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GROUNDWATER RESOURCES IN THE AL HARF PLAIN

Final Report
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DHV CONSULTANTS bv
in association with
TEAM CONSULTING ENGINEERS CO. LTD
DARWISH CONSULTING ENGINEERS

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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 of Hajjah and Sa'dah (see Fig. 2.1). The data for this assessment will be used, together with the results of other specific and general studies carried out within the framework of the project, in the formulation of a Water Management Plan (WMP) for the Project Region. The Regional WMP will be based on WMPs prepared for each of the seven designated Target Areas in the Region.

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

The activities for the well inventory were carried out during the month of December 1991. One team consisting of two engineers and a driver, performed the survey. The drivers assisted in effecting the measurements at the well site. A list of the persons that participated in the activities is presented in Appendix 4.

Before the start of the survey, each team received training in the field and various background information was given on subjects like the local hydrogeological conditions, locating the well sites using the compass, the use of the water level measuring tape, the EC-metre and the measuring of the well discharge. The basic field equipment of each team comprised 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 66 wells were visited in the study area and the same number of questionnaires were filled out, each containing, up to 120 data. Information collected include data on the well location, well details, pump characteristics, measured well observations, water use and well costs. The layout of the questionnaire is presented in Appendix 2. 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 Al Harf Plain is situated in the Central Highlands about midway between the towns Amran and Sa'dah. The alluvial plain covers an area of about 64 km^2 and has a relatively small catchment area of 208 km^2 that extends from the plain up to the major water divide of the Central Highlands in the west. Its location is within the UTM coordinates 1807 000 and 1823 000 north and 394 000 and 400 000 east (16° 20' to 16° 29' north and 44° 00' to 44° 07' east).

The road from Sana'a to Sa'dah Town in the north passes through the plain. The most important towns are Al Harf in the south and Al Hayrah in the northwest. Two major wadi channels enter the plain in the north and northwest: the Wadis Burkan and Ayyan. Two main wadis drain the plain in the southeast: the Wadis Al Ablah and Al Jaww, which both join Wadi Al Fayz that debouches into Wadi Kharid.

Topographic elevations in the plain range from 1640 m amsl (above mean sea level) in the northern tributary valleys down to 1566 m in the southeast of the plain, resulting in a very low average surface gradient of 74 m over a distance of about 10.5 km or 0.7 %.

The surrounding mountain ranges are entirely composed of the limestones of the Amran Series, except between the tributary valleys of Wadis Burkan and Ayyan, where Tawilah sandstone outcrops. The heights of the limestone mountains range from 1800 m east of the plain to 2000 m near the major water divide in the west.

The catchment area of Al Harf Plain forms part of the major catchment area of Wadi al Fayz that drains into Wadi Kharid, which in its turn is a major tributary of Wadi Jawf in the east.

The 1986 Census gave a population estimate for the Kaywan/Al Harf Sufyan Area (approximately the Al Harf and Al Hamra plains taken together) of 9000. At a growth rate of 3.3% this would give a population in 1991 of about 10 600. The width of the valley varies from 3.5 km in the north to 7 km north of Al Harf Town.

2.2 CLIMATE

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

Rainfall is sporadic and scanty and storms are usually short, intense and local. Fig. 2.4 shows the mean monthly rainfall as measured in Huth (about 22 km southwest

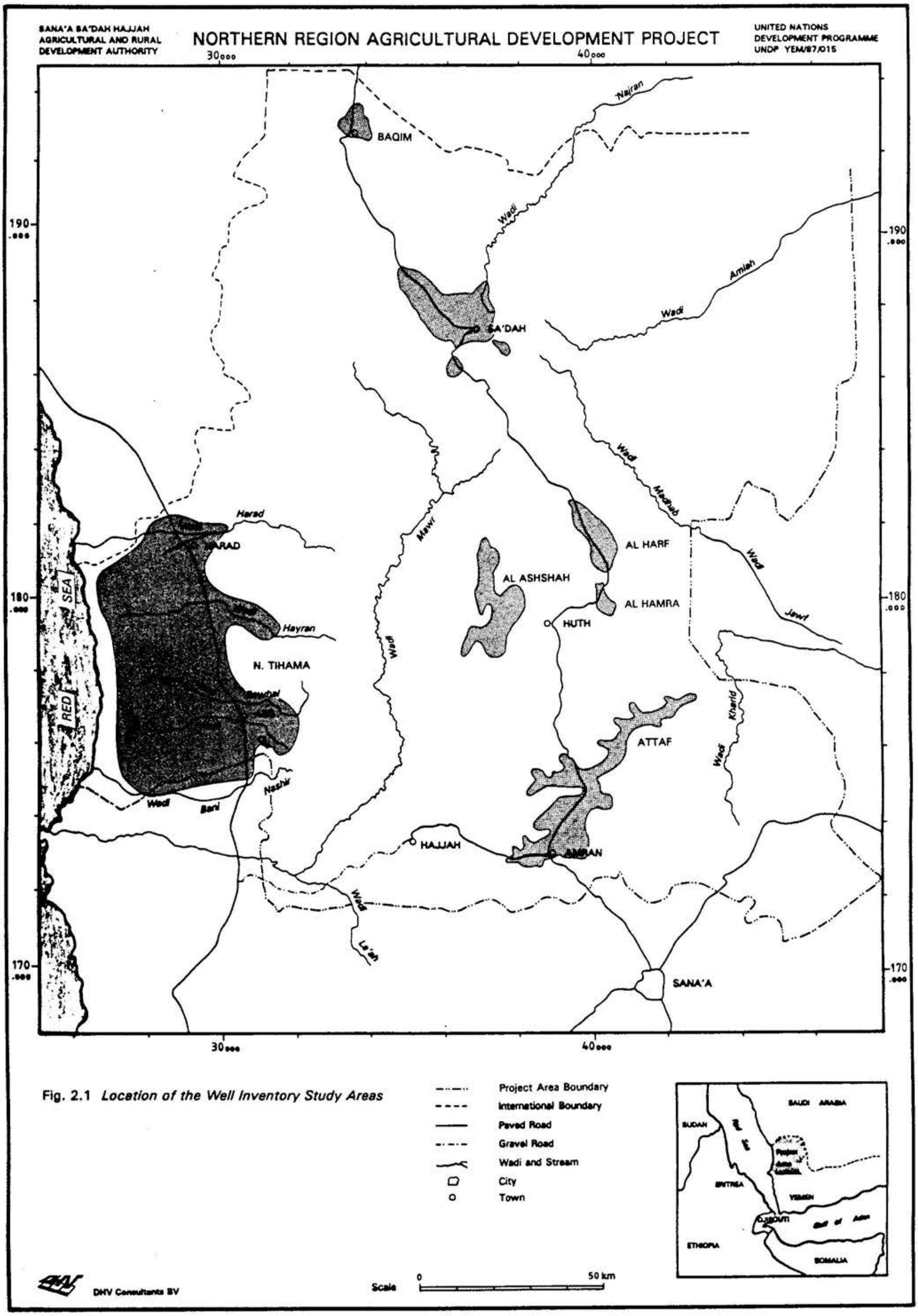


Fig. 2.1 *Location of the Well Inventory Study Areas*

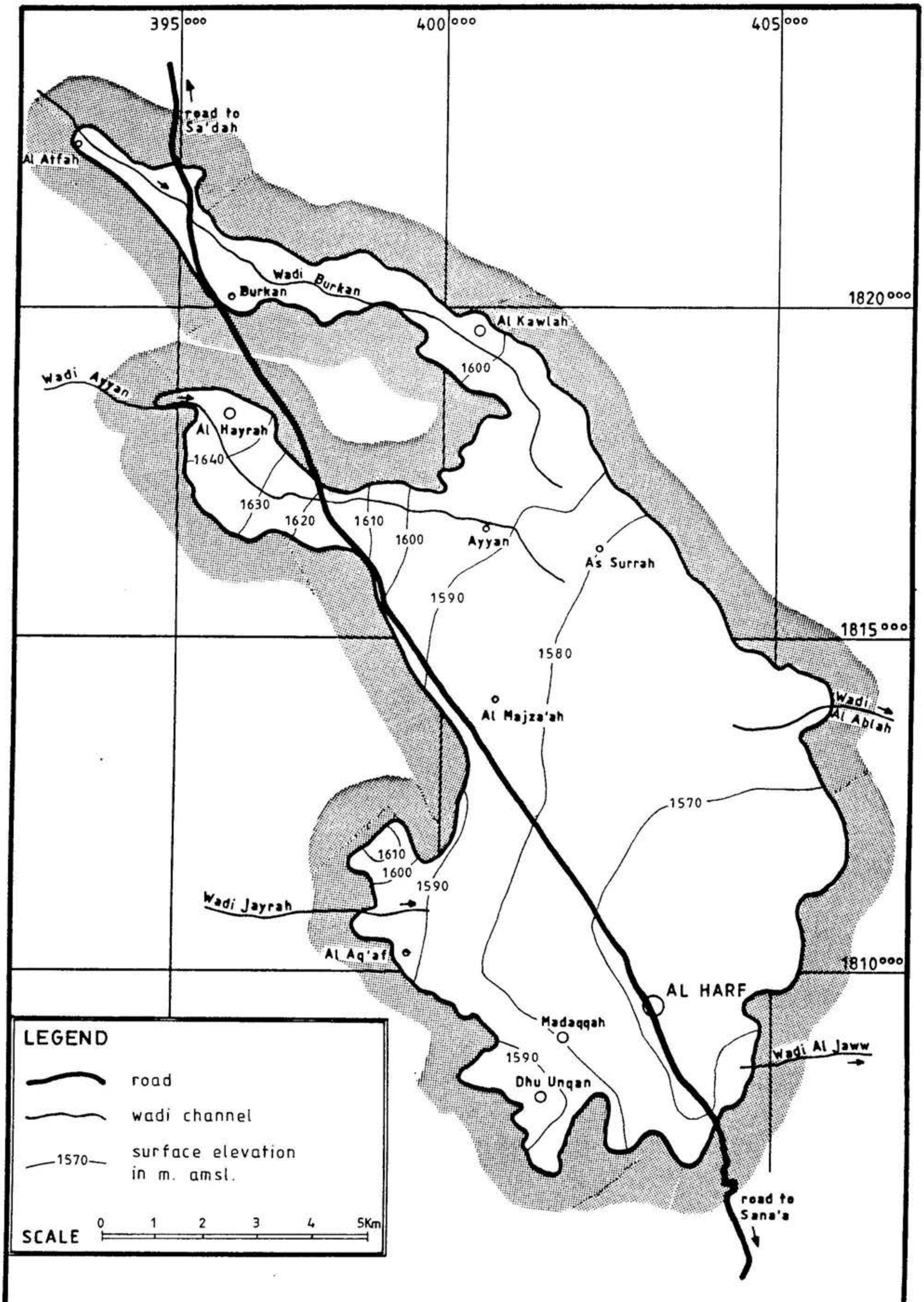


Fig. 2.2 Map of the Al Harf Plain study area

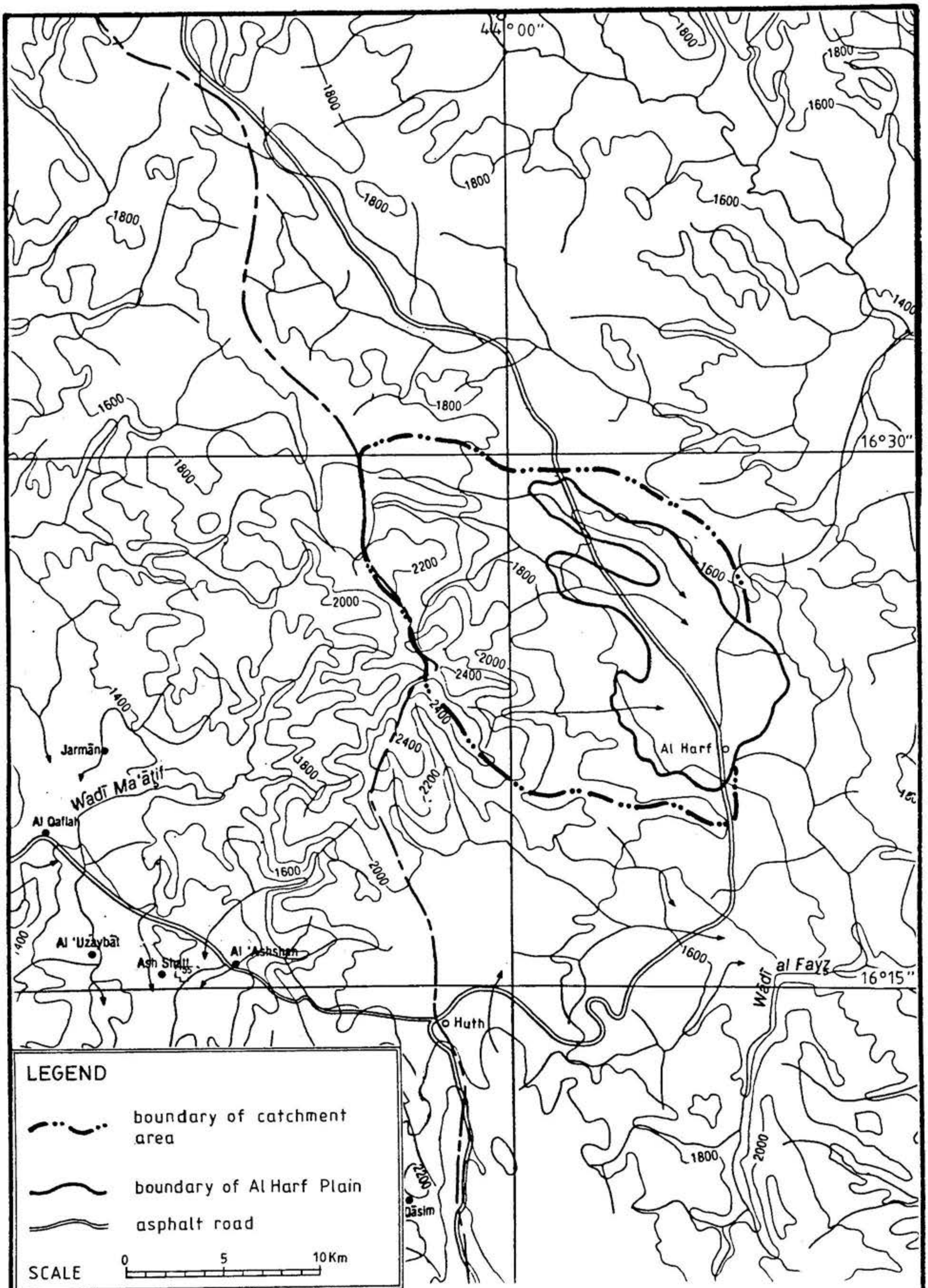


Fig. 2.3 Catchment area of Al Harf Plain

of Al Harf Town), while Fig. 2.5 represents the total annual rainfall at the same rainfall station for the period 1975-1989. Annual totals range from 34 to 559 mm.

Fig. 2.4 *Mean Monthly Precipitation at Huth (1975-1989)*

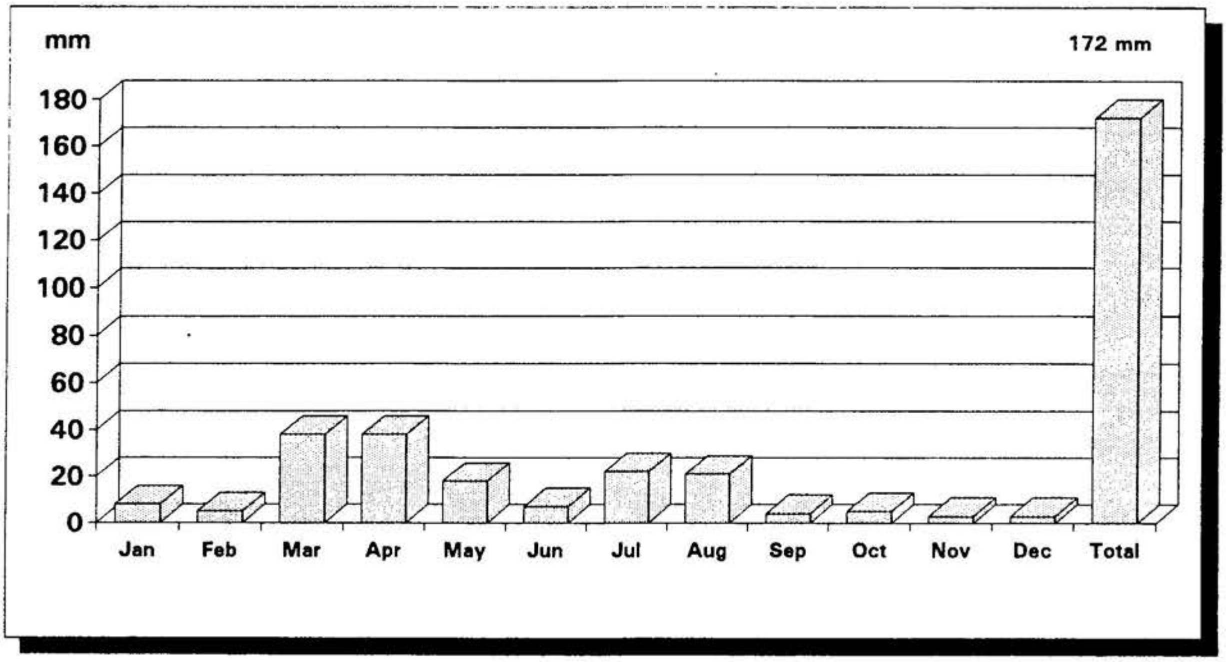
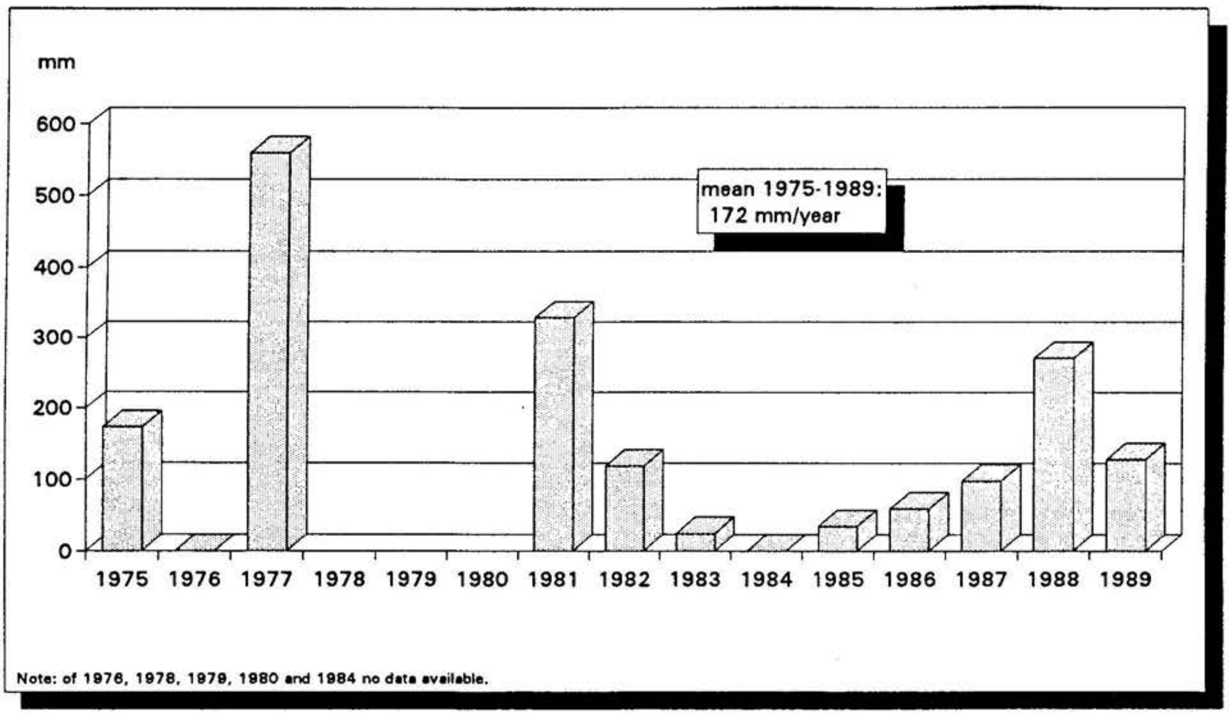


Fig. 2.5 *Total Annual Precipitation at Huth (1975-1989)*



The monthly distribution of rainfall is variable. In general two peaks of rainfall occur during the year: March-May and July-August. The wettest months in most places are March and April.

Temperatures range from 35 degrees Celsius in the summer to four degrees in the winter. The annual average temperature is 15.4 degrees. The mean monthly maximum temperature is 29.6 degrees, while temperatures in the winter can drop to below zero.

Evaporation far exceeds precipitation during most of the year. ETO (Penman) is about 2375 mm per year.

3 GEOLOGY AND HYDROGEOLOGY

3.1 GEOLOGY

3.1.1 Tectonics

Probably during the Oligocene (Tertiary) major northwest-southeast faulting at the eastern margin of the plain caused a downthrow of the limestones of at least 50 m. Like many of the alluvial plains in Yemen the Al Harf Plain was formed by the filling up of a graben system by alluvial deposits during late-Tertiary and Quaternary times. During this deposition intermittent volcanic activities took place at the eastern border of the plain and created several basaltic cratons. In the northwest between the Wadis Ayyan and Burkan, there are remnants of the Cretaceous-Tertiary Tawilah Sandstones upon the limestones of the Jurassic Amran Series.

3.1.2 The Quaternary Volcanics

During the Quaternary volcanic activity resulted in the build-up of basaltic cones at the eastern side; also on the Tawilah Sandstones at the northwestern margin of the plain. The volcanic cones on the east side extend from 80 to 100 m above the surrounding strata. Near the Amran and Attaf vallies, the age of Quaternary volcanic activity was determined as varying between 100 000 and 1700 years. The thickness of the volcanic cover varies from zero to more than one hundred metres. The basalts are dark grey to black coloured. Table 3.1 shows the description of the geological formations and their hydraulic characteristics.

