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NORTHERN REGION AGRICULTURAL DEVELOPMENT PROJECT
TECHNICAL ASSISTANCE FOR ENGINEERING SERVICES
YEM/87/015

GROUNDWATER RESOURCES IN THE BAQIM PLAIN

Final Report
July 1993

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 and the governorate of Hajjah and Sa'dah (see Fig. 2.1). The data from 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 regions.

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

The activities for the well inventory of the Baqim Plain were carried out during the month of January 1992. Four teams, each consisting of two engineers and a driver were used; the drivers also assisted in carrying out the measurements at the well sites. A list of the persons that participated is presented Appendix 4.

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

A total of 111 wells was visited and the same number of questionnaires were filled out, each of which may contain up to 120 data. The Information collected includes well location and construction details, pump characteristics, measured well observations, water use, and well costs. A copy of the questionnaire is presented in Appendix 2. The most important data are summarized and presented in Appendix 3.

2 PHYSICAL SETTING

2.1 LOCATION AND TOPOGRAPHY

The Baqim Plain is situated in the Central Highlands in the northern part of the Sa'dah governorate at a distance of about 60 km northwest of Sa'dah town. It lies within UTM coordinates 1 922 000 and 1 934 000 North and 332 000 and 341 000 East, with a length north to south of about 12 km and a width varying from 7 km at the center to 5 km in the south. (see Fig. 2.2). The alluvial plain covers an area of about 55 km^2 and has a small catchment area of 95 km^2, mainly on the western side of the plain (see Fig. 2.3). The plain and its catchment form part of the catchment area of Wadi Najran which debouches into the Ar Rub Al Khali desert, east of the Baqim Plain.

The road from Sa'dah town to the north passes through the plain. The most important towns are Baqim in the south and Mahydidah in the north.

Several wadi channels enter and cross the plain. The largest of these, Wadi Nagwan, functions as the "surface water outlet" of the plain and leaves the plain south of Baqim town, joining Wadi Najran near Najran town in Saudi Arabia.

Topographic elevations in the plain range from 2240 m amsl (above mean sea level) in the northern part of the plain down to 2100 m in the south. As a result most wadis flow southwards. The surrounding mountains are entirely composed of sandstones of the Wajid formation, with altitudes ranging from 2300 m to 2500 m.

The census of 1986 gave the number of inhabitants of the study area as 7300. A rough estimate of 10 000 was derived from the well inventory data (see Section 5.5).

2.2 CLIMATE AND VEGETATION

The climate in the Baqim Plain is classified (Koppen) as mountainous semi-arid. The natural vegetation is of the briar, succulent, savannah type, represented by trees, shrubs, briar and grassland on moist soils near wadi outlets at the margins of the plain. As a consequence of intensive grazing by sheep and goats little grassland is left on the plain, and the result is a desert-like aspect of the non-cultivated areas.

Rainfall is sporadic and scanty and storms are usually short, intense and local. There are no rainfall or meteo stations in the area, and so data from the nearest rainfall stations, Al Muthef (about 50 km south of Baqim town) and Al Gudami (about 50 km south east of Baqim), have been used here. Both stations are situated in the Sa'dah Plain.

Fig. 2.4 shows the mean monthly rainfall as measured at both stations during the period 1983-1989 while Fig. 2.5 represents the total annual rainfall.

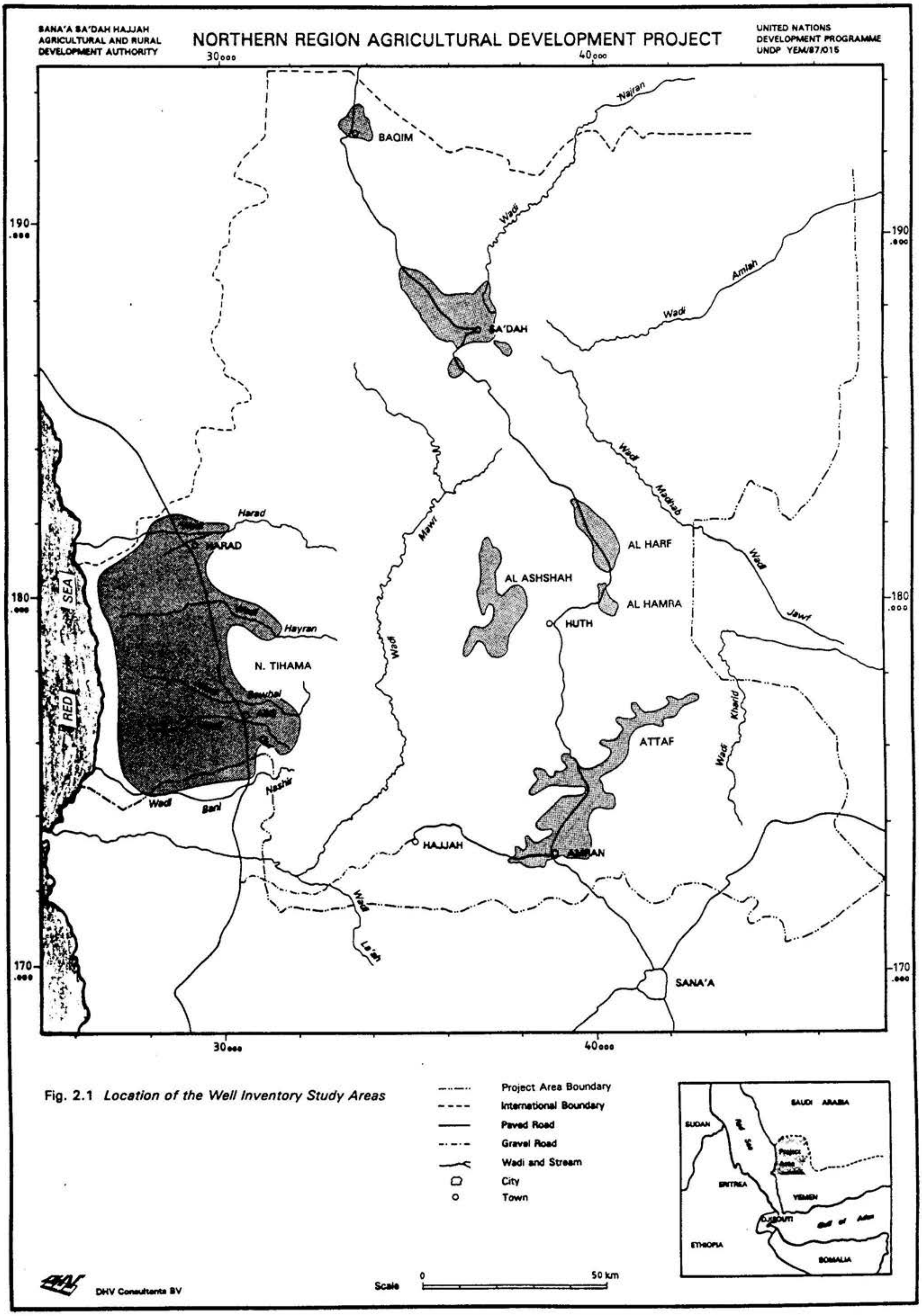

Fig. 2.1 *Location of the Well Inventory Study Areas*

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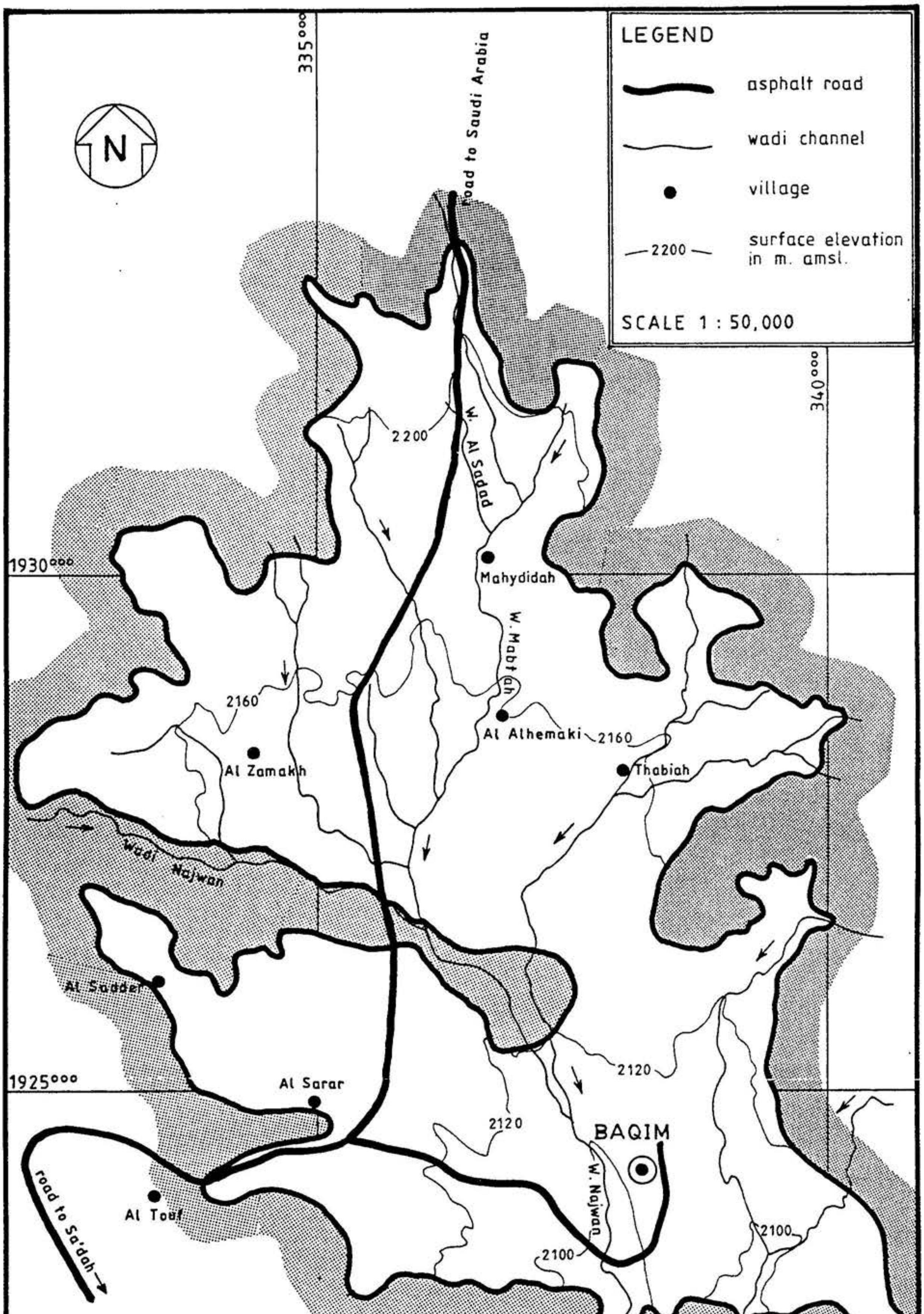


Fig. 2.2 Map of the Baqim Plain study area

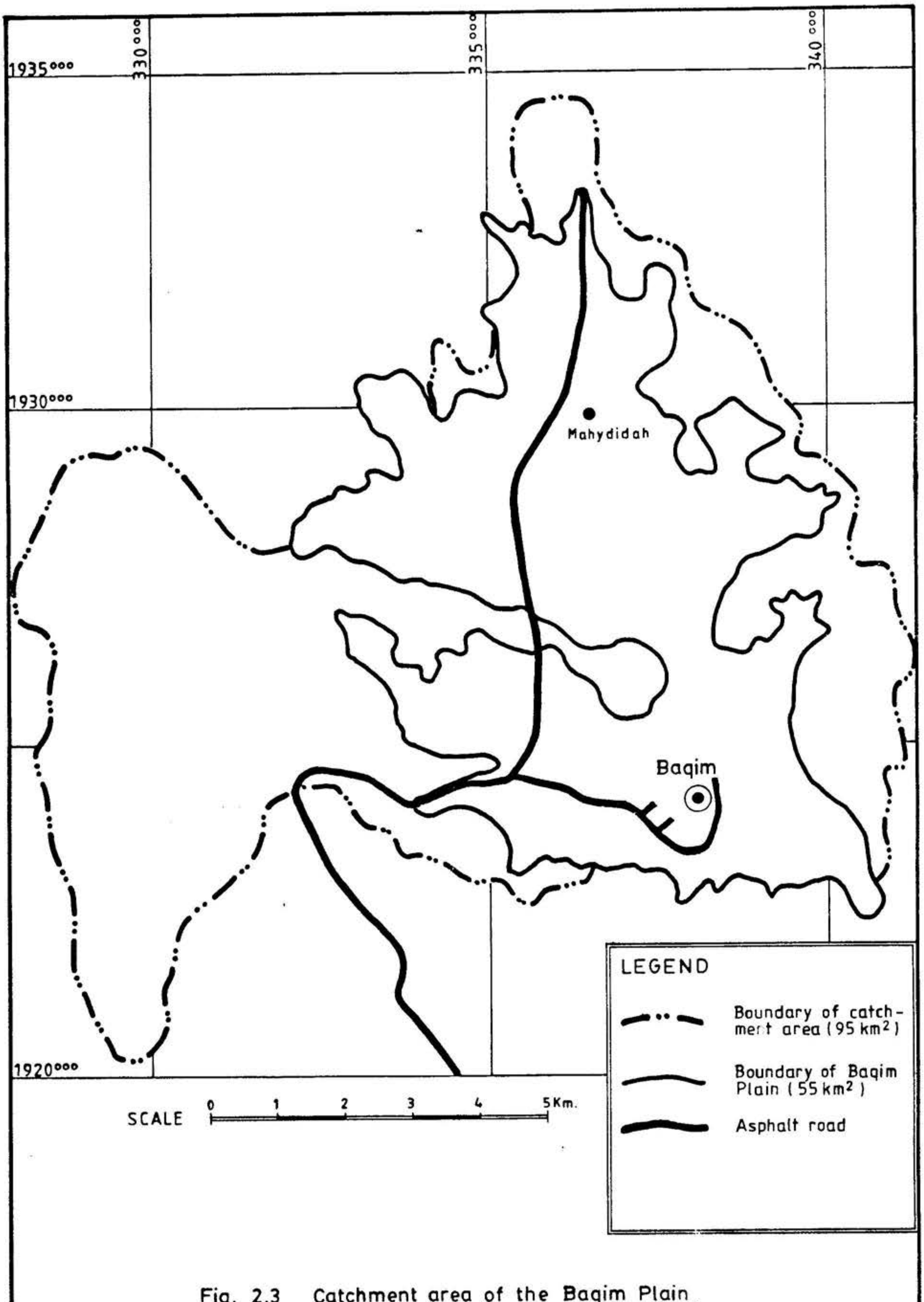


Fig. 2.3 Catchment area of the Baqim Plain

Rainfall at the stations, despite the small distance between them, differs immensely. The mean annual precipitation at Al Muthef, is double that at Al Gudami (200 and 103 mm).

Fig. 2.4 *Mean Monthly Precipitation Near Baqim Plain*

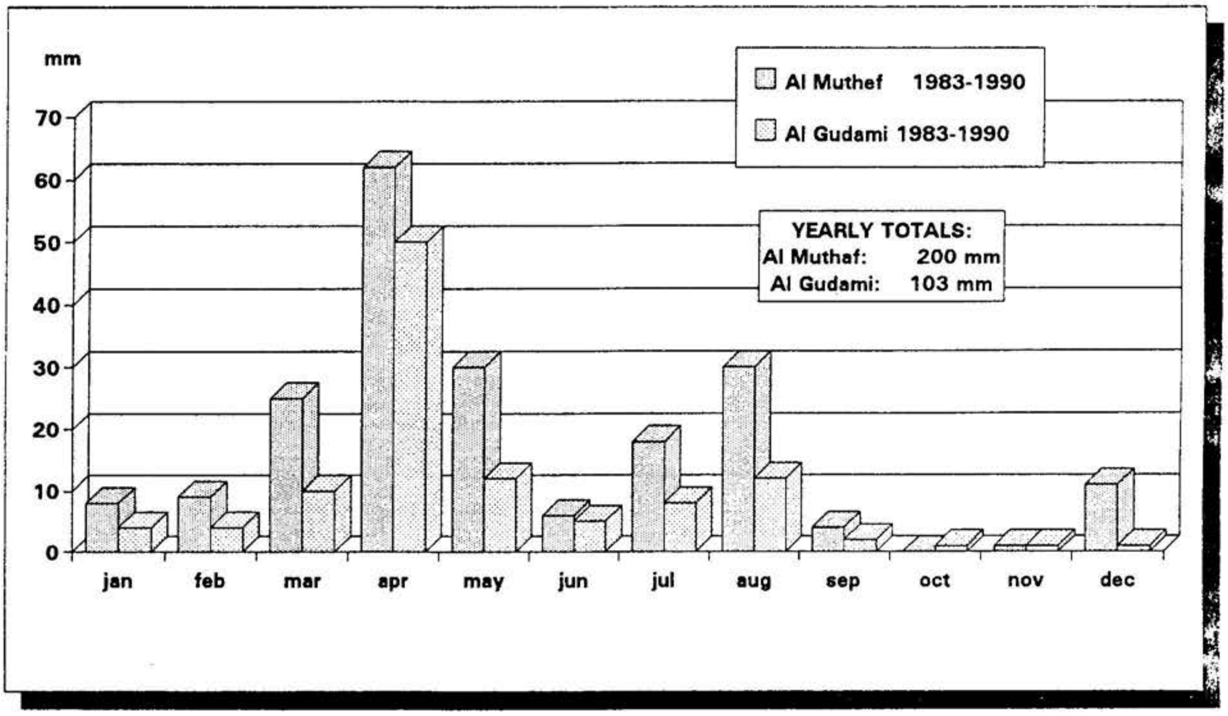
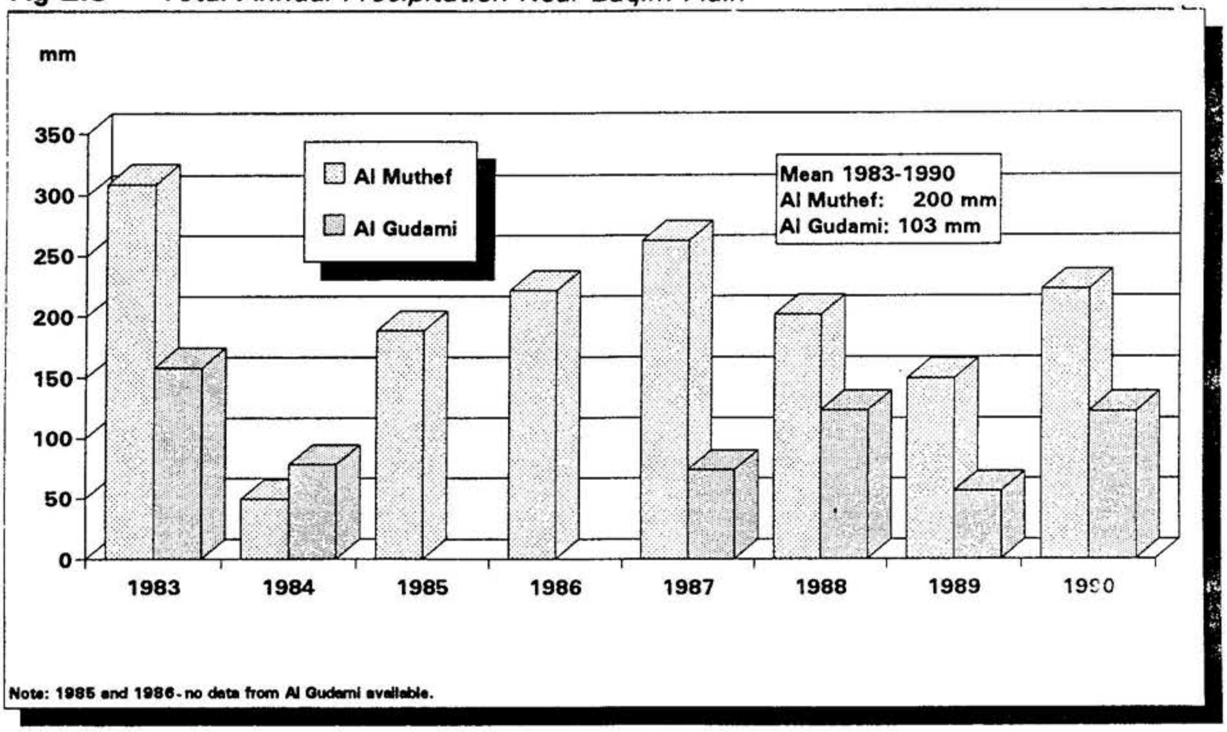


Fig 2.5 *Total Annual Precipitation Near Baqim Plain*



Interpolating the data results in an average annual rainfall of about 150 mm, and this preliminary estimate of the yearly rainfall has been assigned to 1991 for the calculation of the of the yearly total rainfall volume in the plain (see section 5). Annual totals in Al Muthef range from 49 mm in 1984 to 309 mm in 1983; from 56 mm (1989) to 158 mm (1983) in Al Gudami. The monthly distribution of rainfall is rather variable. In general two rainfall peaks occur: March-May and July-August. The wettest month in both locations is April.

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

3 GEOLOGY AND HYDROGEOLOGY

3.1. GEOLOGY

3.1.1 Tectonics

The Baqim Plain was formed by the filling up of a *graben* by alluvial deposits eroded from the surrounding mountains, mainly by surface water flows. The thin alluvial top layer of the plain is underlain by the Wajid Sandstone of Ordovician age. The *graben*, was created, like most other plains in the northern part of Yemen, at the beginning of the Tertiary age, when regional uplift and block faulting took place.

During these tectonic activities volcanic eruptions formed *cratons* built up from basalt flows which now outcrop at the northern side (Jabals Izzam and Mandabah) and western side of the plain. Along the major faults, gneissic granites of Precambrian to Palaeozoic age are exposed, commonly with many mafic dyke intrusions.

3.1.2 The Quaternary Alluvium

Table 3.1 shows the geological formations in and near the Baqim Plain and their hydrogeological characteristics. The Quaternary unconsolidated sediments are principally composed of gravels, sands, silts, clays and loess, which accumulated in the wadi channels and on the plain itself. They are derived mainly from the mountainous sandstone area west of the plain, the major part of the Baqim Plain catchment area which covers an area of about 30 km^2 (see Fig. 2.3). The thickness of the alluvium is very thin, varying between 0 and 6 m.

3.1.3 The Tertiary Yemen Volcanics (Trap Series)

Tectonic movements during early Tertiary times resulted in volcanic activity in many areas of Yemen. Around the Baqim Plain several outcrops can be observed (see Figure 3.1), composed of alkali basalt, rhyolites and pyroclastic basaltic rocks, locally interbedded with clastic wadi alluvial deposits. The eruptions took place 25 to 29 million years ago.

3.1.4 The Wajid Sandstone

The dominant, and oldest, sedimentary rock in the study area is the Wajid Sandstone (see Fig. 3.1 and 3.2). It was deposited from the Cambrian to the Permian, and unconformably overlies the Precambrian basement rocks. It consists of deltaic deposits and can be subdivided into Upper and Lower Wajid units.

The *Lower Wajid Sandstone* is of Ordovician age and shows exposures of yellow to brownish cross-bedded, medium to coarse grained quartz sandstones, locally interbedded with quartzitic ironstone. At the contact with the basement, there is a thin layer of basal conglomerate .

Table 3.1 *Geological Formations and Their Hydrogeological Characteristics In and Near the Baqim Plain*

Table 3.1 — ***Geological Formations and Their Hydrogeological Characteristics In and Near the Baqim Plain***

Stratigraphic age	Litho-stratigraphy	Lithology	Hydrogeology
Quaternary	Thin layer of wadi terrace deposits and alluvial fans	Loam, silt, clay, sand loess, gravel, boulders.	Alluvium does not act as an aquifer, because water level is mainly situated below it in the Wajid Sandstone. Alluvium functions as surface and rain water collector, passing water to the sandstone below it.
Tertiairy	Yemen Volcanics	Volcanic alkalic basalt flows, sills, tuffs and pyro-clastic basalt.	Groundwater circulates only through secondary porosity like fissures, fractures and faults. Poor aquifer, unless fractured. Too far outside study area to play a prominent part in its water balance.
Carboniferous to Permian	Upper Wajid Sandstone	Cross-bedded, light coloured quartz sandstone and intercalations of clay, silt and mud balls.	Major aquifer in and around the study area.
Ordovician and Cambrian	Lower Wajid Sandstone	Yellow to brownish coloured cross-bedded, medium to coarse grained quartz sandstone. Interbedded with quartzic ironstone.	Major aquifer in and around the study area.
Precambrian	Basement complex	Granitic gneiss, intruded by swarms of mafic dykes.	Aquifuge. Impermeable bedrock, neither containing nor transmitting groundwater. No outcrops in or near the study area.

