondary crops cultivated and the irrigated area of each crop type during each season.

All these data are summarized in Table 5.2. Figs. 5.3 to 5.6 show the crop pattern during the seasons.

Table 5.2 *Crops Cultivated During the Seasons*

	Rabi'a		Sayf		Kharif		Shita	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Grape	428.4	60.64	428.4	61.01	428.4	65.07	428.4	60.15
Qat	99.3	14.05	99.3	14.14	99.3	15.08	99.3	13.94
Alfalfa	12.8	1.81	12.8	1.82	12.8	1.94	12.8	1.80
Apple	2.6	0.37	2.6	0.37	2.6	0.39	2.6	0.36
Vegetable	1.6	0.23	1.6	0.23	1.6	0.25	1.6	0.23
Potato	1.3	0.18	1.3	0.18	1.3	0.19	1.3	0.18
Lentils	1.0	0.14	1.0	0.14	1.0	0.15	1.0	0.13
Papaya	0.3	0.05	0.3	0.05	0.3	0.05	0.3	0.04
Orange	0.3	0.05	0.3	0.05	0.3	0.05	0.3	0.04
Pomegranate	0.3	0.05	0.3	0.05	0.3	0.05	0.3	0.04
Sorghum	0.0	0.00	141.0	20.08	92.7	14.08	0.0	0.00
Wheat	136.3	19.30	13.2	1.89	9.3	1.41	121.2	17.01
Barley	22.2	3.14	0.00	0.00	8.4	1.28	43.1	6.06
Total	706.37	100.00	702.09	100.00	658.25	100.00	712.13	100.00

The two main crops are grape and qat. Grape accounts for about 62% and qat for about 14% of the groundwater irrigated in the Attaf Valley. Of the annual crops sorghum is the main crop during Sayf and Kharif (20 and 14% of the total cultivated area), while during Rabi'a and Shita wheat and barley are the most cultivated (22 and 23%).

These crop patterns demonstrate the attractiveness of groundwater irrigation to the farmer. In contrast to the traditional untrustworthy practice of rainfed cultivation and the even less reliable spate irrigated cultivation from which at the most one harvest per year was possible, most crops can now be sown and harvested the whole year round. Moreover, the high risk of crop failure as a consequence of low rainfall diminished significantly when pumped irrigation started. In the 1970s on the rainfed and spate water irrigated land the average loss of sorghum was still 40%, and of wheat and barley 50% (Rethwilm/Brandes, 1979).

Wheat is now sown two times per year by many farmers. The cultivation of sorghum in the winter (Shita) was also mentioned by many 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 April and May and, after harvesting the grain during September to October, the crop is allowed to ratoon solely for the fodder.

Wheat and barley, the other two traditionally cultivated crops in the valley, are sown during June and July. Harvest is during October and November. Usually the next crop is sown during November or December for harvest in March and April.

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

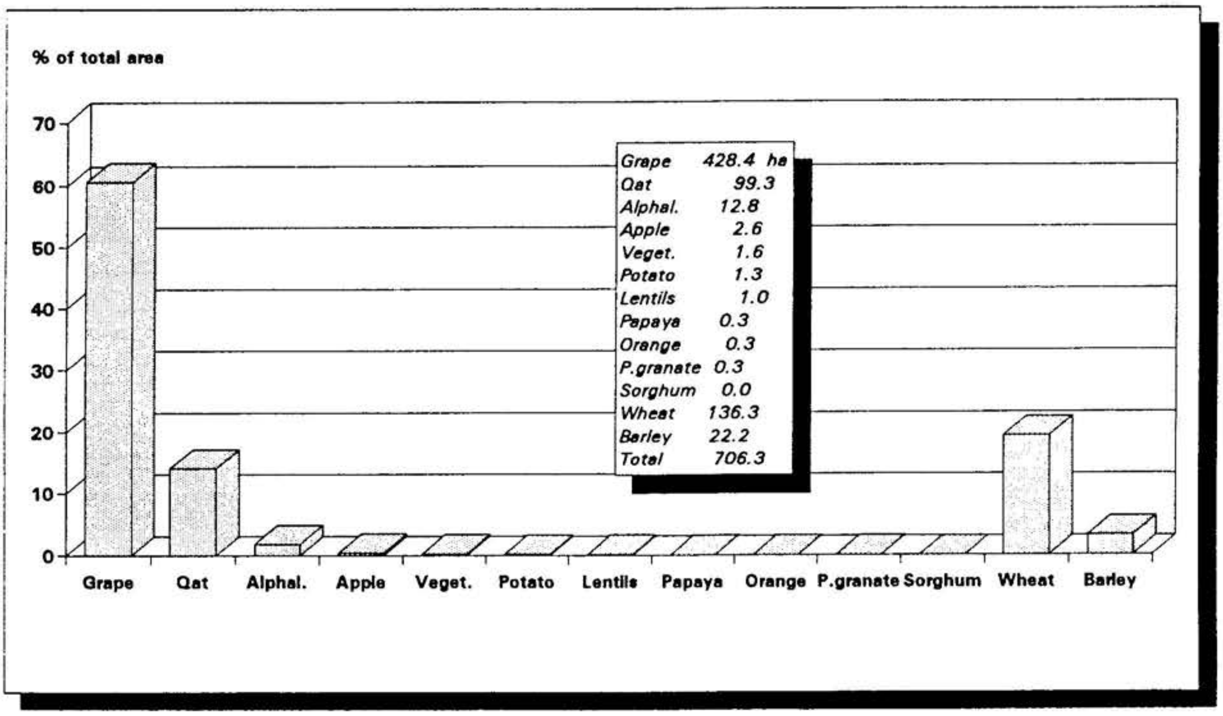
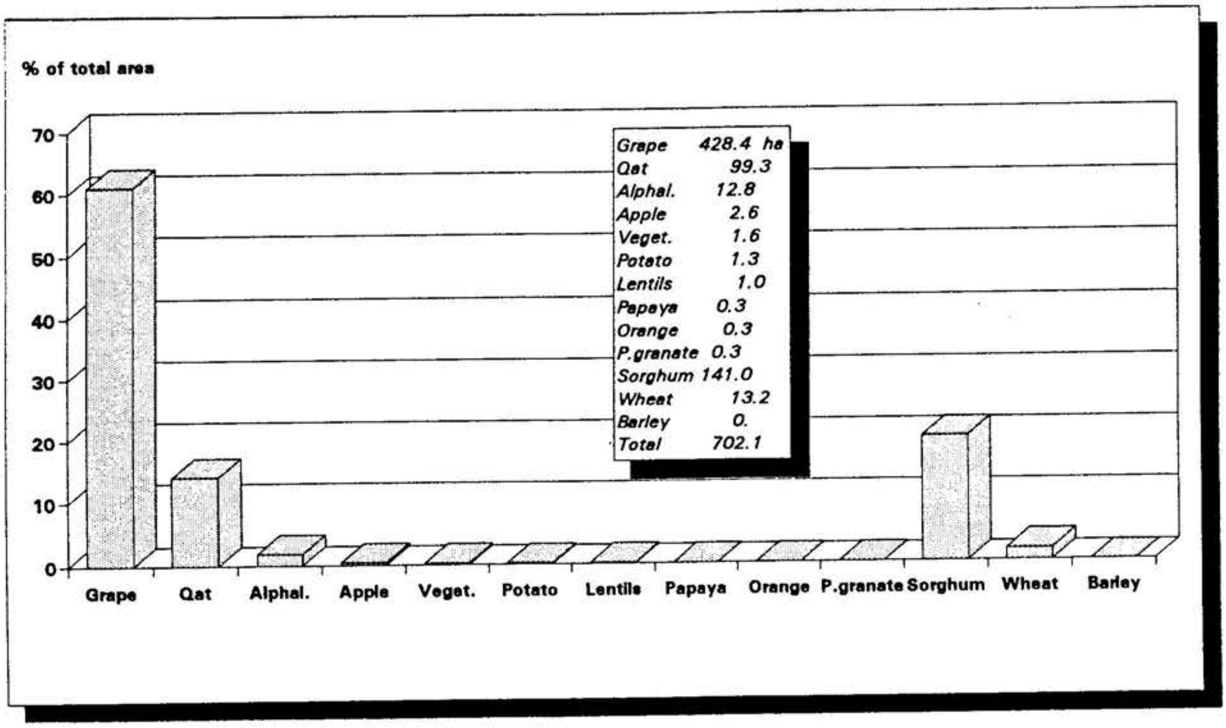