3.1.3 The Quaternary Alluvium

The graben that originated in tectonic movements along major faults was filled up during the Quaternary period by alluvial deposits, consisting of clay, loess, silt, sand, gravel and boulders. This material originated mainly from the surrounding outcropping Amran limestones and the Tawilah sandstone outcrops in the north-west. The thickness of these unconsolidated sediments is limited. Fig. 4.17 shows the thickness of the alluvium. The depth to the underlying limestone ranges from 25 to 50 m. Fig. 4.18 presents a north-south cross-section through the plain giving the thickness of the alluvium and the depth to the groundwater. It clearly shows that water is pumped not from the alluvium but from the limestone below it. The alluvium functions as a sponge or a surface and rain water collecting medium, from where the water can infiltrate into the underlying limestone.

3.1.4 The Amran Limestones

The Al Harf Plain is underlain and enclosed on all sides by limestones of the Amran Series. The type location of the Amran (limestone) Series is situated near Amran Town. It outcrops over a vast area, roughly between the towns of Sana'a, Hajjah, Sa'dah and Marib. The age has been determined by fossils (stromatoporoids, ostrea, brachiopodes) as middle to late Jurassic. During that period an important marine transgression (or land subsidence) took place over the entire country and shallow water marine calcareous deposits were formed.

Table 3.1 *Geological Formations and the Hydrologeological Characteristics*

Stratigraphic Age	Litho-stratigraphy	Lithology	Hydrogeology
Quaternary	Alluvial deposits, locally interbedded with basalt flows	Loam, silt, clay, loess, gravel, boulders. Basalts and tuffs	Alluvium does not act as an aquifer, because water level is situated below it in the limestone. Alluvium functions as surface and rain water collector, where after it infiltrates in the limestone below.
Tertiairy	Yemen Volcanics	Volcanic flows, sills, tuffs, basalts and intrusives.	Poor aquifer, unless fractured. Too far outside study area to be significant in water balance.
Tertiairy/ Cretaceous	Medj-Zir Series and Tawilah Group	Cross-bedded fine to coarse grained quartz sandstones with gravel and conglomerate horizons.	In principle, a potential aquifer. No data are available on the saturated thickness in the study area.
Jurassic	Amran Series	Limestones, dolomites, marl, shale layers and Quaternary basalt dykes.	Main aquifer of the area. In general poor hydraulic properties, except in or near fractured zones. No indications for the occurrence of karst. Low well yields (< 6 l/s).
Triassic	Kohlan Series	Fine grained. partly cemented quartz sandstones with conglomerate horizons.	Not significant for the water supply of the Al Harf Plain. Not outcropping in or near the study area. Probably underlies the Amran Limestone Series.
Precambrian	Basement complex	Granite, gneiss and mica schists.	Practically impermeable and little water storage. Aquiclude and aquifuge, no outcrops in or near the study area.

In the NORADEP Region the Amran Series rest upon the calcareous sandstones of the Kohlan Group and in some areas directly upon the Precambrian Basement. The lower horizons of the Amran Series are represented by the Shuqra Formation and consist mainly of white/yellow/black limestones. Its depositional environment was shallow reefal marine.

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

The late Jurassic was a relatively stable period and fluvio-marine sediments were laid down, now comprising the Al-Ahjur formation, consisting mainly of marly, shaley and sandy mudstones.

Towards the end of late Jurassic there was another regression, resulting in a continental depositional environment. Continental fluviatile sands and conglomerates were then laid down (Tawilah Group).

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

3.2 AQUIFER SYSTEMS

3.2.1 Alluvium

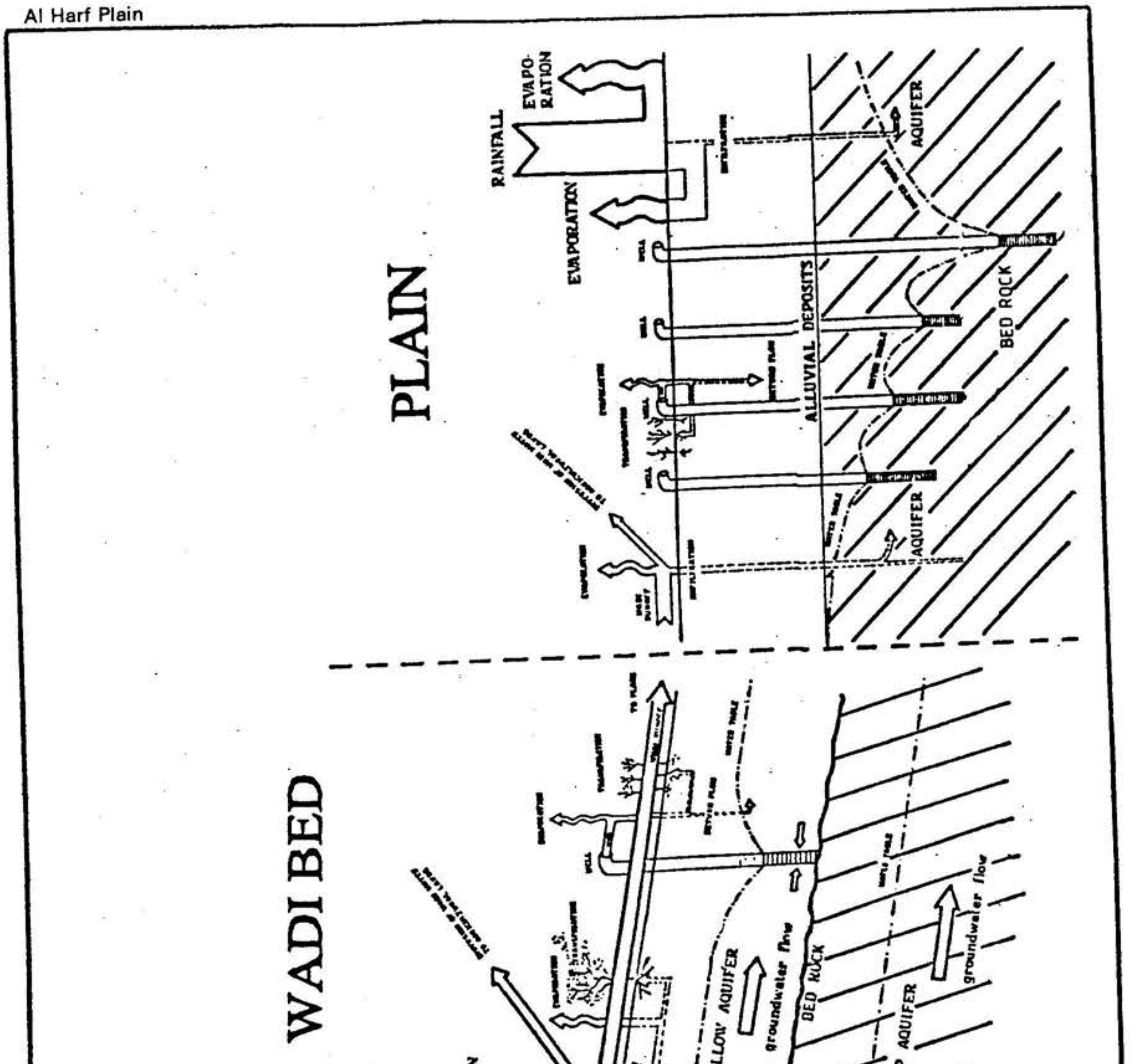
Only in upstream wadi fills does the Quaternary alluvium function as a temporary perched aquifer and, where saturated, it represents a relatively good aquifer. The highest permeabilities are in the interbedded gravel layers. However, in the plain the alluvium is not saturated.

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

The (natural) water table gradient in the Al Harf Plain indicates a groundwater flow directed to the southeast of the plain.

3.2.2 Bedrock

Limestones
The Amran Series, principally composed of limestones, marls and some shales, is generally considered 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 the permeability, decreases with the depth.


MOUNTAIN
SLOPES
RAINFALL
EVAPORATION
EVAPORATION
SURFACE RUNOFF
SOIL
INFILTRATION
BED ROCK
groundwater flow
WADI BED
WADI RUNOFF
EVAPORATION
INFILTRATION
SHALLOW AQUIFER
groundwater flow
BED ROCK
DEEP AQUIFER
groundwater flow
PLAIN
RAINFALL
EVAPO-
RATION
EVAPORATION
ALLUVIAL DEPOSITS
BED ROCK
AQUIFER
AQUIFER

Average well yields from the limestone are almost half those from the alluvium in the Amran Valley.

In the Amran Plain some aquifer tests in the Amran Limestone Series were carried out. Tibbits and Aubel (1980) drilled six boreholes in the limestone. Only one well (near Menjidah) gave a high yield: 14.5 l/s; the remaining five boreholes did not give a substantial discharge.

Volcanics
Most of the test boreholes drilled during the above mentioned study in the volcanic deposits proved to be dry. Water-bearing and water-transporting capacities would only be expected in fractured zones, 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 level of the alluvium (Tibbits/Aubel, 1980). The volcanics in the study area are all situated above the general water table and therefore do not function as aquifers.

4 GROUNDWATER - GENERAL

4.1 DISTRIBUTION OF WELLS

Fig. 4.1 shows the locations of the wells visited during December 1991. A total of 66 wells were inventoried. It was assumed that at least 90% of all existing wells were surveyed and that the remaining 10% were evenly distributed over the total area. Nevertheless large areas with a lower well density show up.

First of all, several parts of the plain are not suited for agriculture, because the topography is irregular and/or inferior soil properties dominate. Secondly, a large area in the centre of the plain, north of Al Harf Town, is entirely covered by sand. As a consequence, it has remained completely fallow. Near the borders of the plains and in the two northern tributary valleys of the Wadis Ayyan and Burkan, spate irrigation dominates, in some places supported by pumped irrigation.

4.2 NUMBER OF WELLS

As mentioned above the number of wells located in the Al Harf Plain during the well inventory was 66. 12% of these wells were not in operation for several reasons. Assuming that 90% of the wells were visited, the total number of wells was estimated at about 73 of which 88% or 64 would have been operational at the time of the well survey.

Most dug wells had fallen dry during the last ten years because of declining water levels. There were only three (manually dug) wells still in operation: one near the southwest mountain border and two in the northeast of the plain near As Surrah. Since the introduction of drilled wells the water levels have fallen to such an extent that (manual) digging and deepening of wells has been forced to stop except in some areas with shallow (perched) groundwater tables, like the borders of the plain. Only the richer farmers could afford to drill deeper wells to reach the lower water levels. Groups of farmers started to cooperate to finance the drilling of a common deep well.

In the past water was abstracted by buckets lifted by donkey power. However, all wells are now pumped by means of turbine lineshaft pumps. Only the three manually dug wells with shallow water levels had low power centrifugal pumps. Fig. 4.2 and 4.3 show the total number and the cumulative number of the wells that were still operational in 1991 and which were drilled during the period 1976 to 1991. It must be noted that the numbers are net figures. That means the number of drilled well minus the number of abandoned wells.

Serious groundwater development in the Al Harf Plain started only in 1976, about 14 years later than in the Amran Valley. The main drilling activities occurred in the period from 1983 to 1986. Since 1987 the rate of drilling had dropped from 3 wells in 1987 to two in 1990. It seemed that the drilling peak had past.

Statistical analysis of the cumulative distribution of the number of wells constructed

Fig. 4.1 *Locations of Inventoried Wells*

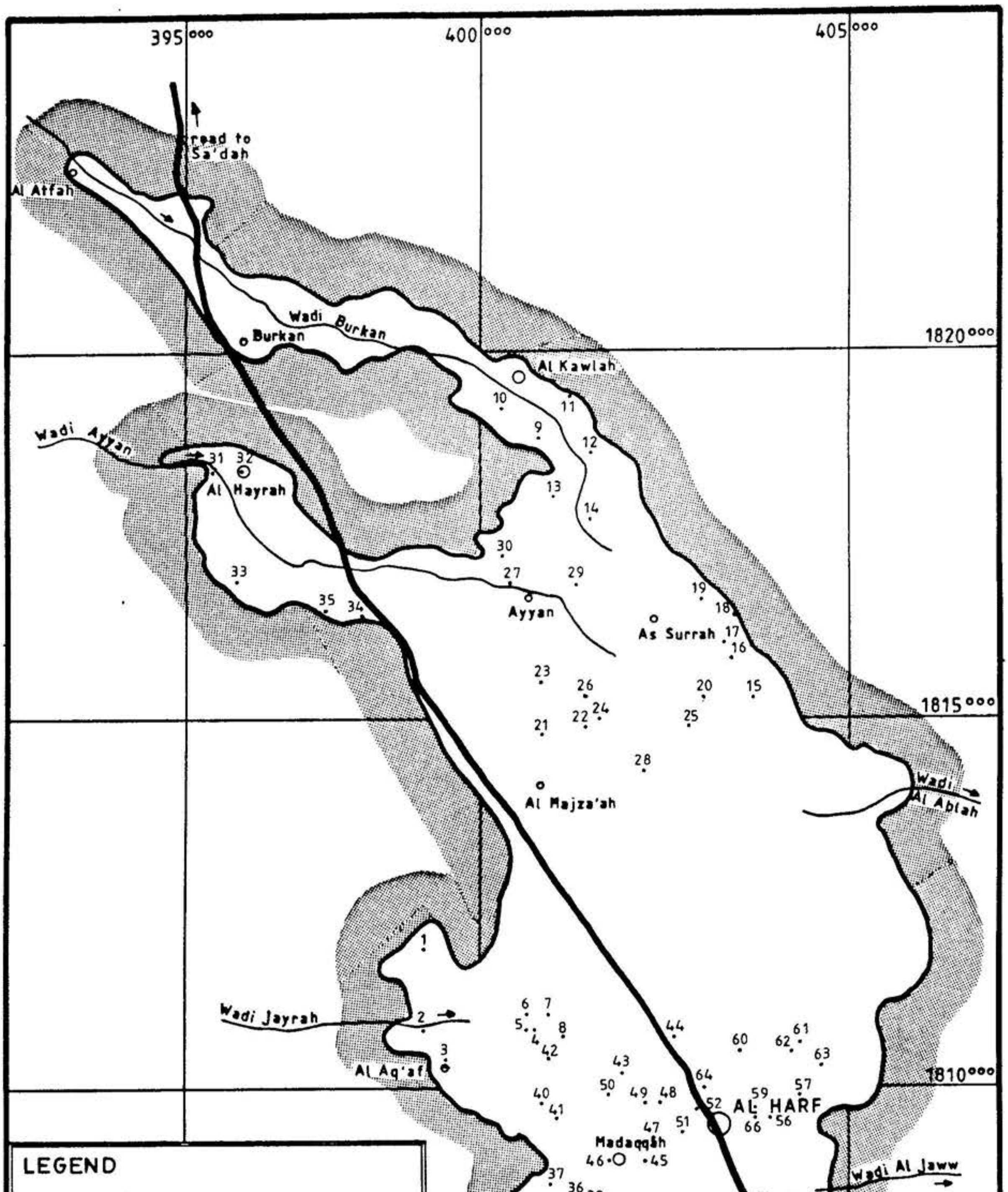
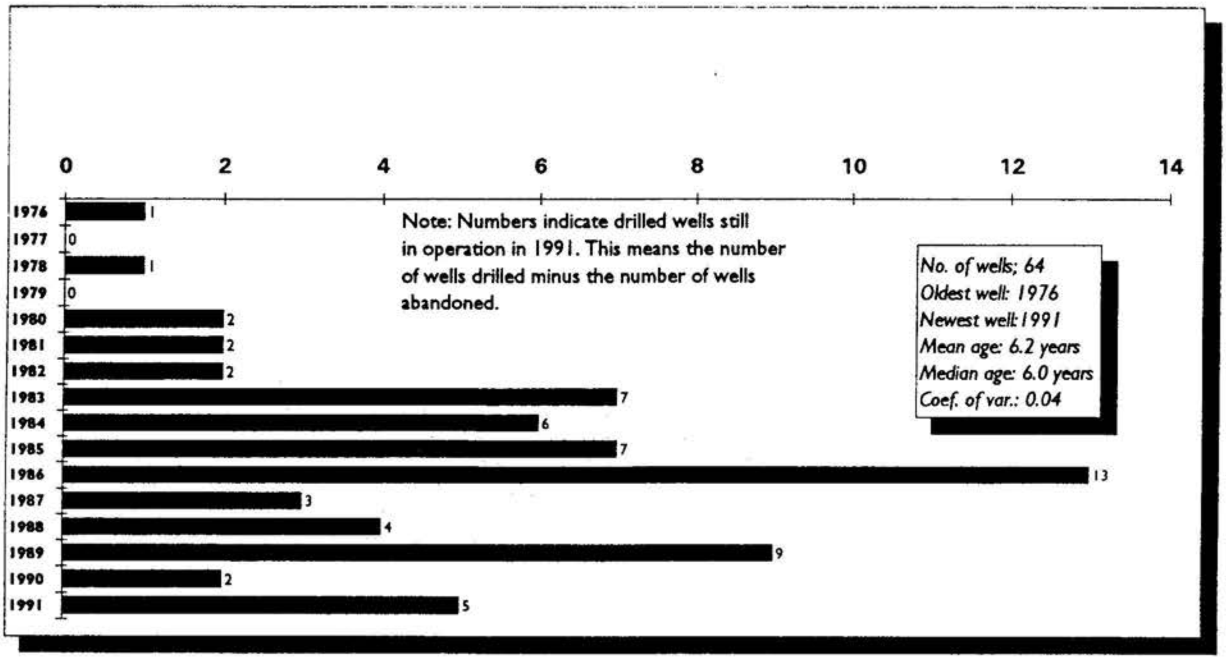


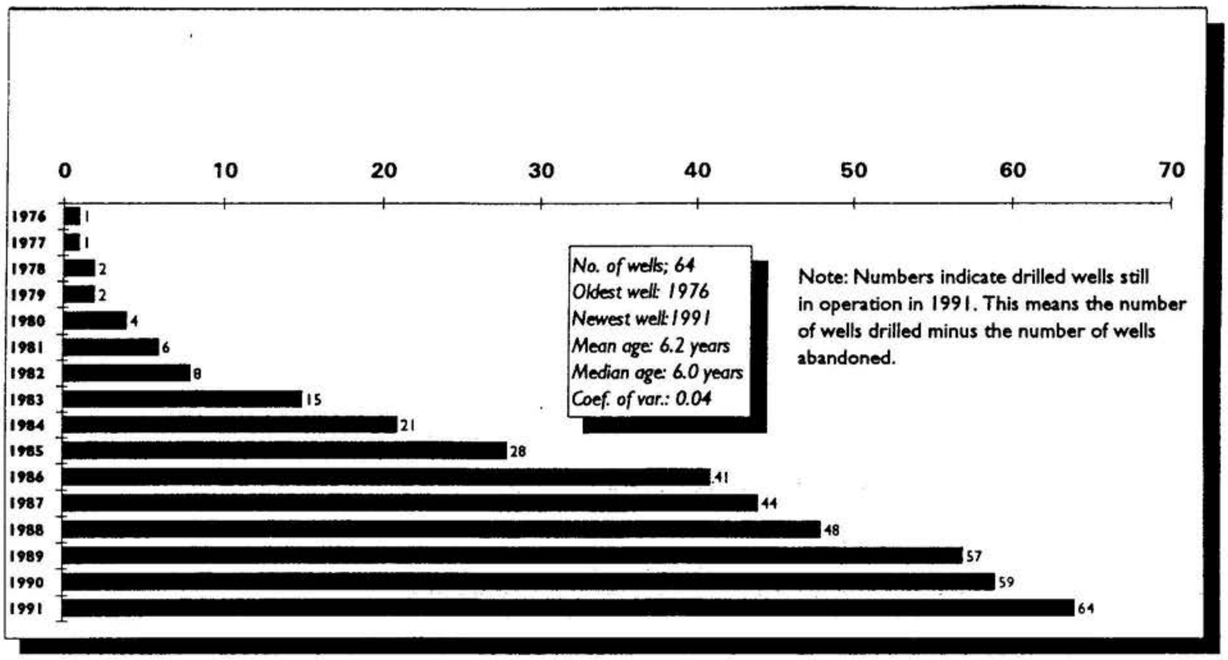
Fig. 4.1 Map of the locations of the inventoried wells

Fig. 4.2 *The Number of Wells Drilled in the Period 1976-1991*



shows that 50% of the existing wells were drilled after 1985, while the average well age is 6.2 years. The oldest well dated from 1976. Because of the falling groundwater table, three wells were deepened during the previous 15 years.