The *Upper Wajid Sandstone*, of Carboniferous to Permian age, also shows a massive depositional environment and consists of cross-bedded, light-coloured quartz sandstone and intercalations of clay, silt and mud balls. Upon this sandstone shales of the Akbra formation of Permian age were deposited.

3.2 AQUIFER SYSTEMS

3.2.1 Alluvium

Only in upstream wadi fills does the Quaternary alluvium sometimes function as a temporary perched aquifer, and where saturated it represents a relatively good aquifer. The highest permeabilities are in the interbedded gravel layers. However, over most of the plain the alluvium is situated above the water table and is not saturated. It functions only as a medium holding the surface and rain water, from where the water percolates into the underlying sandstone aquifer.

General groundwater movement in the plain is directed towards the south. Fig. 3.3, the hydrological cycle, presents a schematic model of the movement of water in the Baqim Plain and its catchment area.

3.2.2 The Wajid Sandstone

In Yemen the best water containing and water transporting geological formations are, when saturated, the Quaternary alluvium and sandstones: the Medj-Zir Series/Tawilah Group (Tertiary and Cretaceous), the Kohlan Series (Triassic) and the Wajid (Cambrian to Permian).

The Wajid Sandstone dominates in the extreme northern part of Yemen and constitutes the main aquifer here. In all the alluvial plains in this area, including the Sa'dah Plain and the Baqim Plain, the Quaternary alluvium overlying the Wajid Sandstone is too thin to function as an aquifer, because the water table is situated below the contact alluvium-sandstone. That means that most of the groundwater is pumped from the Wajid Sandstone aquifer.

The WRAY 3 study (Yominco-TNO, 1985) revealed the following hydraulic properties, obtained from aquifer tests in the Sa'dah Plain: average porosity 0.05 to 0.15, average specific yield (effective porosity) about 0.075, permeabilities from 0.1 to 0.3 m/day and transmissivity values from 20 to 100 m^2/day. These hydraulic capacities classify the Wajid Sandstone as a moderate aquifer.

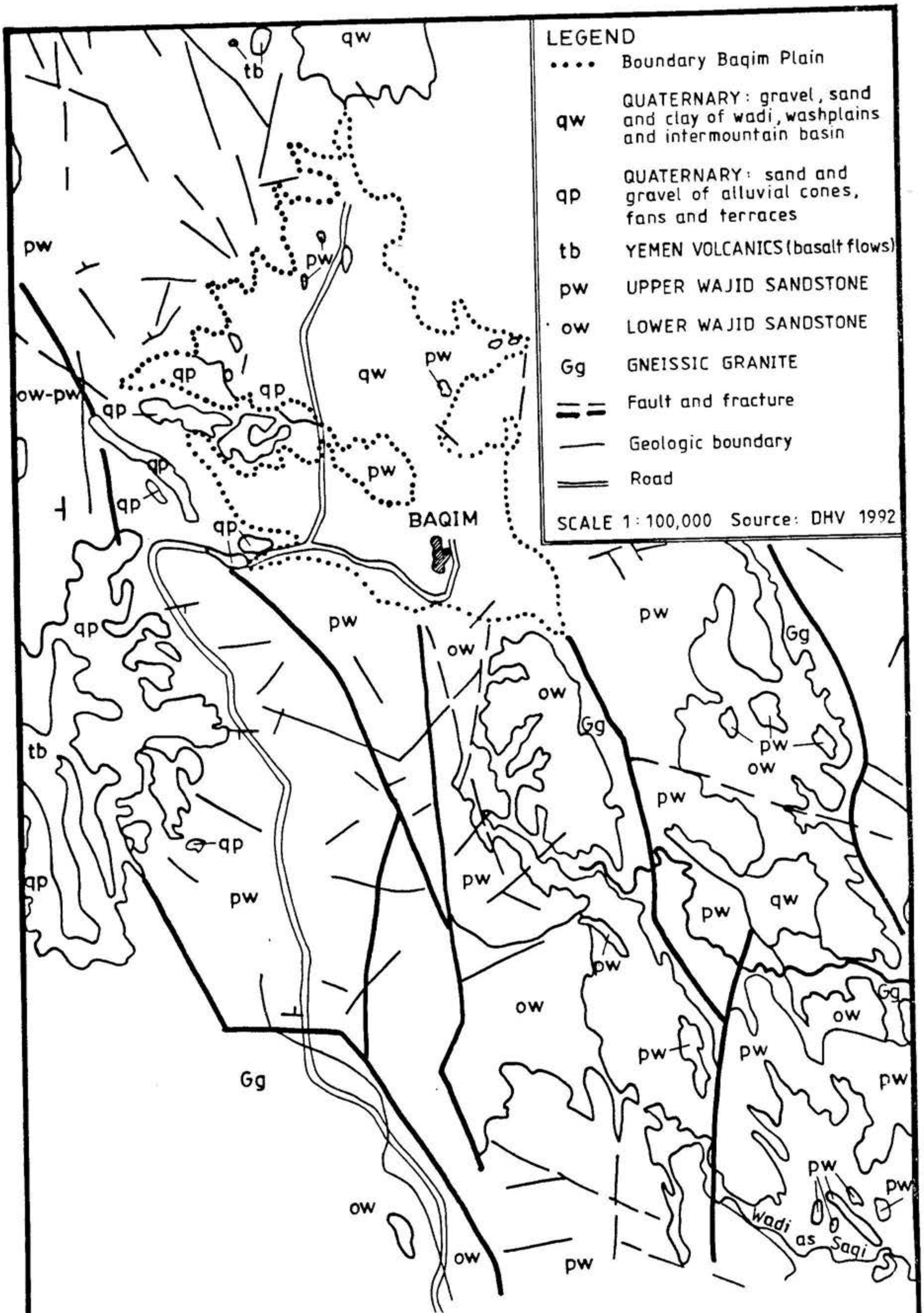


Fig. 3.1 Geology of the Baqim study area

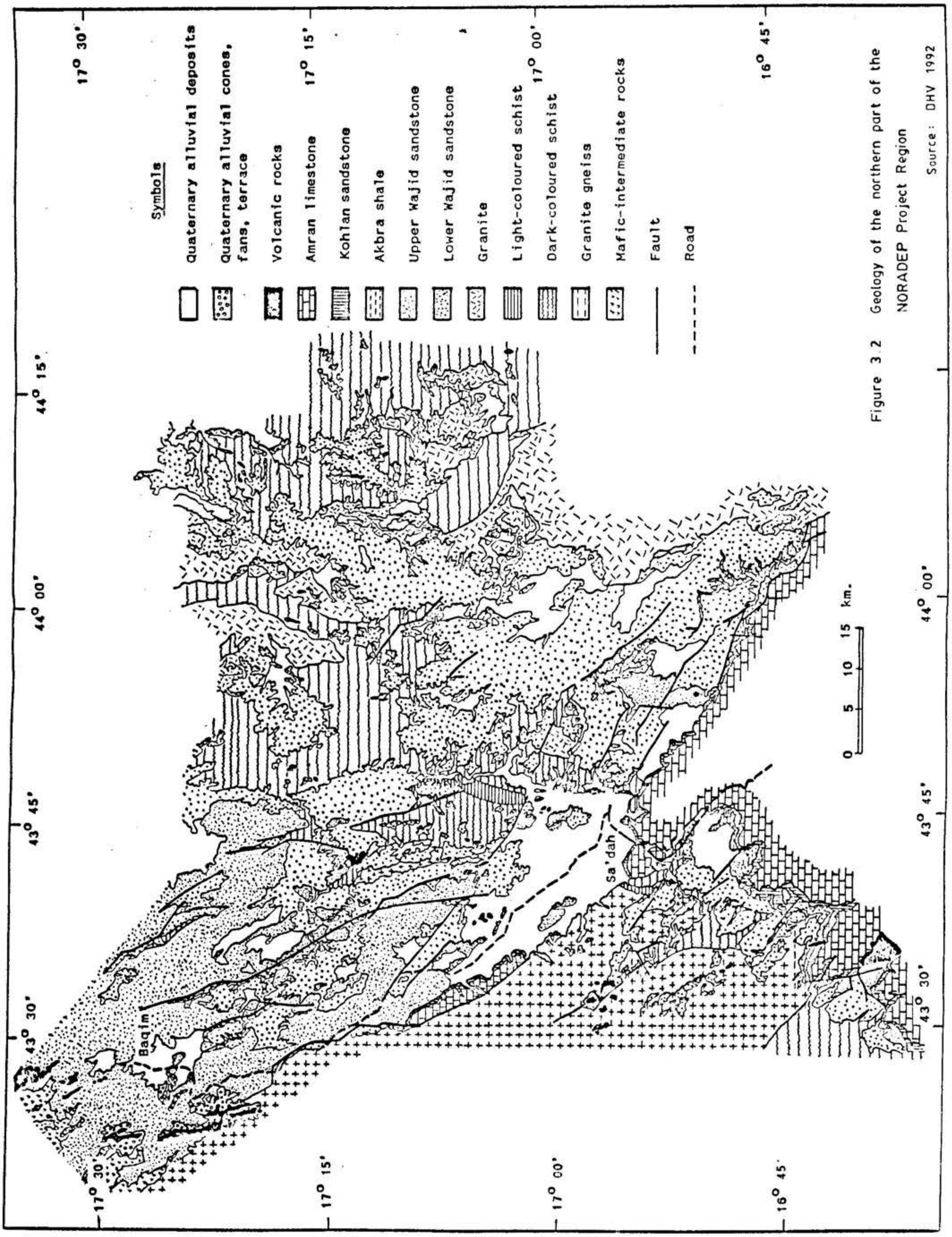


Figure 3.2 Geology of the northern part of the NORADEP Project Region

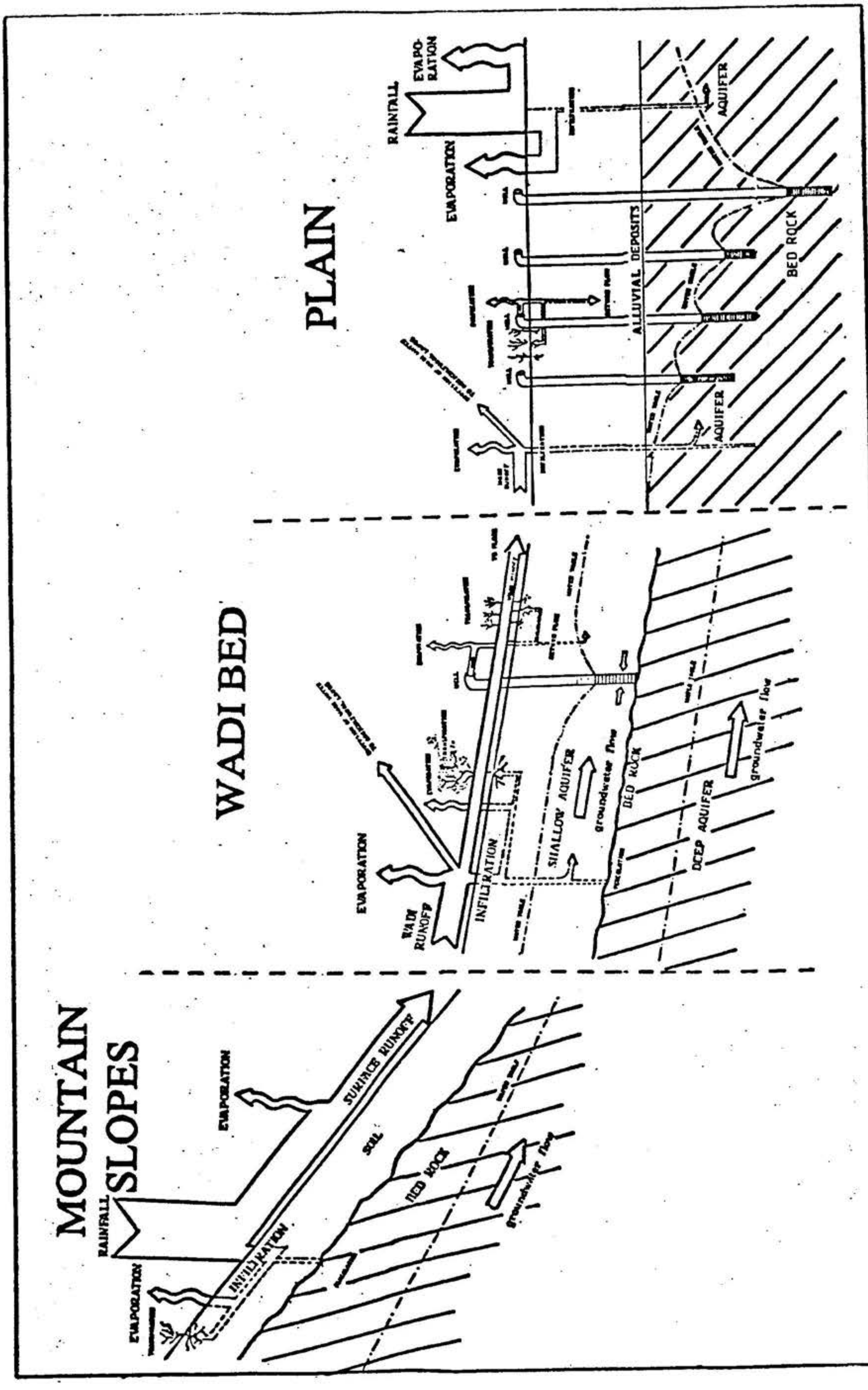


Fig. 33 Hydrological cycle

4 GROUNDWATER - GENERAL

4.1. DISTRIBUTION OF WELLS

Fig. 4.1 shows the locations of the wells that were visited; a total of 111 wells were inventoried. It was assumed that about 90% of all existing wells were surveyed and that the remaining 10% are evenly distributed over the total area.

A large number of wells is concentrated around the western and southern sides of Baqim town, where water can still be found at very shallow depths (less than 15 m). The loamy soils here have also attracted farmers.

Several parts of the plain are not suited for agriculture, because the topography is irregular or soils are not suitable; in the area west of the north-south asphalt road there is no soil at all. Over large areas in the north and south-east of the plain few wells were encountered: here spate irrigation dominates, in some places supported by pumped irrigation.

4.2. NUMBER OF WELLS

Of the 111 surveyed wells, 15 (13.5 %) were permanently out of order because of broken engines/pumps or inadequate groundwater levels. Therefore, the total number of operational wells in 1991 was taken as 107 (assuming that 90 % of the wells were visited of which 13.5 % were not operational).

Many dug wells have fallen dry during the last ten years because of decreasing water levels. Since the introduction of drilled wells water levels have fallen to such levels that manual digging and deepening of wells has had to stop except in some areas with shallow (perched) groundwater tables such as the borders of the plain and in the upper parts of wadi channels. Only the richer farmers can afford to drill deeper wells; groups of farmers have also started to cooperate in the financing of a shared deep well.

In the past, water was abstracted by buckets lifted by donkey power, but now all water is pumped by turbine/lineshaft or centrifugal pumps. Only the manually dug wells with high water levels use the low power centrifugal pumps. Fig. 4.2 and 4.3 show respectively the total and cumulative numbers of wells still operational in 1991 and drilled during the period 1978 (the oldest well located was drilled in this year) to 1991. It should be noted that these are net figures: the number of drilled wells minus the number of abandoned wells. Perhaps drilling started before 1978, but if so these wells have been abandoned.

Serious groundwater development in the Baqim Plain started only in 1978, about 16 years later than in the Amran Valley. The main drilling activity was in the period from 1984 to 1989. However, it is possible that the peak yearly drilling rate has not yet been reached, unlike, for example, in the Amran Valley.

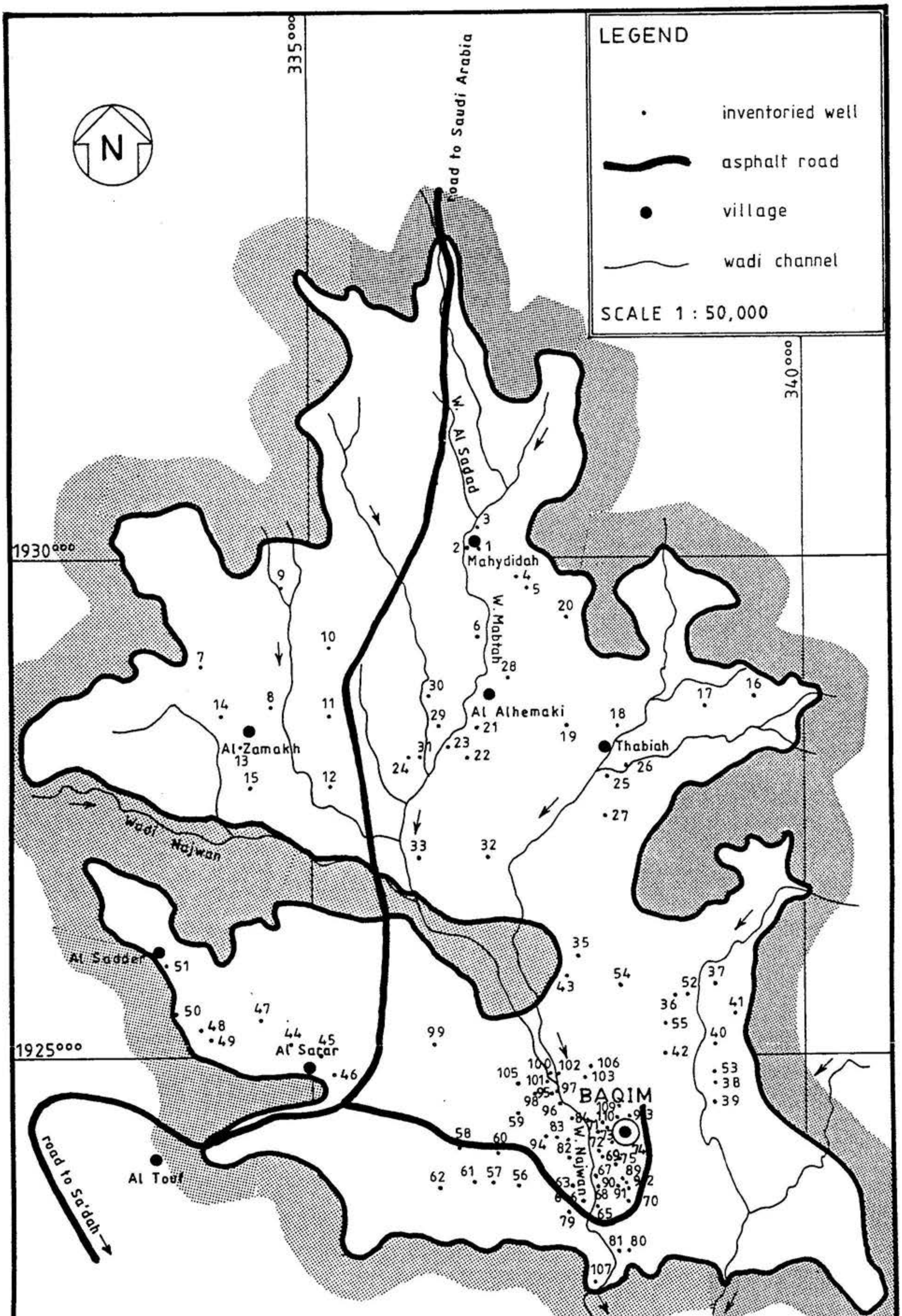


Fig. 4.1 Map of the locations of the inventoried wells

Statistical analysis of the cumulative distribution of the wells constructed shows that 50% of all existing wells were drilled after 1985, with an average age of 7.3 years.

Figure 4.2 *Number of Wells Drilled in the Period 1978 - 1991*

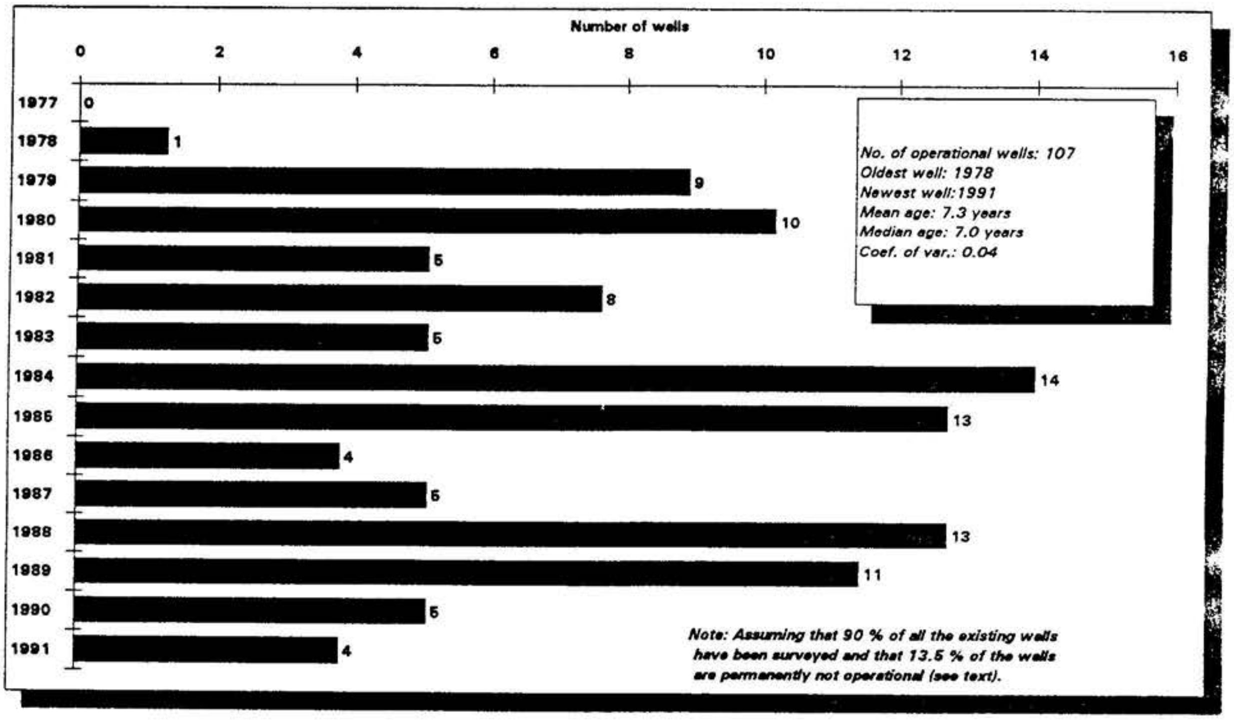
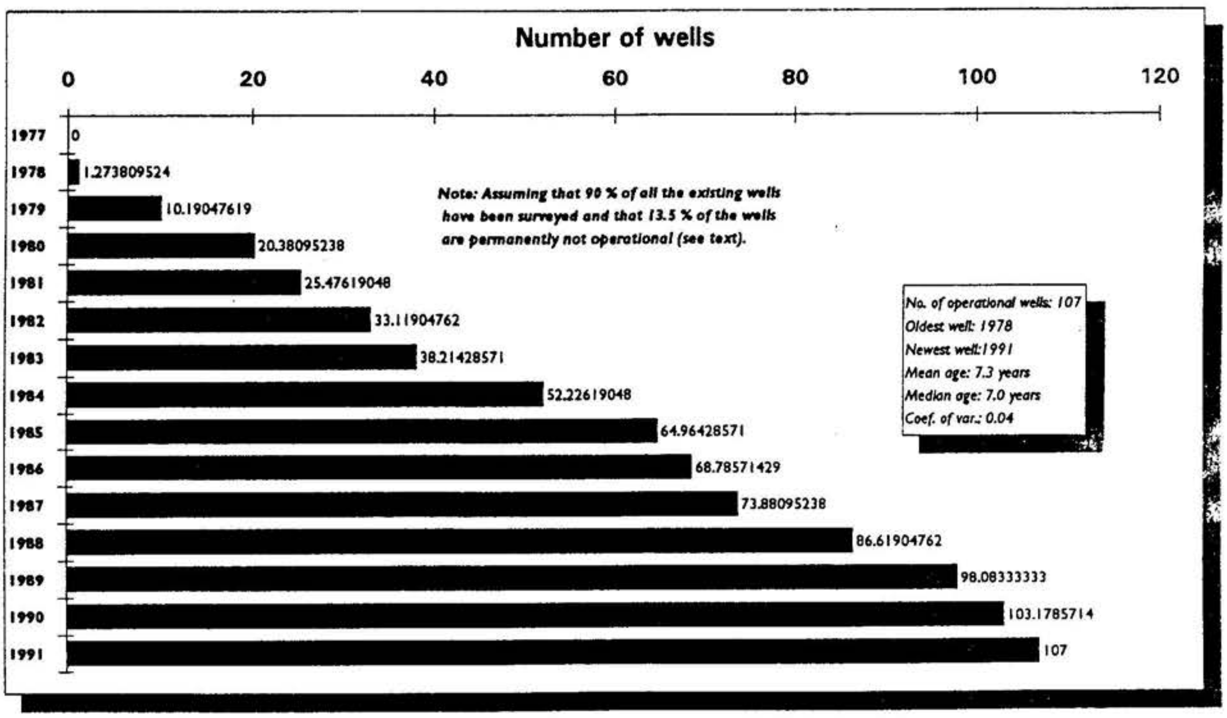