Fig. 5.4 *Crops Cultivated During Sayf (Summer)*



Fruit crops like grape, apple and pomegranate were introduced only recently by progressive farmers. The other most cultivated field crops are vegetables, potato,

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

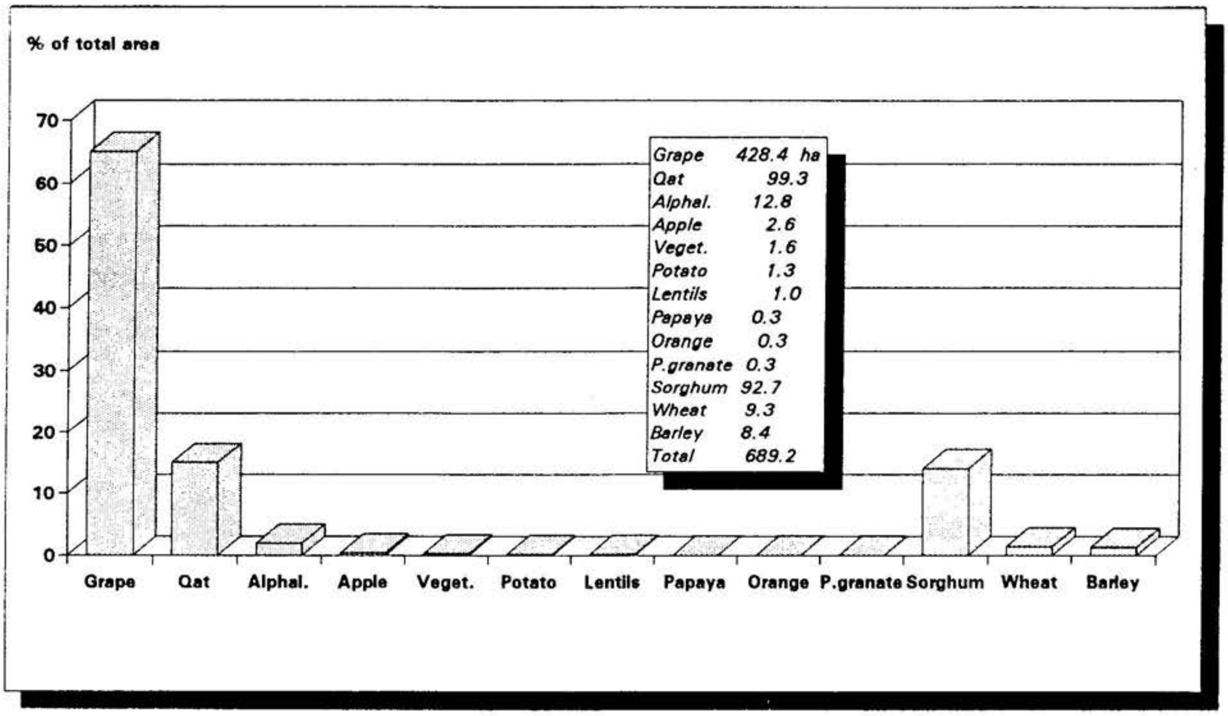
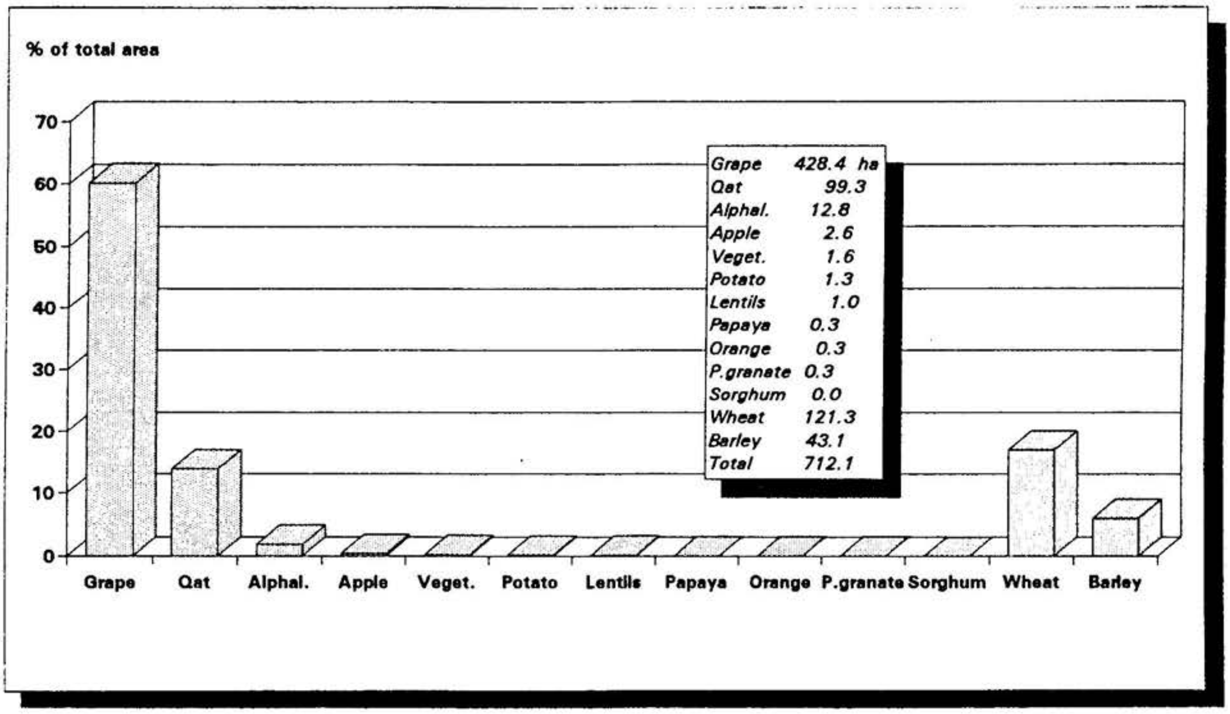


Fig. 5.6 *Crops Cultivated During Shita (Winter)*



lentils and potato. Alfalfa is grown for fodder, but is second in importance to sorghum.

Both pure stand and inter-cropping patterns were observed. Large plots tended 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 water pumped was 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 were usually 50-65%, depending on the distance. Other water losses were a result of over-irrigation.

The irrigation methods used were border, furrow and basin. The border method was usually used for the irrigation of wheat and sorghum, furrow irrigation for potato, tomato and water melon and basin for the fruit crops grape, apple and pomegranate. Time intervals, between irrigation applications of 50-100 mm, ranged from 9 to 15 days depending on the crop type.

The highest frequency of irrigation applications was on grape, apple, tomato and alfalfa, the crops with the highest total costs per hectare, but which also give the greatest benefits (except for alfalfa). The lowest gross margins are on sorghum, wheat and barley (Amran Valley, Hossain/Nouman, 1991).
About 32% of the total cultivatable area of the Attaf Valley remains permanently fallow because of shortage of water.