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



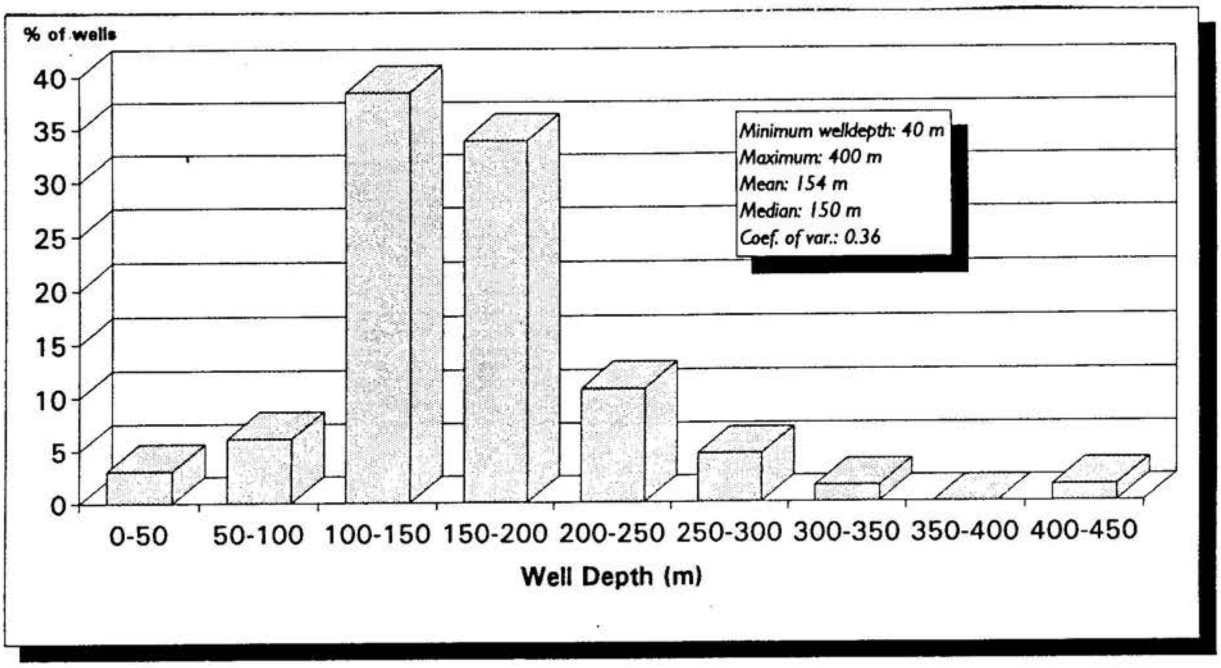
4.3 WELL CHARACTERISTICS

Almost all the wells inventoried were drilled wells. As mentioned above only three dug wells were encountered and only three wells were reported to have been deepened once, a very low figure when compared with the Amran Valley where 23% of the wells had been deepened one or more times.

The drilling method used was predominantly rotary although some older wells were drilled with the cable tool method. Practically all the wells were cased throughout with pipes of six m length. All the wells, except the dug wells, had steel casings. Casing diameters differ significantly from those observed in the Amran Valley: 8 and 10" diameter casings dominate (42 and 40%), followed by 12" diameter casings (18%). The lower section contains a series of 6 m long slotted pipes as a screen.

Fig. 4.4 shows the distribution of the well depths in the plain. Well depths ranged from 40 m to 400 m. The average depth was 154 m. A relatively high concentration of deep wells were found in the northeast part of the plain, southeast of Al Kawlah and in the extreme southern part, south and southwest of Al Harf Town. Here, groundwater levels were relatively deep: more than 100 m (see Fig. 4.15)

Fig. 4.4 *Distribution of Well Depths*

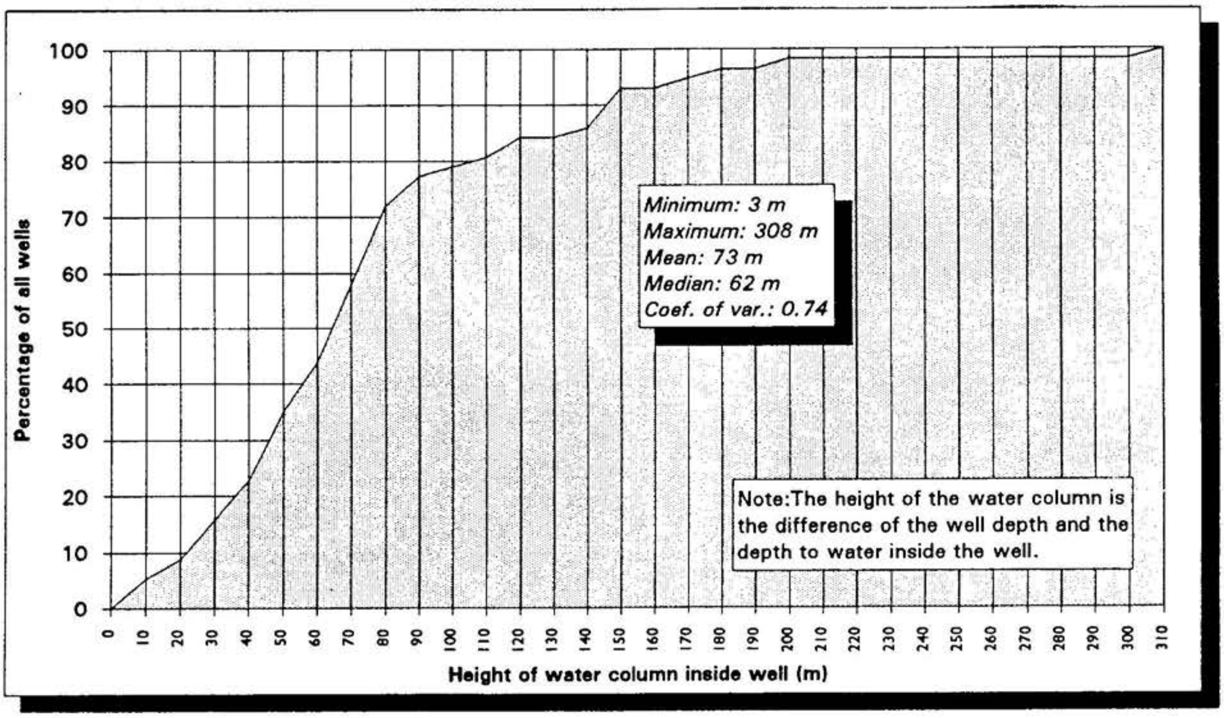


4.4 WATER COLUMN HEIGHTS

To indicate if the wells had been prepared for falling water levels, or in other words how much water column was available inside the wells, the 'water column height' was analysed. The water column height is the difference of 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 will fall dry when the water table drops by a certain amount can be calculated.

Fig. 4.5 shows that the depths of most wells in relation to the water level depths are such that even assuming a substantial drop in water level, a low percentage of the wells would fall dry. The water column heights ranged from 3 to 308 m, the average aquifer penetration was 78 m. The figure shows that if the groundwater were to drop 30 m over the whole plain then 15% (Amran Valley: 9%) would 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 Water Column Heights*



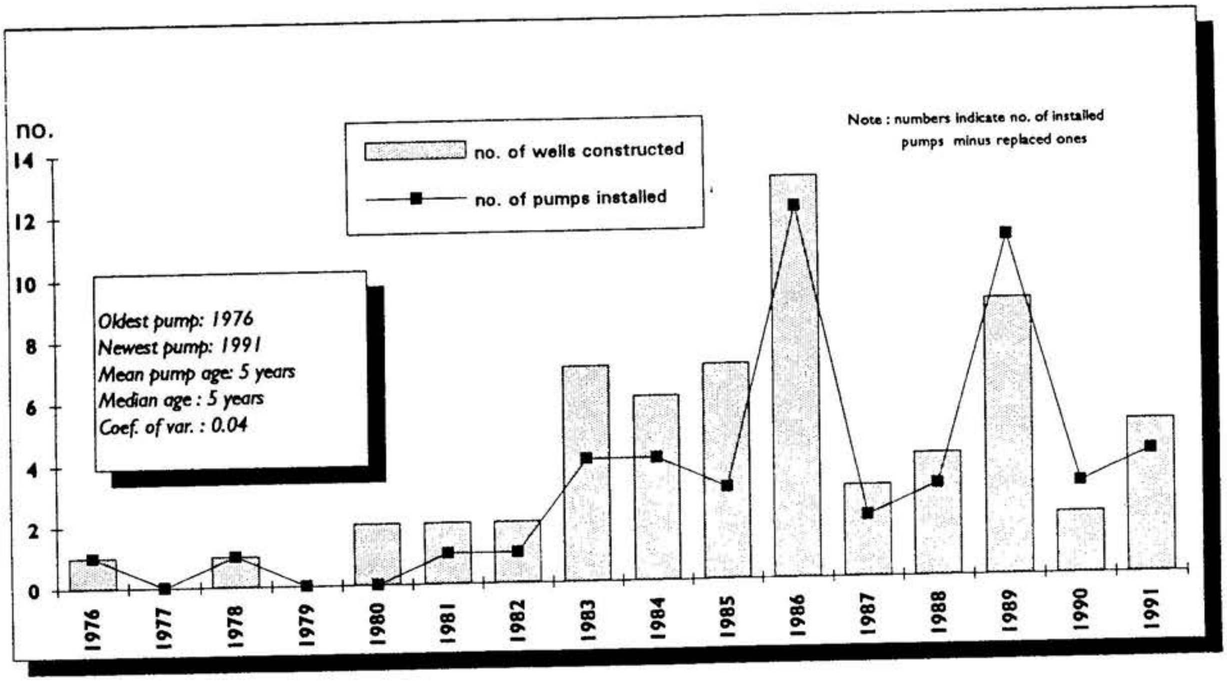
4.5 PUMPING EQUIPMENT

Water was pumped typically by vertical turbine (lineshaft) pumps coupled via crossed webbing belts to diesel engines.

Only two wells were equipped with electro-submersible pumps, driven by electrical power generated by high capacity engines.

A high level of standardization in engine and pumping equipment was observed: 88% of the pumps were made by Caprari. The pump column diameter was mostly three inch (94% of all the wells).

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



The same level of standardization was noticed among the engines that power the pumps: 78% were Japanese Yanmar engines (Yamaha), 5% Mitsubishi. The engines had in most of the cases capacities ranging from 23 to 35 horsepower for the lineshaft pumps.

The average lifetime of the wells was higher than that of the pumps. This was reflected in the average age of the wells and the pumps (in 1991): 6.2 and 5 years respectively. This meant that many wells were equipped with a second pump set. During the years 1989 and 1990 more pumps were installed than wells constructed, replacing pumps from wells constructed before this period (see Fig. 4.6).

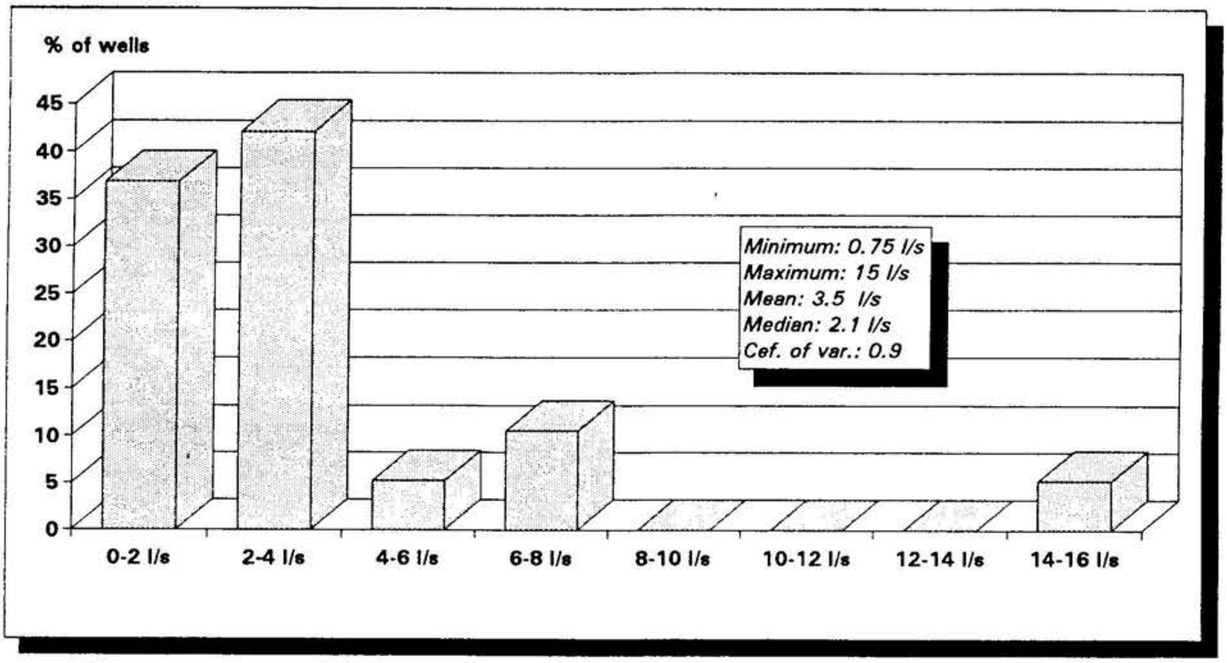
4.6 WELL YIELDS

Well yields were very low in the Al Harf Plain. The mean (3.5 l/s) was almost half that in the Amran Valley (6.5 l/s). Well discharge rates varied from about 0.75 l/s to 15 l/s. The distribution of well yields is presented in Fig. 4.7. These low values are explained by the aquifer. The top layer of alluvium is underlain by the limestone of the Amran Series.

The groundwater level is situated below the alluvium-limestone contact. This means that all the wells were abstracting water from the limestone, which is of low permeability. The magnitude of the well yield is determined by several parameters such as the capacity of the pump, the well efficiency, the screen length, the depth to the water and aquifer parameters like transmissivity and storage coefficient.
Drawdowns during pumping were moderate: in the order of 2 metres at a discharge rate of about 2 l/s up to 9 m at a yield of 5 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 for well construction and for the purchase and installation of the pumping equipment are presented in Fig. 4.8. The costs of well construction included the drilling of the well, the installation of the casing, the screen (slotted pipes), the gravel pack and the development (air lift) of the well.

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

The same figure shows the distribution of the costs. Well construction costs ranged from YR 60 000 (a 108 m deep well, drilled in 1989) to YR 460,000 (a 163 m deep well drilled in 1991). Median well costs were YR 160 000. Pumping equipment costs had a much larger variation: from YR 74 000 to YR 600 000 and a median of YR 205 000. Well construction costs appeared to be lower than in the Amran Valley. As a consequence of the harder medium to be drilled (limestone instead of alluvium) the opposite might have been expected. However, pumping equipment costs were higher than in the Amran Valley. This can partly be explained by the younger age of the wells and pumps in the Al Harf Plain (more recent prices).

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

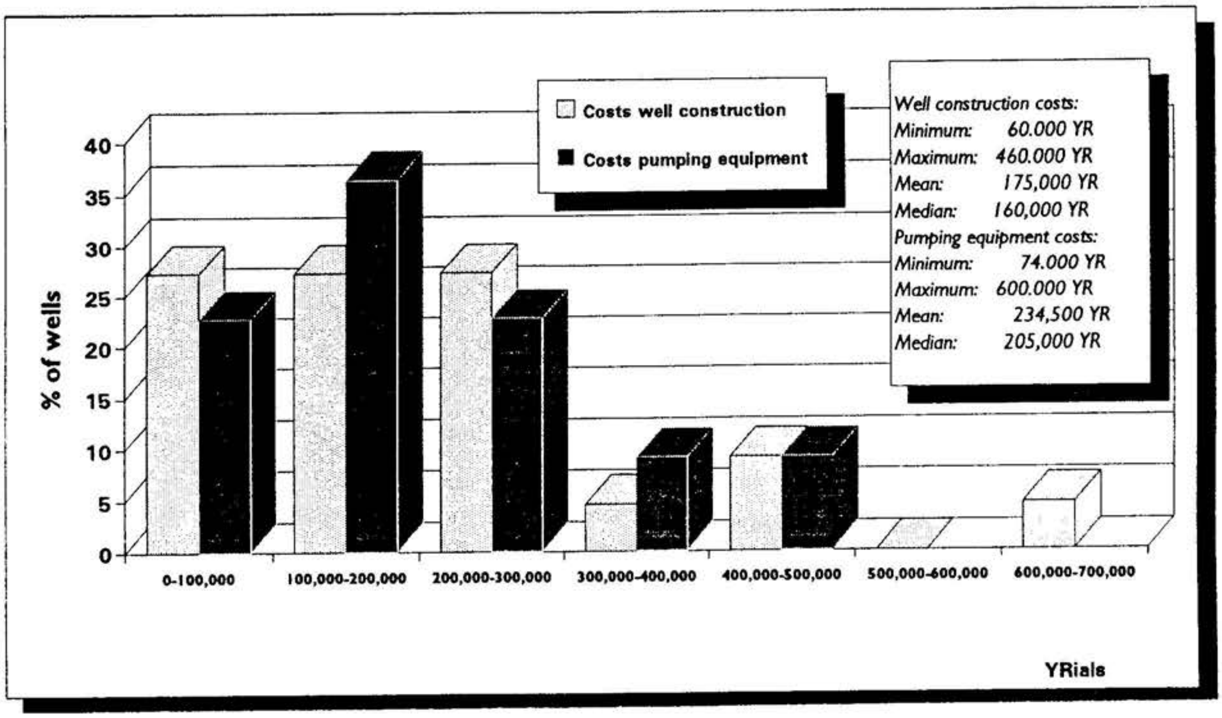
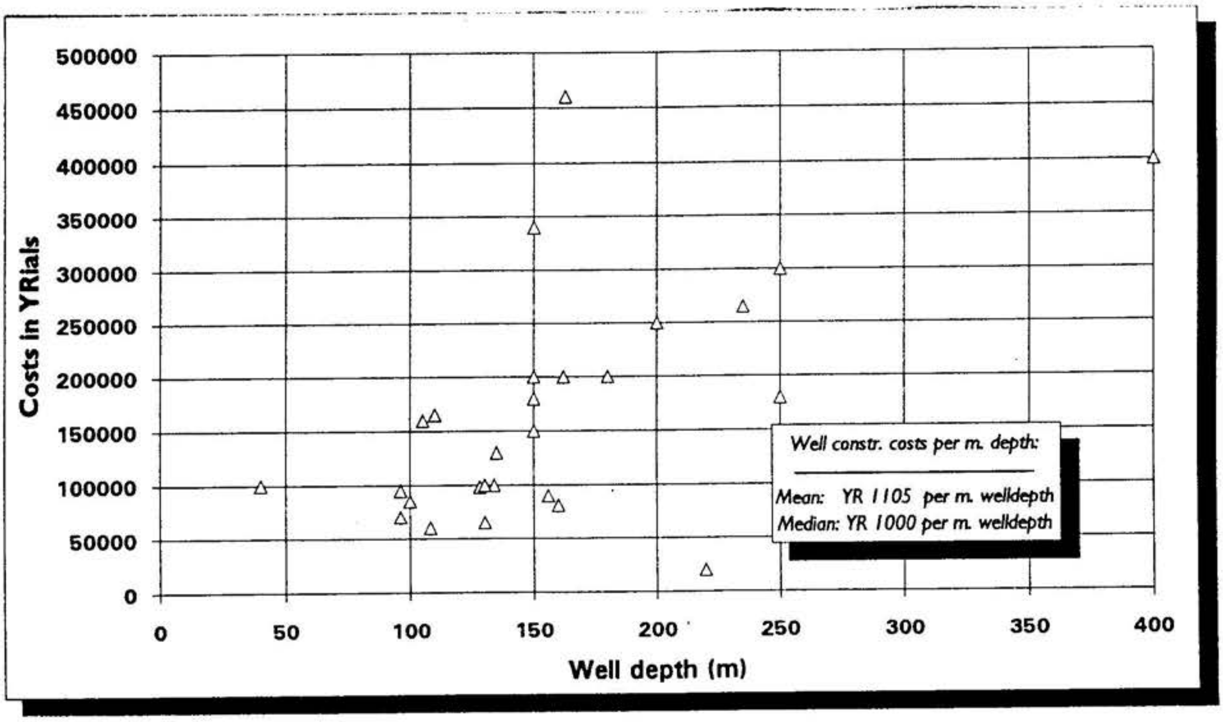


Fig. 4.9 *Relation of Well Depths to Well Construction Costs*

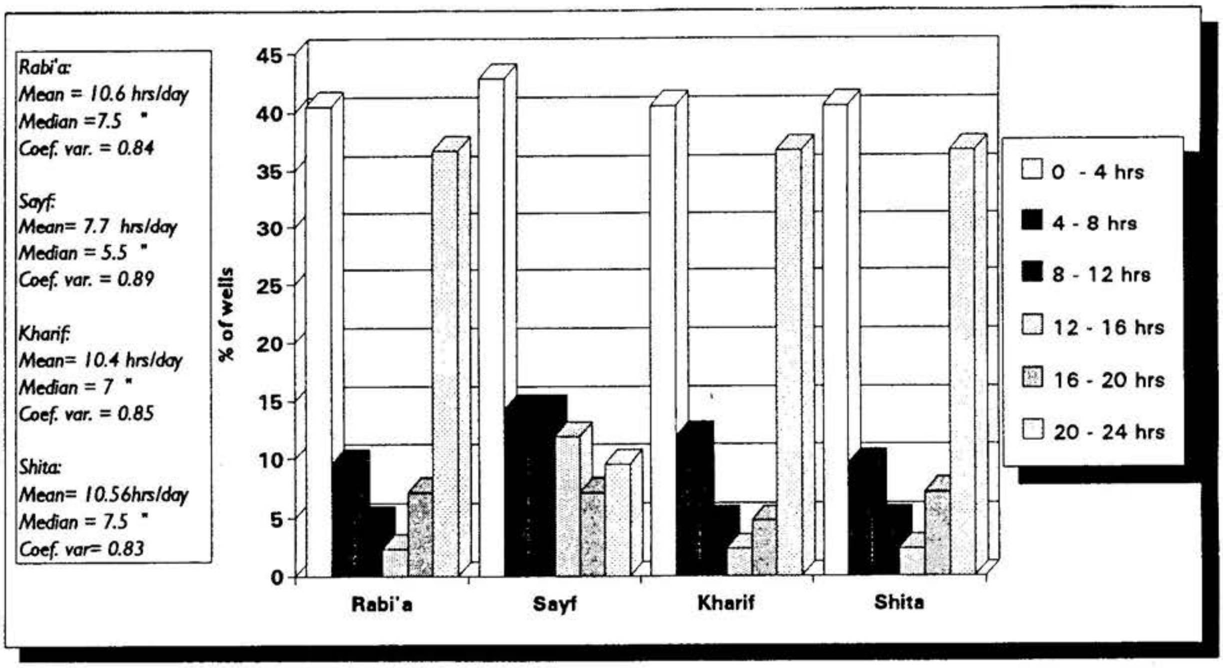


In Fig. 4.9 the costs of well construction excluding the costs of pumps and related equipment are plotted against the well depth. It must be remembered that these costs were costs at the time of construction or purchase and that the data concern wells drilled during the period of about 1976 to 1991. As a consequence of currency inflation, the mean current costs (1991 YRials) must be somewhat higher. The average price per metre drilled well for this period was YR 1100.