Figure 4.3 *Cumulative Number of Wells Drilled in the Period 1978 - 1991*



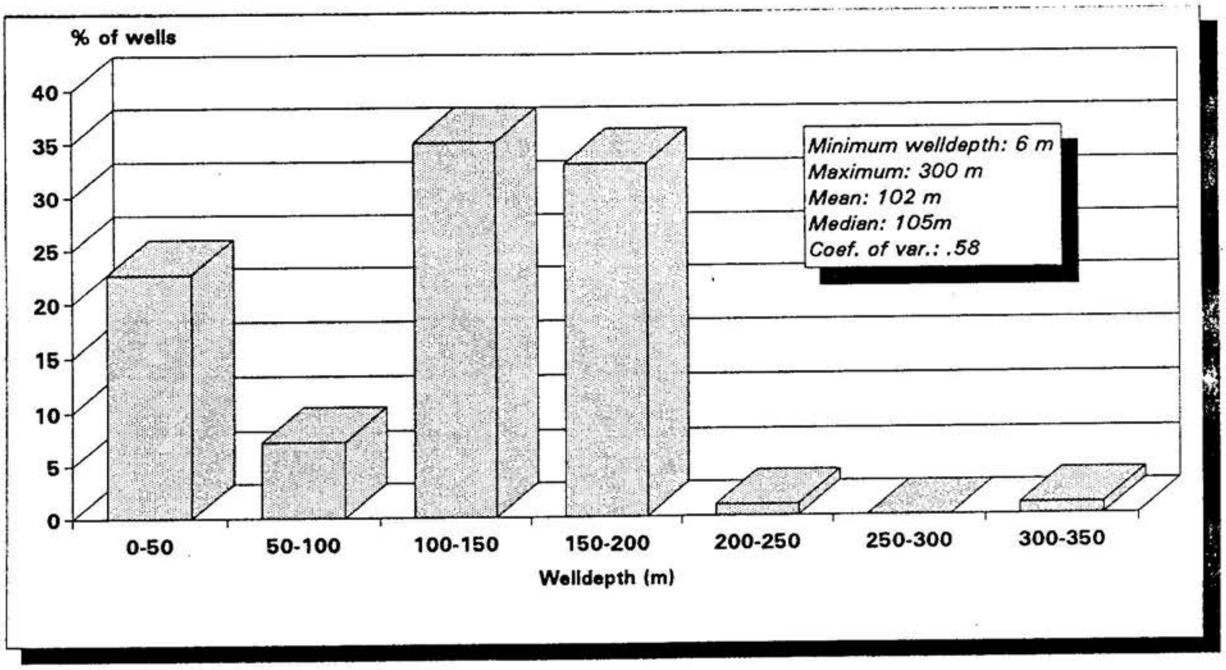
4.3 WELL CHARACTERISTICS

Most of the surveyed wells (73%) are drilled wells; the remaining 27% are shallow dug wells. Only four wells were reported as having been deepened once or twice relatively a very low figure when compared with the Amran Valley, where about 23% of the wells have been deepened one or more times.

The drilling method used was predominantly rotary. Practically all the wells are fully cased with six metre long pipes. Most of the casings are steel, of relatively large diameter: 12" (87%), 14" (8%) or 10" (5%), slotted at lower levels.

Fig. 4.4 shows the distribution of the well depths. The depth to the water, in general, is not very large, ranging from 3 m to 84 m (see also Fig. 4.16), and as a consequence well depths are not very large either. They range from 6 m to 300 m, although most (68%) are between 100 m and 200 m (the coefficient of variation is 0.54). Only one well is deeper than 200 m; all dug wells are less than 50 m. The average depth is 102 m.

Fig 4.4 *Distribution of Well Depths.*



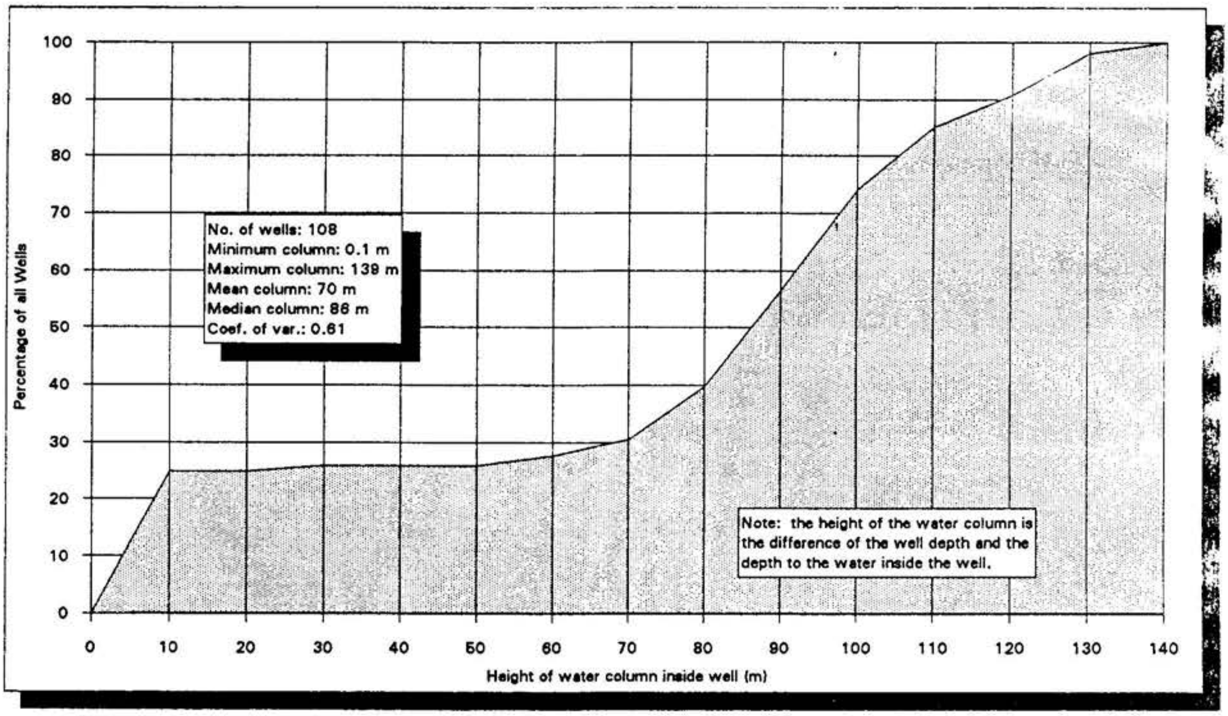
4.4. WATER COLUMN HEIGHTS

To illustrate the extent to which the wells have been designed for falling water levels in the near future or, in other words, the length of the water column in the wells, the "water column height" has been defined and analysed . The water column height is the difference between the depths of the well and the static water table. By analysing the cumulative distribution plot of the water column heights of all the wells, the percentage of wells that will fall dry when the water table drops by a certain amount can be deduced.

Fig. 4.5 shows that water column heights range from 0.1 to 139 m; the average aquifer penetration is 70 m; also that, if the static groundwater level drops 10 m over the whole plain, then about 24% (Amran Valley 9%) of wells will become dry. This percentage would increase to a minor extent when the drawdown brought about by pumping is also taken into account.

The percentage seems high, but, it represents only the shallow dug wells (27% of all wells). The water columns in the drilled wells are such that, in the near future, probably none will become dry.

Fig. 4.5 *Cumulative Distribution of Water Column Heights*



4.5 PUMPING EQUIPMENT

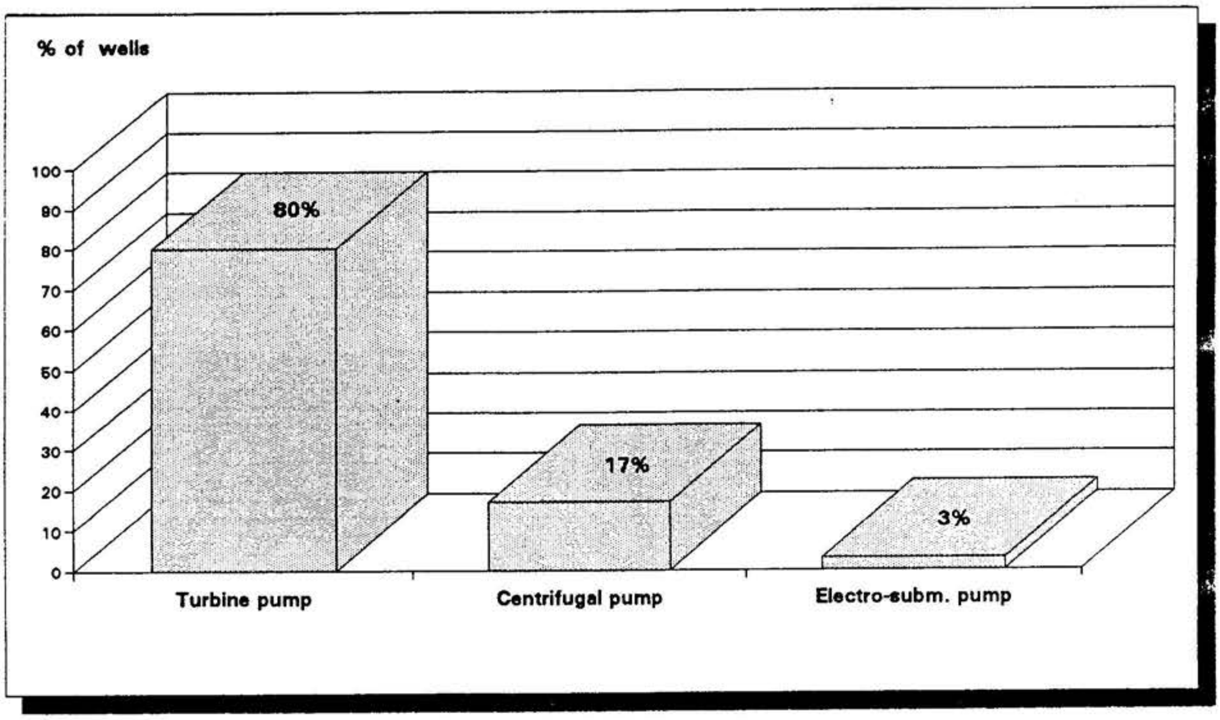
In deep drilled wells water is pumped either by vertical turbine (lineshaft) pumps coupled via crossed webbing belts to diesel engines (80%) or electro-submersible pumps (3%). In the shallow dug wells the most common pump type is the centrifugal pump (83%) with turbine pumps installed in the remaining 17% (see Fig 4.6).

A high level of standardization in engine and pumping equipment was observed. 93% of all turbine pumps were supplied by two manufacturers: 62% by Caprari (model V16P/3L/20A), 31% by Porcelli (model VE80). The mean number of bowls is 10, the pump column diameter mostly three and two inches (95% and 5%, respectively). Japanese Yanmar (Yamaha) engines (models NP22 to NP35 - 22 to 35 horsepower) power about 96% of the farms.

The most common centrifugal pump-in 63% of the shallow dug wells-is fabricated by Abary, with a capacity of 8 HP, with 2" or 3" diameter suction and delivery hoses.

The wells and pumps in the Baqim Plain are quite new (the oldest well and pump date from 1978). The average lifetime of the wells is about equal to that of the pumps. at 7.3 years (in 1991). This means that most wells are still equipped with the original pump set. In only 9% of the wells has a second pump been installed.

Fig. 4.6 *Methods of Water Abstraction*



4.6 WELL YIELDS

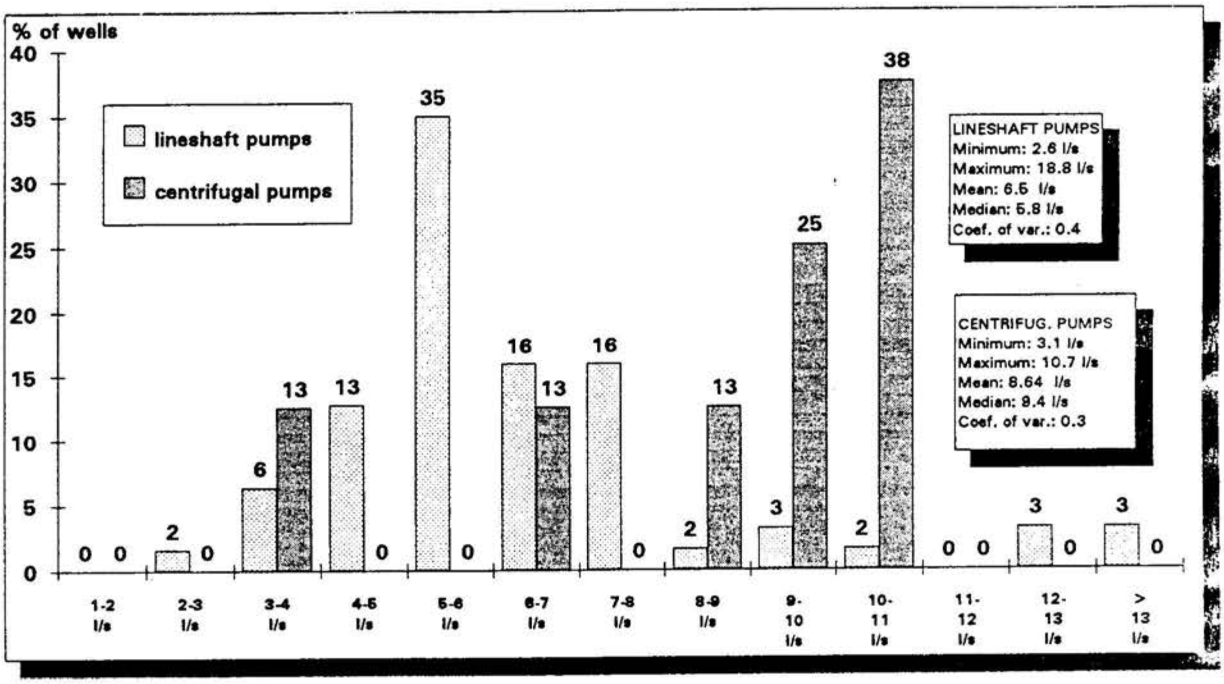
The magnitude of the well yield is determined by several parameters, eg. the capacity of the pump, the well efficiency, the screen length, the depth to water, and aquifer parameters like transmissivity and storage coefficient. Data on the yields of wells with centrifugal pumps and wells with lineshaft turbine pumps have been analysed separately.

The centrifugal pumps used in the Baqim Plain are quite powerful (8 horse power), and the depth to water is small, explaining the high discharge rates ranging from 3.1 to 10.7 l/s with a mean of 8.6 l/s (see Fig. 4.7). The lineshaft pumps have a lower capacity, and producing on average 6.5 l/s (2.6 to 18.8 l/s).

The majority of the wells abstract water from the Wajid Sandstone below the alluvial surface layers. The Wajid Sandstone is classified as a moderate to good aquifer, which partly explains the relatively high well discharge values observed.

The specific discharge, defined as the discharge divided by the drawdown in the well, gives 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. In 22 wells both the static water level (level without pumping) and the dynamic water level (steady state water level during pumping) could be measured. The drawdowns vary from 0.5 to 26 m. with a mean of six metres. Specific discharge values range from 0.3 to 10 l/s/m, with a mean of 2.1 l/s/m.

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



4.7 COSTS OF WELL CONSTRUCTION AND PUMPING EQUIPMENT

Data on the costs of well construction and the purchase and installation of the pumping equipment are presented in Fig. 4.8 and 4.9. The costs of well construction include the drilling of the well, the installation of the casing, the screen (slotted pipes), the gravel pack and the development (air lift) of the well.

The pumping equipment costs involve a more variable package of items. In all cases are included the costs of the pump and the engine; also 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 for the purchase and installation of pipes and tubes to convey the water.

Well construction costs range from YR 6000 (a shallow dug well) to YR 250 000 (a 100 m deep well drilled in 1990). The median well is costs YR 55 000. Well construction costs appear to be much lower than in the Amran Valley (mean YR 228 000). The opposite could have been expected, because of the harder medium to be drilled (sandstone instead of alluvium).

Pumping equipment costs have a much larger variation: from YR 1500 YR 460 000 and a median of YR 110 000. Pumping equipment costs are higher than in the Amran Valley. This can be explained by the younger age of the wells and pumps in the Baqim Plain, ie. more recent prices.

Fig. 4.8 *Distribution of Costs of Well Construction*

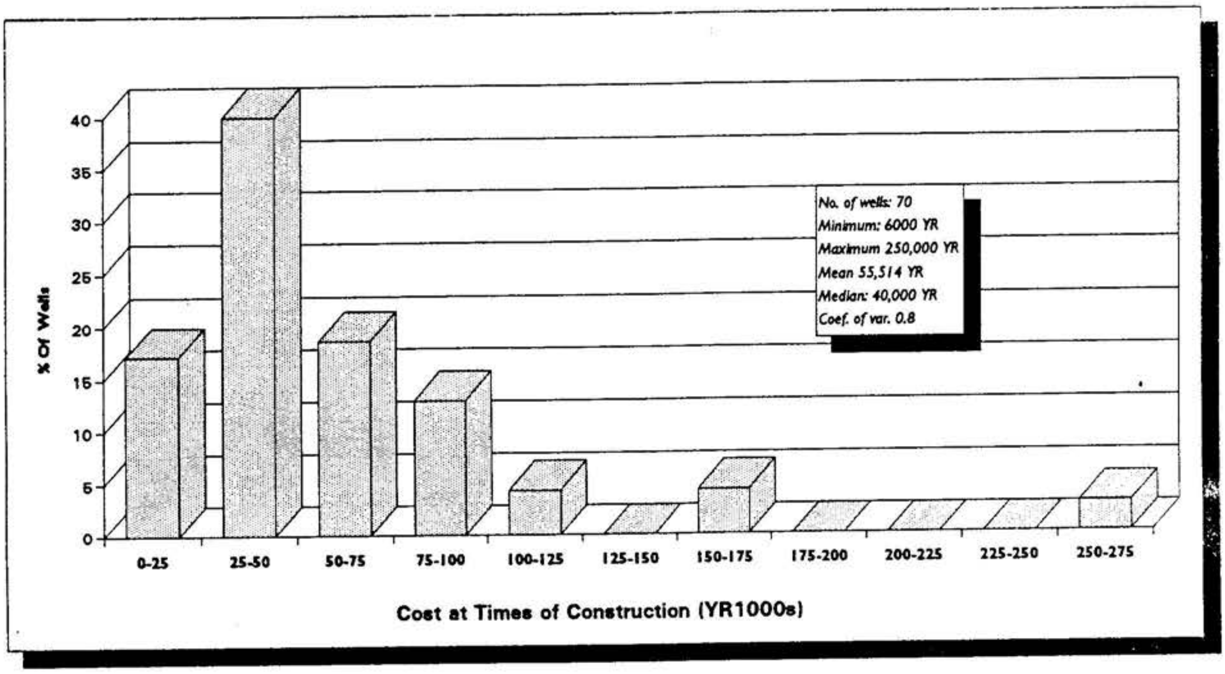
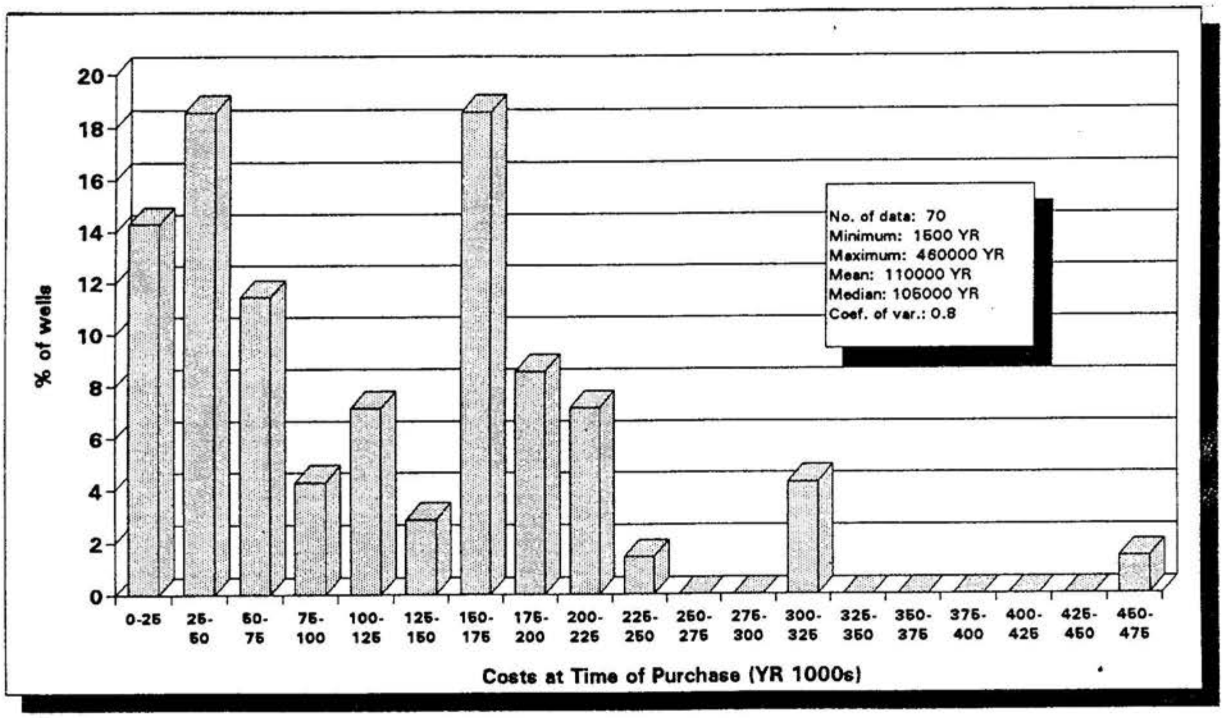


Fig. 4.9 *Distribution of Pumping Equipment Costs.*



In Fig. 4.10 the costs of well construction, excluding the cost of pumps and related equipment, are plotted against the well depth. It must be remembered that these costs are costs at the time of construction or purchase and that the data concern wells drilled during the period from 1978 to 1991.