5.4 USE OF FERTILIZERS

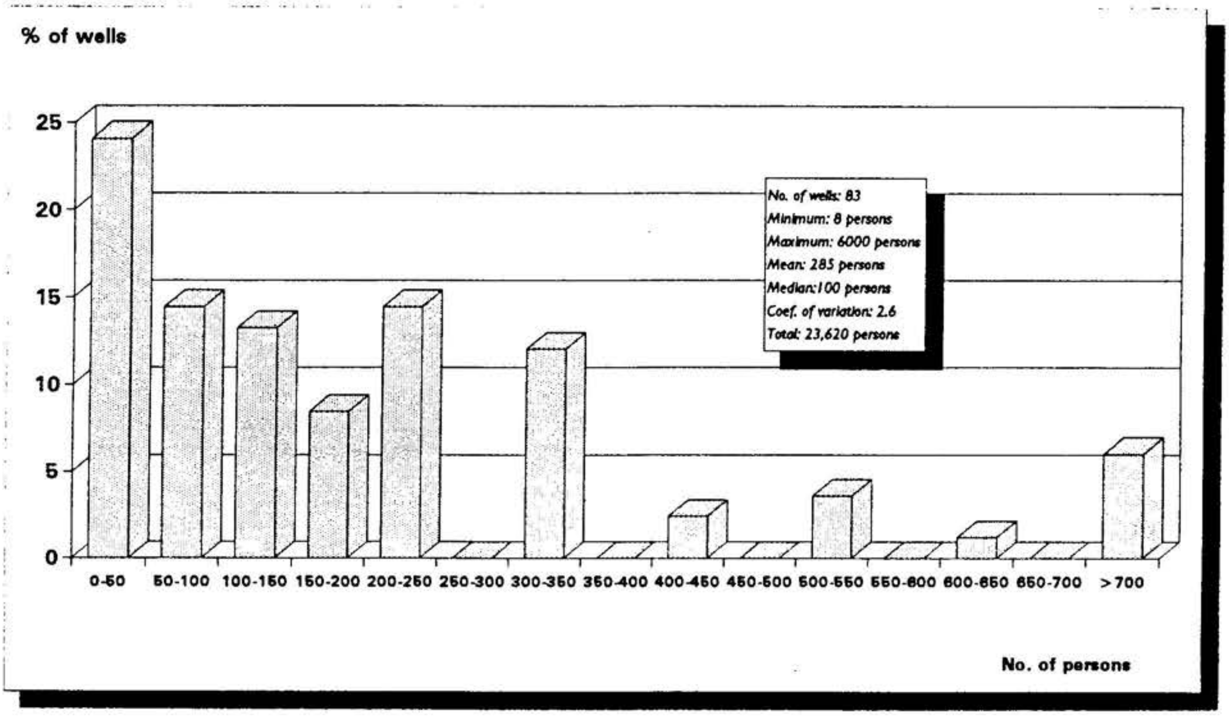
Crop rotation including a fallow was used to maintain soil fertility and to economise on the use of fertilisers. Both chemical fertilisers and organic matter were used, the first at regular intervals but on only 58% of the farms. Urea was the most used chemical fertiliser and chicken manure the principal organic fertiliser. The latter was added only once a year. Livestock waste was usually not used as fertiliser, but dried for fuel.

5.5 DOMESTIC WATER USE

Fig. 5.7 shows the distribution of the number of persons that depended on one well. A wide dispersion was observed in the number of persons (coefficient of variation = 2.6) that consumed water from one well: from eight to 6000, a well that supplied the drinking water to Bani Azayr village in Qa' Ashshams.

The average number of persons depending on one well was 285, but this figure was distorted by the high numbers consuming water from a few wells. The median, about 100 persons, gives a better picture.

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



A total number of 23 620 persons were dependent on 83 wells, being the total number of wells where domestic water consumption data were collected. When extrapolated to the total of 113 wells, and assuming the same distribution of data, a total number of 31 873 people consumed well water in 1991. This number might also indicate the number of inhabitants in the valley (see Table 5.3).

Table 5.3 *Domestic Water Use*

	No. of persons using water from the well	Domestic water use per well (assuming 40 l/day/capita
Per well: Mean Minimum Maximum	285 8 6000	4161 m³/year 117 m³/year 87 600 m³/year
Total: (based on 83 wells data)	23 620	344 852 m³/year
Grandtotal: (extrapolated, assuming a total of 113 operational wells)	31 873	465 346 m³/year

It must be remembered that many farmers sell the water from their well to consumers elsewhere in the valley. Transport was usually by tank-cars. The average number of persons per house or per family was about 12, so that a mean of 24 houses was supplied by one well.

Assuming an average daily water consumption of 40 l per capita the mean yearly domestic water use per well was determined at 4161 m^3 (Amran Valley 4132) and a total water consumption from all the wells in the Attaf Valley at 465 000 m^3 per year (see Table 5.3).

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.

5.6 IRRIGATION WATER APPLIED

The present study is intended to deal with the water resources of The Attaf Valley with emphasis on groundwater and its use. The reason for including in the inventory information concerning cultivated crops and agricultural practices was to enable a fair appraisal to be made of the volume of return flow (or water loss) occurring during irrigation. The water loss would be 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 requirements needed for the evapotranspirational demand of the cultivated crops and the volume of pumped water.

As has been explained in the chapter on crops a detailed description of the land use of each farmer would require 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 neighbouring Amran Valley. Eger (1987) published values of crop water requirements for the main crop types. From this it appeared that most crops have a consistent average daily net crop evapotranspirational need of about 3.0 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 1095 mm has been established for the groundwater irrigated part of the Attaf Valley.

Spate irrigation values have been 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 water requirements.
- Farmers' irrigation scheduling is not optimum.
- Water conveyance and application is not efficient: there is seepage from unlined conveyance canals (about 50% 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 taken into account in the compilation of Table 5.4, 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 5.4 *Attaf Plain - Annual Groundwater Use in 1991*

Total Groundwater Abstracted (Mcm)	14.83
Domestic Water Use (Mcm)	0.48
Irrigation Water Use (Mcm)	14.35
Commands Area (ha) (1)	1012
Average Area Irrigated (ha) (2)	648
Gross Irrigation Application (mm)	3679
Total Efficiency (%) (3)	35.8
Irrigation Water Losses (mm)	2364
Aquifer Recharge (Mcm	3.83
Net Irrigation Application (mm)	1315
Effective Rain (mm) (4)	126
Effective Spate (mm)	19
Total Effective Water (mm)	1460
Annual Crop ET (ETc-mm)	1460