4.8 PUMPING SCHEDULES

The average farmer pumped groundwater about 10 hours per day, throughout the seasons. The mean yearly number of pumping hours per day was 9.8.

Fig. 4.10 *Seasonal Distribution of Daily Pumping Hours*



Pumping activities were highest during Rabi'a[1] (mean 10.6 hrs/day), followed by Shita (mean 10.56 hrs/day), Kharif (mean 10.4 hrs/day) and Sayf (mean 7.7 hrs/day).Fig. 4.10 shows the distribution of the daily pumping hours throughout the seasons. No reason could be found why the lowest pumping activity occurs in the summer time. Perhaps farmers during the summer months, when it is mostly sorghum that is cultivated, rely partly on rainfall. About 3% of the farmers operate the pump 24 hours per day.

Over the whole year the average number of pumping days per month was 28.2 (see Fig. 4.11). The number of pumping hours per month was 280, an average of 10 hours per day (see Fig. 4.12).

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1 The season in Yemen are Rabi'a, Sayf, Kharif and Shita, corresponding approximately with spring, summer, autumn and winter.

Fig. 4.11 *Monthly Number of Pumping Days*

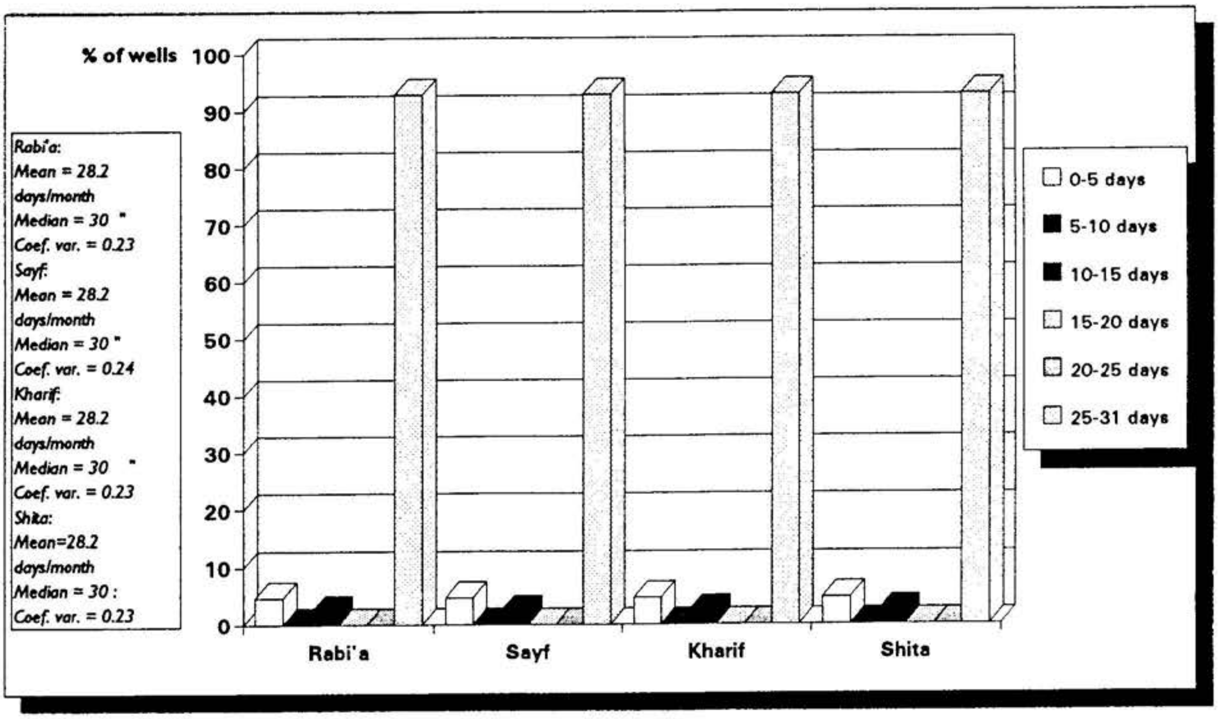
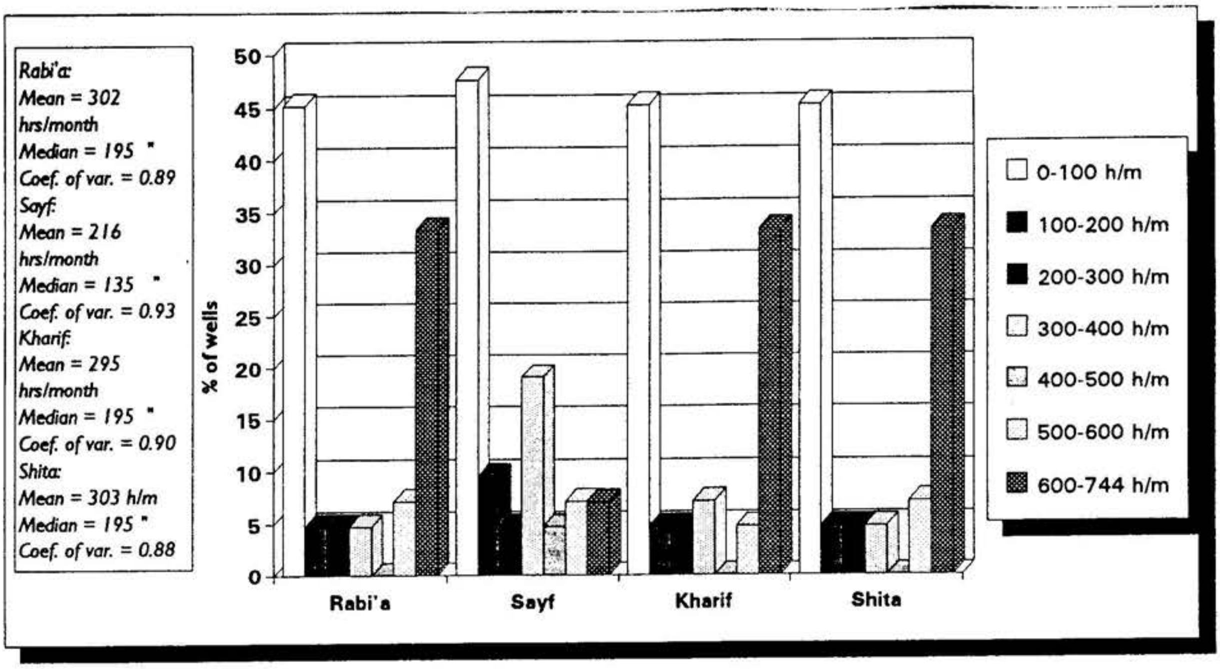


Fig. 4.12 *Monthly Number of Pumping Hours*



4.9 GROUNDWATER ABSTRACTION

To enable the assessment of the total groundwater abstraction a reasonable estimate has first to be made of the total number of operational wells. At 38 wells (of the total of 66 wells visited) the discharge could be measured. At the remaining 28 wells no discharge measurements could be carried out for the following reasons: the well was

dry, no pump and/or engine was present, no diesel and/or oil were available, or because of a broken pump/engine. Sometimes there was just nobody to switch on the pump. At another four wells no data on the pumping schedule could be collected. This resulted in a sample of 34 wells from which the seasonal and yearly discharge were calculated.

Table 4.1 *Volumes of Groundwater Abstracted in 1991*

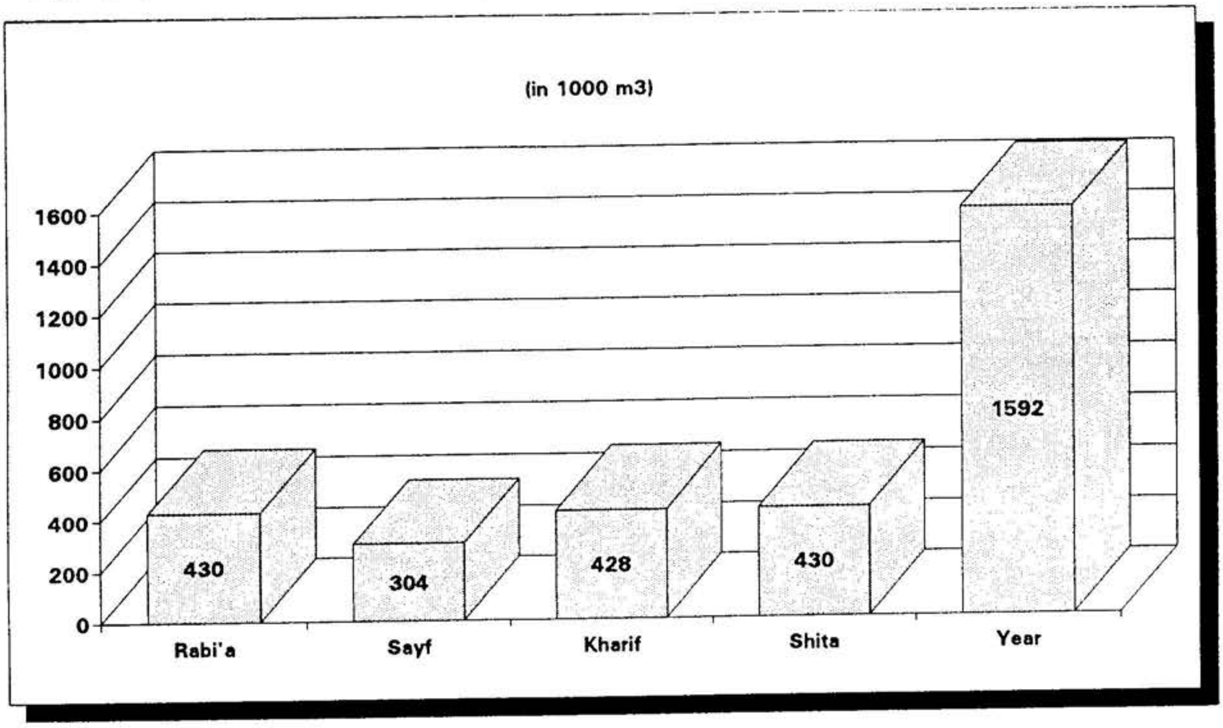
	Rabi'a	Sayf	Kharif	Shita	Year
Groundwater abstracted per well (in 1000 m^3)					
Mean	6.7	4.7	6.7	6.7	24.9
Median	4.8	2.4	4.8	4.8	19.2
Minimum	0.3	0.0	0.3	0.3	0.9
Maximum	22.7	16.8	22.7	22.7	73.8
Coef. of variance	0.93	0.96	0.93	0.93	0.9
Total volume of groundwater abstracted (in 1000 m^3)	228.5	161.4	227.6	228.5	846
Based on no. of wells	34	34	34	34	
Total volume of groundwater abstracted (in 1000 m^3) (extrapolated assuming a total of 64 operational wells)	430	303.8	428.4	430.1	1592.4

For the calculation of the yearly total discharge in the plain, these wells were not taken into consideration. Assuming the total wells to be about 73, and applying the same percentage of fall out, then about 64 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 6.5% 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.

In Table 4.1 and Fig. 4.13 are calculated and presented the seasonal groundwater abstractions. A yearly total of approximately 1.6 Mcm of groundwater abstraction was estimated for the Al Harf Plain in 1991.

Fig. 4.13 *Seasonal and Yearly Groundwater Abstraction in 1991 ('000 m^3)*



The abstracted volumes during the individual seasons were 0.43, 0.3, 0.43 and 0.43 Mcm for Rabi'a, Sayf, Kharif and Shita, respectively.

Fig. 4.14 *Estimated Increase of Yearly Groundwater abstraction During the Period 1976 to 1991 (Mcm)*

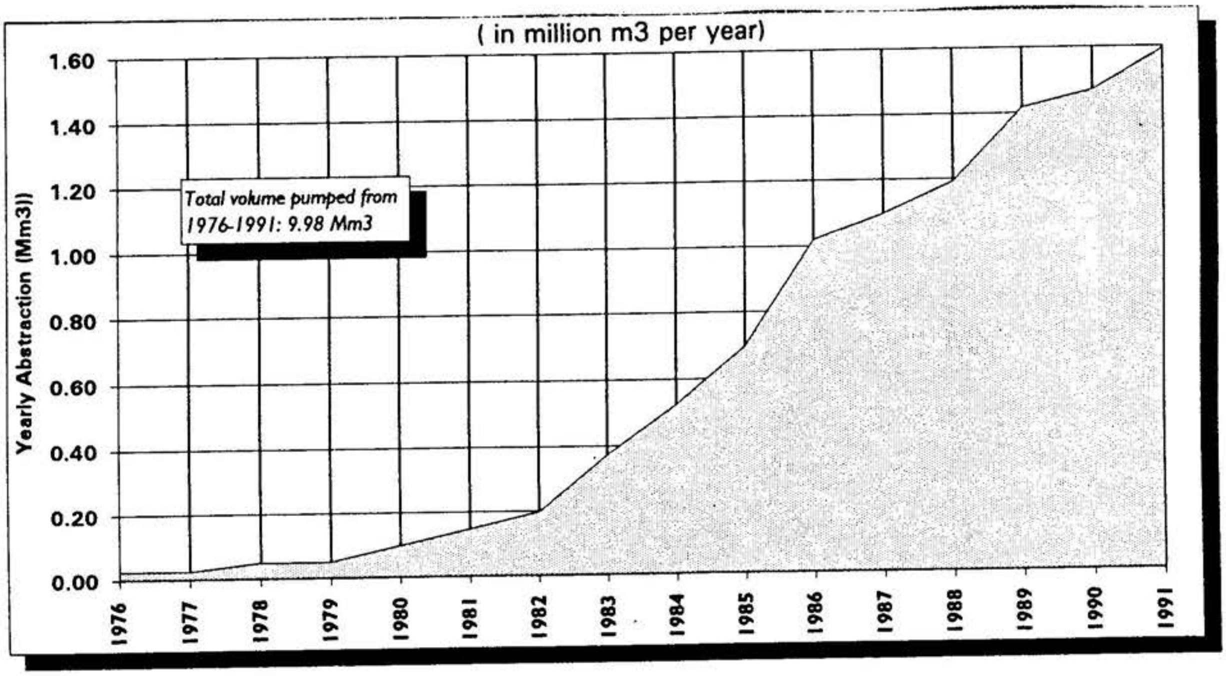


Fig. 4.14 displays the yearly increase and volumes of groundwater abstraction during the period 1976 to 1991.

It shows that the highest growth occurred from 1983 to 1986. After 1986 up to 1991. this increase diminished. A (very rough) estimate of all the groundwater pumped in the Al Harf Plain, using figures from 1976 (when abstraction became significant) to 1991, gave about 10 Mcm. This represents a water layer of 0.16 m depth covering the whole Al Harf Plain (64 km^2). Expressed in terms of lost aquifer, assuming an average effective porosity (specific yield) of 3%, then the volume pumped during the 15 years corresponds to a lost saturated aquifer thickness of 100/3 * 0.16 = 5.33 metres, covering the whole Al Harf Plain.

4.10 DEPTH TO GROUNDWATER

Data on groundwater levels were collected either by measuring with a sounding tape or by questioning the well owner. In many cases it proved to be rather difficult to measure the groundwater level. Firstly, because a large number of the wells were completely sealed with masonry. If not, then the space between the pump column and the casing was mostly so small that the sounding probe could hardly pass through it.

During the well inventory several tapes were lost, stuck in the annular space between the two pipes. This was the reason that in many cases the farmer had to be questioned on the water depth. The depth to the water table was usually 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 knew the depth of the pump setting (expressed in the number of pump column pipes above the pump). Because this figure looked to be a more reliable depth indicator than a stated water depth, a contour map of the depth to the pump setting was composed, as a quality control. The pattern of the groundwater depths almost completely corresponds with the pump depth contour map.

Groundwater depths have a wide range in the Al Harf Plain: from 35 m (near Ayyan Town) to 135 m (near Dhu Unqan). When analysing Fig. 4.15 it can be observed that there are two areas where the groundwater level is significantly deeper than the general groundwater level in the plain. First, south of Al Harf Town, where a cone had developed in the groundwater table with a water level drop of about 40 m. Then, northwest of Dhu Unqan where the depression in the water table was more than 50 m. The general depth of the groundwater in the plain ranged from 70 to 90 m below surface.

4.11 GROUNDWATER PIEZOMETRIC LEVEL

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

Piezometric levels showed little variation in the Al Harf Plain. Their range was between 1570 m amsl in the upstream part of the tributary valley of Wadi Ayyan and 1480 m in the extreme south of the plain. The general groundwater flow is directed