Fig. 4.10 *The Relation of Well Depths to Construction Costs.*

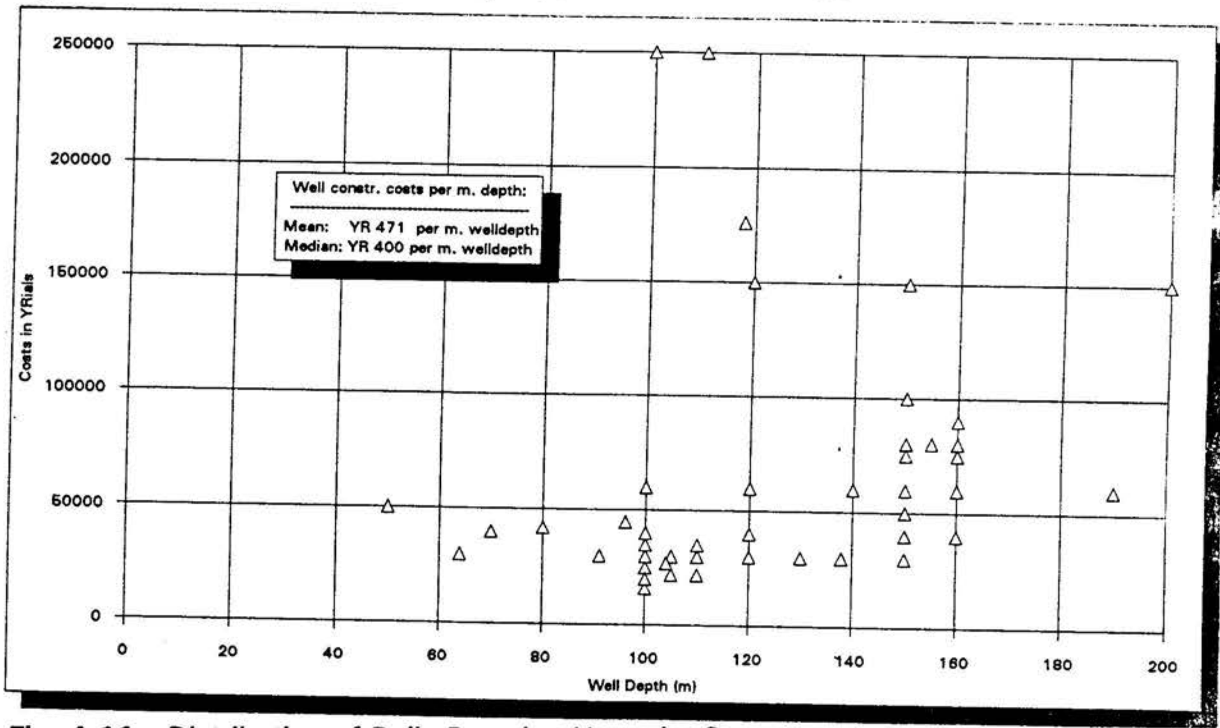
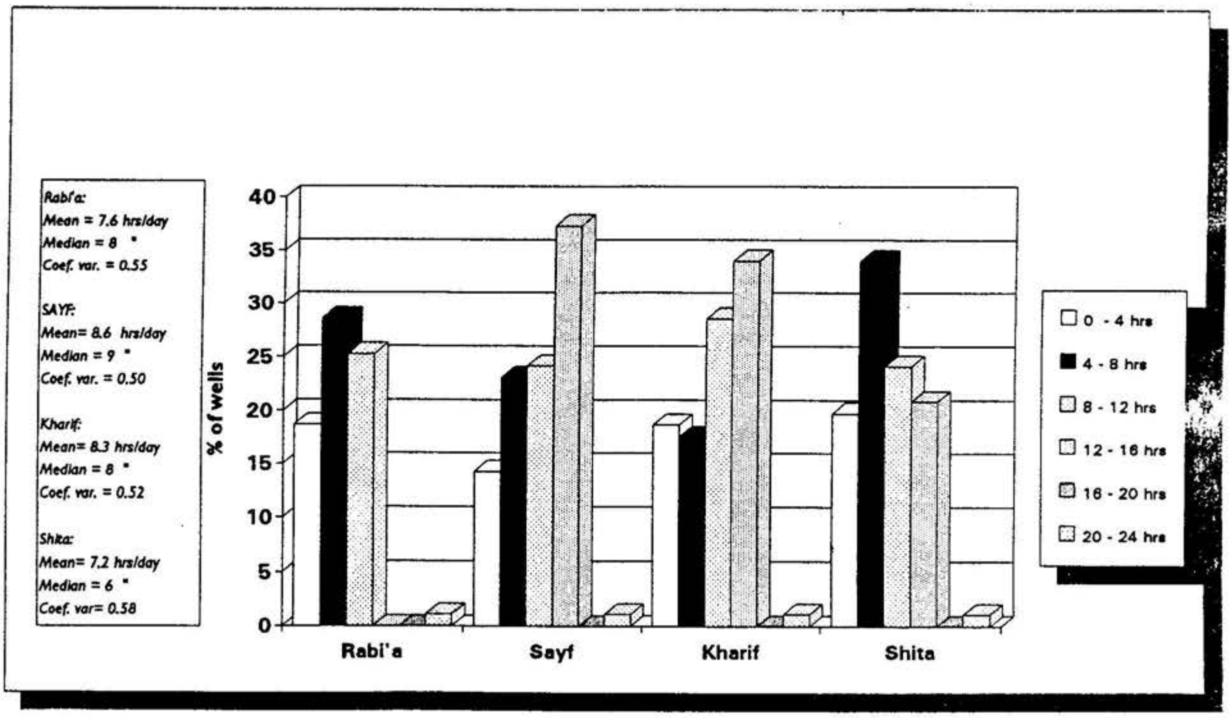


Fig. 4.11 *Distribution of Daily Pumping Hours by Season*



As a consequence of currency inflation, the mean real costs (1991 Y Rials) would be somewhat higher. Almost all wells were drilled in sandstone, but nevertheless drilling costs are very low: an average price per metre of YR 471.

Fig. 4.12 *Monthly Number of Pumping Days*

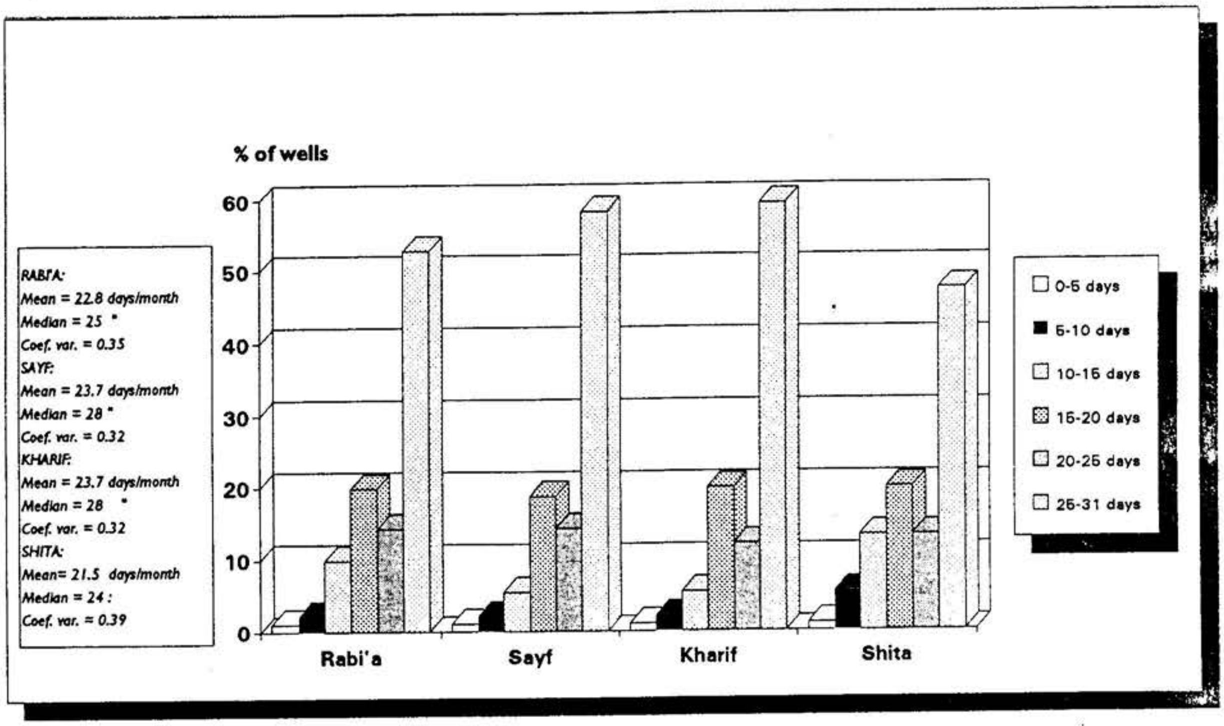
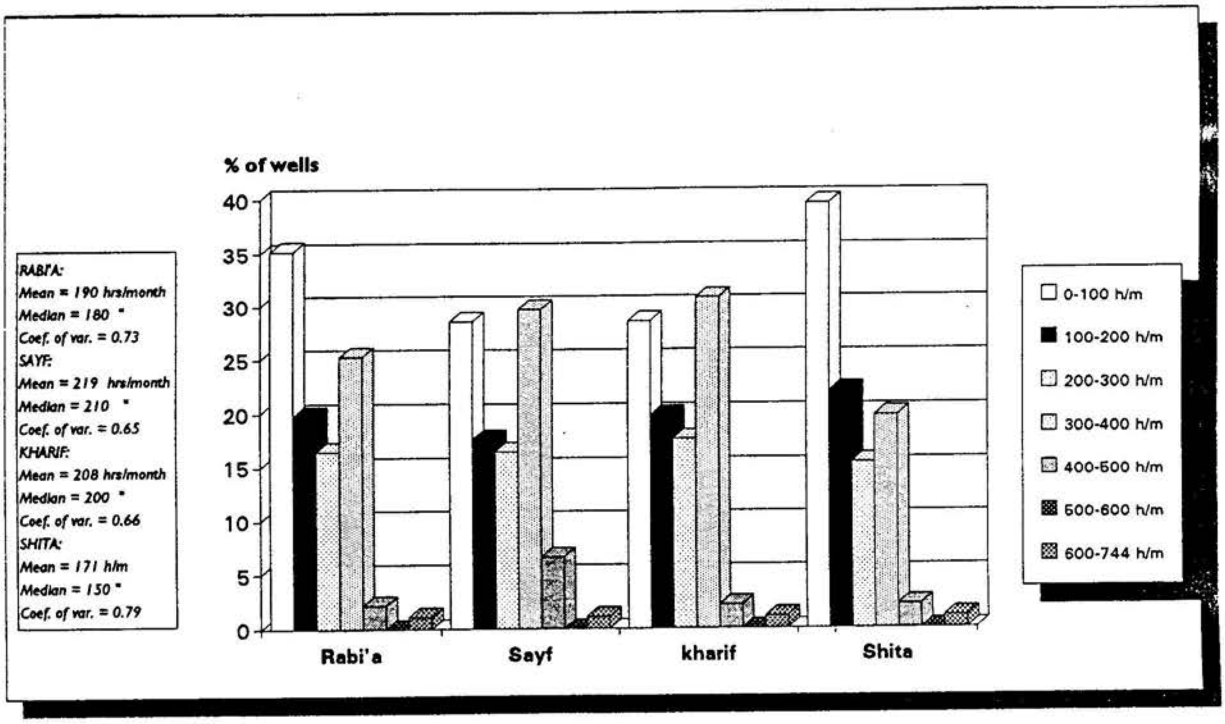


Fig. 4.13 *Monthly Number of Pumping Hours*



4.8 PUMPING SCHEDULES

The average farmer in the Baqim Plain pumps groundwater for 7 to 8 hours per day throughout the seasons; the mean yearly number of pumping hours per day is 7.9. Pumping activities are highest during Sayf[1] (mean 8.6 hrs/day), followed by Kharif (mean 8.3 hrs/day), Rabi'a (mean 7.6 hrs/day) and Shita (mean 7.2 hrs/day).

Fig. 4.11 shows the distribution of the daily pumping hours through the seasons. About 1% of farmers operate the pump 24 hours per day. When considering the whole year, the average number of pumping days per month is 22.9. (see Fig. 4.12). The average farmer pumps 197 hours per month, taken over the whole year (see Fig. 4.13).

4.9 GROUNDWATER ABSTRACTION

To enable the assessment of total groundwater abstraction in the Baqim Plain a fair estimate has first of all to be made of the total number of operational wells. The survey showed that 13.5 % of the wells were permanently out of order (see Section 4.2), so for the calculation of the yearly total discharge, these wells were not taken into consideration. Assuming that 90% of existing wells were surveyed and applying the same percentage of fall out, then about 107 wells would have been operational in the Baqim Plain in 1991.

Table 4.1 *Volumes of Groundwater Abstracted .*

	Rabi'a	Sayf	Kharif	Shita	Year
Groundwater abstracted per well (in 2000 m^3)					
Mean	14.1	16.3	15.6	11.1	57.1
Median	11	12.2	11.8	9.8	47.4
Minimum	0.48	0.67	0.48	0.48	2.1
Maximum	68.9	68.9	68.9	27.3	211.3
Coef. of variance	0.89	0.84	0.84	0.67	0.73
Total volume of groundwater abstracted in Mcm	1	1.16	1.11	0.79	4.05
Based on no. of wells	71	71	71	71	71
Total volume of groundwater abstracted in Mcm (extrapolated assuming a total of 107 operational wells)	1.5	1.74	1.67	1.19	6.11

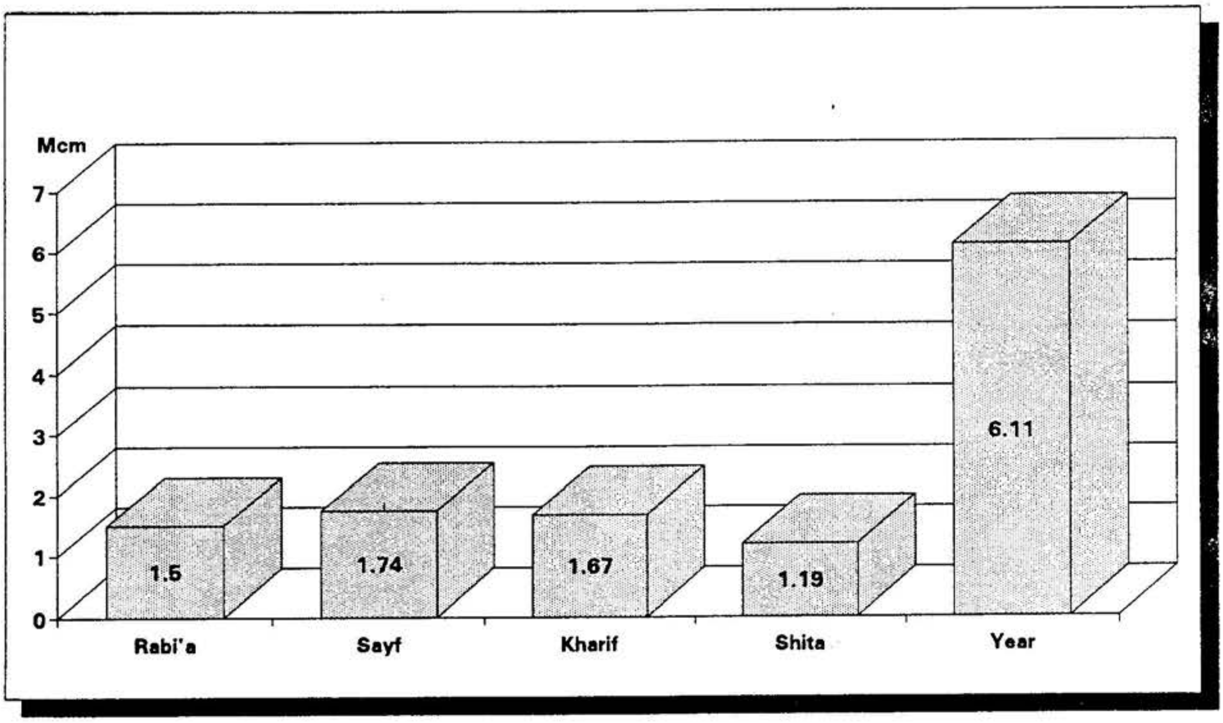
At 71 wells (of the 111 visited) the discharge was measured and data collected on

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

the pumping schedule. At the remaining 40 wells these data could not be collected for the following reasons: the well was dry, no pump and/or engine, no diesel, no oil available, or because of a broken pump/engine; or there was just nobody to switch on the pump and/or to give information on pumping activities. This resulted in a sample of 71 wells for which seasonal and yearly discharges have been calculated.

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. It appeared that the wells were not pumping on these grounds for 5.5% of the time. This was also taken into account when calculating the seasonal and total yearly abstracted groundwater volumes.

Fig. 4.14 *Volumes of Seasonal and Yearly Groundwater Abstraction in 1991*



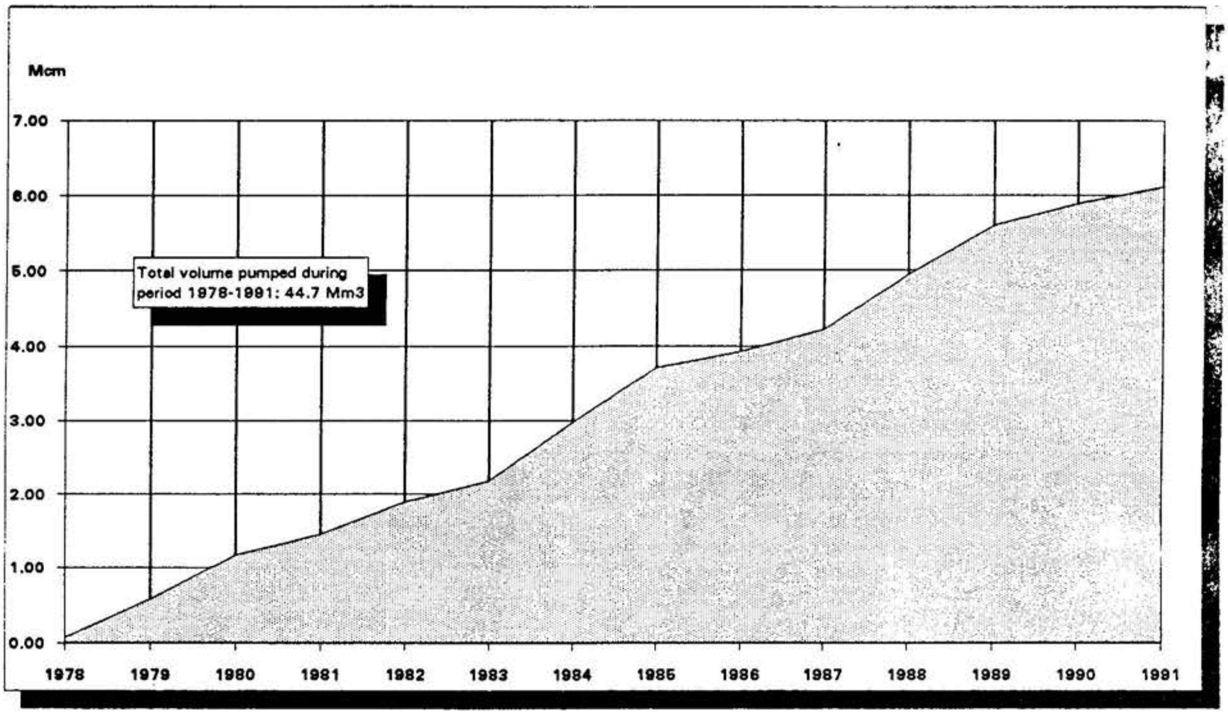
In Table 4.1 and Fig. 4.14 are calculated and presented the seasonal groundwater abstractions. A yearly total of approximately 6.11 million m^3 (Mcm) of was abstracted in the Baqim Plain during 1991.

The abstracted volumes are 1.50, 1.74, 1.67 and 1.19 Mcm for Rabi'a, Sayf, Kharif and Shita, respectively.

Fig. 4.15 displays the yearly increase and volumes of groundwater abstraction during the period 1980 to 1991. It shows that, just as in several other plains in the NORADEP Project region, the rate of increase of the annual abstracted volume has diminished somewhat during the period 1989-1991. A (very rough) estimate of all the groundwater pumped in the Baqim Plain, using figures from 1978 (when abstraction became significant) to 1991, is about 44.7 Mcm, which represents a layer of water 0.81 m deep over the whole Baqim Plain (55 km^2). This, expressed in terms of lost aquifer with an average effective porosity (specific yield) for the Wajid

Sandstone aquifer of 0.075 (Yominco-TNO, 1985), corresponds to a lost saturated aquifer thickness of 100/7.5 * 0.81 = 10.8 metres, over the entire plain.

Fig. 4.15 *Estimated Increase of Yearly Groundwater Abstraction, 1978 to 1991*



4.10 DEPTH TO GROUNDWATER

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

During the well inventory several tapes were lost, stuck in the annular space between the two pipes. This in many cases was the reason that the farmer had to be questioned on the water depth. Usually the depth to the water table was approximately known to him expressed as the number of three metre long pump column pipes; many farmers also measure the water level regularly with a marked cord.

However, practically all farmers know the depth of the pump - expressed as the number of pump column pipes above the pump. Because this figure appears to be the more reliable indicator of depth a contour map of the depth to pump has also been composed, as a quality control. It was found that the pattern of groundwater depth almost completely corresponds with the pump depth contour map. Thus the map of water depth could be regarded as fairly reliable, and is presented as such in Fig. 4.16. Groundwater depths in the Baqim Plain range from 3 m (in the extreme south

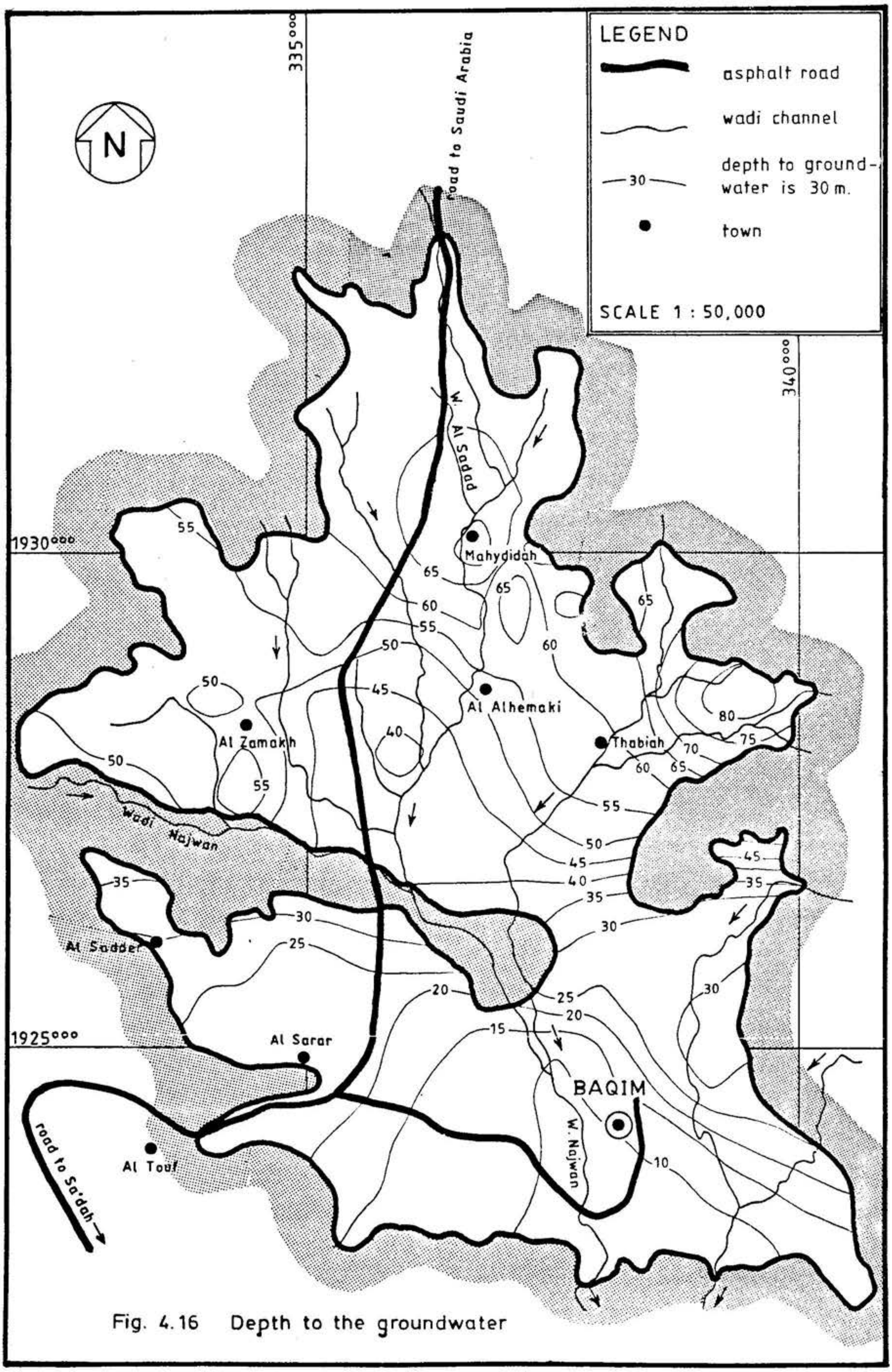


Fig. 4.16 Depth to the groundwater

near Wadi Nagwan) to 84 m (in the tributary valley east of Thabiah). Groundwater levels are also relatively deep (65 to 80 m) in the northern part of the plain. Despite the high concentration of wells around Baqim town, groundwater depths here are extremely shallow (less than 10 m). This might be the result of recharge from wadi Nagwan which crosses this area. No depressions in the water table as a result of excessive pumping were observed in the plain.