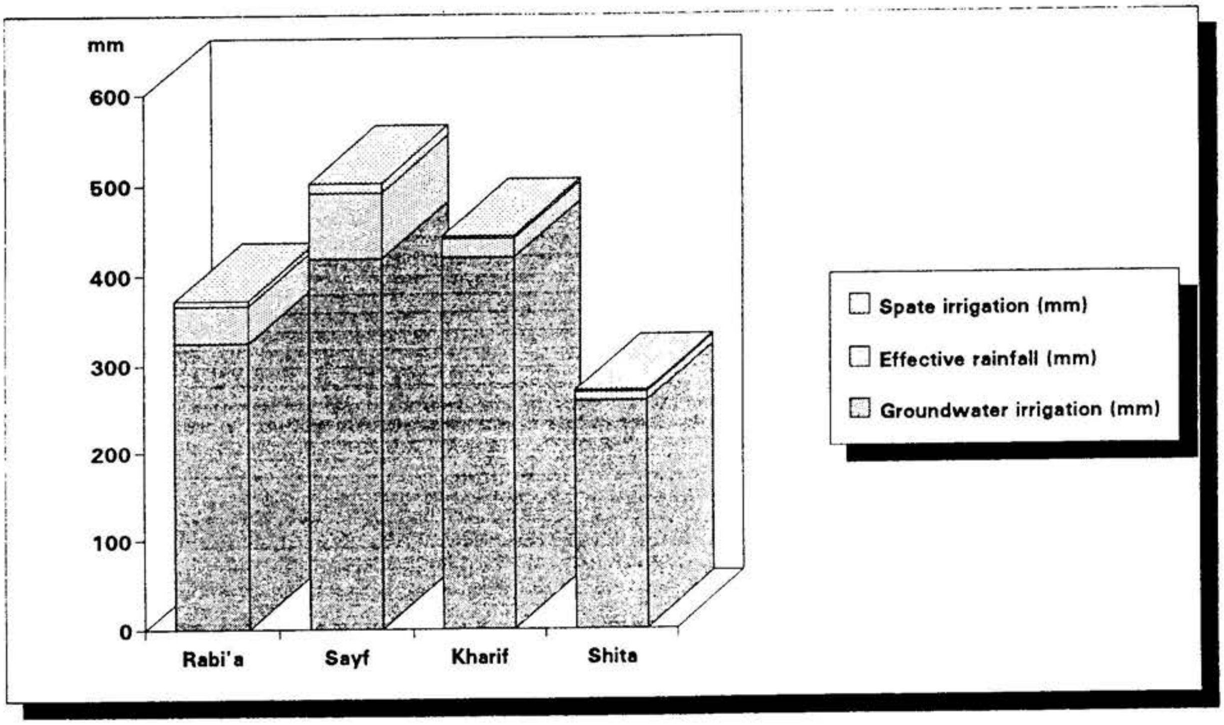
NOTES

(1) Table 5.1
(2) Adjusted to achieve balance between ETc and Total effective water
(3) Conveyance efficiency 75 % (50% piped conveyance)
Application efficiency 55% (Uneven levelling and slopes)
Total efficiency 41.3%
(4) Based on data for Sana'a Central (TS-HWC, 1992 (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. 5.8 shows the distribution of contributions from the several water sources used for irrigation during the seasons, and demonstrates clearly that rainfall and spate irrigation represent only a minor contribution compared with groundwater.

Fig. 5.8 *Irrigation Water Application During the Seasons*



6 THE COST OF PUMPING GROUNDWATER

A model has been made for the calculation of the cost of one hour of groundwater pumping and of one m^3 of pumped groundwater. Various cost items have been 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, ie. they expressed per operation hours not fixed for a certain number of years. The reason was 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, so a higher pumping intensity would result in a shorter lifetime, and the reverse.

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 greater than the lifetime of the well.
- The higher cost of pumping from greater depths is fully represented by deeper and more costly wells, more powerful and thus more expensive pumps and engines, and higher diesel consumption rates per operation hour.
- Interest costs were not considered in the calculation model because the majority of the farmers in the Attaf Valley invest in wells from their own savings or by getting interest-free credit from private sources (friends or family).
- Opportunity costs are not accounted for in the model because the farmer, in general, only invests in his farm and does not realize 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 were drilled to such a depth in relation to the local water table, that deepening was not considered necessary during the calculation period of 80,000 operation hours.

In the model (Table 6.1) the calculation period was set at 80 000 operation hours, the assumed lifetime of the most valuable components of the well - the casing and the screen. In the Attaf Valley, where the average farmer pumps 3800 hours per year, this corresponds to a well lifetime of 21 years.

The pumping equipment, when considering its most costly components: the pump and the engine, has a much lower lifetime. This has been set at half the lifetime of the well or 40 000 operation hours, approximately corresponding with the lifetime given by the manufacturers. When operated at 3800 pumping hours per year, a lifetime of about 10.5 years would result for both the engine and the pump. Therefore, during the entire lifetime of the well, two sets of pumping equipment would be needed.

Table 6.1 *Calculation Model for Pumped Groundwater Costs (1991 YR)*

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 cost item "pumping equipment", collected as field data during the well inventory, generally included 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 operation hours and as a result do not need to be renewed when a second set of pumping equipment is installed.

The formula in Table 6.1 were applied to the following data, which were available for most of the wells:

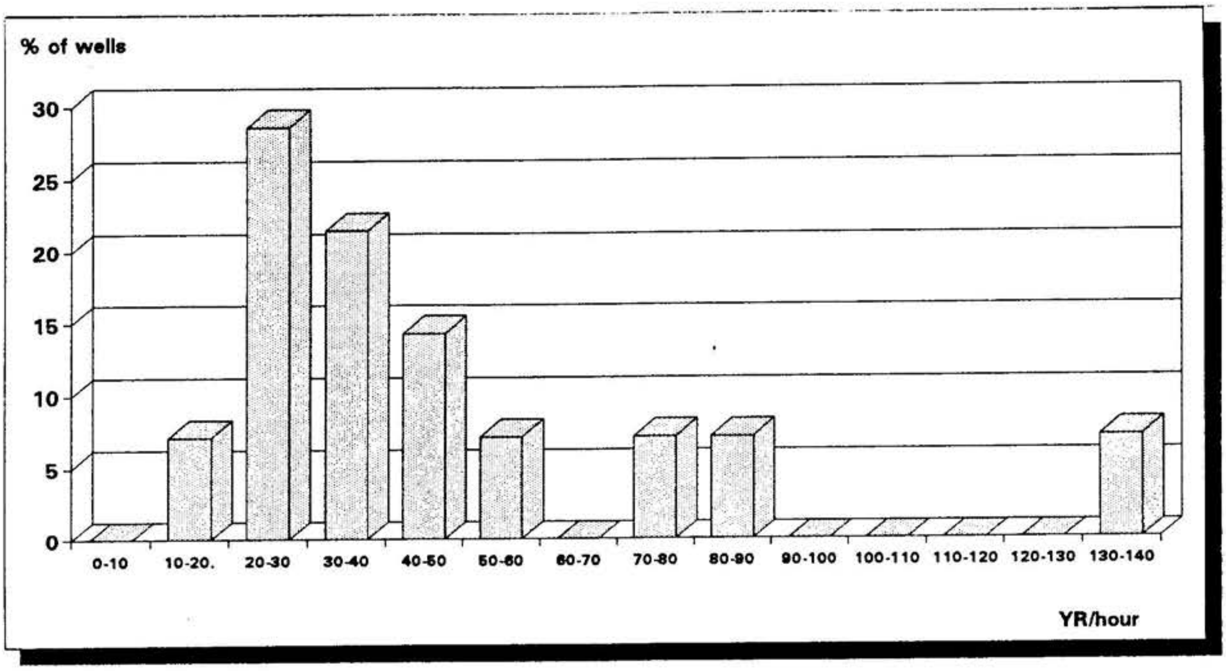
- The costs of well construction.
- The costs of pumping equipment.
- Well yields.
- Number of pumping hours per day.
- Daily engine diesel consumption.
- The price of diesel.

The calculation results are presented in Fig. 6.1 and Fig. 6.2. The average costs of one hour of pumping was YR 51.4, that of one m^3 of pumped groundwater YR 2.5 of which 38% was capital cost, 36% for diesel and 26% operation and maintenance.

Assuming an average price of 2.5 YR/m^3 then a total of YR 36.3 million was spent during 1991, pumping about 14.5 Mcm for irrigation purposes of which about YR 21.4 million was wasted by water losses.