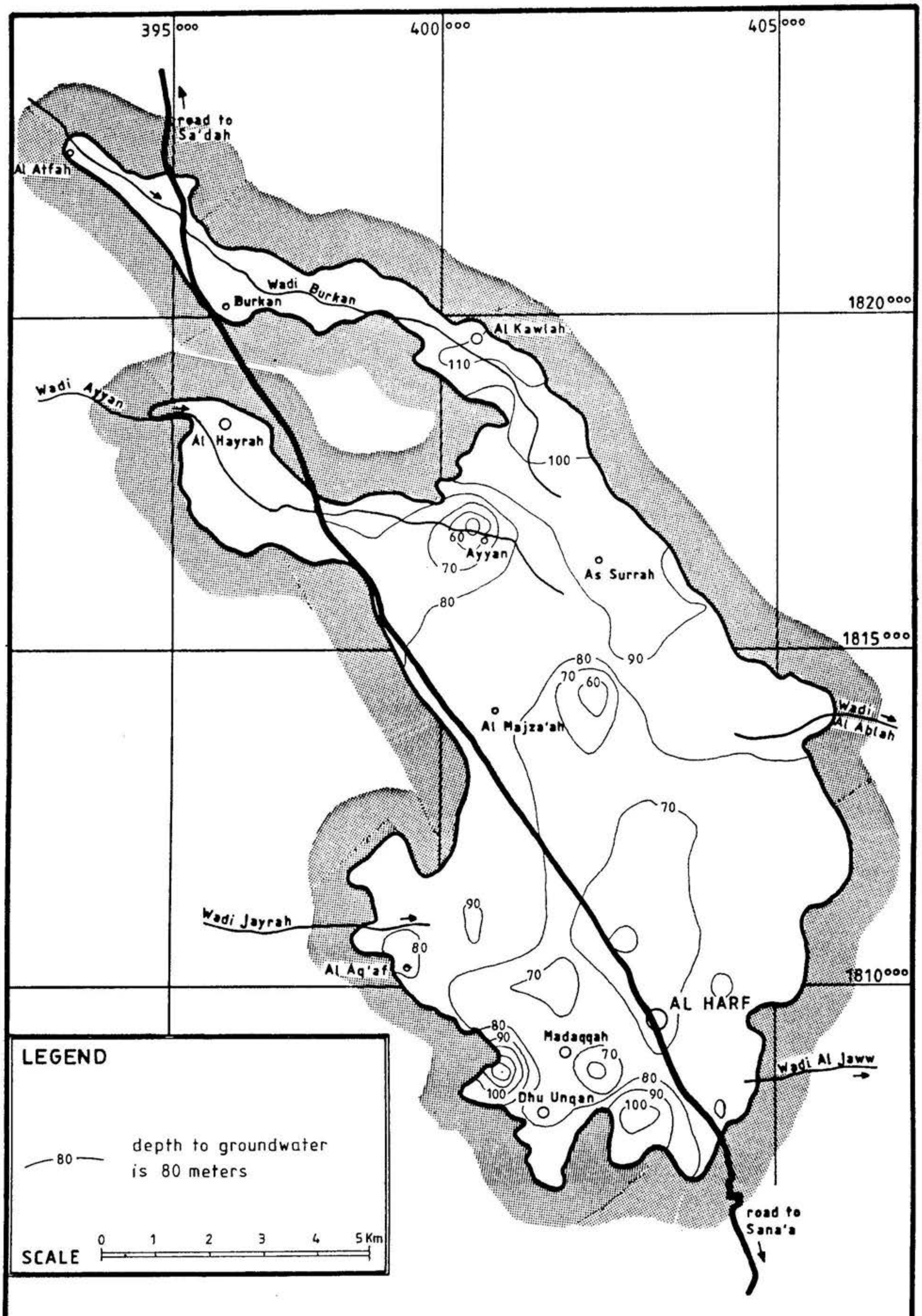


Fig. 4.15 Map of the depth to groundwater

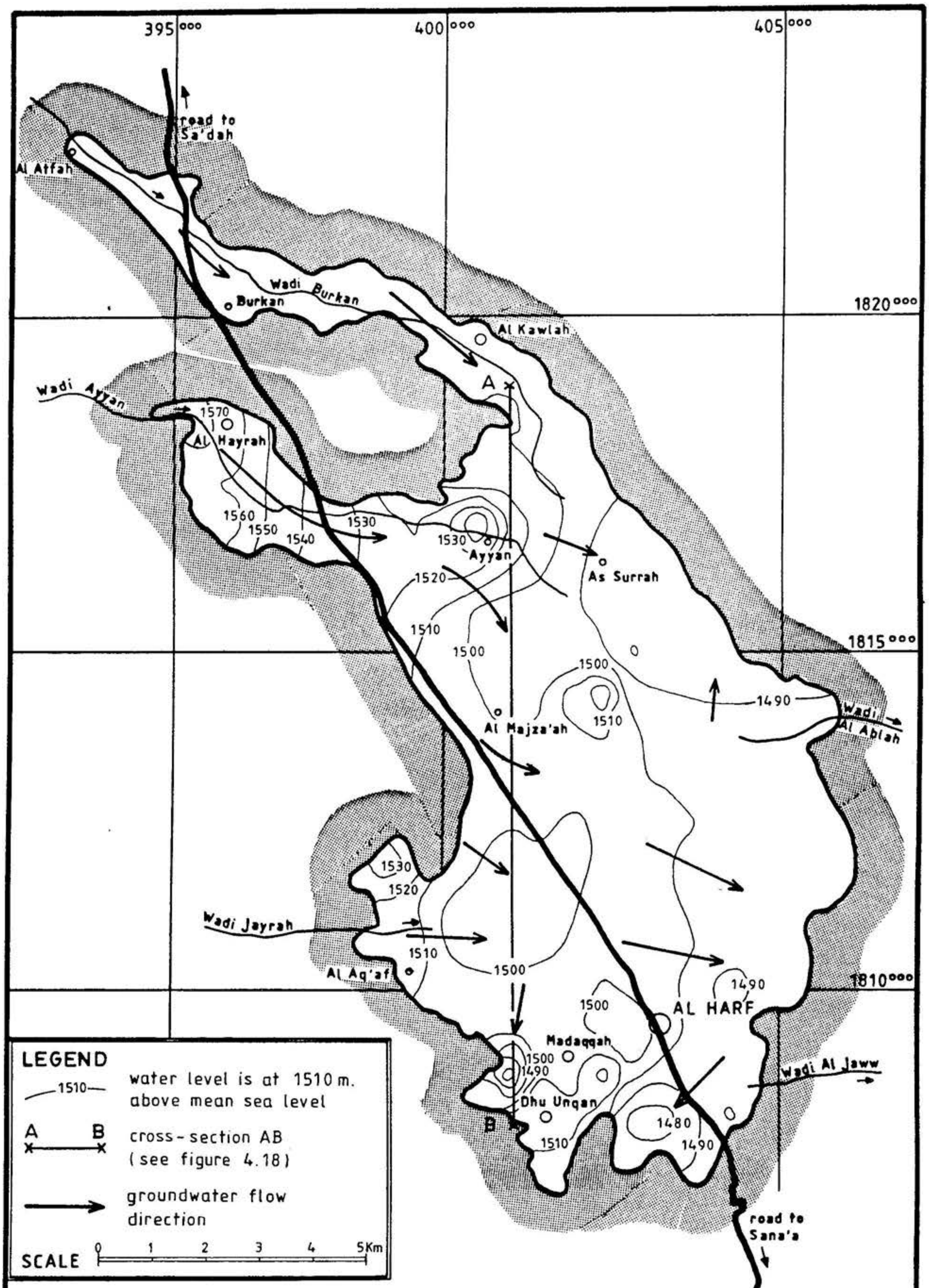


Fig. 4.16 Map of the piezometric groundwater level

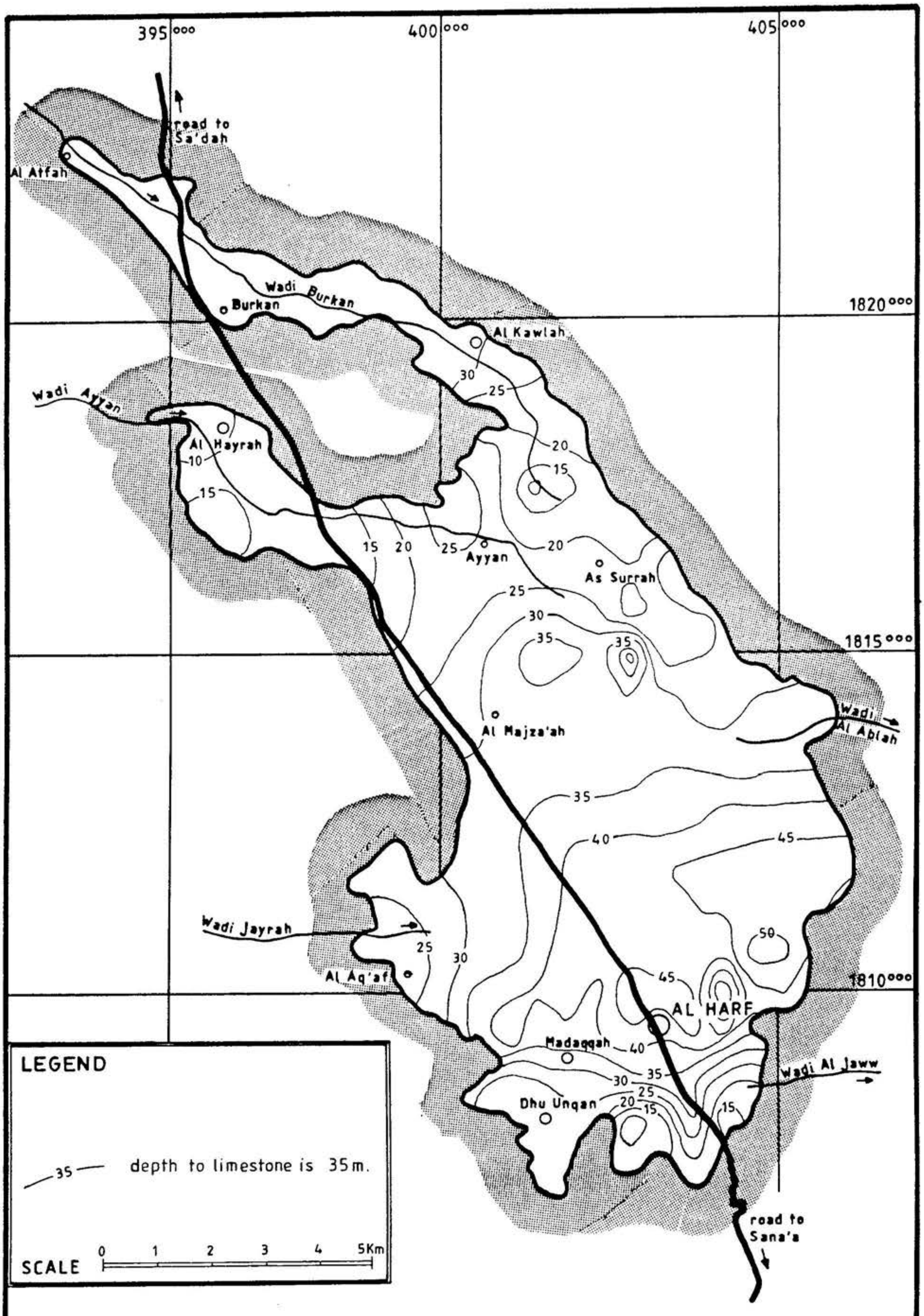


Fig. 4.17 Depth to the limestone (m) (below the alluvium)

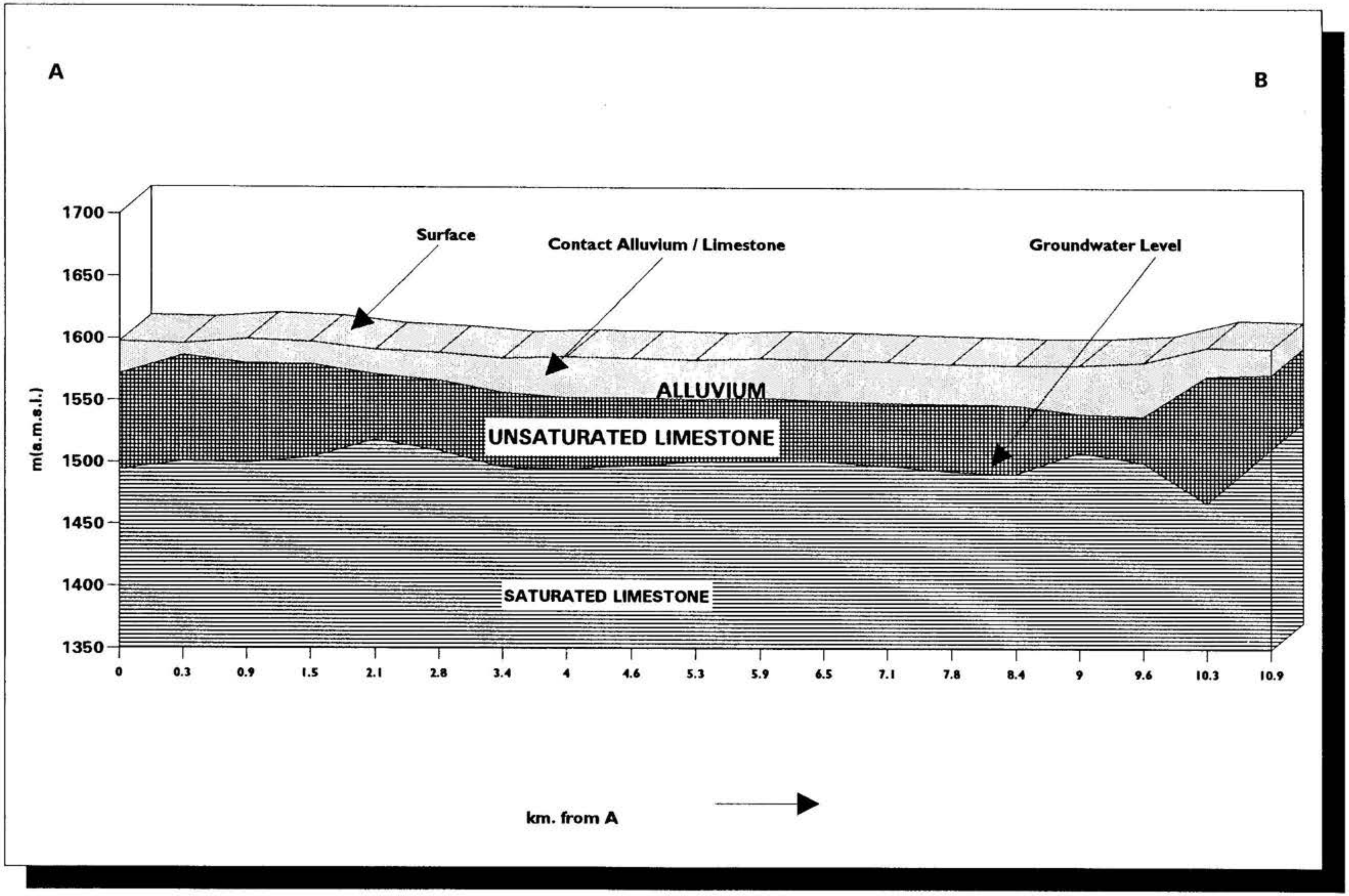


Figure 4.18 Cross-section A-B (for location, see fig. 4.16)

to the southeast. The plain surface drains in the same direction via Wadis Al Jaww and Al Ablah (see Fig. 2.2). These two wadis join and drain into Wadi Kharid southeast of the plain.

Fig. 4.18 shows a north-south cross-section. Its location, is presented in Fig. 4.16. Included in this section are the surface elevation, the groundwater level and the contact alluvium-limestone (see also Fig. 4.17). All three units are plotted in m amsl. The section clearly indicates that the groundwater level is situated in the limestone. This is true for the whole Al Harf Plain.

The hydraulic gradient in the plain, measured along the groundwater flow direction southeastwards, is only 0.4%; the water table in the Wadi Ayyan tributary valley had a gradient of 0.8%.

4.12 LOWERING OF GROUNDWATER LEVELS

For an analysis of time dependent trends in groundwater levels time series of groundwater depths are needed. However, no long term data on water levels are available in the Al Harf Plain. Serious pumping from drilled wells started there only in the mid 1970s, about 14 years later than in the Amran Valley. The density of well sites is not as great as in the Amran Valley. However, the hydrogeological situation is not promising: water is being abstracted from a limestone aquifer that has, in general, low water bearing and transporting capacities. Water only circulates through secondary porosity such as fissures , fractures and faults. Thus, a relatively large groundwater level drop can be expected in this area as a consequence of pumping. Moreover, this setting increases the risk of drilling poorly yielding well.

4.13 GROUNDWATER QUALITY

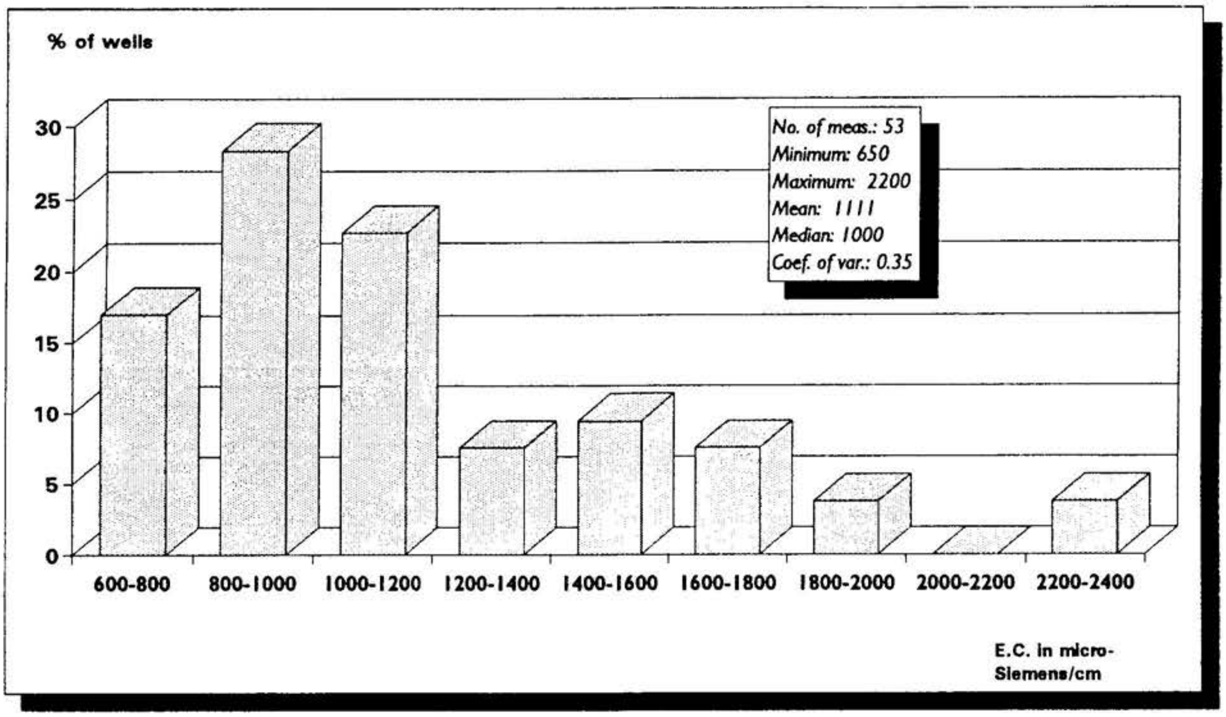
The electrical conductivity (EC) of water is a measure of its salinity. The more salts that are dissolved, the higher the EC will be. In almost all the visited wells, the EC of the pumped water was measured (in microSiemens/cm at 25 °C).
Fig. 4.19 shows the distribution of the electrical conductivity values. The minimum value was 650, the maximum 2200 and the mean 1111 microS/cm. This means that the groundwater of the Al Harf Plain is quite severely mineralized. The mean EC value was twice the mean calculated for the Amran Valley (571). Some justification might be found in that the water here originates from the limestone, where low flow rates and thus long travel times might have caused the high degree of mineralization.

The coefficient of variation of the measured EC-values was calculated as 0.35. It represents a measure of deviation from the mean (standard deviation/mean). This 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 722 to 1500 microSiemens/cm.

The measured values were contoured and are presented in Fig. 4.20. Two areas with high groundwater salinity (up to 1800 microSiemens/cm) were situated around Al Harf Town and 1 km to the south. In the higher part of the tributary valley of Wadi

Ayyan in the northwest values of above 1400 microSiemens/cm were measured. Probably, in these localities water is being tapped from saline shaley layers in the Amran Limestone Series.

Fig. 4.19 *Distribution of Groundwater Electrical Conductivity*



A comparison of Figs. 4.16 and 4.20 indicates that there is no consistent relationship between local depressions in the groundwater table and salinity. EC is high in the Wadi Ayyan Valley where groundwater levels do not appear (at the scale of the survey) to be depressed; to the northwest of Dhu Unqan there is a marked cone of depression, but EC levels are among the lowest measured. Local depressions near Al Harf, Ayyan village and east of Al Majza'ah are however, associated with high EC levels.

The only overall conclusion that can safely be drawn is that the Amran Limestone aquifer is not uniform and that extensive investigations would be required to define its structure and properties.

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 are presented in figure 4.21. Temperatures ranged from 21 to 32 °C, with a mean and a median of about 27 °C. Dispersion was low: the coefficient of variation was only 0.09 and most measurements ranged from 24 to 30 °C .

The mean groundwater temperature in the Al Harf Plain is almost 3 degrees higher than in the Amran Valley. From Fig. 4.22 there are no areas with extreme groundwater temperatures.

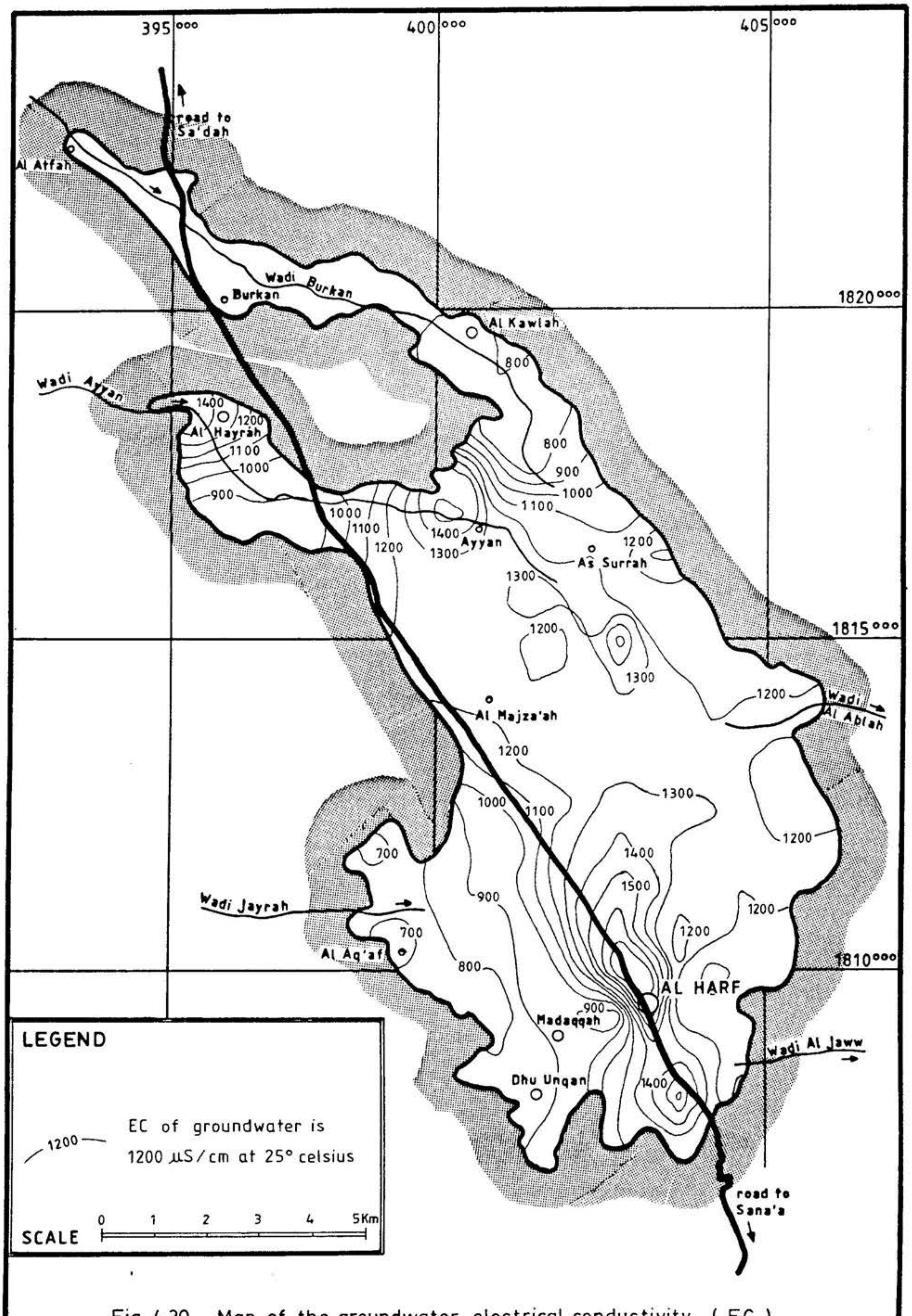
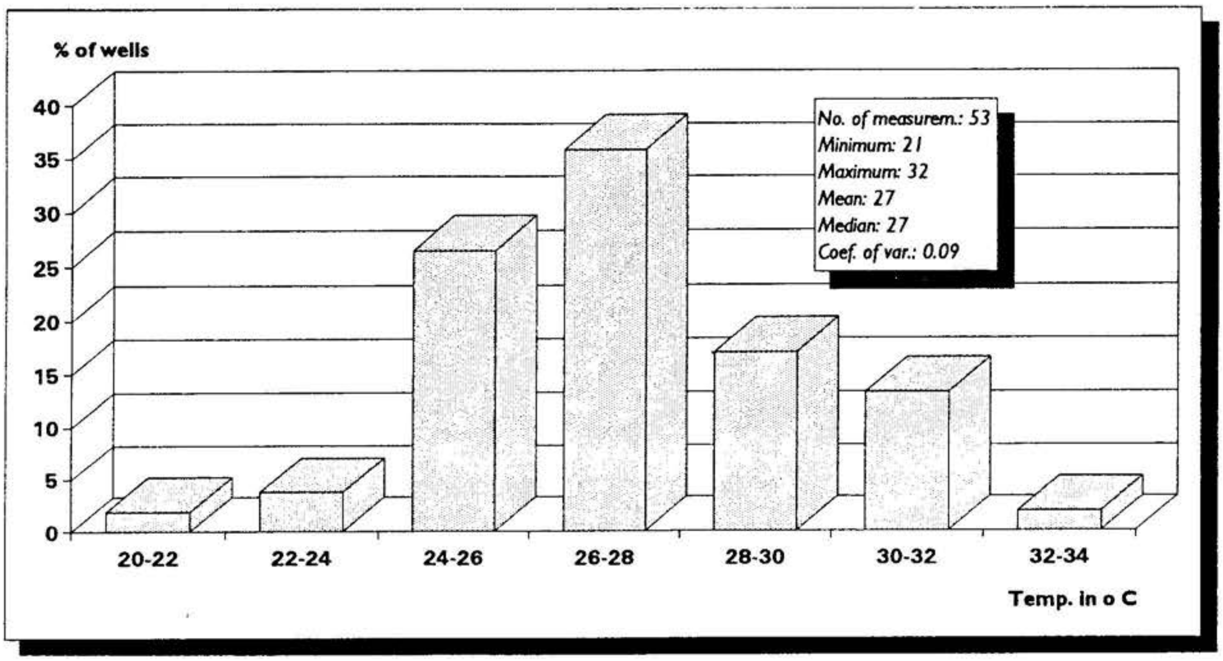