4.11 GROUNDWATER PIEZOMETRIC LEVEL

A piezometric map (Fig. 4.17) has been composed by contouring the piezometric levels - being the difference between groundwater depth and ground surface elevation above mean sea level (amsl) at each well site. Thus, the piezometric contour lines indicate the groundwater level, expressed in metres amsl.

Piezometric levels lie within a small range dropping from 2140 m in the north to 2072 m in the extreme south near Wadi Nagwan. As can be observed on the piezometric map general groundwater flow is directed towards the south. Because the north-south decline in the piezometric level is less than the drop in the surface altitude, depth to groundwater decreases towards the south. This can be clearly observed in Fig. 4.18, a north-south cross-section through the Baqim Plain.

Taking the water levels at the extreme margins of the cross-section, the hydraulic gradient of the water table is equal to 0.0055 (42 m /7600 m).

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

4.12 LOWERING OF GROUNDWATER LEVELS

To enable analysis of the time dependent trends in groundwater levels a time series of groundwater depth is needed. However long term data on water levels are available for the Baqim Plain. There is a high concentration of deep wells around Baqim town (see Fig. 4.1), but no dramatic lowering of water levels has occurred, yet. In fact the water level here is still strikingly shallow (about 10 m below ground level). A relatively large catchment area west of the plain, combined with the permeable sandstone, seem to ensure replenishment of groundwater.

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. For almost all the wells visited, the EC of the pumped water was measured in microSiemens/cm converted to 25°C (microS/cm). The measurements not only give an indication of the areal distribution of water quality, but can also indicate its variation with depth, because the measured value is often related to the depth from where the water is pumped.

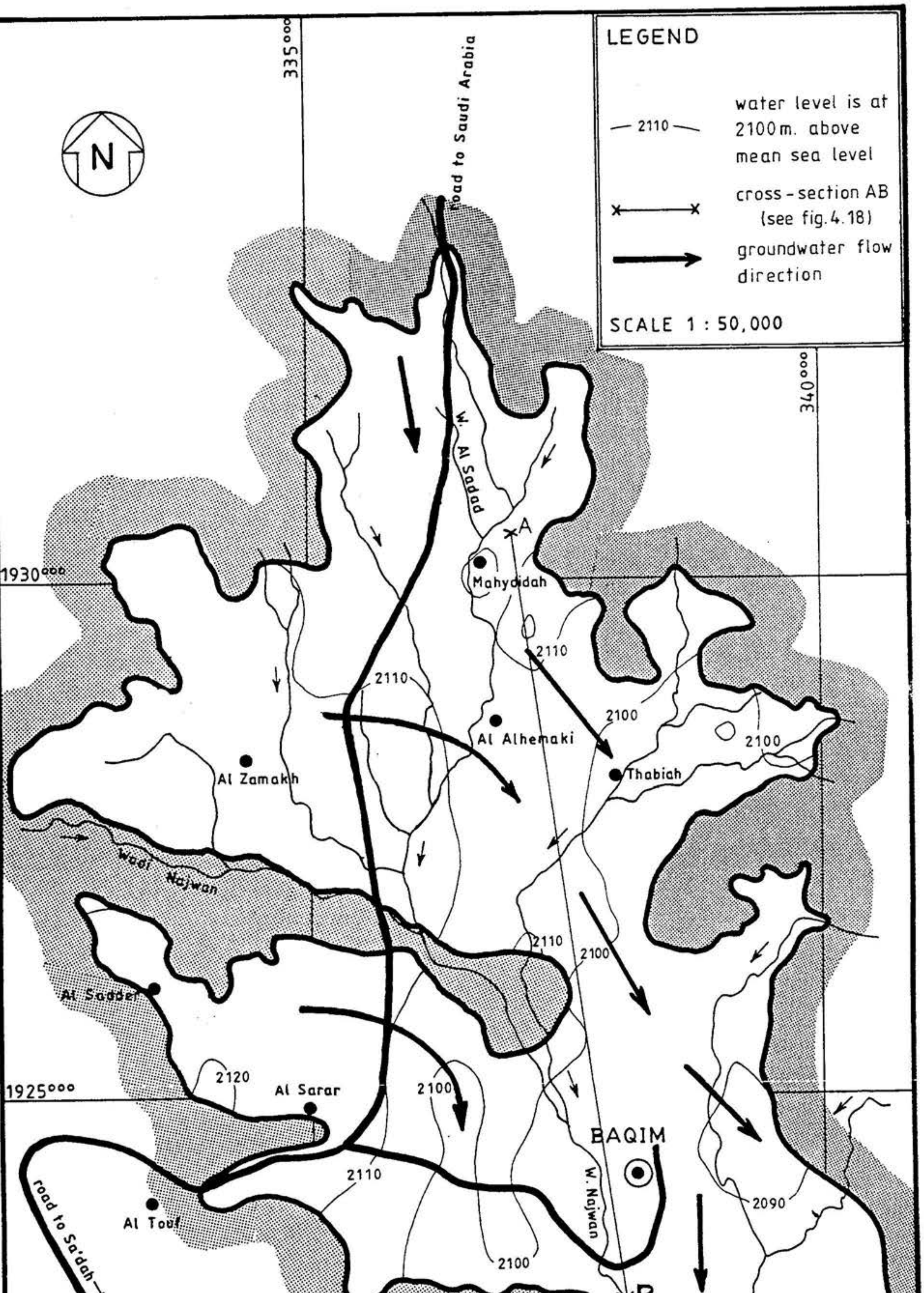


Fig. 4.17 Map of the piezometric groundwater level

Fig. 4.18 *Cross-section A - B (For location, see Fig. 4.17)*

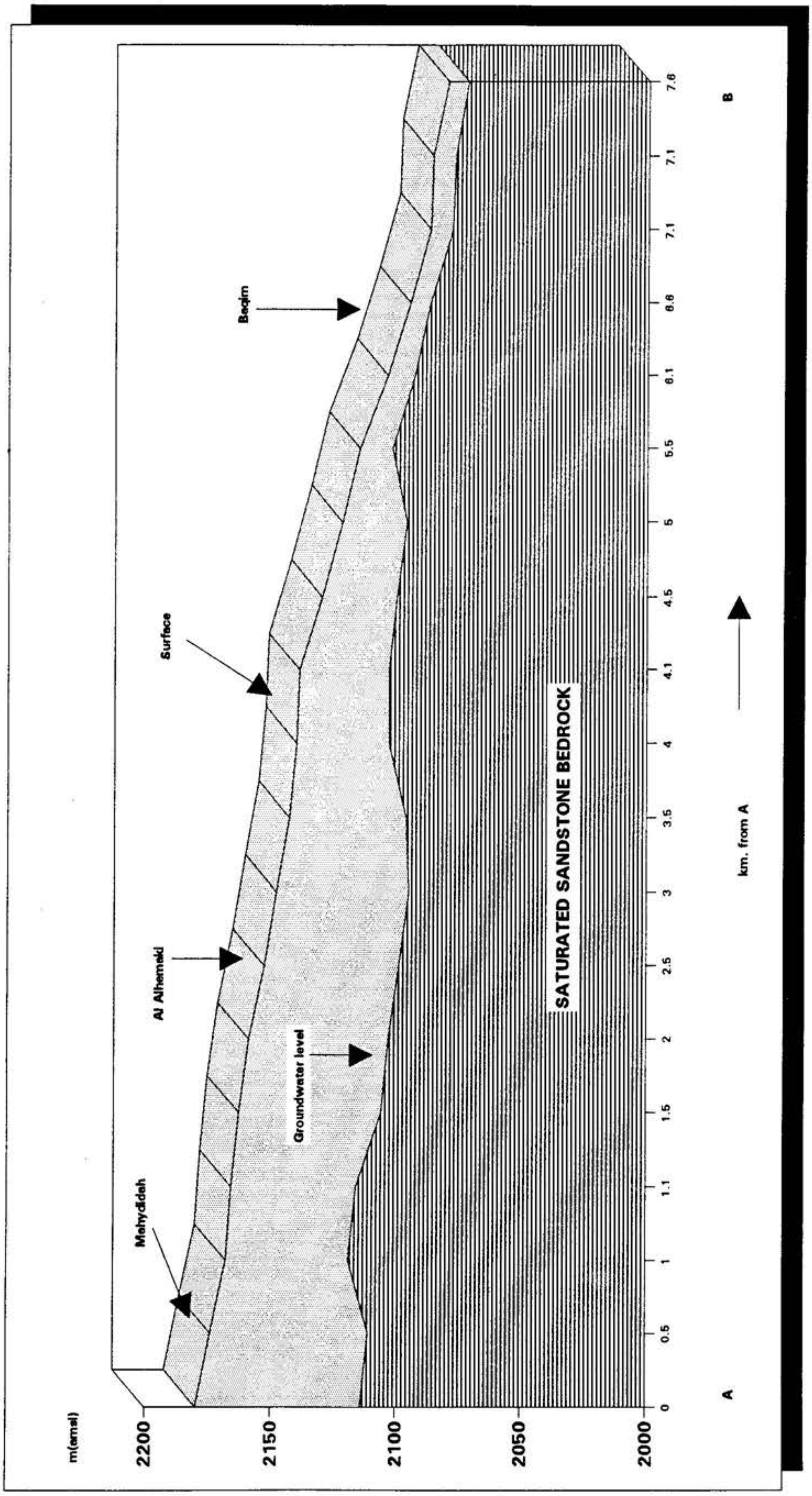


Figure 4.18 Cross-section A-B (for location, see fig. 4.17)

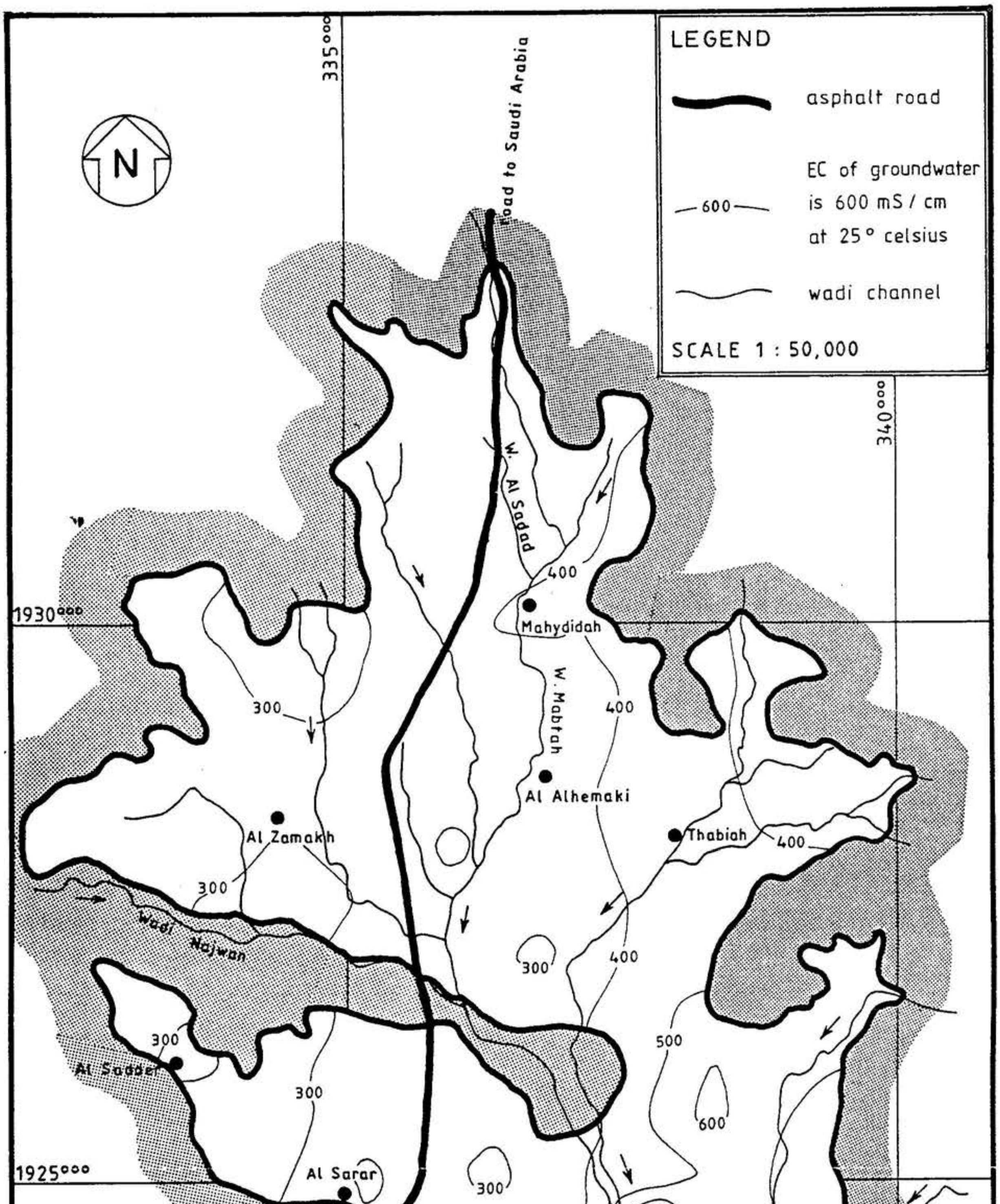
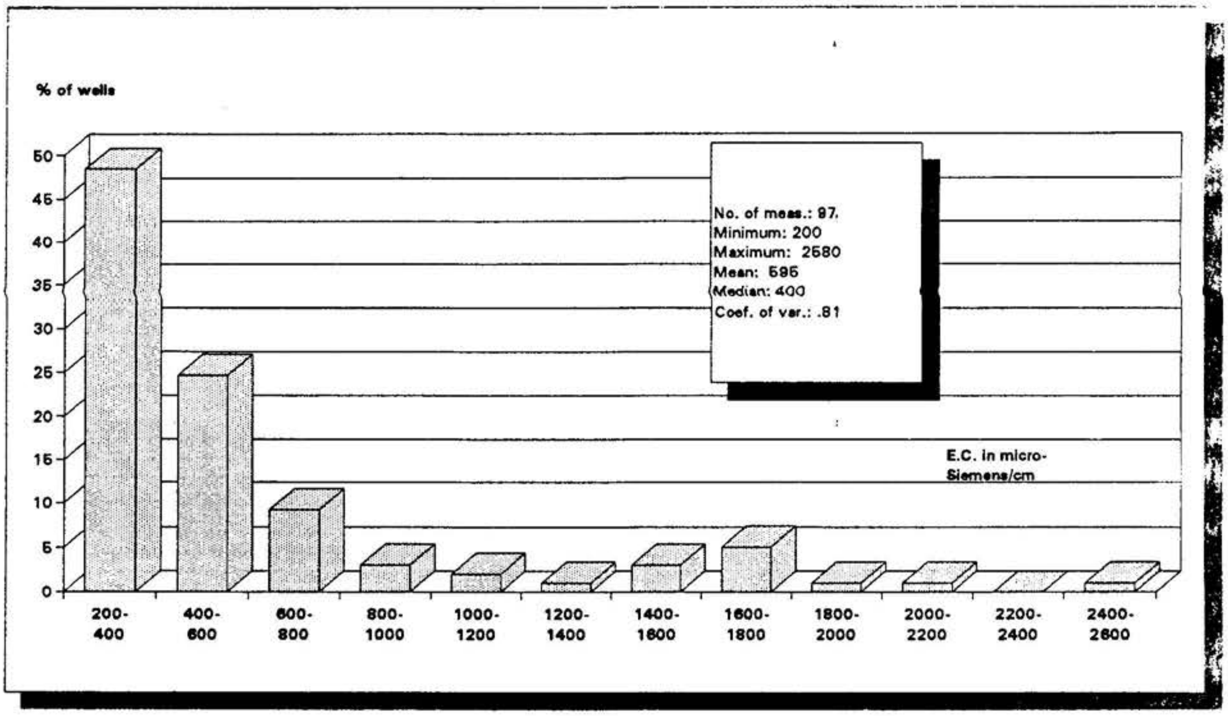


Fig. 4.20 Map of the groundwater electrical conductivity (EC)

Fig. 4.19 shows the distribution of the electrical conductivity values over all the measurements carried out. The minimum value was 200, the maximum 2580, and the mean was 595 microS/cm. A high percentage (73%) of all measurements showed values lower than 600 microS/cm. This means that, in general, the groundwater of the Baqim Plain has a low salinity. The mean EC-value of all the measurements is slightly higher than the mean for the Amran Valley (571).

An explanation for these low values might be that the water here originates from the Wajid Sandstone. As a consequence of its reasonably high permeability the residence time of water is relatively short and little mineralization will occur.

Figure 4.19 *Distribution of the Electrical Conductivity of Groundwater*

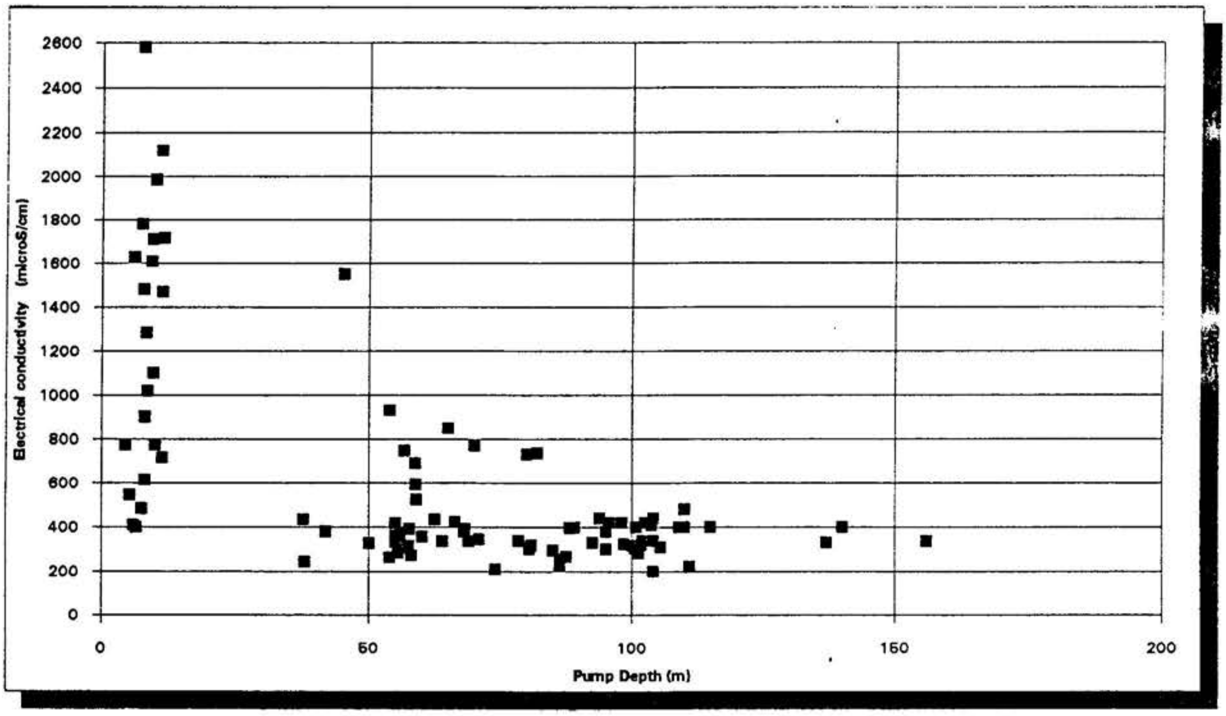


The coefficient of variation of the measured EC-values was 0.81. It represents a measure of deviation from the mean (standard deviation/mean), and implies, assuming a normal distribution of all the values, that 67% of the EC-values are within the range (1-0.81) * mean and (1+0.81) * mean, ie. 67% of the measurements have EC values ranging from 113 to 1077 micro S/cm.

The measured values have been contoured and presented in Fig. 4.20. The groundwater salinity in most of the plain is low and ranges from 300 to 600 microS/cm. However, in the south the situation is different: high EC-values (from 1000 up to 2580) have been measured west and south of Baqim Town and also at the extreme southern margin of the plain. All these high salinity values were measured in shallow dug wells; nearby deep wells showed typical low EC-values. The high salinity in these shallow wells might be a result of water pollution and or evaporation. Another (geological) explanation might be found in the possible occurrence of shaley layers at shallow depths (Akbra Shale?).

Fig. 4.21 shows the relation (or rather the absence of relation) between the measured EC and the depth of groundwater; there is no evidence that salinity increases with depth. High salinity seems to be determined only by the presence of shaley layers interbedded with, or on top of the Wajid Sandstone.

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



4.14 GROUNDWATER TEMPERATURE

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

Temperatures range from 13 to 25°C, with a mean of 21°C and a median of 22°C. Dispersion is low: the coefficient of variation is only 0.14. Extremely low temperatures (13-16°C) have been measured during pumping from some shallow dug wells, which are not representative of the groundwater and must be attributed to the fact that the measurements were carried out in January 1992, in winter time. Deep wells show higher temperatures, varying between 20 and 25°C.

Fig. 4.23 shows contour lines of equal groundwater temperatures. The southern part of the plain shows lower water temperatures, but here as a result of shallow water depths most of the shallow dug wells are sited.

To find out if a relation exists between water depth and water temperature, values of the temperature have been plotted against the "effective depth" of the well (see Fig. 24). The effective depth has been introduced to get a better indication as to the depth from which water originates during pumping, and is defined as the depth to

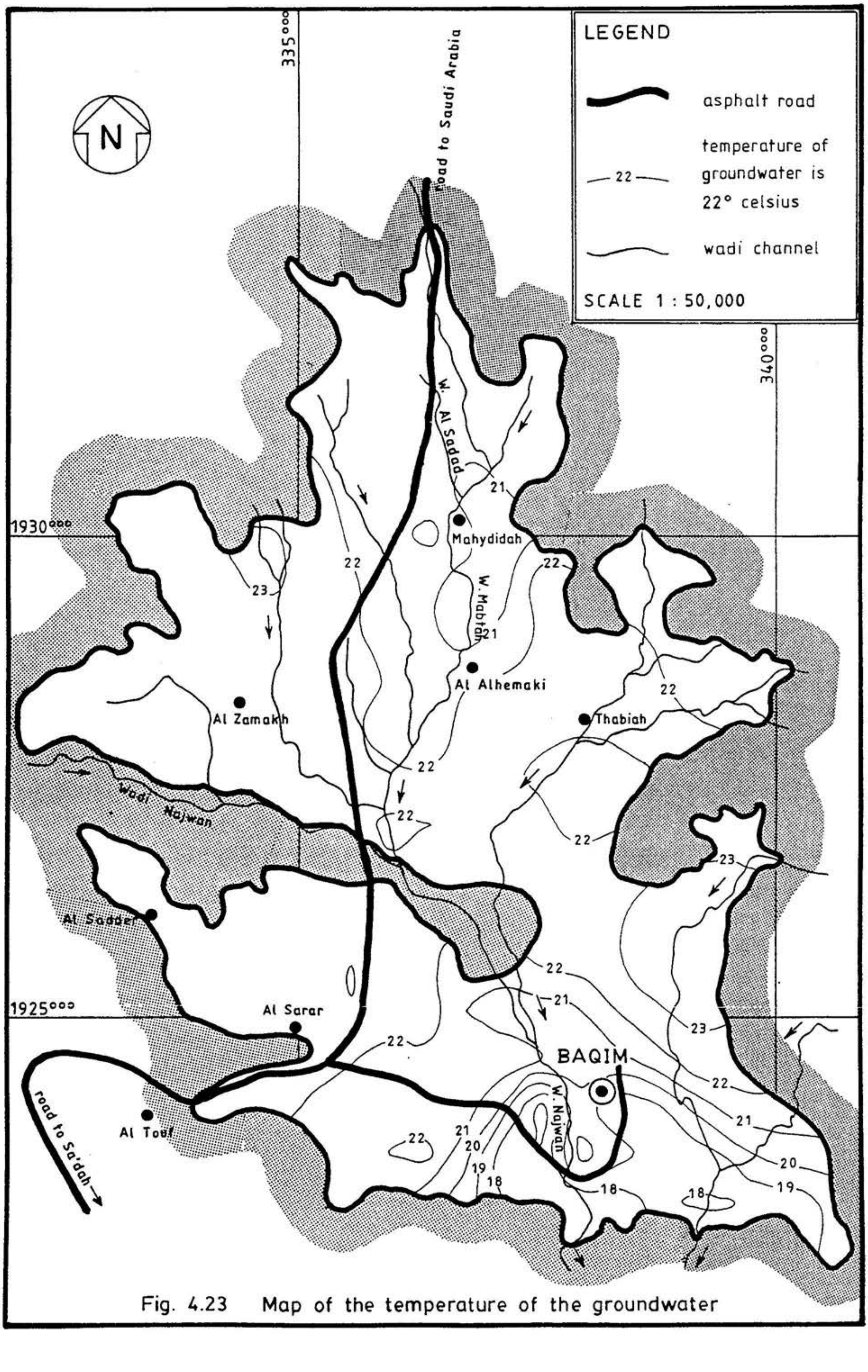


Fig. 4.23 Map of the temperature of the groundwater

static water level inside the well plus the difference between well depth and the static water level depth ie. the effective depth is that depth halfway between the static water level and the bottom of the well.