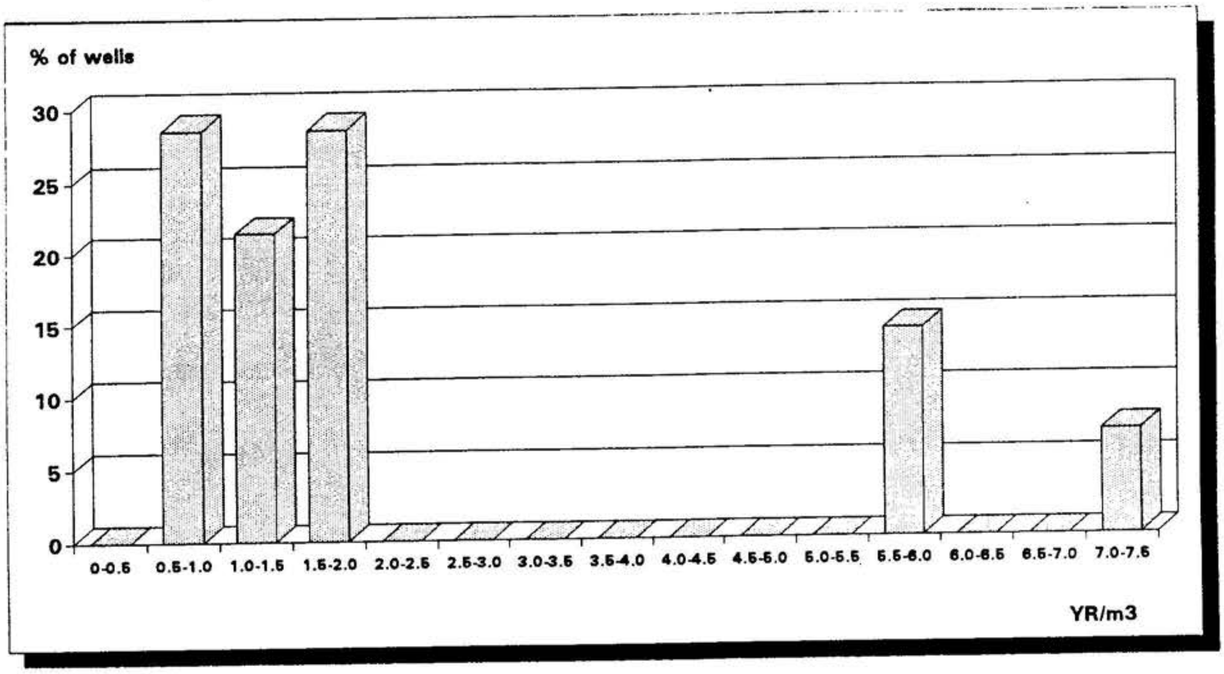
The cost of one m^3 of pumped water was calculated at the level of the pump. However, due to conveyance, application and scheduling water losses, not

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



all the pumped water will reach the crops effectively. This means that the price of water at the crop level would be higher. Assuming the estimated overall irrigation efficiency of 41% as calculated in Table 5.4, then the average cost of the water at crop level would be YR 6.10, and the average yearly water costs per irrigated hectare (net application 913 mm) YR 55 670.

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



7 SUMMARY AND CONCLUSIONS

A total of 113 wells were inventoried. It was assumed that 90% of all existing wells were surveyed. The actual total number of wells was thus estimated at about 125, of which 113 were operational.

Questionnaires were filled out, each containing up to 120 data from each well site. Information collected included data on the well location, well details, pump characteristics, measured well observations, water use, well costs, among others.

Large areas of the Attaf Valley are covered with a carpet of basalt layers and/or basalt stones (pyro-clastics and clastic basalt). They remained fallow.

Only one dug well was found. Most dug wells have fallen dry during the last ten years because of reducing water levels. It is obvious that since the introduction of drilled wells the water levels fell to such a deep level that the manually digging and deepening of wells was forced to stop.

Serious groundwater development in the Attaf Valley started about 10 years (1971) later than in the Amran Valley (1962).

It is interesting to note that the main drilling activities occurred in the period from 1981 to 1987. Since 1987 the rate of drilling has dropped from 15 wells in 1987 to only three in the following year. 1990 and 1991 also show relatively very low figures.

Statistical analysis of the cumulative distribution of the number of wells constructed during the years showed that 50% of all existing wells were drilled after 1984, while the average well age is 7.5 years. The oldest well dates from 1971.

Almost all the wells inventoried were drilled wells. Only one dug well was encountered. Only two wells were reported to have been deepened once, a relatively very low figure when compared with the Amran Valley, where 23% of the wells had been deepened one or more times.

Casing diameters differ significantly from the diameters observed in the neighbouring Amran Valley: small diameters (8") dominated. They ranged from 8" to 12" (8" diameter: 58%, 10": 26% and 12": 14%). The lower section contained a series of 6 m long slotted pipes as a screen.

Well depths ranged from 50 m to 450 m. The average depth is 170 m. A relatively high concentration of deep wells exists in the southwest of the valley. Here, groundwater levels are very deep: from 200 to more than 350 m. There are two dominant groups of well depths: one ranging from 50 to 150 m (mostly wells in the northeast with shallow water depths) and one from 300 to 400 m (wells in the southwest with deep water levels).

The depths of most wells in relation to water level depths were such that a rather high percentage of the wells may soon fall dry. The average aquifer penetration was 58 m. If groundwater should drop 30 m over the whole plain, then 35% (Amran Valley: 9%) would fall dry. This percentage would increase to a minor extent when the drawdown brought about by pumping is also considered.

Water was pumped in 73% of the wells by vertical turbine (lineshaft) pumps coupled via crossed webbing belts to diesel engines. However, a relatively high percentage (27%) of the wells were equiped with electro-submersible pumps driven by electrical power generated by high capacity engines, most of which generally were found in the southwest of the valley where water levels are very deep.

72% of the pumps were supplied by two manufacturers: Caprari (68%) and Iperson (8.5%), while the remaining 28% were fabricated by nine different manufacturers. The pump column diameter was mostly three inch (71% of all wells) or four inch (19%).

The same level of standardization was noticed among the engines: the Japanese engines comprise about 60% (Yanmar 46% and Mitsubishi 14%). The remaining 40% was divided over 17 makes. The engines had capacities ranging from 20 to 35 horsepower for the lineshaft pumps and 74 to 250 kiloWatt for the electro-submersible pumps.

The average age of the wells and the pumps (in 1991) was 7.5 years. During the period 1988-1991 more pumps were installed than wells constructed, replacing pumps installed before this period.

Well discharge rates varied from about 1.4 l/s to 25 l/s, with a mean of 8.8 l/s.

Well construction costs ranged from YR 66 000 (a 66 m deep well) to YR 500 000 (a 350 m deep well). Median well costs were YR 254 000. In general, the average price per metre for this period was about YR 1250.

Pumping equipment costs had a much larger variation: from YR 30 000 up to YR 1 000 000 (a 340 m deep well); the median was YR 238 000.

Both well construction and pumping equipment costs were higher than in the Amran Valley. This can be partly explained by the younger age of the wells and pumps in the Attaf Valley (more recent prices) and the expensive engines for the electo-submersible pumps.

The average farmer switches the pump on at sunrise and switches the pump off at sunset, throughout the seasons. This is reflected in the mean yearly number of pumping hours per day: 12. Pumping activities are highest during Sayf (mean 13.7 hrs/day), followed by Kharif (mean 13.6 hrs/day), Rabi'a (mean 11.9 hrs/day) and Shita (mean 10.5 hrs/day).

Over the whole year the average number of pumping days per month was 26, pumping hours per month 339, an average of 11.3 hours per day.

10.6% of the wells were permanently out of order, and on average the wells were not pumping 6% of the time. These percentages were taken into account when calculating the seasonal and total yearly abstracted groundwater volumes.