Fig. 4.20 Map of the groundwater electrical conductivity (EC)

Fig. 4.21 *Distribution of Groundwater Temperature*



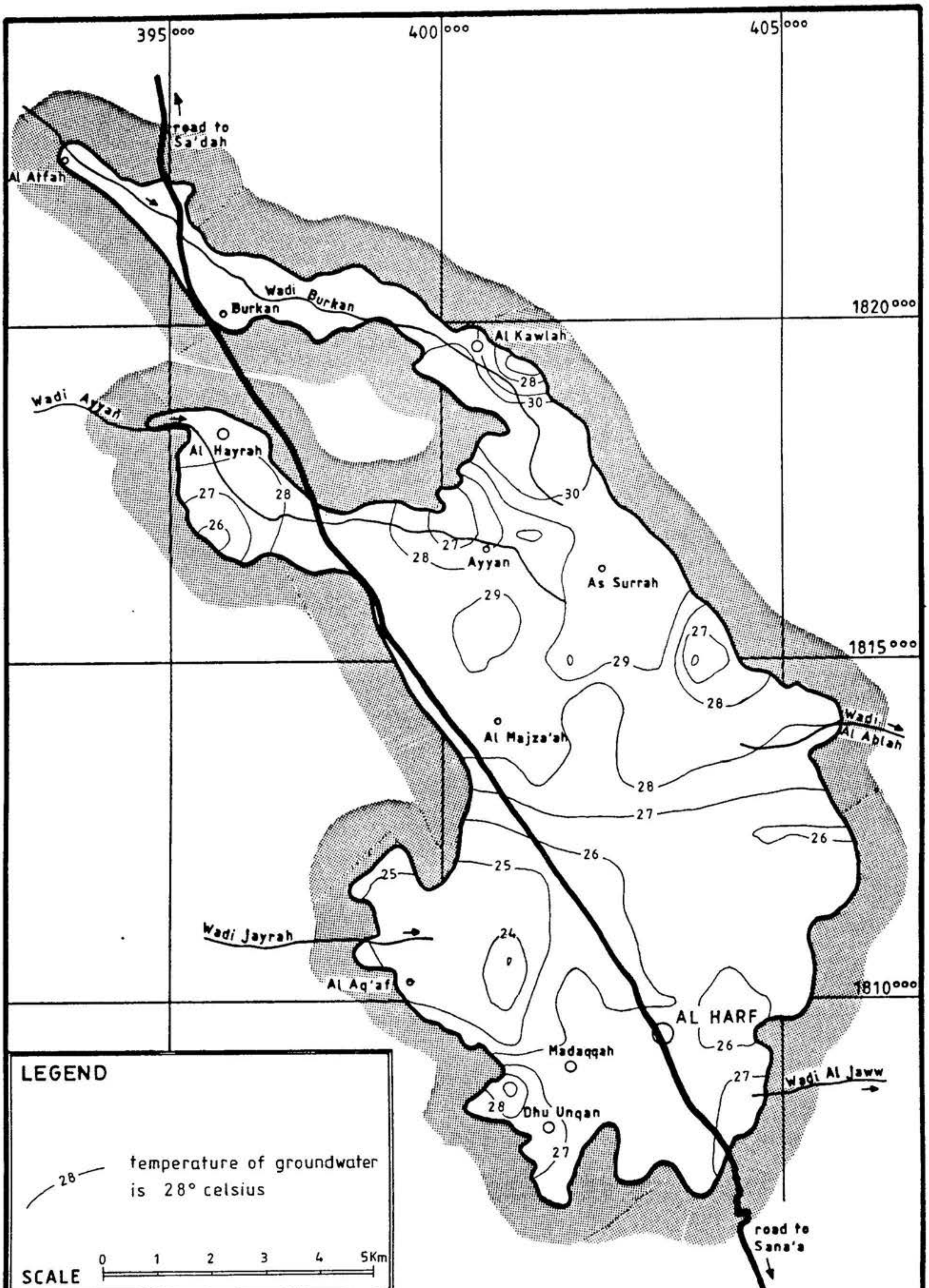


Fig. 4.22 Map of the temperature of the groundwater

5 GROUNDWATER USE

5.1 LAND AREAS

The total area of land associated with the 48 wells visited in December 1991 was 1383 ha, of which 330 ha were cultivated and under irrigation command, and 1053 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 48 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 64 well areas (see Section 4.2) and the same population distribution for the additional data, resulted in a total well area of 1844 ha, of which 440 ha were commanded by irrigation and 1404 ha were fallow (see Table 5.1).

Table 5.1 *Breakdown of Land Area*

	Based on data of 48 visited wells	Extrapolating assuming a total of 64 wells
Total land associated with wells	1383 ha	1844 ha
Area Commanded by groundwater	330 ha	440 ha
Fallow	1053 ha	1404 ha

It must be emphasized that these figures are based on areas where groundwater irrigation is used so rainfed farms were not included. The 440 ha translates to an average command area of about 7 ha per well.

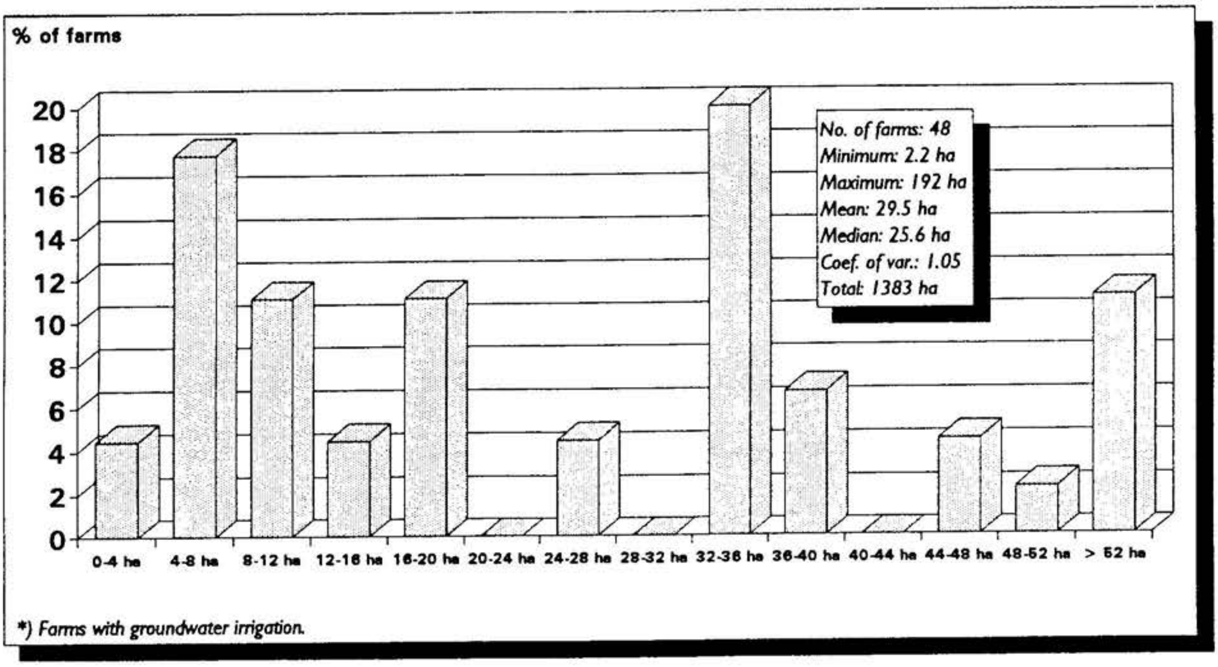
Fig. 5.1 shows the distribution of the well areas. The smallest plot was 2.2 ha, the largest 192 ha, an extensive farm about 1.5 km northwest of Al Harf Town where only 5 ha were irrigated; the remaining part was fallow. The mean well area was 29.5 ha and the median 25.6 ha.

From Fig. 5.2, the part of the area actually commanded by groundwater was much smaller: the mean was 7.3 ha (median: 6.4 ha). The smallest irrigated plot was 0.6 ha and the largest 26 ha. The dispersion, expressed as coefficient of variation was high (0.78). Most farms had commanded areas ranging from 2 to 10 ha.

5.2 CROPS

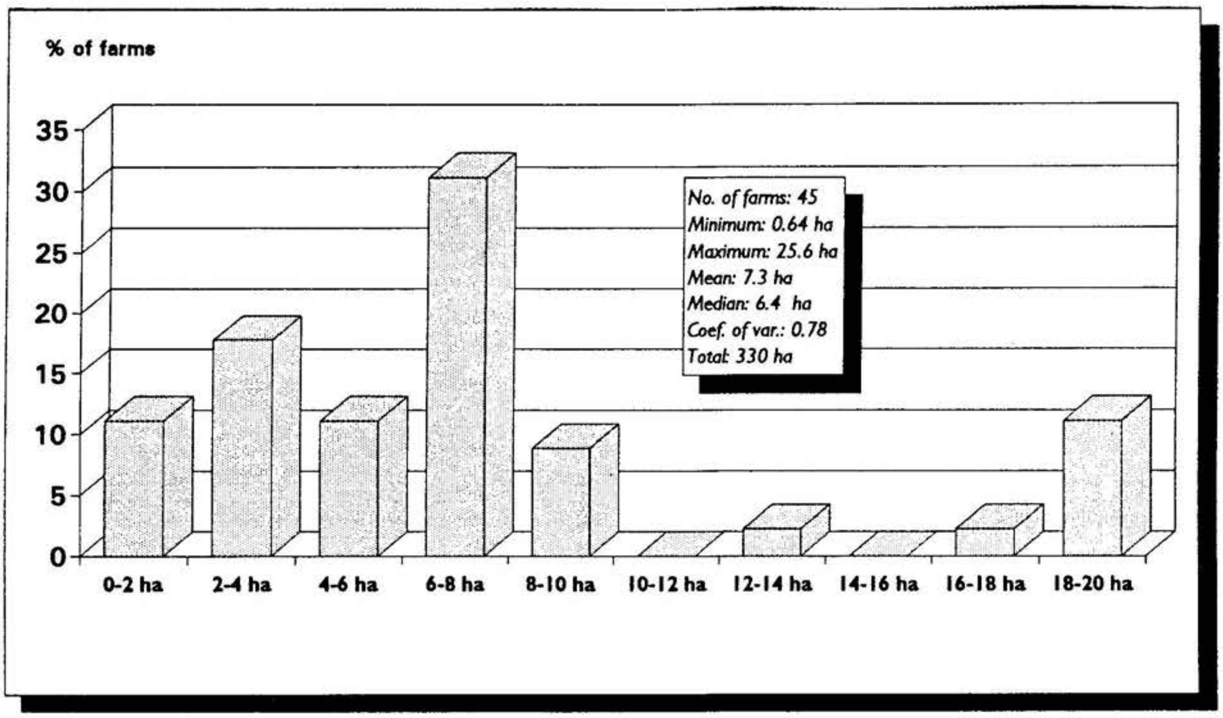
In the well inventory questionnaire space was made to collect information on crop

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



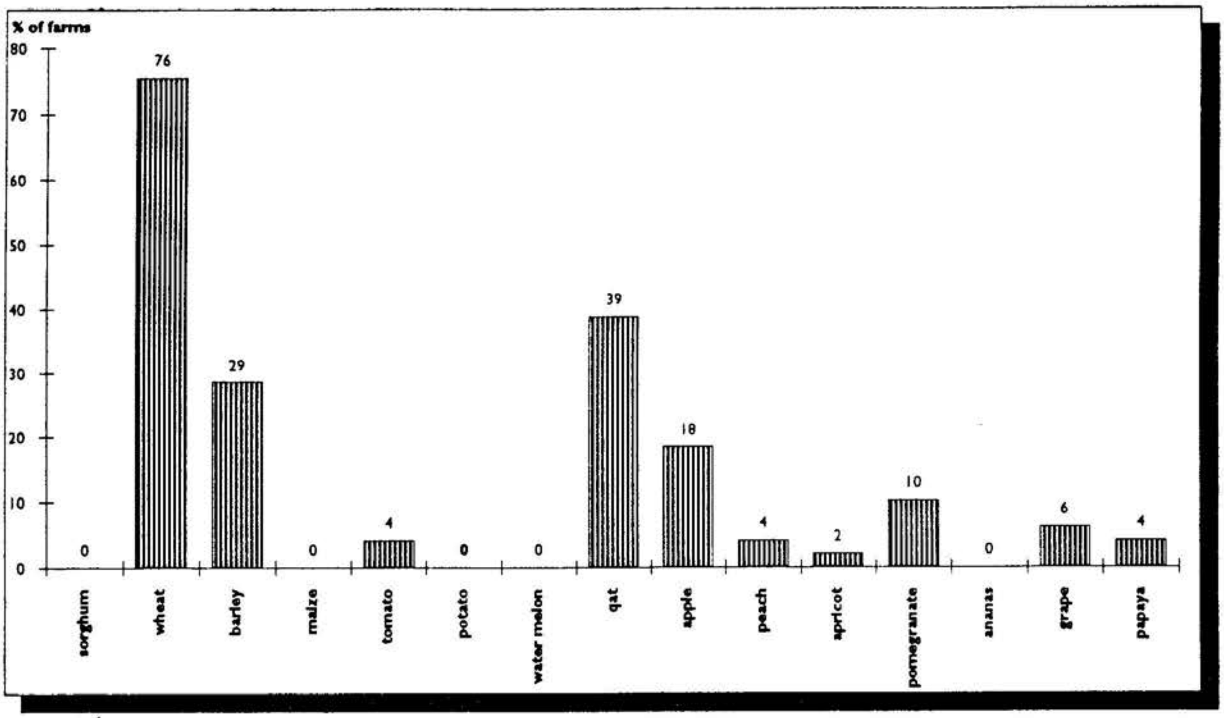
*) *Farms with groundwater irrigation.*

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



patterns during the seasons. The year is subdivided into four seasons: Rabi'a, Sayf, Kharif and Shita, approximately corresponding with spring, summer, autumn and winter, respectively. The information dealt with the major and secondary crop types and their total irrigated area during each season. All these data and crop patterns during the seasons are summarized in the Fig. 5.3 to 5.6.

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



The figures show that of the perennial crops qat was grown by 35% of the farmers, followed by apple (18%), pomegranate (10%) and grape (6%). Of the crops, wheat was cultivated by 76% of the farmers during the seasons Shita and Rabi'a. During the same seasons barley was grown on 26% of the farms. Sorghum was the major annual crop during Sayf and Kharif (73% of the farms). Other cash crops observed were tomato, potato, maize and water melon.

These crop patterns demonstrate the attractive aspects of groundwater irrigation for the farmer: in contrast with the traditional unreliable practices of spate irrigated and rainfed cultivation where at the most one harvest per year was possible, now most crops can be sown and harvested the whole year round. Moreover, the high risk of failure of the harvest, common with the two traditional cultivation systems, diminished significantly when pumped irrigation practice started. In the 1970s on the rainfed and spate water irrigated areas the average loss of sorghum was 40%, of wheat and barley 50% (Rethwilm/Brandes, 1979).

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

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

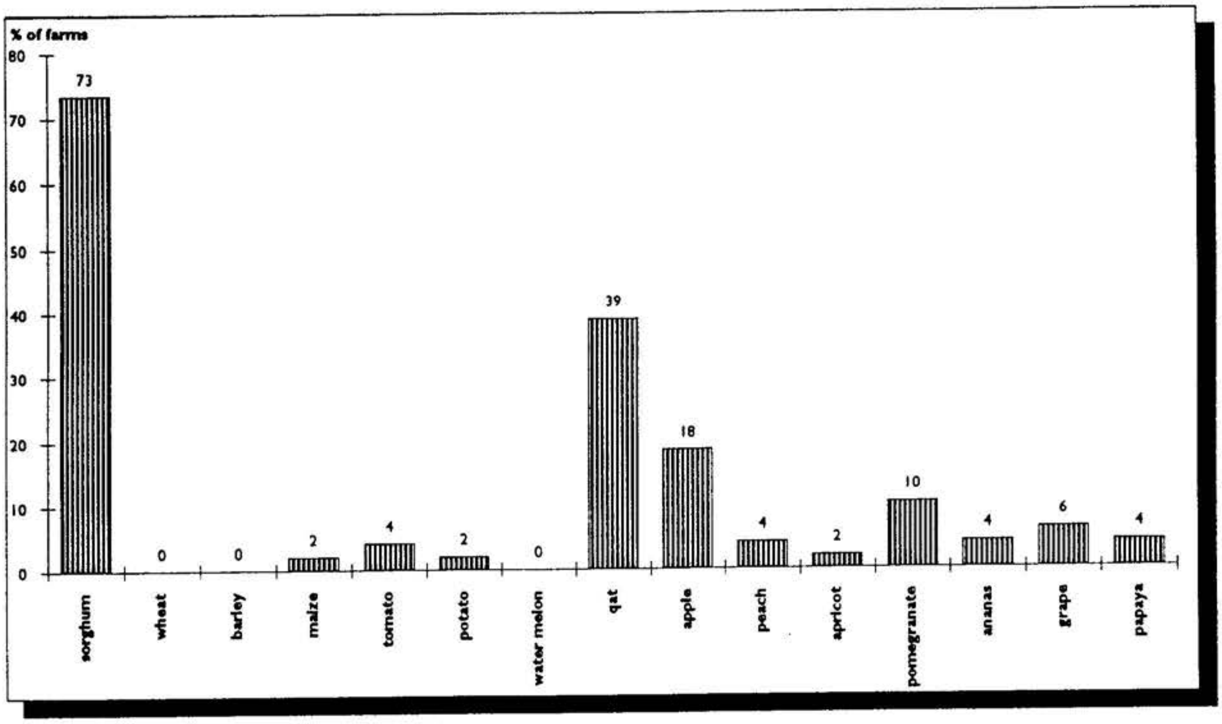


Fig. 5.5 *Crops Cultivated during Kharif (Autumn)*

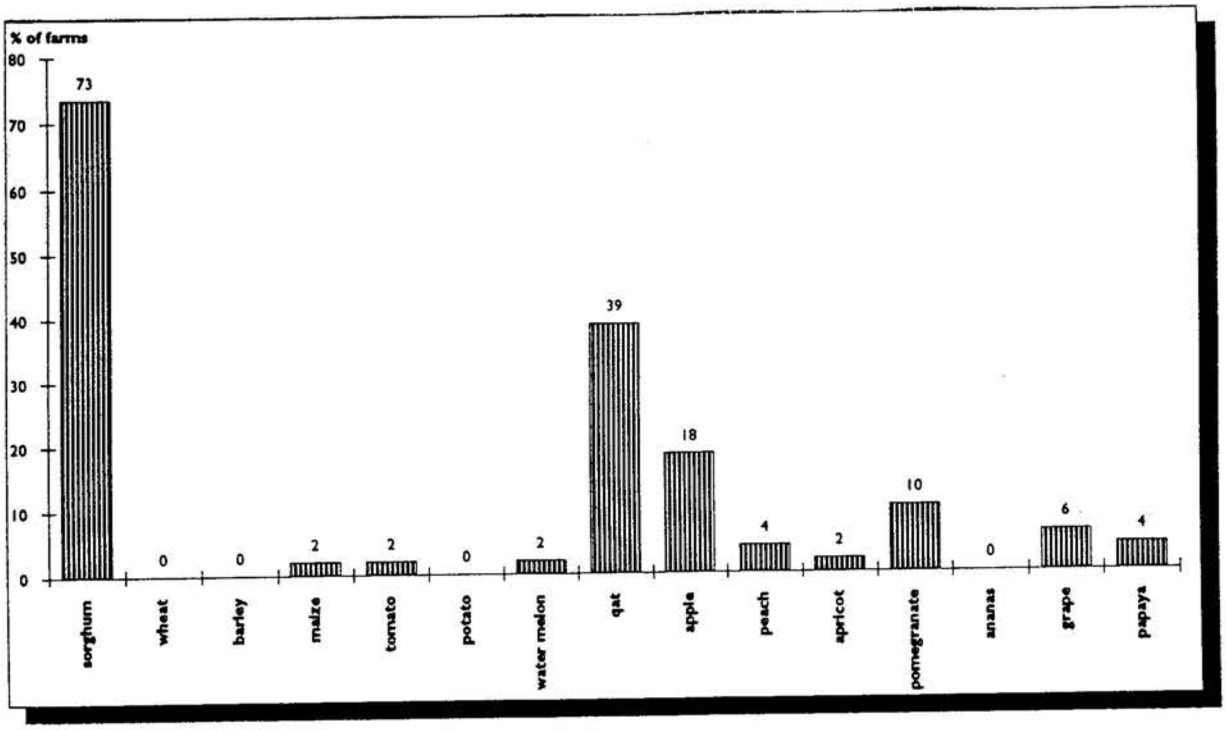
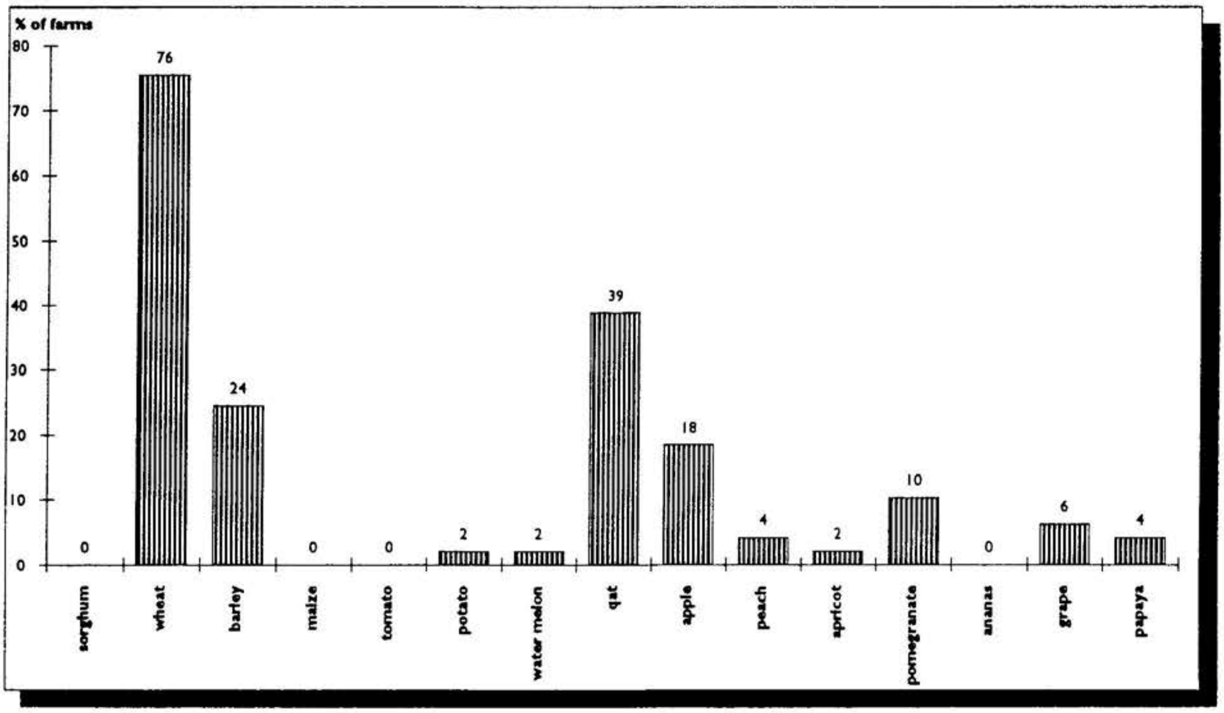


Fig. 5.6 *Crops Cultivated during Shita (Winter)*



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

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

5.3 IRRIGATION PRACTICE

Pumped water is conveyed through earthen channels or pipes to the fields. According to field tests carried out by GTZ in Qa' al Boun in 1979, water losses during conveyance in the traditional open irrigation channels were usually about 50-65%, depending on the distance. Other water losses result from over-irrigation. The irrigation methods generally used are border, furrow and basin. The border method was usually used for the irrigation of wheat and sorghum; furrow for potato, tomato and water melon and basin irrigation for fruit crops like apple, grape and pomegranate. Time intervals between irrigation applications of 25-75 mm ranged from 9 to 15 days depending on the crop type.