Fig. 4.22 *Distribution of Groundwater Temperature*

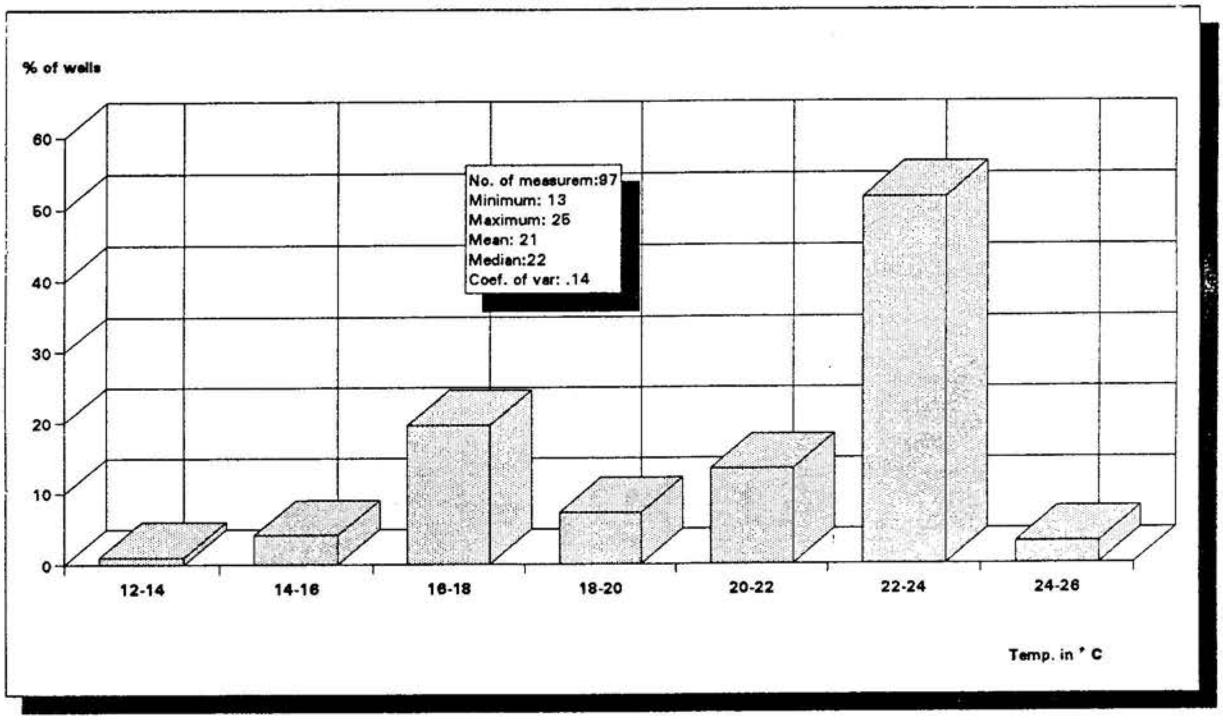
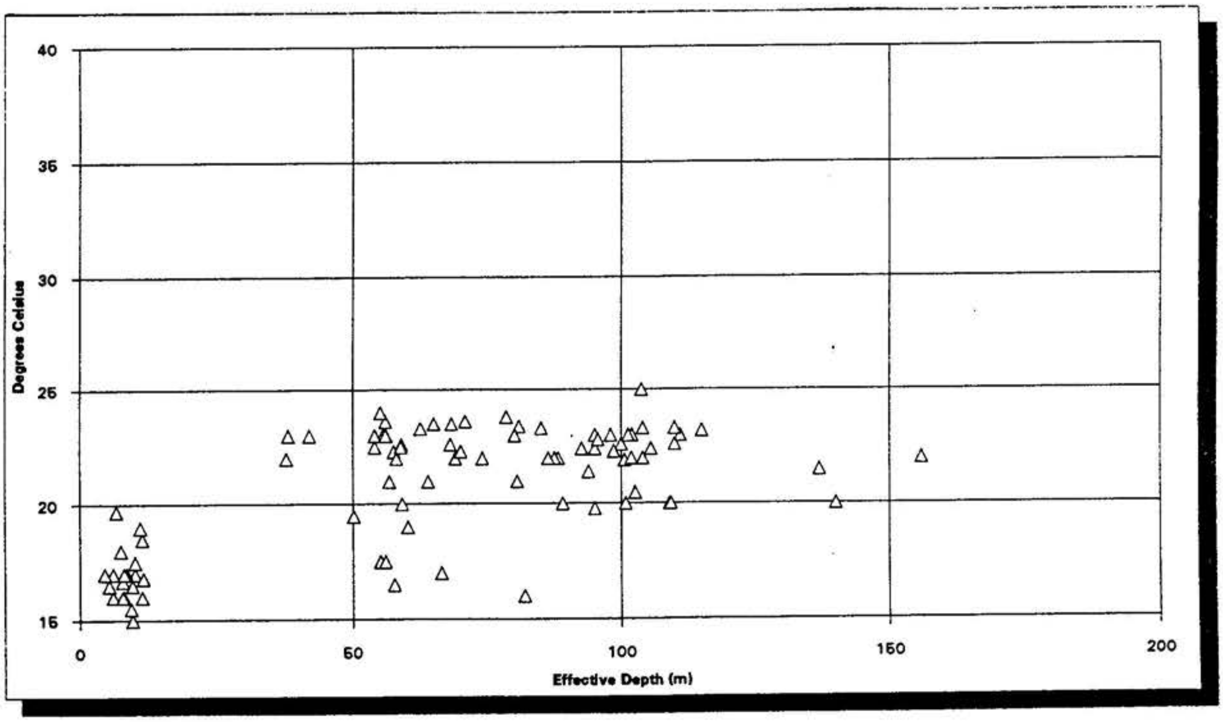


Fig. 4.24 *Relationship between Water Temperature and Depth.*



There is no significant positive correlation between water depth and water temperature. However, the figure clearly demonstrates the low water temperature in the shallow (less than 20 m) dug wells.

5 GROUNDWATER USE

5.1 GROUNDWATER IRRIGATED FARM SIZE

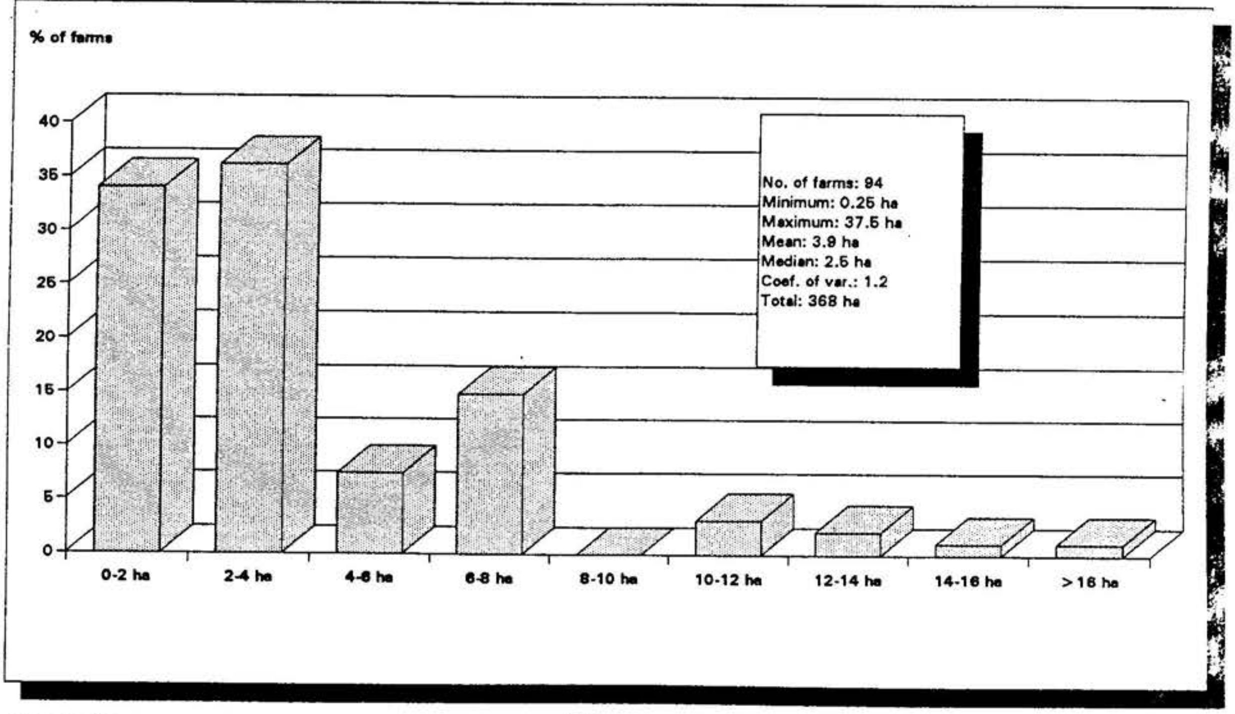
In January 1992, data was collected on the size of 94 of the farms visited as part of the well inventory. The total area was 368 ha, of which 216 ha (59%) were cultivated and 152 ha were fallow (assumed local measure 1 habla = 25 m^2).

An estimate of the total commanded area was obtained by extrapolating from these figures, assuming: a total of 107 farms with groundwater irrigation (see section 4.2), and the same sample distribution for the additional data as for the collected data. On this basis the total area commanded by groundwater is 246 ha (see Table 5.1). The average command area was about 2.3 ha per well.

Table 5.1 *Farm Area.*

	Based on available 94 farm data	Extrapolating assuming a total of 107 groundwater irrigated farms
Total area of farms where groundwater is applied	368 ha	419 ha
Area Commanded by groundwater	216 ha	246 ha
Fallow	152 ha	173 ha

Fig. 5.1 *Distribution of the Total Farm Size (ha)*



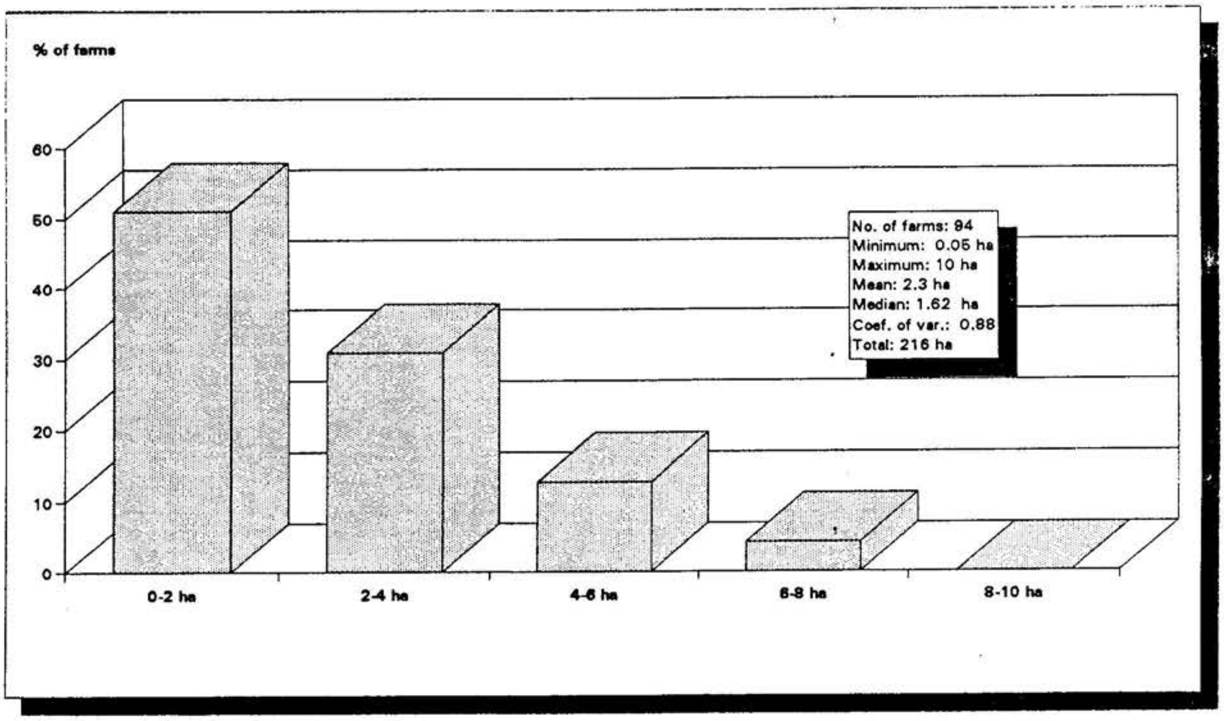
It must be emphasized that these figures are based on farms where groundwater irrigation is applied, so rainfed cultivated farms are not included.

Fig. 5.1 shows the distribution of farm size for farms that apply groundwater irrigation, and that were visited. The smallest plot was 0.25 ha, the largest 37.5 ha- an extensive farm near Al Sadder in the west, where, however, only 2.5 ha were cultivated, while the remaining part was fallow.

Most farms were small: 70% had an area of between 2 and 4 ha; the mean total farm size was 3.9 ha and the median 2.5 ha.

Fig. 5.2 shows the distribution of the farm area commanded by groundwater. The mean commanded area was 2.3 ha with a median of 1.62 ha. The smallest plot was 0.05 ha and the largest 10 ha. The dispersion, expressed as coefficient of variation, was rather high (0.88). Most irrigated farms (82%) had a total commanded area ranging from 0 to 4 ha.

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



5.2 CROPS

In the well inventory questionnaire space was also made to collect information on crops: major and secondary crop types and their total irrigated areas for each season.

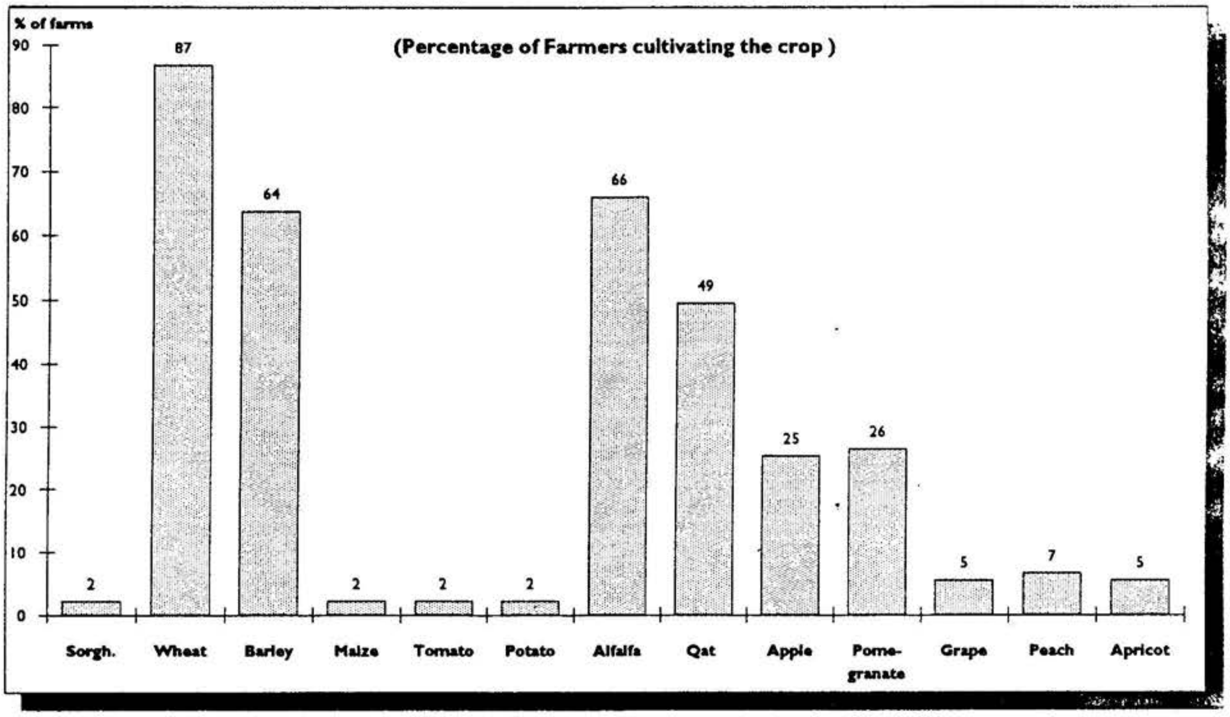
These data are summarized in Fig. 5.3 to 5.6, which show that of the perennial crops, alfalfa was grown by most of the farmers (66%), followed by qat (49%), and the fruits pomegranate (26%), apple (25%), peach (7%), apricot (5%) and grape (5%).

Of the annual crops, wheat was cultivated by 87% of the farmers during the seasons Shita and Rabi'a. During the same seasons, barley was grown on 64% of the farms. Sorghum was the major annual crop during Sayf and Kharif (97%).

Other cash crops recorded were tomato - cultivated during Rabi'a and Sayf and potato - grown during Rabi'a, Sayf and Kharif. These crop patterns demonstrate the attractive aspects of groundwater irrigation for the farmer. In contrast to the traditional but unpredictable practice of spate irrigation and even less reliable rainfed cultivation, where at the most one harvest per year was possible, most crops can now be sown and harvested the whole year round. In the Baqim Plain, for instance, wheat and sorghum are cultivated by some farmers during the whole year. Moreover, the high risk of crop failure as a consequence of the absence of rainfall and spate water, diminished significantly with the start of pumped irrigation. In the 1970s on the rainfed and spate irrigated land, the average loss of sorghum was 40%, and of wheat and barley up to 50% (Rethwilm/Brandes, 1979).

The cultivation of sorghum in the winter (Shita) was mentioned by some of the farmers, which would be either the first ratoon phase of the crop sown in May and April or a second planting. Commonly sorghum is sown during April and May, and many farmers, after harvesting the grain during September and October, let the crop grow again (ratoon) solely for fodder .

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



Wheat and barley, the other two traditionally cultivated crops in the plain, are sown during November or December; harvest is in March and April. This is the most common practice, but on some farms a second crop of wheat is sown during June and July, to be harvested in October and November.

Fruit crops like apple, pomegranate, grape, peach and apricot were introduced only recently by some progressive farmers. Both single and inter-cropping patterns were observed.

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

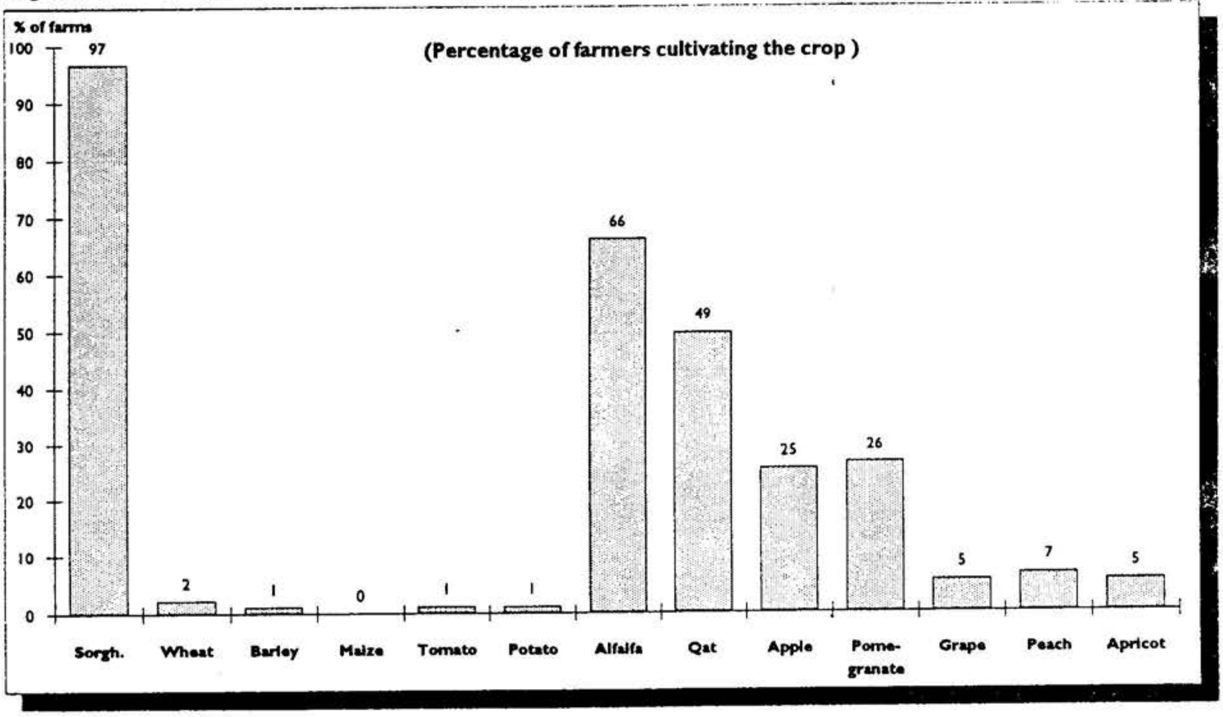
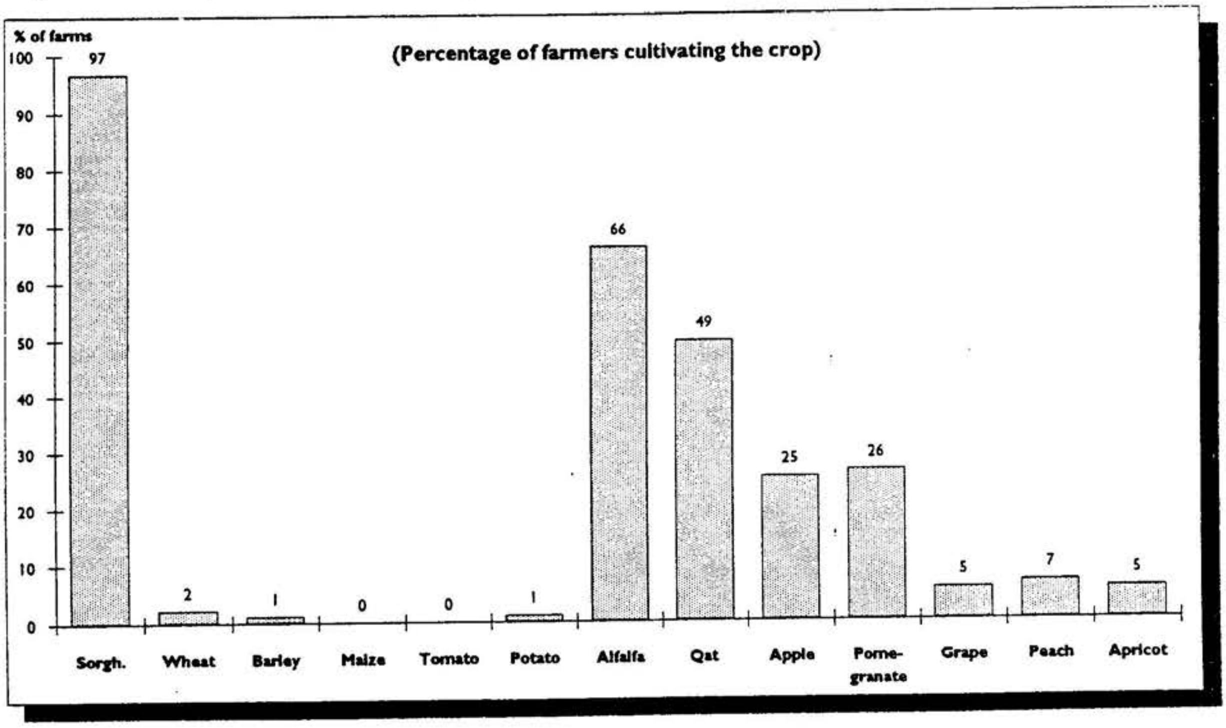
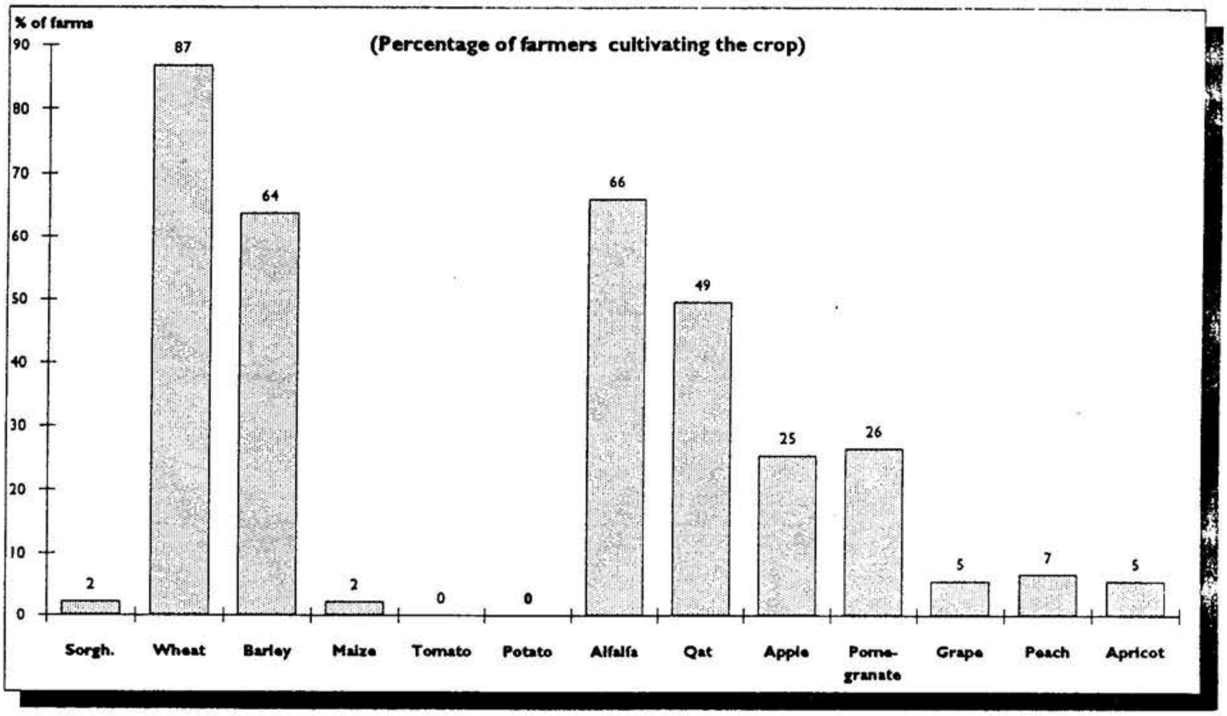