A yearly total of approximately 15 million m^3 of groundwater abstraction was estimated for the Attaf Valley in 1991. The highest growth in groundwater abstraction occurred from 1981 to 1987.

A (very rough) estimate of all the groundwater pumped in the Attaf Valley, using figures from 1971 (when abstraction became significant) up to 1991, amounted to about 114 million m^3. This represents a water layer of 0.8 m depth covering the whole Attaf Valley.

Expressed in terms of lost aquifer, assuming an average effective porosity (specific yield) of 5%, then the volume pumped during 20 years corresponds to a lost saturated aquifer thickness of 100/5 * 0.8 = 16 metres over the whole Attaf Valley.

Groundwater depths showed a wide range in the Attaf Valley from 25 m (4 km southwest of Sinwan) to 320 m (4 km southeast of Dhi Bin) and up to 370 m at 1 km northwest of Bilsin).

The southwest part of the valley (west of UTM 411 000) had extremely deep groundwater levels (ranging from 160 to 370 m). The northeast part of the valley (east of UTM 411 000) had much lower water depths, varying from 25 to 85 m. This sudden change in the groundwater depth was caused by a very high topographic gradient of 100 m over a distance of 1 km (10%) in the valley east-north-east of Dhi Bin, resulting from the downthrow along a large southeast-northwest fault.

Excessive pumping was taking place in the area southeast of Dhi Bin for irrigation but also for the water supply of this village. The area had a large elongated cone in the water table. The natural northeastwards groundwater flow was reversed.

Piezometric levels varied between 1880 m in the southwest near Mahall Athar and 1440m near Wadi Attaf in the northeast, representing an average hydraulic gradient of 440 m over a distance of about 39 km (= 1.13 %). However, the main drop in groundwater level occured from the west of Suwat to Bilsin, where over a stretch of 4 km the water level falls a considerable 240 m. Here the hydraulic gradient was 6 %. The remaining part of the Attaf Valley had a gradient of only 0.7 %.

No long term data on monitored water levels were available.

A first impression is that groundwater depletion in the Attaf Valley is not as serious as in the Amran Valley. It is true that depths to groundwater in the southwest are very large, but the relatively low drop in water level near the Amran Valley during the period 1977-1991 suggests that water levels here always have been rather deep.

The distribution of the electrical conductivity values of the groundwater over all the measurements carried out in the Attaf Valley showed a minimum value of 350, a maximum of 1600 and a mean of 676 microS/cm.

An area with high groundwater salinity (up to 1400 microS/cm) was situated on the southwest margin of the valley near Amran Valley. In the higher parts of the tributary valleys of Qa' Ashshams and Bayt Bin Shiran values of above 1000 microS/cm were also measured.

In general water quality, expressed in terms of EC, was good in most of the valley, ranging from 400-800 microS/cm. However, it was higher (20% of mean) than in the Amran Valley.

Groundwater temperatures ranged from 18 to 33 °C, with a mean and a median of about 28 °C. Dispersion was low: the coefficient of variation amounted to only 0.09 and most measurements showed values that ranged from 26 to 30 °C.

The mean groundwater temperature in the Attaf Valley was about 3 degrees higher than in the Amran Valley. Higher temperatures occured at the volcanic side of the valley. Here temperatures rose above 29 °C. It seems reasonable to conclude that the geo-thermal gradient here is higher than in the limestones.

On opposite side of the valley low temperature groundwater influxs take place from the wadi alluvium aquifers of the tributary valleys of Qa' Ashshams, Dhi Bin and Wadi Warwar. Here, water temperatures ranged from 21-27 °C.

No relation was observed between data on water depths and water temperatures. Probably as a consequence of the mixing of data of measurements from both the 'colder' and 'warmer' areas.

The total cultivated area of the 94 visited well areas amounted to 1254 ha of which 849 ha were tilled land commanded by groundwater, while 405 ha were fallow (assumed local measure 1 libna = 64 m^2). Extrapolating to an assumed number of wells equal to 113 resulted in a total well area of 1494 ha, of which 482 ha was fallow. These figures translated to an average well area of almost 9 ha.

The distribution of the well areas gave the following: the smallest parcel was 2 ha, while the largest was 58 ha. Most farms had an area ranging from 2 to 14 ha. The mean well area was 13.4 ha and the median 10 ha.

The mean commanded area was 9 ha (median: 6 ha). The smallest was 1 ha and the largest 32 ha. Most command areas ranged from 2 to 8 ha.

The two main crops were grape and qat. Grape accounted for about 62% and qat for about 14% of all the groundwater irrigated area in the Attaf Valley. Of the annual crops sorghum was the main crop during Sayf and Kharif (20 and 14% of the total cultivated area), while during Rabi'a and Shita wheat and barley were the most cultivated (22 and 23%).

Only on 58% of the farms were fertilisers applied. Urea was the most used chemical fertiliser and chicken manure the principal organic fertiliser.

The distribution of the number of persons that consumed water from a well gave the following statistics: minimum eight to an extremely high maximum of 6000 persons (for a village water supply). The average number of persons depending on one well was 285, but this value was distorted by the number of persons consuming water from only a few wells. The median of about 100 persons, gave a better picture.

Assuming a total number of 113 active wells in the Attaf Valley, then a total number of 31 873 people consumed well water in 1991.

Assuming an average daily water consumption of 40 l per capita, the mean yearly domestic water use per well would be 4161 m^3 (Amran Valley: 4132 m^3) and a total water consumption from all wells at 465 000 m^3 per year.

The gross irrigation water applied was estimated at 14.35 Mcm annually. At the low overall efficiency assumed (38%), about 9 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. The average cost of one hour of pumping was YR 51.4, and of one m^3 of water YR 2.5.

Assuming an average price of 2.5 YR/m^3 of pumped groundwater, then a total of YR 36.3 million was spent during 1991 in pumping about 15 Mcm of which about YR 21.4 million was wasted through water losses.

The average cost of the water at the crop level was estimated at YR 6.10/m^3 and the average yearly water costs per irrigated hectare (913 mm net applied) YR 55 670.

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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 been composed for the data entry of the NORADEP well inventory results. To minimize errors during data entry, the layout of the pages on the screen was 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 to cover all the data of the sheet. A total of 113 wells were been surveyed in the Attaf Valley, so 113 times 123 is 13 900 data had to be entered and subsequently processed and interpreted.

The entry of data was carried out by two Yemeni engineers. The entry of these data did not cause any bottle-neck in the reporting activities. However, the verifying and correcting of wrong data copied from the questionnaires caused a substantial delay. Also it turned out that altitudes measured with the altimeter showed errors up to 10%. Therefore, most of the well site altitudes had to be determined all over again by interpolating from the elevation contour lines on the 50 000 scale topographic maps. 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 programs, such as statistical, spreadsheet, contouring and graphics. 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 — ………….yes/no
    (if yes, put well number and date on bottle)

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 Attaf Valley (selection)