The highest frequency of irrigation was on grape, apple, tomato and alfalfa, the crops with the highest total costs, but also the greatest benefits, except for alfalfa. The lowest gross margin was on the growing of cereals (Amran Valley, Hossain/Nouman, 1991).

A high percentage (76%) of the total cultivatable area of the Al Harf Plain remains permanently fallow because of shortage of water.

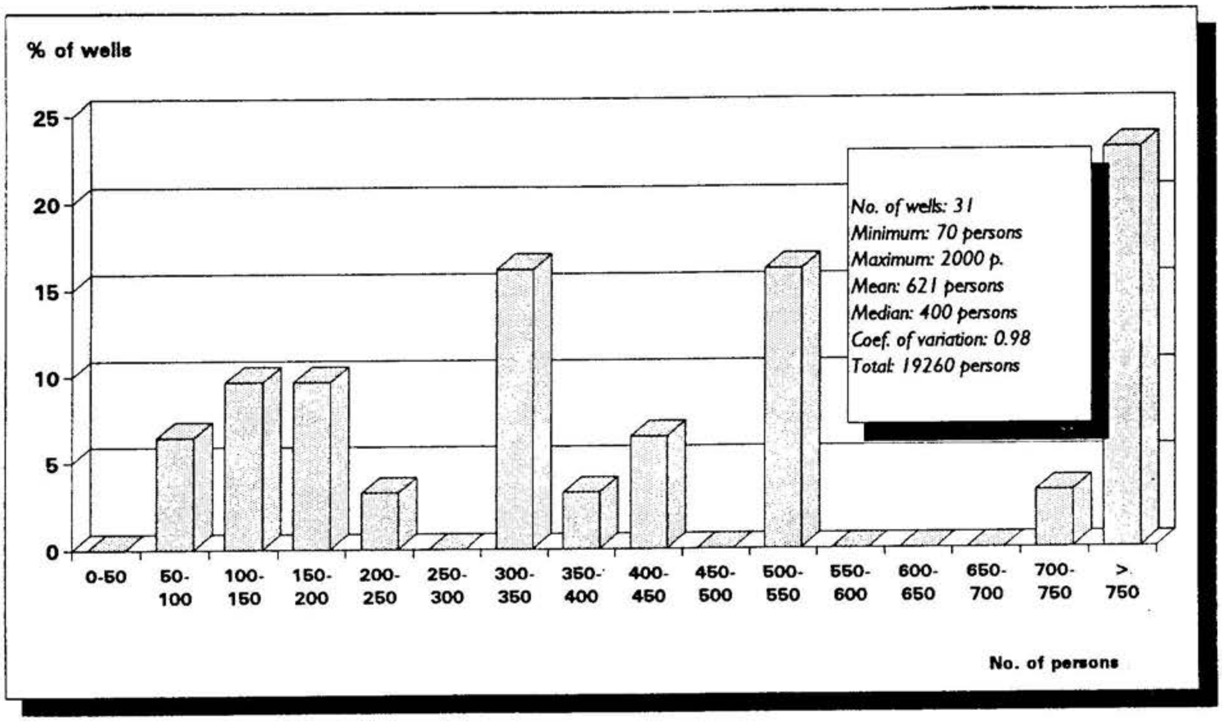
5.4 USE OF FERTILISERS

Crop rotation and crop rotation including a fallow period was used to maintain soil fertility and to economise on the usage of fertilizers. Both chemical fertilizers and manure were added, the first at regular intervals. On 88% of the farms fertilizers were applied, urea alone on 37% of the farms, manure on 22% and both on 40%.

5.5. DOMESTIC WATER USE

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

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



The number ranged from 70 to 2000 persons. A relatively very large percentage of the pumped groundwater appeared to be used for domestic purposes: 36%. (compare Amran Valley: 4%). Two neighbouring wells in Al Harf town supplied water for about

3000 persons. On three other wells, 6000 people were dependent. The mean number of persons that use water from one well was 621, a value that is probably distorted by the high extreme values, mentioned above. However, the median also shows 400 persons (compare Amran Valley: 100 persons).

A total number of 19 260 persons were apparently dependent on 31 wells, the number for which the collected domestic water consumption data were complete. When extrapolated, assuming a total number of 64 wells and the same distribution of data, then a total number of 39 763 people could have consumed well water in 1991. This number is unrealistically high compared with the 1986 census (Section 2.1). For the purposes of estimating domestic water use a population of 6000 people was assumed.

Assuming an average daily water consumption of 40 l per capita, the total domestic water consumption would have been 85 000 m^3/year.

Livestock water consumptions is low in relation to the domestic and agricultural water use (1.3 m^3/year per sheep or goat or 9% of the human water consumption) was neglected.

5.6 IRRIGATION WATER APPLIED

The present study is intended to deal with the water resources of the Al Harf Plain with emphasis on groundwater and its use. The reason for including in the inventory the collection of information on crops was to enable a reasonable appraisal to be made of the volume of return flow (or water loss) occurring during irrigation. The water loss would be a valuable component of the water balance, because it represents the feedback of pumped groundwater to the aquifer.

The return flow or irrigation water losses can be defined as the difference between the water needed for the evapotranspirational demand of the crops and the volume of water pumped.

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 collected data concerning crops and land-use, combined with the qualitative data obtained in the SONDEO Survey, allowed for a reasonable estimate to be made of the yearly crop water requirements in the study area.

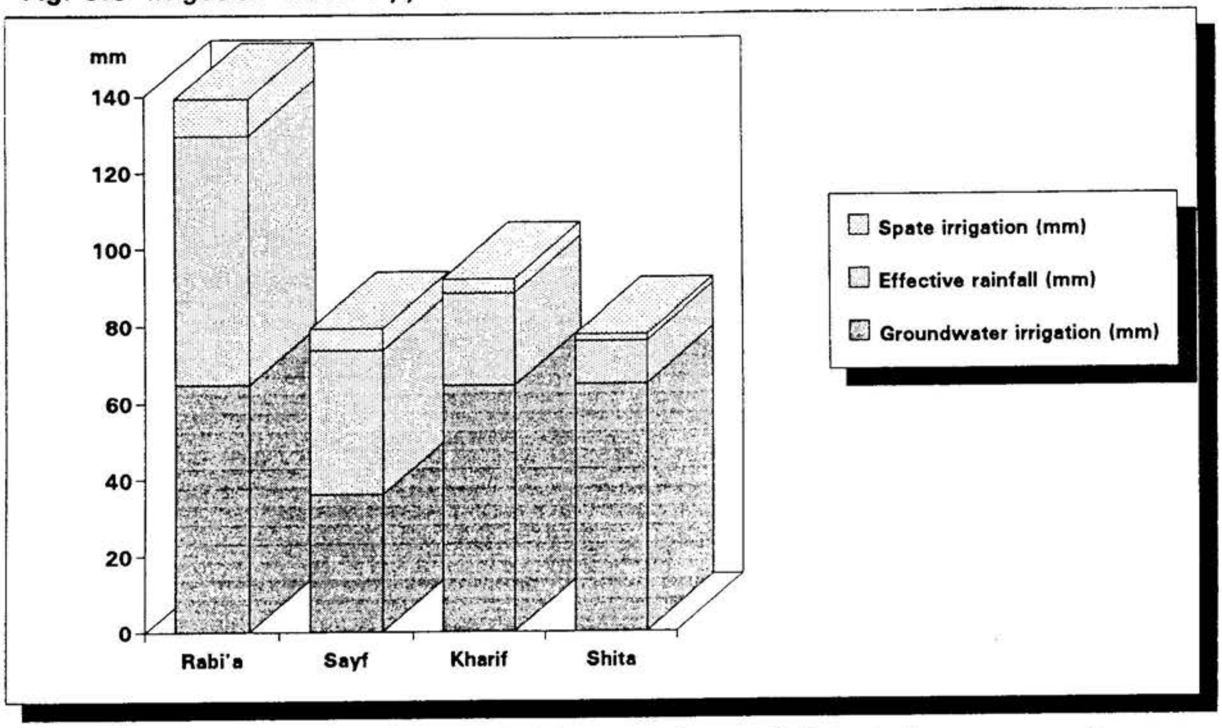
Firstly an acceptable estimate of the total groundwater commanded area was determined (Table 5.1). Secondly , groundwater abstraction data are available for each season, and a clear general picture has been formed of the types of crops cultivated and the cropping pattern during the four seasons. However,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

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

Chaudry *et al* (1992) published values of crop water requirements for the main cultivated crop types. Most crops have a fairly consistent average daily net evapotranspirational need (ETc) of about 4.0 mm over the whole growing period. Because the calculation of applied water quantities was made on a yearly basis, this figure will be sufficient to arrive at an adequate estimate of the annual crop water requirements. Thus, an annual potential evaporational demand of 1460 mm was established for the groundwater irrigated part of the Al Harf Plain.

Rainfall data were measured in Huth (15 km south of Al Harf Town) during the period 1975-1989. Spate irrigation values were derived from farmers' information and the local rainfall data.

Fig. 5.8 *Irrigation Water Application*



- Not all of the area commanded by groundwater is irrigated at any one time, because not enough water is pumped to meet crop water requirements.
- Farmers' irrigation scheduling is not optimum.
- Water conveyance and application is not efficient: there is seepage from unlined conveyance canals (about 30% of the water is conveyed in pipes from pump to field-edge); land levelling is poor; the layout of basins, borders and furrows is not always ideal; and farmers tend to apply more water than the crop actually requires, leading to excessive deep percolation.

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

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 different water sources used.

Table 5.2 *Al Harf Plain - Groundwater Use in 1991*

Total Groundwater Abstracted (Mcm)	1.59
Domestic Water Use (Mcm)	0.09
Irrigation Water Use (Mcm)	1.51
Commands Area (ha) (1)	440
Average Area Irrigated (ha) (2)	41
Gross Irrigation Application (mm)	3640
Total Efficiency (%) (3)	35.8
Irrigation Water Losses (mm)	2338
Aquifer Recharge (Mcm	0.97
Net Irrigation Application (mm)	1301
Effective Rain (mm) (4)	138
Effective Spate (mm)	21
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 65% (30 % piped conveyance)
Application efficiency 55% (Uneven levelling and slopes)
Total efficiency 35.8 %
(4) Based on data from Huth (USBR method)

5.7 ACCURACY OF DATA

The data collected on domestic water use appeared to be flawed, indicating as they did an unrealistically high population in the Target Area. Therefore, the apparent population figure was adjusted downwards to a more likely, though still conservative, number.

Even when the reduced domestic water consumption was used in Table 5.2 the estimated area irrigated in 1991 was still only about 10% of the commanded area. In other target areas this figure is of the order of 50%.

The conclusion must be that there was probably some systematic error in the data collection process.

6 THE COST OF PUMPING GROUNDWATER

A model was made for the calculation of the cost of one hour of groundwater pumping and of one m^3 of pumped groundwater (Table 6.1). Various cost items were taken into account in the calculation procedure. Costs were subdivided into investment and O&M (Operation and Maintenance). All costs, including the investment costs, were treated as variable costs, that is, they were expressed per operation hour and 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 and so a higher pumping intensity would result in a shorter lifetime, when expressed in years 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 larger than the lifetime of the well.
- The higher cost of pumping from greater depths is fully expressed by deeper and more costly wells, more powerful and thus more expensive pumps and engines and, as a consequence higher diesel consumption rates.
- Interest costs were not considered in the calculation model since the majority of the farmers in the Al Harf Plain invest in wells from their own savings or by getting interest-free credit from private sources (friends or family). A negligible number of credits were requested from the Agricultural Credit Bank or government, because the farmer is against paying interest (Islamic principle) and because of the complex procedures (Hossain/Noman, 1991). When borrowed from friends or neighbours, the only credit costs are food and qat for pleasing the lender. In many cases investments in a well were made by several shareholders.
- Opportunity costs were not accounted for in the model because the farmer, in general only invests in his farm and does not realise that his capital (saved or borrowed) could yield a profit elsewhere.
- Discharge rate and diesel consumption are constant during the entire lifetime of the well and pumping equipment.
- Costs for deepening wells were not included, because the majority of the wells were drilled to such a depth in relation to the local water table that deepening was not considered necessary during the considered period of 80 000 operation hours.

In the calculation model the period taken for defining the costs per operation hour and the cost of one m^3 of pumped water was 80 000 operation hours, the assumed lifetime of the most valuable components of the well, the casings and the screen. In the Al Harf Plain, where the average farmer pumps 3350 hours per year, this corresponded to a well lifetime of 24 years.

The pumping equipment, when considering its most costly components, the pump and the engine, has a much lower lifetime. This was 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 3350 pumping hours per year, a lifetime of about 12 years can be assumed 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

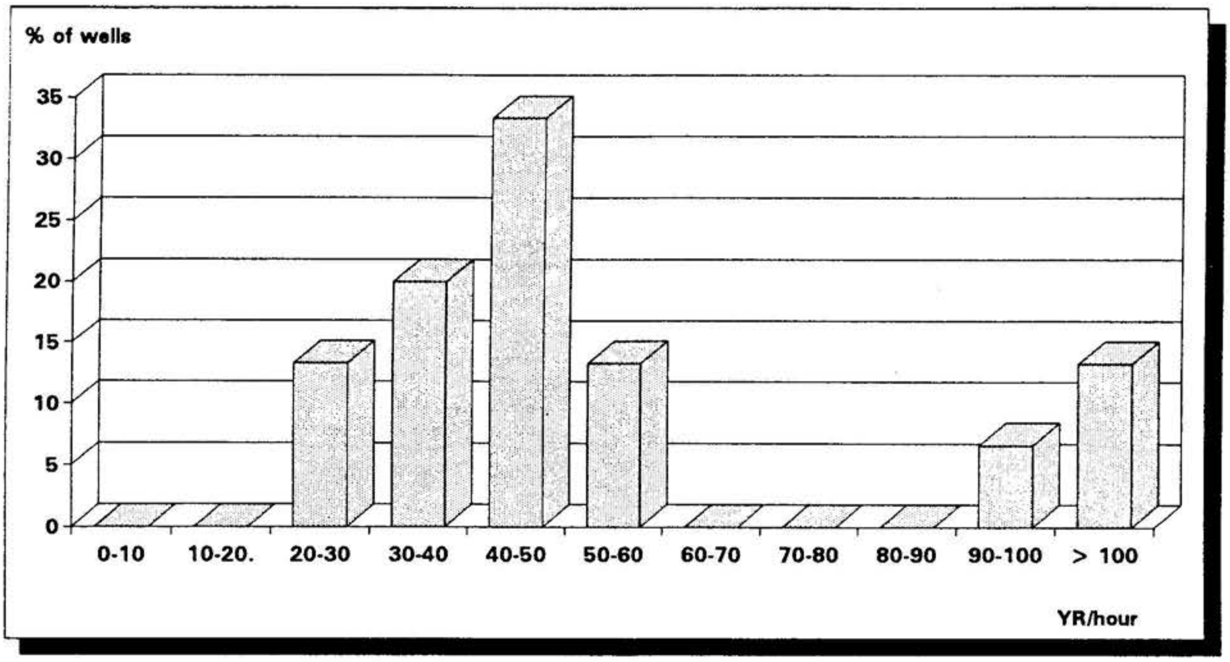
The cost item 'pumping equipment' collected as field data during the well inventory, generally included not only the pump and the engine, but also the costs of reservoir, pump house and conveyance pipes (1991: 100 YR/metre length). However, these components have a lifetime longer than 80 000 operation 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 was applied to the data from the 64 inventoried wells in the Al Harf Plain, comprising for most 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 apparent costs of one hour of pumping varied from 23.5 YR to 436 YR, with a mean of 92.3 YR. The price of one m^3 of pumped groundwater ranged from 2.6 YR to 40.2 YR with a mean of 9.9 YR. These costs are about twice those for the Sa'dah Plain, where drawdowns are very similar. The only major difference between the two Target Areas is that the Sa'dah boreholes are not cased. Since O&M costs are the major component, this would not be significant. The mean cost for 1 m^3 of water in the Al Hamra Plain was YR 1.8, but there, although the water is also abstracted from the Amran Limestone, specific yields are perhaps as high and depth to groundwater somewhat less - about 60 m as opposed to 70 m.

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

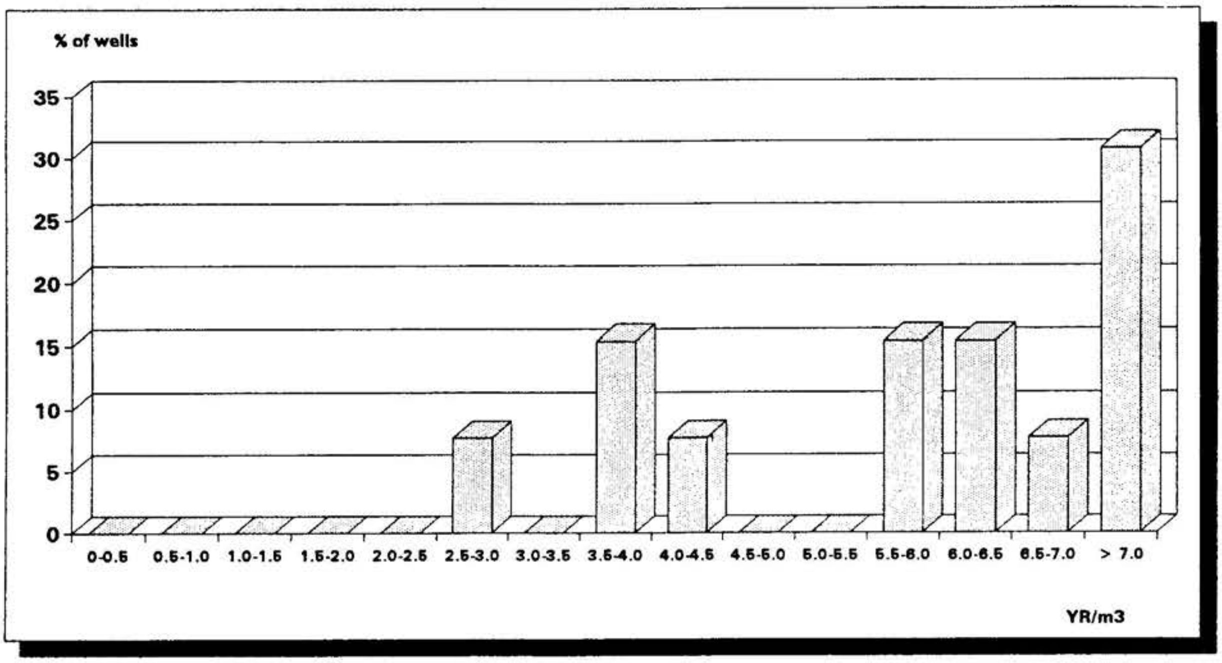


Once more the evidence is that there were data collection errors. For the calculations that follow an average unit costs of YR 5/m³ will be used. Thus, a total of YR 8 million was spent during 1991 in pumping about 1.59 Mcm.