Fig. 5.5 *Crops Cultivated during Kharif (Autumn).*



Large plots tending to show more single crop cultivation - sorghum, wheat and barley - than the smaller plots, where, generally, a more mixed crop pattern was found.

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



5.3 IRRIGATION PRACTICE

After it has been pumped the water is conveyed through earthen channels or pipes to the fields. According to field tests carried out by GTZ in Al Boun Plain in 1979, water losses during conveyance in the traditional open irrigation channels are usually some 50-65%, depending on the distance. Other water losses can result from over-irrigation and/or inefficient irrigation schedules (see Section 5.6). The irrigation method generally used is one of the surface spreading systems: border, furrow or basin. The border method is usually used for the irrigation of wheat and sorghum, furrow irrigation for potato, tomato and water melon, and basin (also some furrow) irrigation for fruit crops.

The frequency of irrigation application is highest for tomato, alfalfa, and the fruit trees, the crops with the highest total costs and, except for alfalfa, the greatest benefits. The lowest margins are on the growing of cereals like sorghum, wheat and barley (Amran Valley, Hossain/Nouman, 1991).

A high percentage of the total cultivatable area of the Baqim Plain not irrigated by groundwater irrigated (about 90%) is used for rainfed and spate irrigated crops. The remainder is permanently fallow because of the shortage of water.

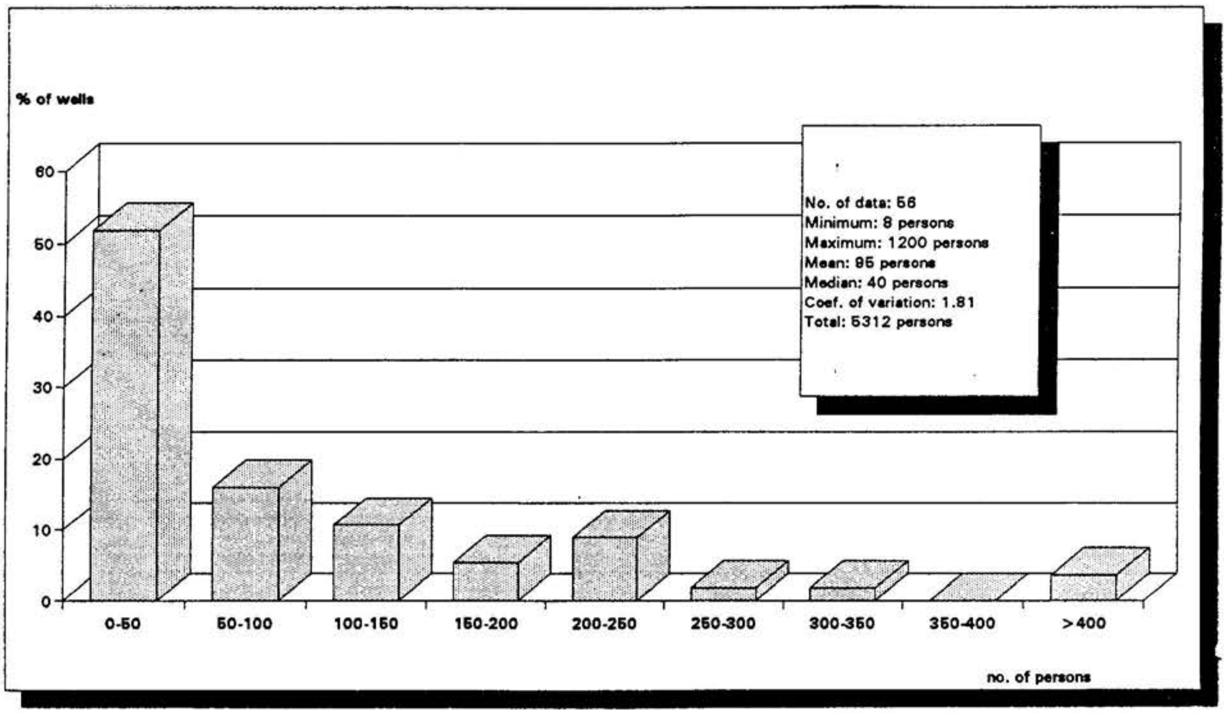
5.4 USE OF FERTILIZERS

Crop rotation including following is used to maintain soil fertility and to economize on the usage of fertilizers. Both chemical fertilizers and organic matter are added, the former at regular intervals. On 72% of the farms fertilizers were applied, chemical fertilizer alone on 17%, and both chemical fertilizers and organic matter on 55%. Livestock waste is usually not used as fertilizer, but is dried for fuel.

5.5 DOMESTIC WATER USE

The distribution of the number of persons depending on one well is presented in Fig. 5.7. There is a wide dispersion (1.81); the number of persons ranges from 8 to 1200 persons (for a 300 m deep well that supplies the northern part of Baqim town). About 5% of the pumped groundwater is used for domestic purposes (compare Amran Valley - 4%). The average number of persons that use water from one well is 95 (Amran Valley - 283). Due to the large number of persons consuming the water from a few wells this value is distorted. A better impression is given by the median of about 40 persons (Amran - 100). A total of 5,312 persons were dependent on 56 wells, the number of wells for which the domestic water consumption data were complete. When extrapolated, assuming a total number of 107 operational wells and the same statistical distribution for the missing data, a total of 10 150 people would have consumed well water in 1991, perhaps a general indication of the number of inhabitants in the valley (see Table 5.2). The census of 1986 gave a figure of 7300, which with population growth at 3.3% per year would be 8600 in 1991.

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



It must be remembered that many farmers sell water from their well to consumers elsewhere in the plain; transport is usually by tank-trucks. The average number of persons per house is high: the mean number of persons supplied by one well (95) corresponded with an average of 12 houses, giving 7.9 persons per house.

Table 5.2 *Domestic Water Use.*

	Person using water	Domestic water use assuming 40 l/day/capita (m^3/year)
Per well:		
Mean	95	1387
Minimum	8	117
Maximum	1200	17520
Sum (based on 56 wells)	5312	77555
Total (extrapolated, assuming a total of 197 operational wells)	10150	148186

Assuming an average daily water consumption of 40 l per capita, the mean annual domestic water use per well was 1387 m^3 (Amran Valley 4,132 m^3), and total water consumption from all the wells in the Plain was 148 186 m^3 per year (see Table 5.2).

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

5.6. IRRIGATION WATER APPLIED

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

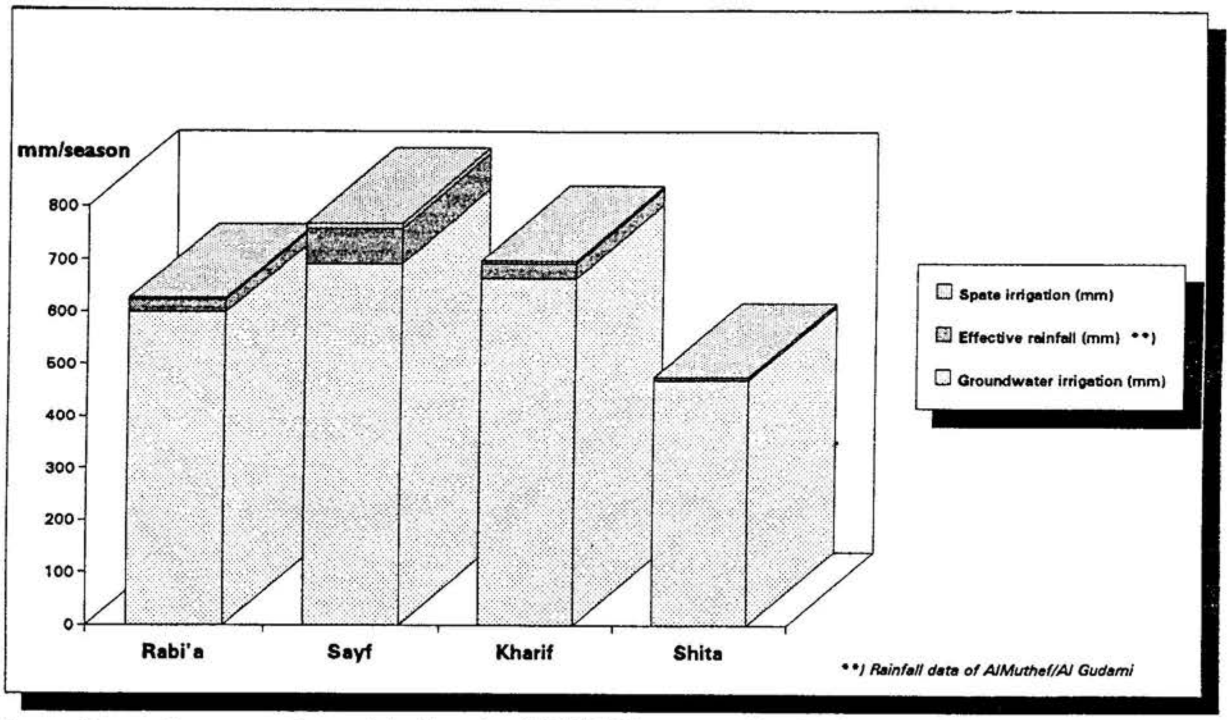
As has been explained in the section on crops a detailed description of the land use of each farmer would need information on crop types, cropping calendar and cropping patterns throughout the seasons. The collection of these data would be too elaborate and time consuming in the context of a well inventory.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

Firstly, an acceptable estimate of the total area commanded 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.

No data on potential evaporation are available for the Baqim Plain. A tentative solution has been found by applying already existing potential evapotranspiration data, valid for the nearby Amran Valley. Eger (1987) published values of crop water requirements for the main cultivated crop types. From this it appears that most crops have a consistent average daily net crop evapotranspirational need of about 4.0 mm, when considering the whole growing period. With no more appropriate and specific data on potential evaporation from the Baqim Plain itself, these figures have been used to arrive at a total yearly crop water demand. Because calculations of applied water quantities are made on a yearly basis, these figures will be sufficient to arrive at an adequate estimate of the annual crop water requirements in the study area. Thus an annual crop evaporational demand (ETc) of 1460 mm has been established for the groundwater irrigated part of the Baqim Plain.

Rainfall data were obtained from Al Muthef and Al Gudami (about 30 km south east of Baqim town) for the period 1983-1989. Spate irrigation values were derived from farmers' information and the rainfall data.

Fig 5.8 *Seasonal Irrigation Water Application*



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

- Not all the area commanded by ground water is irrigated at any one time, because not enough water is pumped to meet crop water requirements.

- Farmers' irrigation scheduling is not optimum.
- Water conveyance and application is not efficient: there is seepage from unlined conveyance canals (no more than 30% of water is conveyed in pipes from pipe to field-edge); land levelling is inconsistent; the layout of basins, border 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 5.3, in which the volume of water abstracted in 1991 is balanced with domestic and irrigation usage, and the return flow to the aquifer through deep percolation.

Table 5.3 *Baqim Plain - Annual Groundwater Use in 1991*

Total Groundwater Abstracted (Mcm)	6.11
Domestic Water Use (Mcm)	0.15
Irrigation Water Use (Mcm)	5.96
Commands Area (ha) (1)	246
Average Area Irrigated (ha) (2)	162
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 65 % (30 % piped conveyance)
Application efficiency 55 % (Uneven levelling and slopes)
Total efficiency 35.8 %
(4) Based on data from Al Muthef & Gudami (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 that in groundwater irrigated farms spate irrigation and rainfall represent only a minor contribution to the total irrigation water volumes.

6 THE COST OF PUMPING GROUNDWATER

A model has been made for the calculation of the cost of both one hour of groundwater pumping, and of one m^3 of pumped groundwater. Various cost items have been taken into account in the calculation procedure, and have been subdivided into investment and O&M (Operation and Maintenance).

All costs, including the investment costs, are treated as variable costs, ie. they are expressed per operation hour and not fixed for a certain number of years. The reason is that the lifetime of the most valuable components of the well and pumping equipment is not a fixed period, but depends on the farmer's pumping schedule: the intensity of use. For example, the pump and the engine have a lifetime of a certain number of operation hours and so a higher pumping intensity will result in a shorter lifetime when expressed in years, and the reverse. The O&M costs are all defined on an operation hour basis and are, therefore, variable.

The following assumptions have been 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 pump house are longer than the lifetime of the well.
- The higher cost of pumping from greater depths is fully covered by deeper and more costly wells; more powerful and thus more expensive pumps and engines and, as a consequence, higher diesel consumption rates per operation hour,
- Interest costs are not considered in the calculation model because the majority of the farmers in the Baqim 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 are being 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 are made by several shareholders that also will hold rights in the well according to the size of their share.
- 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 are not included. because the majority of the wells are drilled to such a depth in relation to the local water table that deepening is considered not necessary during the considered period of 80000 operation hours.

In the calculation model a (variable per well) period has been taken for defining the costs per operation hour and the cost of one m^3 of pumped water. This period has been set equal to 80 000 operation hours, the assumed lifetime of the most valuable components of the well - the casing and the screen. In the Baqim Plain where the average farmer pumps 2374 hours per year this corresponds to a well lifetime of almost 34 years.

The pumping equipment when considering its most costly components - the pump and the engine - has a much shorter lifetime. This has been set at half the lifetime of the well, or 40 000 operation hours, which corresponds with the lifetime given by the manufacturers. When operated for 2374 hours per year a lifetime of almost 17 years can be set for both the engine and the pump. Therefore, during the lifetime of the well two sets of pumping equipments will be needed.

The cost item "pumping equipment", collected as field data during the well inventory, generally covers 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 the second set of pumping equipment is installed.

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

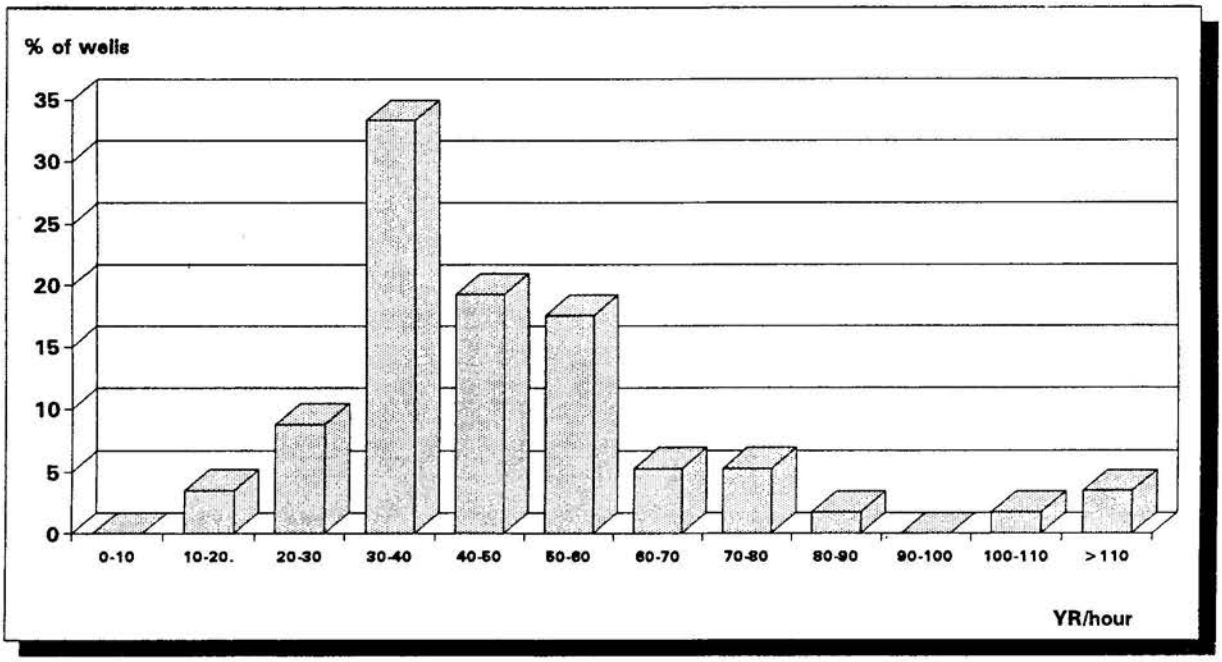


Table 6.1 shows the calculation model for determining the cost of one hour of pumping, and the cost of one m^3 of pumped water. The formula derived in this table has been applied to the data for the 107 inventoried wells in the Baqim Plain.

The following relevant data from the well inventory were available for most of the wells:

- The costs of well construction.

Table 6.1 *Calculation Model for Pumped Groundwater Costs*

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

**) hr = operation hour*

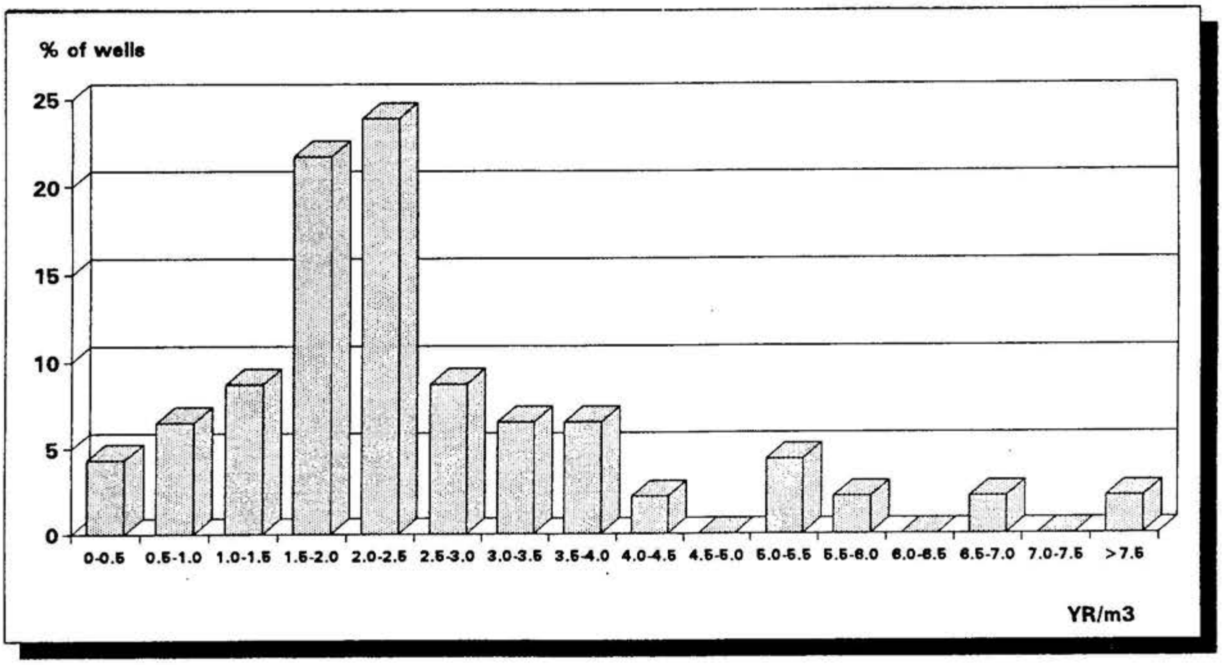
- The costs of pumping equipment.[1]
- Well yields.
- Number of pumping hours per day.
- Daily engine diesel consumption.
- The price of diesel.

The calculation results are presented in Fig. 6.1 and Fig. 6.2. The average cost of one hour of pumping was YR 30.1, that of one m^3 of pumped groundwater YR 1.6 of which 71% was capital cost, 16% for diesel and 13% operation and maintenance.

Assuming an average price of 1.6 YR/m^3 for pumped groundwater, then a total of YR 9.8 million has been spent during 1991 in pumping about 6 Mcm for irrigation purposes.

The cost of one m^3 of pumped water has been 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 is higher. Assuming the overall irrigation efficiency is 41% (see Table 5.3), then the average cost of the water at the crop level will be 3.9 YR/m^3 and the average yearly water costs per irrigated hectare (net application of 1315 mm) YR 51 317.

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



[1] The item pumping equipment costs, being one sum, involves a variable number of installed equipment components. In all the cases a pump and engine are included; additional equipment may consist of reservoir, pump house and conveyance pipes.

7 SUMMARY AND CONCLUSION

A total of 111 wells were inventoried in the Baqim Plain. Of these surveyed wells 15 (13.5%) were permanently out of order for reasons of broken engines/ pumps or too low groundwater levels. The objective was to visit all the existing wells and it can be assumed that about 90% of the wells were visited. Therefore, the total number of operational wells in 1991 was estimated to be about 107.