Well no.	Village (nearest)	Coordinates (UTM) N	Coordinates (UTM) E	Altitude m abv msl	Year of constr.	Well depth (m)	Diameter casing (inch)	Screen/open from (m)	Screen/open to (m)	Year inst. pump	Depth of pump (m)	Depth to water (m)	Well yield (l/s)	Total farm size (ha)	Water use Irrigtd (ha)	Water use Domest. (persons)	Temp. (o C)	E.C. mS 25 o C	Annual abstr. (*1000 m3)
1	MAHAL ALMAJZAR	1762200	406800	1976	89	350	8	326	350	89	303	200	6.5	32.0	19.2	300	29.7	550	40
2	AL AASAR	1760900	406600	1975	82	330	8	254	290	82	126	90		12.8	19.2				
3	MAHAL ALMAJZAR	1762500	406700	1975	89	340	8	310	340	89	303	300		9.6	7.7	100			
4	MAHAL ALMAJZAR	1763800	407200	1870	83	360	8	336	360	83	315	300		12.8	12.8	200			
5	GADER - THIBIN	1764900	407500	1810	83	388	8	364	388	84	295	246		32.0	32.0	60			
6	THIBIN	1765800	407700	1817	86	312	8	288	312	86	257	252		12.8	12.8	150	30.0	477	
7	DHIBIN	1765850	406750	1816	81	320	8			81	225			3.2	0.8	100			
8	DHIBIN	1766250	407450	1840	89	320	8	296	326	89	303	290					22.2	640	
9	THIBIN	1765650	409300	1810	85	345	8	333	345	85	243	240		12.8	6.4	400			
10	THIBIN - ALJOLAH	1766050	407800	1825	81	312	8	288	312	81	267	252	13.9	22.4	22.4	300	29.9	740	150
11	THIBIN	1765450	406650	1820	85	312	8	288	312	85	267	252		22.4	22.4	10			
12	THIBIN	1766000	407400	1835	80	312	8	288	312	80	267	252		19.2	16.0	60			
13	THIBIN-ALJOLAH	1765900	408500	1850	81	350	8	338	350	80	333	320	12.5	19.2	19.2	200	28.8	583	98
14	THIBIN	1765750	408700	1860	88	350	8	338	350	88	333	320		12.8	12.8	200			
15	THIBIN	1767200	405500	1815	84	360	8	360	360	84	285	258		19.2	6.4	300			
16	THIBIN	1766800	407400	1815	82	360	8	348	360	82	273	258		19.2	16.0	800			
17	WARWAR	1768600	411100	1670	81	170	8		170	81		100		4.5	4.8	15			
18	WARWAR	1768700	411000	1670	77	130	8		130			100		3.2	3.2	15			
19	WARWAR	1768800	410950	1670	84	100	8	88	100	84	80	65	18.8	19.2	19.2	20	27.2	623	230
20	WARWAR	1769000	410800	1660	82	120	12		120	82		70	17.9	7.7	7.7	80	27.9	687	218
21	WARWAR	1769100	410850	1660	80	110	12		110	80		70		9.6	3.2	80			
22	SHE'AP NAKHAS	1769500	410500	1680	87	90	10	72	90	88		70		32.0	25.6	80			
23	WARAWR (OM ALEY.	1769700	410400	1680	82	130	12	121	130	82	93	80	20.0	12.8	12.8	30	27.1	912	221
24	WARWAR	1770200	410300	1690	79	170	12	140	170		93	80	8.1	19.2	6.4	200	29.0	749	76
25	WARWAR	1770400	410200	1680	84	160	12	145	130	84		70	9.0	6.4	6.4	150	26.0	591	97
26	ALKHEBAH	1770800	409900	1700	87	200	8	170	200	87	153	100		12.8	12.8	100	26.3	710	
27	BAM DALLAM	1770800	410200	1700	79	300	10	265	300	79	168	100		25.6	25.6	20			
28	ALKHEPAH	1770850	410550	1700	89	120	8	114	120	89	105	100	6.6	1.9	1.9	50	25.3	690	61
29	BAIT ALSHETWE	1768800	411700	1660	81	150	8		150	81	84	100	6.3	12.8	12.8	100	25.0	519	92
30	WADI AR RAKIYAH	1767650	413100	1643	87	105	12	81	105	87	81	42	10.5	4.5	3.2	50	28.7	887	118
31	WADI AR RAKIYAH	1766800	413250	1655	89	100	12	70	100	89	71	70	7.7	7.0	4.5	200	29.0	790	149
32	ALJOLAH NAKHADAI	1766500	412800	1680	86	80	10	62	80	86	63	60		25.6	16.0	30			
33	ALJOLAH NAKHADAI	1766200	412900	1740	84	86	8	62	86	84	63	55		25.6	16.0		33.2	603	
34	JOLAH NAKHADAH	1766700	411900	1740	91	126	8	108	126	91	93	89		9.0	6.4		30.4	536	
35	BAIT NASER AR RAK	1767500	414150	1620	71	90	12		90	71	75	62	4.9	1.9	1.9	500	28.8	880	151
36	BAIT NASER AR RAK	1767550	414200	1620	86	92	8	74	92	86	78	62	6.3	3.2	3.2	500	28.9	883	115
37	AR RAKHIYAH	1767750	414500	1625	87	84	10	67	84	87	60	44	6.4	5.1	5.1	30	29.8	772	55
38	HAJZ ASWAD	1768000	413600	1620	89	110	10	98	110	89	81	80	8.1	1.6	1.6	35	29.4	770	99
39	HAJZ ASAWAD	1768000	413750	1620	87	100	12	82	100	87	78	62	11.5	5.8	5.8	100	29.1	672	223

Data of well inventory of Attaf Valley (selection)