From example in Table 6.1 the contribution of the O&M costs to the total cost is about one and a half times the investment cost component. The highest contribution in the total costs is from the cost of diesel consumption, that accounts for 38% of the total cost.

The cost of one m³ of water was calculated at the level of the pump. However, due to conveyance, application and scheduling water losses, not all the pumped water will reach the crops effectively. This means that the price of water at the crop level would be higher. Assuming an overall irrigation efficiency of 36% (Table 5.3), then the average cost of the water at crop level would be YR 13.9 and the average yearly water costs per irrigated ha (net application of 1301 mm): YR 180 694.

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



7 SUMMARY AND CONCLUSIONS

The number of wells located in the Al Harf Plain during the well inventory was 66. 12% of these wells were not in operation for different reasons. The objective was to visit all the existing wells and it was assumed that more than 90% of the wells were visited. Therefore, the total number of wells was estimated at about 73 of which 88% (or 64) would have been operational at the time of the well survey.

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

A large area in the centre of the plain, north of Al Harf town, is entirely covered by sand. As a consequence, it was completely fallow.

Serious groundwater development in the Al Harf Plain started only in 1976, about 14 years later than in the Amran Valley.

The main drilling activities occurred in the period from 1983 to 1986. Since 1987 the rate of drilling had dropped from 3 wells in 1987 down to two in 1990. It appears that the peak of the yearly drilling rate has past.

Statistical analysis of the cumulative distribution of the number of wells constructed during the years showed that 50% of all the existing wells were drilled after 1985, while the average well age was 6.2 years. The oldest well date from 1976.

Only three wells had been deepened during the last 15 years.

All the wells, except the dug wells, had steel casings. Casing diameters differed significantly from the diameters observed in the Amran Valley: 8" and 10" diameter casings dominated (42 and 40%), followed by 10" diameter casings (18%). The lower section contains a series of 6 m long slotted pipes as a screen.

Well depths ranged from 40 m to 400 m. The average depth was 154 m. A relatively high concentration of deep wells exist in the northeast part of the plain, southeast of Al Kawlah and in the extreme southern part, south and southwest of Al Harf Town. Here, groundwater levels were relatively deep at more than 100 m.

The depths of most wells in relation to the water level depths were such that, even assuming a substantial drop in the groundwater level, few of the wells would fall dry. The water column heights ranged from 3 to 308 m; the average aquifer penetration was 78 m. If groundwater were to drop 30 m over the whole plain, then 15% (Amran Valley: 9%) would fall dry. This percentage would increase to a minor extent if the drawdown brought about by pumping is also considered.

Water was pumped typically by vertical turbine (lineshaft) pumps coupled via crossed webbing belts to diesel engines. Only two wells were equipped with electro-submersible pumps, driven by electrical power generated by high capacity engines.

A high level of standardization in engine and pumping equipment was observed: 88% of the pumps were supplied by Caprari. The pump column diameter was mostly three inch (94% of all the wells).

The same level of standardization was noticed among the engines that power the pumps: the Japanese Yanmar engines (Yahama) comprised 78% of the total and Mitsubishi 5%. The engines had, in most of the cases, a capacity ranging from 23 to 35 horsepower.

The average lifetime of the wells is higher than that of the pumps. This was reflected by the average age of the wells and the pumps in 1991 (6.2 and 5 years). This means that many wells were equipped with a second pump set. During 1989 and 1990 more pumps were installed than wells constructed.

Well yields were low in the Al Harf Plain. The mean well yield (3.5 l/s) was almost half the mean well yield in the Amran Valley (6.5 l/s) but almost exactly the same as in the Sa'dah Plain. Well discharge rates varied from about 0.75 l/s to 15 l/s.

Drawdowns during pumping were moderate: in the order of 2 metres at a discharge rate of about 2 l/s up to 9 m at 5 l/s.

Well construction costs ranged from YR 60 000 (a 108 m deep well, drilled in 1989) to YR 460 000 (a 163 m deep well, drilled in 1991). Median well costs were YR 160 000.

Pumping equipment costs had a much larger variation: from YR 74 000 to YR 60 0000 and a median of YR 205 000. Well construction costs appeared to be lower than in the Amran Valley. As a consequence of the harder medium to be drilled (limestone instead of alluvium) the opposite might have been expected. However, pumping equipment costs were higher than in the Amran Valley. Partly this can be explained by the younger age of the wells and pumps in the Al Harf Plain (more recent prices).

The average farmer pumped groundwater about 10 hours per day, throughout the seasons. The mean number of pumping hours per day was 9.8. Pumping activities were highest during Rabi'a[2] (mean 10.6 hrs/day), followed by Shita (mean 10.56 hrs/day), Kharif (mean 10.4 hrs/day) and Sayf (mean 7.7 hrs/day).

Over the whole year, the average number of pumping days per month was 28.2; pumping hours per month were 280, an average of 10 hours per day.

At 38 wells (of the total of 66 wells visited) the discharge could be measured. At the remaining 28 wells no discharge measurements could be carried out for the following reasons: the well was dry, no pump and/or engine was present, no diesel and/or oil

[2] The seasons in Yemen are Rabi'a, Sayf, Kharif and Shita, corresponding approximately with spring, summer, autumn, and winter

was available, or because of a broken pump/engine. Sometimes there was just nobody to switch on the pump. At another four wells no data on the pumping schedule could be collected. This resulted in a sample of 34 wells from which the seasonal and yearly discharge could be calculated.

12% of the wells were permanently out of order. For the calculation of the yearly total discharge in the plain, these wells were not taken into consideration. Assuming the real total of wells to be about 73 and applying the same percentage of fall out, then about 64 wells would have been operational.

It appeared that for reasons of maintenance and repair, in average, 6.5% of the time the wells were not pumping. This percentage was also taken into account when calculating the seasonal and total yearly abstracted groundwater volumes.

A yearly total of approximately 1.6 million Mcm of groundwater abstraction was estimated for 1991. The abstracted volumes during the individual seasons were 0.43, 0.3, 0.43 and 0.43 Mcm for Rabi'a, Sayf, Kharif and Shita, respectively.

A (very rough) estimate of all the groundwater pumped in the Al Harf Plain, using figures from 1976 (when abstraction became significant) up to 1991, was about 10 Mcm. This represents a water layer of 0.16 m. depth covering the whole Al Harf Plain (64 km^2). Expressed in terms of lost aquifer, assuming an average effective porosity of 3%, then the volume pumped during 15 years corresponded to a lost saturated aquifer thickness of 100/3 * 0.16 = 5.33 metres, covering the whole Al Harf Plain.

Groundwater depths showed a wide range in the Al Harf Plain, 35 m (near Ayyan Town) to 135 m (near Dhu Unqan). There were two areas where the groundwater level was significantly deeper than the general groundwater level in the plain. First, south of Al Harf Town, where by pumping, a cone had developed in the groundwater table with a water level drop of about 40 m. Then, northwest of Dhu Unqan where a depression in the water table had reached a magnitude of more than 50 m. The general depth of the groundwater in the plain ranges from 70 to 90 m below surface.

Piezometric levels showed little variation, ranging between 1570 m amsl in the upstream part of the tributary valley of Wadi Ayyan and 1480 m, in the extreme south of the plain. The general groundwater flow was directed to the southeast. The plain surface also drains in the same direction via the Wadis Al Jaww and Al Ablah. These two wadis join and drain into Wadi Kharid, southeast of the plain.

The hydraulic gradient in the plain, measured along the groundwater flow direction was 0.4%, while the water table in the Wadi Ayyan tributary valley sloped at 0.8%.

No long term data on monitored water levels are available in the Al Harf Plain.

Serious pumping from drilled wells started here only in the 1970s, about 14 years later than in the Amran Valley.

The hydrogeological situation is not promising: water is being abstracted from a limestone aquifer that has, in general, rather low water bearing and water transporting capacities. Water only circulates through secondary porosity such as fissures, fractures and faults. This also signifies that a relatively large groundwater level drop could be expected in this area as a consequence of pumping.

The groundwater electrical conductivity (EC) values show a minimum of 650, a maximum of 2200 and a mean of 1111 microS/cm. This means that the groundwater of the Al Harf Plain is quite severely mineralized. The mean EC value of all the measurements was twice the mean for the Amran Valley (571), and 40% higher than the mean for the Al Hamra Plain (810) where the same aquifer is used.

There is no consistent relationship between local depressions in the groundwater table and Ec. The only overall conclusion that can safely be drawn is that the Amran Limestone aquifer is not uniform and that extensive investigations would be required to define its structure and properties.

Water temperatures ranged from 21 to 32°C, with a mean and a median of about 27°C; most measurements were between 24 and 30°C .

Mean groundwater temperature in the Al Harf Plain was almost 3 degrees higher than in the Amran Valley, and about one degree higher than in Al Hamra.

At 48 wells data on land areas were available. The total area associated with wells was 1383 ha of which 330 ha (24%) were tilled land, while 1053 ha were fallow (assumed local measure 1 libna = 64 m^2). Extrapolating and assuming a total number of 64 wells resulted in a total well area of 1844 ha, of which a large part (76% or 1404 ha) was fallow. This figure translated to an average command area of about 7 ha per well.

The size of the smallest area was 2.2 ha, the largest 192 ha. The mean total well area was 29.5 ha and the median 25.6 ha.

The part of the well area commanded by groundwater, was much smaller: the mean was 7.3 ha (median: 6.4 ha). The smallest plot was 0.6 ha and the largest 26 ha. Most irrigated farms had a total area ranging from 2 to 10 ha.

Of the perennial crops, qat was grown by 35% of the farmers, followed by apple (18%), pomegranate (10%) and grape (6%). Of the annual crops, wheat was cultivated by 76% of the farmers during the seasons Shita and Rabi'a. During the same seasons, barley was grown on 24-29% of the farms. Sorghum was the major seasonal crop during Sayf and Kharif (73% of the farms). Other cash crops observed were tomato, potato, maize and water melon.

Both chemical fertilisers and manure were added, the first at regular intervals. On 88% of the farms fertilizers were applied, urea alone on 37%, manure on 22%, and both urea and manure on 40%.

The apparent number of persons depending on one well ranged from 70 to 2000. A relatively large percentage of the pumped groundwater appeared to be used for domestic purposes: 36%. (compare Amran Valley: 4%). Two neighbouring wells in Al Harf Town supplied water for about 3000 persons. On three other wells, 6000 people were dependent.

The mean number of persons that use water from one well was 621, a value that probably somehow was distorted by the high extreme values, However, the median was also high: 400 persons (compare Amran Valley: 100 persons).

A total number of 19 260 persons were apparently dependent on 31 wells, being the number for which the collected domestic water consumption data were complete. When extrapolated, assuming a total number of 64 wells in the Al Harf Plain and the same distribution of the missing data, then a total number of 39 763 people consumed well water in 1991. This number is unrealistically high compared with the 1986 Census. For the purposes of estimating domestic water use a population of 6000 people was assumed.

Assuming an average daily water consumption of 40 l per capita, the total domestic water consumption was 85 000 m^3 in 1991.

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

The pumping costs in the Al Harf Plain appeared to be extremely high.

The costs of one hour of pumping varied 23.5 YR to 436 YR, with a mean of 92.3 YR. The price of one m^3 of pumped groundwater ranged from 2.6 YR to 40.2 YR, with a mean of 9.9 YR, more than four times the mean costs in the Amran Valley and twice those in the Sa'dah Plain where discharges, depth to water and specific drawdowns are very similar. Some descrepancy in data collection is indicated and so an average unit cost of YR 5/m^3 was assumed.

From this a total of YR 8 million was spent during 1991 in pumping about 1.59 Mcm.

The price of water at the crop level would be higher. Assuming an overall irrigation efficiency of 36% , then the average cost of the water at the crop level would be YR 13.9 and the average yearly water costs per irrigated (net application of 1301 mm): YR 180 694.

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APPENDIX 1

PROCESSING OF THE

WELL INVENTORY DATA

APPENDIX 1 PROCESSING OF THE WELL INVENTORY DATA

A tailor-made database computer program was prepared for the analysis of the NORADEP well inventory results. To minimise errors during data entry the layout of the pages on the screen is the same as the pages of the questionnaire. Each record in the database corresponds with a complete well inventory sheet and has space for the 123 fields necessary. A total of 66 wells were surveyed in the Al Harf Plain, and so 66 times 123 (8118) data had to be entered and subsequently processed and interpreted.

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

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

APPENDIX 2

WELL INVENTORY

QUESTIONNAIRE

WELL INVENTORY QUESTIONNAIRE NORADEP

SSHARDA

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

A. WELL LOCATION

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

Fill out after fieldwork:

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

SKETCH OF WELL LOCATION

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

↑
NORTH

B. WELL DETAILS

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

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

3. DIAMETER of WELL .... m

4. DIAMETER of CASING .... inch

5. WELL DEPTH .... m

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

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

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

9. DESCRIPTION of UNDERGROUND:

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

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

C. PUMP DETAILS

1. PUMP INSTALLED yes/no

2. YEAR of INSTALLATION PUMP 19....

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

4. PUMP NAME ....

5. PUMP MODEL ....

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

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

8. DIAMETER of PUMP COLUMN .... inch

9. ENGINE NAME ....

10. ENGINE MODEL ....

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

12. DEPTH of PUMP .... m

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

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

D. OBSERVATIONS AT WELL

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

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

E. WATER USE

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

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

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

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

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

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

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

ONLY IN CASE OF DOMESTIC USE OF WATER:

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

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

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

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

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

E. WATER USE (continued)

14. IS WELL SOMETIMES DRY ? yes/no

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

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

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

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

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

F. COSTS

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

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

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

G. MISCELLANEOUS

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

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

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

APPENDIX 3

WELL INVENTORY

SUMMARIES

Data of well inventory of Al Harf Plain (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)
1	DHU SHAHWAN	1811900	399200	1617	83	250	8	120	150	84	150	80	1.6	1000	300	800	25.0	680
2	ALSHAATAH	1810800	399200	1600	81	40												
3	ALQAF	1810400	399500	1597	85	100	12	28	100	85	90	76	3.0	3000	1500	300	25.0	650
4	JAYRAH	1810800	400700	1582	80	180	8			86	105	92		5000	200	700	25.0	940
5	JAIRAH	1810800	400600	1582	80	170	8					92						
6	JAIRAH	1811000	400600	1582	83	400	8	204	300		150	92						
7	JAYRAH	1811000	400900	1580	84	300	8											
8	JAYRAH	1810700	401100	1578	84	200	8					85						
9	ALQAHIRAH	1818800	400800	1595	90	156	10			90	114	90	1.7	4000	400	300	31.0	800
10	ALKAWLAH	1819200	400300	1605	88	170	8			89	126	115	1.4	10000	3000	1500	31.0	710
11	ALMAYAN	1819400	401200	1600	86	150	10			86	135	120	1.9	6000	1500	500	25.0	810
12	RAYK	1818800	401500	1597	84	150	8	114	150	84	114	110	2.1	10000	1000	500	31.0	720
13	ALSORPAH	1818000	401000	1600	91	162	10	132	162	90	111	100	1.7	3000	500	300	31.0	700
14	ALSORPAH	1817700	401500	1600	87	128				89	111	100	3.8	5000	1000	500	31.0	700
15	ALMAHJAR (ALWAQBAH	1815300	403700	1575	87	150	12			87	102	85	1.7	600	600	100	23.3	1100
16	ALMAHJAR	1815800	403400	1577	89	108	8	78	108	89	93	100	2.1	6000	1000		31.0	940
17	AS SURRAH(AL AORANI)	1816000	403300	1577	89	135	12			89	93	98	1.6	1000	200	70	28.0	1500
18	AS SURRAH	1816400	403500	1580	78	135	8			78	78	72	2.7	8000	1000	100	29.9	1400
19	ASSURRAH(ALGOLSOM)	1816600	403000	1580	90	134	10	90	120	90	111	106	2.1	1500	500	150	29.5	940
20	ALWAGBAH	1815300	403000	1580	89	105	8			89	96	90	2.8	1000	2000	300	31.8	1000
21	ALMODAYYAR	1814800	400800	1590	83	200	8			83								
22	ALMODAYYAR	1814900	401400	1582	84	220	8			84	93	88	3.4	2000	1000		27.8	1150
23	SAHBAL	1815500	400800	1585	91	183	10	75	150	91	111	90	6.3	5000	1000		29.9	1200
24	HAJARAN	1815000	401600	1578	83	235	10	148	218	83	125	90	3.8	5100	1000	2000	32.2	1000
25	ALWAQBAH	1814900	402800	1572	91	150	10	88	110	91	90	95	15.0	1000	1000		29.0	1600
26	SALIL HAGRAN	1815300	401400	1582													27.3	1700
27	AYYAN	1816800	400400	1595	88	150	8					35						
28	SHPAREJ	1814300	402200	1577	88	120	10	60	120	88	108	45		5000	1000	400	26.5	1200
29	AL-ANAB	1816800	401300	1588	87	116	10	47	65	87	102		2.5	1500	500	300	27.7	1200
30	ALZAFG	1817200	400300	1597	88	130	12	60	90	88	108	98	0.8	2000			24.9	1800
31	AL HAYRAH	1818400	396400	1650	86	175	10	139	175	86	150	75	2.1			2000	28.6	1500
32	AL HAYRAH	1818400	396800	1650	82	180	8											
33	AL HUSHIN	1816900	396700	1635	86	210	8	108	170	86	90	70	2.5	350	700	500	25.6	800
34	ALHAWL	1816300	398400	1615	89	160	8	142	160									
35	AL ALAWL	1816500	397900	1620	85	130	8	70	130	86	126	80	2.5	3000	500	150	28.8	800
36	AL UGLAH	1808500	401200	1590	85	250	8	60	72			53						
37	ALHAJAR	1808700	400900	1595	89	200	8	152	200	89	153	138	1.4	1000	100	1000	29.6	800
38	OMCAN	1808300	401500	1600	83	170	8	40	70			75		700				
39	OMCAN	1808400	401400	1598	86	130	8	36	60	86	105	90				2000	27.6	900

Data of well inventory of Al Harf Plain (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)
40	DAMM	1809800	400800	1580		48						48						
41		1809600	401000	1580	81	250	10			81	150	85				350	23.7	650
42	JAYRAH	1810400	400900	1578	86	100	10	70	100	86	99	97		5000	200	150	21.1	750
43	DHU SALEH	1810200	401900	1573	83	150	10	70	150	83	90	70	1.7	5000	1000		27.0	850
44	DHU SALEH(ALJALLAH)	1810700	402600	1568	89	96	10	78	96	89	81	54		30000	800	100	25.6	1750
45	MADAJAH	1809000	402200	1575	84	160	8	124	160	84	90	20	2.1	10000	500	200	26.2	900
46	ALMADACAH	1809000	401700	1580	88	175	8	111	135	88	100	100	2.1	800	700	90	25.6	900
47	MADACAH	1809300	402300	1574	86	120	10	70	100	88	90	80	1.9	10000	3000		26.2	800
48	ALGERZAN	1809800	402400	1572	88	130	10	60	90		90	80	1.9	1500	200		25.6	1400
49	WADI ALGAHM	1809800	402200	1573	86	150	10	72	96	86	96	80		5000	3000		26.0	1150
50	DHU-SALEH (GUBIR)	1809900	401700	1574	85	96	10	38	96	85	78	50	1.9	6000	700		26.5	1050
51	QA'A ZOAITEERAH	1809400	402700	1573	83	105	10	75	105	83	90	84		1000	1000		27.0	700
52	QA'A DHU SALEH	1809700	402900	1568	85	140	10	122	140	85	90	62		1500	800	500	26.9	1850
53	AL-RYANY	1808300	403800	1567	89	140	10	50	110	89	75	80		5000	2500		26.0	1750
54	ALSHEAP	1808300	404300	1568	86	200	8	50	140	86	130	60		5500	3000	400	28.6	1100
55	QUTHA	1808000	403000	1580	91	155	10	94	130	91	129	117		3000				
56	BERJUS	1809600	403900	1570	84	120	12				78	70		3000	1500		25.8	1200
57	ALHUMR	1809900	404300	1570	91	138	8	94	134	91	71	90	15.0	400	1200		24.0	950
58	ALSHEAP	1808300	404600	1578	85	99	10	63	99	86	75	82		4000	4000		27.7	1000
59	ALQA'A	1809700	403700	1565	82	150	12			82	90	75	0.9				26.5	1000
60	BADEA AL HASAM	1810500	403500	1565	85	143	12			89	90	60	3.8	8900	1000		27.3	1050
61	AL TALH	1810600	404300	1570	88	150	12			86	90	75		7000	1500		26.7	1100
62	AL TALH	1810500	404200	1567	86	135	12				90	75	7.5	7000	1500		25.9	1400
63	SHULPA	1810300	404600	1568	89	144	10	91	144	89	90	72	6.3	3000	1100		27.1	1150
64	MAGLAD	1810000	403000	1568	89	72	12	48	72	89	63	63	7.5	1800	800		25.0	2200
65	AL HARF	1809600	403300	1568	76	110	12	78	102	76	96	50	5.0			1500	26.7	2200
66	ALHARF	1809600	403700	1566	86	120	10			86	120	80	5.8			1500	25.7	800

APPENDIX 4

STAFF PARTICIPATING

IN THE

WELL INVENTORY

APPENDIX 4 STAFF PARTICIPATING IN THE WELL INVENTORY

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

The following SSHARDA engineers were involved in the well inventory:

Wasfi Mohd Abdo Alezzi (team leader)
Abdul Halim Hazza

Drivers in charge were:

Abdullah Alyazidi
Ali Ahmed Al Montassar

Database entry was carried out by the SSHARDA engineers:

Samir Al Shamiri
Abdul Al Shamiri

Planning and reporting

W.J. Honijk (hydrogeologist)