Well no.	Village (nearest)	Coordinates (UTM) N	Coordinates (UTM) E	Altitude m. abv msl	Year of constr.	Well depth (m)	Diameter casing (inch)	Screen/open from (m)	Screen/open to (m)	Year inst. pump	Depth of pump (m)	Depth to water (m)	Well yield (l/s)	Total farm size (ha)	Water use Irrigtd (ha)	Water use Domest. (persons)	Temp. (o C)	E.C. mS 25 o C	Annual abstr. (*1000 m3)
40	ATHAYBANIYAH	1768500	414310	1600	86	74	8	62	74	86	69	54	5.0	6.4	6.4	150	29.7	677	
41	HAQ ALHAIJ	1768350	414750	1615	86	63	8	51	63	86	57	40		6.4	10.9	40	29.5	610	
42	HAQ ALHAIJ	1768600	415500	1612	84	54	10	48	54	84	54	25	5.5	5.8	5.8	300	29.5	653	71
43	HAQ ALHAIJ	1768600	415200	1615	80	70	10	60	70	80	51	43	8.9	5.1	5.1		29.2	767	138
44	HAQ ALHAIJ	1768800	415500	1610	82	62	8	50	62	82	51	43	6.1	2.6	2.6	30	29.1	742	87
45	BAKHRAH	1765900	413600	1700	84	62	8		62	84	57	45		9.6	1.3	24	28.9	676	
46	BAKHRAH	1766000	414500	1660									5.9				27.8	747	
47	BAKHRAH	1766200	414650	1650	82	74	10			82	60	50	5.0	7.7	3.8	50		570	78
48	BAKHRAH	1766250	415100	1640	83	84	8	72	84	83	78	82		2.6	2.6	12		810	
49	BAKHRAH	1766500	415350	1625	84	92	8		84			46		3.8	2.6				
50	BAKHRAH	1766750	415350	1620	87	122	8		122	87	87	68	6.6	3.8	2.6	30	29.0	572	102
51	BAKHRAH	1766400	415750	1630	89	100	10	91	100	89	78	60		2.2	2.2	30		543	
52	BAKHRAH	1766000	415800	1635	83	66	8	48	66	83	54	40		4.5	3.2	12		646	
53	SAWDAN	1760700	406100	2034	85	250	12			86	213	190		6.4	3.2			371	
54	BAYT ASAWR	1760200	405000	2030	90	247	8	232	250	90	226	175		57.6	9.6	300		426	
55	BAYT ASAWR	1759800	404450	2035	82	230	8	200	230	82	183	180		19.2	6.4	500		435	
56	WUDAYD	1760200	404350	2035	83	225	8	195	225	88	183	155	4.9	16.0	7.7			437	
57	WADAYD	1759700	403700	2035	83	300	8	220	250	83	204	180		32.0	9.6	200		450	
58	MAHDAH	1761500	403500	2030	90	270	8	190	220	90		170		32.0	6.4	150		576	
59	MAHDAH	1761400	403200	2050	86	260	8			86	195	190		5.1	3.2	900		588	
60	BAKHRAH	1766480	415150	1630	87	75	10	63	75	87	57	40		4.5	4.5	35	27.9	584	
61	BAKHRAH	1766400	415150	1630	87	85	10	64	85	87	60	50		6.4	6.4	65	26.5	841	
62	BAKHRAH	1765800	415850	1660	83	90	8	81	90			50		2.6	2.6	100	25.0	824	
63	BAIT EBN AED(SADA	1765450	416500	1670	82	120	12	108	120	82	99	90		6.4	1.3	300	27.0	1290	
64	BAIT SHERAN	1766300	417900	1660	86	118	10	106	118	86	108	65	4.3	32.0	5.1	150	27.2	579	100
65	BAIT ABO MARYAM	1766200	416200	1650	84	66	8		66	84	57	53		11.5	4.5	50			
66	BAKHRAH	1766500	416000	1650	81	90	10	72	90	81	75	50	7.0	6.4	6.4	40	27.0	620	109
67	HAQALHAIJ	1767250	415700	1630	86	90	12			86		60		3.8	3.8	8	25.0	610	
68		1768400	415700	1610	87	70	10	52	70	87	55	35	9.4	12.8	12.8	100	25.0	686	97
69	ALHARAGAH	1768900	415900	1605	77	70	8		70	77	48	38		9.6	9.6	400	22.0	598	
70	ALHARAGAH	1769100	415400	1610	85	68	10		68	86	57		8.0	12.8	12.8		27.0	630	114
71	ALHARAGAH	1769150	416000	1605	84	76	8	46	76	87	61	60		19.2	12.8	100			
72	ALHARAGAH	1769100	416000	1605	86	74	10		74	85	57	45	9.4	6.4	6.4		22.0	776	140
73	ALHARAGAH	1769400	416500	1600	87	90	8		90	87	84	80	12.2	19.2	12.8	200	27.8	607	182
74	ALGAFGAF	1770800	420000	1535	85	75	10		75	85	51	45		9.6	9.6	300	29.0	617	345
75	SINWAN	1772250	420500	1522						86							29.2	688	
76	SIWAN	1773100	423700	1480															
77	ALGIDIRAH	1771600	418300	1540	85	72	8	60	72	85	63	50	14.4	6.4	6.4	300	29.0	518	187
78	ALGIDIRAH	1771800	418250	1550	87	80	12		80	88	71	48	12.3	9.6	6.4	200	28.4	830	191

Data of well Inventory of Attaf Valley (selection)

Well no.	Village (nearest)	Coordinates (UTM) N	Coordinates (UTM) E	Altitude m abv msl	Year of constr.	Well depth (m)	Diameter casing (inch)	Screen/open from (m)	Screen/open to (m)	Year inst. pump	Depth of pump (m)	Depth to water (m)	Well yield (l/s)	Total farm size (ha)	Water use Irrigtd (ha)	Water use Domest. (persons)	Temp. (o C)	E.C. mS 25 o C	Annual abstr. (*1000 m3)
79	ALDAHAMIYAH	1771300	418800	1545	87	75				83	63	40	10.4	6.4	6.4	150	29.0	652	230
80	ALDAHAMIYAH	1771550	418900	1535	89	97	8	79	97	89	78	40	8.2	9.6	5.1	130	27.6	710	192
81	QAHER	1771800	418950	1532	88	85	8		85	89	48	40		9.6	6.4	200	27.8	647	
82	GERW ALGETAF	1771000	419400	1541	86	75	8			86	48	40	8.0	12.8	6.4	80	29.2	504	177
83	ALHAZM	1771300	420500	1530	84	70	10		70	85	51	40	5.9				30.3	618	
84	BAIT AMSHERAN	1769500	419200	1570		90				84	51	30					29.6	749	
85	BAIT SHERAN	1769500	420250	1560	88	90	8	60	90	88	60	44		25.6	5.1	50	30.0	672	
86	SINWAN	1773600	423800	1480	84	70	12			84	63	40	25.0			600	26.5	1090	389
87	SINWAN	1773200	424400	1470	86	35				86	33	25					20.7	451	
88	SINWAN	1773300	425500	1460	85					85		30					28.8	440	
89	SINWAN	1772750	423700	1480	85					85		25					31.0	540	
90	SINWAN	1772600	423500	1485	85							25					24.2	424	
91	HAZM ALJEFJAF	1771250	420100	1530	85	78	8		78	85	51	32		12.8	6.4	100	26.3	400	
92	WADI SINWAN	1771000	421400	1530	85	105	10	73	85	85	71	60	13.7	3.8	3.8	100	30.0	919	195
93	WADI SINWAN	1769800	420350	1550	87	105	10	93	105	87	34	30	8.4	3.2	32.0	19	30.0	1043	119
94	WADI SINWAN	1769400	419400	1570	79	105	8	92	105	79	51	40	4.9	5.1	5.1	200	28.0	440	95
95	WADI SINWAN	1769400	420000	1560	82	70	10	58	70	82	40	36		6.4	6.4				
96	BANI SHERAN	1769200	419000	1580			10	50	75		75	60		16.0	16.0		28.0	757	
97	BANI SHERAN(ALKH/	1769750	419250	1570	83	105	8	187	105	83	63	40		12.8	12.8		27.0	540	
98	BANI SHERAN(ALKH/	1769650	418700	1582	86	105	8	187	105	86	66	40	6.5	32.0	19.2	200	28.0	350	195
99	ALHESN	1771800	420500	1530	87	180	8	162	180	84	42	40		14.1	10.2	300	29.0	440	
100	ALRAJEH-ALSOBAY/	1771300	419400	1530	85	78	8	66	78	85	47	40		25.6	9.6	150	29.3	378	
101	QAHER	1771650	419750	1528	81	74	8	56	74	81	45	40		16.0	12.8	300	26.0	450	198
102	AL AASAR	1760900	406600	2015	82	330	8	254	290	82	126	90		12.8	19.2				
103	ALWADI(ALBATAH)	1760600	399800	2100	83	300	10			89				32.0	9.6				
104	ALWADI	1760300	399700	2100	79	280	8				135					6000		1500	
105	ALWADI	1760700	399900	2100															
106	QWADER(ALWADI)	1760700	400500	2080	83	325	10			83	225			44.8	3.2			1600	
107	ALWADI	1760800	401100	2070	72	315	10			79	270	220				3200			
108	SHUK HUMIDAN	1760800	401300	2060	89	225	8	132	150	89	207	150							
109	AL MA'AMAL	1760600	401600	2060	87	265	8	205	260		241	100	7.5	25.6	1.9	200		450	
110	ATHAR (HAREF)	1756200	401300	2170	81	370				91	324	291							
111	ATHAR	1756400	401300	2170								290						1500	
112	THIBIN	1766500	406500	1820	82	370	8			82	286	150				1000	18.0		
113	BELSEN	1763200	408300	1965	86	450	10			90		370							

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 Attaf Plain

The following SSHARDA engineers were involved in the well inventory:

Wasfi Mohd Abdo Alezzi (team leader)
Yahya Yahya Abdul Khader
Sultan Hassan Al Barakani

Drivers

Ali Khorap
Nasser Atef

Database entry was carried out by the SSHARDA engineers:

Samir Al Shamiri
Abdul Al Shamiri

Planning, supervision and reporting

WJ Honijk (hydrogeologist)