Serious groundwater development in the Baqim Plain started only in 1978, about 16 years later than in the Amran Valley. Most drilling activity occurred in the period from 1984 to 1989. The first impression is that the yearly drilling rate peak has not passed yet, as it has for example in the Amran Valley.

Statistical analysis of the cumulative distribution of the number of wells constructed shows that 50% of all existing wells were drilled after 1985, and the average well age is 7.3 years. The oldest well dates from 1978.

Most of the wells surveyed (73%) are drilled wells. The remaining part (27%) are shallow dug wells. Only four wells were reported to have been deepened one or two times, a relatively very low figure when compared with the Amran Valley where about 23% of the wells have been deepened one or more times up to 1991.

The drilling method used was predominantly rotary. Practically all the wells are cased throughout their depth with pipes of six metres in length. Most of the wells have steel casings. Casing diameters are relatively large: 12" (87%), 14" (8%) or 10" (5%). The lower section contains a series of 6 m long slotted pipes for water intake.

The depth to the water, in general, is not very great ranging from 3 to 84 m. As a consequence wells are not very deep. They range from 6 m to 300 m, although most (68%) have a depth between 100 and 200 m (the coefficient of variation is 0.54). Only one well is deeper than 200 m . All dug wells were of less than 50 m. The average depth of all the wells was 102 m.

The water column heights range from 0.1 to 139 m; the average aquifer penetration is 70 m. If the groundwater drops 10 m over the whole plain, then about 24% (Amran Valley: 9%) will fall dry. This percentage would increase to a minor extent if the drawdown brought about by pumping is also considered. This percentage seems high. However, the wells that would fall dry are only the shallow dug wells (23% of all wells). The water columns in the drilled wells (73% of all wells) are of such a height that in the near future probably none will become dry.

From the deep drilled wells groundwater is pumped either by vertical turbine (lineshaft) pumps coupled via crossed webbing belts to diesel engines (in 80% of the wells) or electro-submersible pumps (in 3% of the wells). In the shallow dug wells the most common pump type is the centrifugal pump (83%); in 17% of these wells turbine pumps are installed.

A high level of standardization in engine and pumping equipment was observed. 93% of all turbine pumps were supplied by two manufacturers; 62% by Caprari (model

V16P/3L/20A), (31%) by Porcelli (model VE80). The mean number of bowls is 10. Pump column diameters are mostly three and two inches (95% and 5%, respectively). The same level of standardization was noticed among the engines that power the turbine pumps. 96% of pumps are driven by Japanese Yanmar (Yamaha) engines, models NP22 to NP35 of a capacity ranging from 22 to 35 horsepower.

The most frequently observed centrifugal pump (in 63% of the shallow dug wells) was one fabricated by Abary, of 8 HP, with suction and delivery pipes of 2" or 3".

The wells and pumps in the Baqim Plain are quite new (the oldest well and pump date from 1978). The average lifetime of the wells is about equal to that of the pumps. This is reflected by the average age of the wells and the pumps (in 1991) - 7.3 years. This meant that most wells were still equipped with the first pump set. In only 9% of the wells had a second pump been installed.

The relatively high power of the centrifugal pumps used, and the small depth to the water explain the high discharge rates of these pumps, which range from 3.1 to 10.7 l/s and have a mean of 8.6 l/s. Lineshaft pumps have a lower capacity and produce on average 6.5 l/s (range from 2.6 to 18.8 l/s).

In most of the plain the groundwater table is situated below the alluvium. This means that the majority of wells abstract water from the Wajid Sandstone, which can be classified as a moderate to good aquifer, partly explaining the relatively high well discharge rates observed in this area.

In 22 wells both the static water level (level without pumping) and the dynamic water level (steady state water level during pumping) could be measured. The drawdowns varied from 0.5 m to 26 m. with a mean of 6 m. Specific discharge values (discharge/drawdown) range from 0.3 to 10 l/s/m with a mean of 2.1 l/s/m.

Well construction costs range from YR 6000 (a shallow dug well) to YR 250 000 (a deep well of 100 m drilled in 1990). Median well costs were YR 55 000. Well construction costs much lower than eg. in the Amran Valley (mean YR 228 000). As a consequence of the harder medium to be drilled (sandstone rather than alluvium) the opposite would have been expected. The average price per metre drilled for this period (1978-1991) was YR 471.

Pumping equipment costs have a much larger variation; from YR 1500 to YR 460 000 with a median of YR 110 000. Pumping equipment costs are higher than in the Amran Valley. This can be partly explained by the younger age of the wells and pumps in the Baqim Plain (more recent prices).

The average farmer in the Baqim Plain pumps groundwater for 7 to 8 hours per day - throughout the seasons. This is reflected by the mean yearly number of pumping hours per day (7.9). Pumping activities are highest during Sayf[1] (mean 8.6 hrs/day), followed by Kharif (mean 8.3 hrs/day), Rabi'a (mean 7.6 hrs/day) and Shita (mean

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

7.2 hrs/day). About 1% of the farmers operate the pump for 24 hours per day. Over the whole year the average number of pumping days per month was 22.9. The average farmer pumps 197 hours per month, taken over the whole year.

At 71 wells the discharge could be measured and data was collected on the pumping schedule. On average the wells were not pumping for reasons of maintenance and repair for 5.5% of the time. This percentage was also taken into account when calculating the seasonal and total yearly abstracted groundwater volumes.

The yearly total in 1991 of groundwater abstraction was approximately 6.11 million m^3 (Mcm).

A (very rough) estimate of all the groundwater pumped in the Baqim Plain, using figures from 1978 (when abstraction became significant) up to 1991, amounts to about 44.7 Mcm which represents a layer of water 0.81 m deep over the whole Baqim Plain (55 km^2). Expressed in terms of lost aquifer, the volume pumped during this 13 years corresponds to a saturated aquifer thickness of 10.8 metres.

Depths to groundwater range from 3 m (in the extreme south near Wadi Nagwan) to 84 m (in the tributary valley east of Thabiah). In the northern part of the plain groundwater levels are also relatively deep (65 m to 80 m). Despite the high concentration of wells around Baqim town, groundwater depths here are extremely shallow - less than 10 m. This might be the result of the recharge from Wadi Nagwan which crosses this area. No depressions in the water table as a result of excessive pumping were observed in the plain.

Piezometric levels have a small range in the Baqim Plain, dropping from 2140 m amsl in the north to 2072 m in the extreme south near Wadi Nagwan; the general groundwater flow is southwards. Because the north-south decline in the piezometric level is less than the drop in surface altitude, depths to groundwater decrease toward the south. The groundwater in the plain itself is only present in the Wajid Sandstone, underlying the thin alluvial cover. The alluvium in the wadis outside the plain may contain some groundwater stored under perched aquifer conditions. The hydraulic gradient (north-south) of the water table is 0.0055.

Only around Baqim town is there a high concentration of deep wells. Nevertheless no dramatic lowering of water levels has occurred as yet. On the contrary, water level here is still remarkably shallow (about 10 m). A relatively large catchment area west of the plain combined with the permeable sandstone, seem to ensure replenishment of the groundwater.

The minimum value of groundwater electrical conductivity was 200 microS/cm, the maximum 2580 and the mean 595. A high percentage (73%) of all measurements showed values lower than 600 microS/cm. This means that, in general, the groundwater of the Baqim Plain has a low salinity. An explanation of these low values could be that the water here originates from the Wajid Sandstone, and, as a consequence of its quite good permeability, the residence time of water is relatively short and little mineralization occurs.

67% of the EC-values ranged from 113 to 107.7 microS/cm. However, in the south the situation was different: high EC-values (from 1000 up to 2580) were measured west and south of Baqim town and at the extreme southern margin of the plain. These high salinity values were only found in shallow dug wells; nearby deep wells had low EC-values. The high salinity in these shallow wells might be a result of water pollution and or evaporation. Another (geological) explanation might be found in the possible occurrence of shaley layers at shallow depths (Akbra Shale?).

Water temperatures ranged from 13 to 25°C, with a mean of 21°C and a median of 22°C. Dispersion was low; the coefficient of variation was only 0.14. Extreme low temperatures (13-16°C) were measured in some shallow dug wells. These low temperatures were not representative of the groundwater and can be attributed to the fact that the measurements were carried out in January 1992, in winter time. Deep wells had higher temperatures, varying between 20 and 25°C.

The total area of the farms, where groundwater irrigation is practiced was 419 ha, of which 41% or 173 ha was fallow. The 246 ha commanded by groundwater irrigated represents an average command area of about 2.3 ha per well.

The smallest plot was 0.25 ha, the largest 37.5 ha, of which only 2.5 ha were used; the remainder was fallow. Most farms were small: 70% had an area ranging from 2 to 4 ha. The mean total farm size was 3.9 ha and the median 2.5 ha.

The smallest plot commanded by irrigation was 0.05 ha and the largest 10 ha. The dispersion, expressed as coefficient of variation, was rather high (0.88). Most farms (82%) had a total command area ranging from 0 to 4 ha.

Of the perennial crops, alfalfa was grown by most of the farmers (66%), followed by qat (49%) and the fruits pomegranate (26%), apple (25%), peach (7%), apricot (5%) and grape (5%). Other cash crops observed were tomato, cultivated during Rabi'a and Sayf and potato, grown during Rabi'a, Sayf and Kharif.

Of the annual crops, wheat was cultivated by 87% of the farmers during the seasons Shita and Rabi'a. During the same seasons, barley was grown on 64% of the farms. Sorghum was the major annual crop during Sayf and Kharif (97% of the farms).

Both chemical fertilizers and organic matter were used. On 72% of the farms fertilizers were applied: chemical fertilizer alone on 16% of the farms and both chemical fertilizers and organic matter on 53%. Livestock waste was not usually used as fertilizer, but is dried for fuel.

The number of persons that depend on one well ranges from 8 to 1200 (the latter is a 300 m deep well that supplies the northern part of Baqim town). The percentage of the pumped groundwater that is used for domestic purposes amounts to about 5%. The average number of persons that use water from one well is 95. Due to the large number of persons consuming the water from some wells, this value seems distorted. A better impression is given by the median: about 40 persons. Extrapolation of the collected data resulted in a total number of 10 150 people that consumed well water in 1991. This number might indicate the number of inhabitants in the valley (census 1986: 7300 inhabitants). Assuming an average daily water consumption of 40/l per capita, a total water consumption from all the wells in the whole Baqim Plain was determined at 148 186 m^3 per year .

Irrigation efficiency is low: there are conveyance losses (in unlined canals); irrigation scheduling is not optimum; land levelling is not always good; and farmers tend to apply more water than is required by the crop. As a result not all the area commanded can be irrigated at any one time, because not enough water is pumped. Of the approximately 6 Mcm of water used for irrigation annually some 3.5 Mcm returns to the aquifer as seepage or deep percolation.

A model has been made for the calculation of the cost of both one hour of pumping of groundwater, and of one m^3 of pumped groundwater. The average cost of one hour of pumping was YR 30.1, that of one m^3 of pumped groundwater YR 1.6.

Assuming an average price of 1.6 YR/m^3 a total of YR 9.8 million was spent during 1991 in pumping about 6 Mcm for irrigation purposes.

Taking the estimated overall irrigation efficiency of 41%, the average cost of the water at crop level would be 3.9 YR/m^3, and the average yearly water costs per irrigated ha (net application of 1315 mm) YR 51 317.

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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 111 wells were surveyed in the Baqim Plain, and so 111 times 123 (13 653) 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

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

....
....
....

E. WATER USE

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

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

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

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

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

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

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

ONLY IN CASE OF DOMESTIC USE OF WATER:

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

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

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

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

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

E. WATER USE (continued)

14. IS WELL SOMETIMES DRY ? yes/no

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

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

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

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

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

F. COSTS

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

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

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

G. MISCELLANEOUS

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

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

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

APPENDIX 3

WELL INVENTORY

SUMMARIES

Data of well inventory of Baqim Plain (selection of data)

Well no.	Village (nearest)	Coordinates (UTM) N	E	Altitude m above msl	Year of constr.	Well type *)	Casing diam. (m)	Well depth (m)	Thickness alluvium (m)	Year install pump	Type of pump **)	Depth water (m)	Well yield (l/s)	Total farm size (ha)	Water use Irrigtd (ha)	Domest. (persons)	Temp. (o C)	EC micro-S (25 o C)
	*) 1=dug well 2=drilled 3=dug+drilled			**) 1=lineshaft pump 2=electro 3=centrifugal														
1	MAHDIDAH	1930100	336700	2170	80	2	8	200		80	1	80	5.8	2.0	1.5	40	20.0	400
2	MAHDIDAH	1930100	336600	2170	88	2	12	140		88	1	67	5.8	0.5	0.1	30	25.0	410
3	MAHDIDAH	1930300	336700	2170	79	2		150		79	1	68	5.6	7.5	2.5	400	20.0	400
4	MAHDADAH	1929800	337100	2180	85	2	12	150		86	1	69	6.0	1.5	0.5	20	20.0	400
5	MAHDIDAH	1929700	337200	2170	82	1	12	150		82	1	28	5.8	1.5	0.8	20	20.0	400
6	MAHDIDAH	1929200	336700	2165	88	2	12	138		88	1	64	5.8	5.0	2.5	30	20.0	400
7	ALLIZAMAH	1928900	333900	2160	80	2	12	150		80	1	54	6.6	7.5	5.0	50	23.0	340
8	ALLIZAMAH	1928500	334600	2165	84	2	12	150		84	1	50	5.4	7.5	5.0	100	22.6	320
9	ALLIZAMAH	1929700	334700	2170	87	2	12	150		87	1	58	4.2	7.5	5.0	15	23.3	200
10	ALLIZAMAH	1929100	335200	2160	80	1	12	150		80	1	58	3.9	7.5	7.5	12	22.0	340
11	ALLIZAMAH	1928400	335200	2165	88	2	12	150		88	1	40	6.8	5.0	3.8		23.0	300
12	ALLIZAMAH	1927700	335200	2170	88	2	12	150		88	1	40	5.4	5.0	3.8		22.4	300
13	ALLIZAMAH	1928100	334300	2170	89	2	12	150		89	1	56		0.8	0.8	200		
14	ALLI ZAMAH	1928400	334100	2160	79	2	12	150		79	1	46	4.2	6.3	5.0	200	23.0	420
15	ALLI ZAMAH	1927700	334400	2170	80	2	12	160		80	1	62	4.2	2.0	1.3	100	23.0	220
16	DABIA	1928600	339500	2190	80	2	12	190		80	1	84	7.5	10.0	5.0	50	21.5	330
17	DABIA	1928500	339000	2170	82	2	12	180	1			84						
18	DABIA	1928300	338100	2155	81	2	12	160		82	1	60	6.8	10.0	3.0	80	23.3	400
19	ALLI MOGRAM	1928300	337600	2165	82	2	12	160		82	1	60	5.8	6.3	2.5	130	22.6	480
20	MAHDIDAH	1929400	337600	2175	83	2	12	160		83	1	70	6.3	12.5	5.0	40	23.2	400
21	ALLI ALHOMAKI	1928300	336700	2155	88	2	12	150		88		51	6.8	2.5	0.9	10	21.9	305
22	ALLI ALHAMAKI	1928000	336600	2150	82	2	12	120		82	1	50	5.0	10.0	5.0	200	23.3	295
23	ALLI ALHAMAKI	1928100	336400	2150	80	2	12	150		80	1	40	6.5	7.5	7.5	150	19.8	380
24	ALLI ALHAMAKI	1928000	335990	2185	83	2	12	150		82	1	38	5.8	7.5	7.5	100	21.4	440
25	ALLI MOGRAM	1927800	338000	2156	79	2	12	150	1	79	1	58	4.2	2.5	0.5	60	22.0	440
26	ALLI MOGRAM	1927900	338200	2159	89	2	12	150	2			60						
27	ALLI MOGRAM	1927400	337990	2153	89	2	12	150	2	89	1	55	5.4	2.5	1.3	50	20.5	420
28	ALLI ALHAMAKI	1928800	337000	2165														
29	ALLI ALHAMAKI	1928300	336300	2155	84	2	12	160		84	1	51	4.2	3.0	2.0	50	22.4	310
30	ALLI ALHAMAKI	1928600	336200	2150	89	2	12	160	2	89	1	44	5.4	2.5	1.3		22.0	320
31	ALLI ALHAMAKI	1928000	336100	2150	81	2	12	160	2	82	1	37	5.4	3.8	2.3		22.3	325
32	ALLI ALHAMAKI	1927000	336800	2140	91	2	12	160	1	91	1	43	5.0	2.0	2.0		23.0	280
33	ALLI MOAID	1927000	336100	2145	88	2	12	120	1	89	1	42	5.4	2.5	2.0	15	23.4	320
34	ALLI MOAID	1926200	337200	2150	80	2	12	120	6	80	1	38		3.8	3.8	25		
35	ALLI MOAID	1926000	337700	2145	87	2	12	100	6	87	1	25	4.7	2.5	2.5	8	23.3	435
36	ALMAHGAR	1925600	338700	2120	84	2	12	110	2	84	1	32	5.0	2.5	2.5	20	23.6	345
37	ALMAHGAR	1925700	339100	2120	90	2	12	100	2	90	1	25		1.3	1.3			
38	ALMAHGAR	1924700	339100	2110	84	2	12	100	2	84	1	36	4.2	1.5	1.5	9	22.6	380
39	ALMAHGAR	1924500	339100	2110														
40	ALMAHGAR	1925100	339100	2115	87	2	12	100	1	87	1	37	5.0	1.5	1.5	16	23.5	390
41	ALMAHGAR	1925400	339300	2120	86	2	12	120	1	86	1	37	5.8	6.3	2.0	25	23.8	340
42	ALMAHGAR	1925000	338600	2115	84	2	12	110		84	1	30		3.8	3.8			
43	ALLI MOAID	1925800	337600	2145	85	2	12	150	6	85	1	41	5.8	0.8	0.8	16	22.8	420
44	ALSERAR	1925100	334800	2135	84	2	12	120		84	1	18	6.8	12.5	5.0	30	22.0	335
45	ALSERAR	1925000	335100	2135	79	2	12	50		79	1	26	12.6	7.5	7.5	200	22.0	434
46	ALSODAH	1924800	335250	2135	83	2	14	150		83	1	26	7.5	5.0	5.0	250	22.0	398

page 1 of 3

Data of well inventory of Baqim Plain (selection of data)

Well no.	Village (nearest)	Coordinates (UTM) N	E	Altitude m above msl	Year of constr.	Well type *)	Casing diam (m)	Well depth (m)	Thickness alluvium (m)	Year install pump	Type of pump **)	Depth water (m)	Well yield (l/s)	Total farm size (ha)	Water use Irrigtd (ha)	Domest. (persons)	Temp. (o C)	EC micro-S (25 o C)
	*) 1=dug well 2=drilled 3=dug+drilled			**) 1=lineshaft pump 2=electro 3=centrifugal														
47	ALSODAH	1925350	334500	2135	85	2	12	150		85	1	25		2.3	1.8	200	22.0	266
48	ALZOBEYRAH	1925250	333900	2150	82	2	12	150		82	1	23	18.8	2.0	1.0	30	22.0	226
49	ALZOBEYRAH	1925150	334000	2140	83	1	12	150		83	1	23	17.6	5.0	5.0		22.0	256
50	ALZOBEYRAH	1925400	333600	2155	89	2	14	118		89	1	30	2.6	3.5	2.5		22.0	210
51	ALSEDR	1925900	333550	2160	79	2	14	155		79	1	30	3.2	37.5	2.5	22	22.4	330
52	ALFUSSUR	1925600	338820	2120	88	2	12	105		88	1	25	9.4		2.5	60	23.5	850
53	BOQEM	1924800	339100	2120	84	2	14	100	3		1	18	12.5	5.0	5.0		22.6	595
54	BAQEM	1925700	338150	2130	81	2	14	120	5	81	1	20	9.4		10.0	20	22.3	770
55	BAQEM	1925300	338600	2120	90	2	14	130		90	1	30	7.5	5.0	2.5		23.0	730
56	ALMASAHIF	1923650	337100	2110	88	2	10	150		88	1	14		1.5	1.5	300	16.0	735
57	ALMASAHIF	1923700	336830	2110	79	1		13	3	85		10	3.1	7.5	2.5		18.5	715
58	ALMASAHIF	1924080	336510	2115	85	2	10	150		85	1	11		2.5	2.5		21.0	300
59	ALMASAHIF	1924400	337100	2115	87	2		100		87	1	12	3.4	7.5	2.5		23.0	308
60	ALMASAHIF	1924000	336880	2111	85	2	10	100		85	1	15		2.5	2.5		22.3	316
61	ALMASAHIF	1923700	336650	2110	90	2	10	100		90	1	12		1.5	1.5		23.0	355
62	ALMASAHIF	1923650	336300	2120	79	2	12	96		79	1	16	5.8	3.8	5.0		23.0	365
63	ALGAFILAH	1923650	337630	2110	89	2	12	100		89	1	10		1.3	1.3	100	17.5	332
64	ALGAFILEH	1923500	337730	2109	89	2		100		89	1	12		1.3	1.3	50	17.5	354
65	ALGAFILEH	1923450	337880	2110	85	2	12	100		85	1	11	8.3	1.3	1.3	20	23.0	285
66	ALGAFILEH	1923500	337750	2100		1		13		85	3	7		1.3	1.3		17.0	774
67	ALGAFILEH	1923750	337870	2100		1		9		78	3	8					14.0	1285
68	ALGAFILEH	1923650	337890	2100		1		10		78	3	5		0.5	0.1		18.0	485
69	ALGAFILEH	1923850	337900	2100		1		11		79	3	8		1.0	0.3		15.0	1100
70	BAGEM	1923500	338200	2105	85	2	12	100		85	1	12	4.7	2.3	1.3		23.0	375
71	BAGEM	1924010	337910	2100	88	2	12	105		88	2	8	7.5	2.5	0.8		21.0	748
72	BAGEM	1923950	337950	2110		1		7		84	3	5	9.4	0.4	0.3		17.0	1625
73	BAGEM	1924100	338050	2105				9		90	1	7	10.7	0.5	0.1		16.0	900
74	BAGEM	1923950	338100	2105	91	2		105		91	1	13	3.4	0.8	0.6		22.5	690
75	BAGEM	1923860	338080	2106	86	2	12	80		86	1	11	7.5	2.5	1.5		13.0	1550
76	BAGEM	1924250	338000	2105	89	2	12	110		89	1	8		3.8	3.8		20.0	525
77	BAGEM	1924290	337950	2100		1		12	3	85	3	10	8.3	1.3	0.5		19.0	2120
78	BAGEM	1924200	337890	2106		1		7		86	3	5		0.5	0.1		16.0	408
79	ALGAFLAH	1923400	337600	2100		1		6		84	3	5		0.5	0.1		16.5	544
80	ALATF	1923010	338200	2100		1		14			1	9		1.3			16.8	1715
81	ALATF	1923000	338100	2102		1		11			1	8		1.3			16.5	1710
82	BAGEM	1924130	337600	2100		1		8			1	7					14.0	1780
83	BAGEM	1924150	337500	2105		1		11		78	3	9	10.7	3.5	0.2		17.5	1985
84	BAGEM	1924350	337650	2100		1		10		80	3	7					17.0	1020
85	BAGEM	1924010	337680	2100		1		10				9		1.3			15.5	1610
86	BAGEM	1923950	337600	2100		1		13		80	3	10						
87	BAGEM	1923950	337700	2100		1		9		80	3	7			0.5		16.0	2580
88	BAGEM	1924300	338000	2105		1		23			1	22						
89	BAGEM	1923700	338150	2105		1		12			1	11					16.0	1470
90	BAGEM	1923650	338100	2105		1		8			1	8					16.7	1480
91	BAGEM	1923600	338190	2104		1		8		85	3	5	10.7	2.5	0.5	10	19.7	400
92	BAGEM	1923630	338200	2103		1		10		79	3	6	6.8	1.3	1.3		17.0	614

Data of well inventory of Baqim Plain (selection of data)

Well no.	Village (nearest)	Coordinates (UTM) N	E	Altitude m above msl	Year of constr.	Well type *)	Casing diam. (m)	Well depth (m)	Thickness alluvium (m)	Year install pump	Type of pump **)	Depth water (m)	Well yield (l/s)	Total farm size (ha)	Water use Irrigtd (ha)	Domest. (persons)	Temp. (o C)	EC micro-S (25 o C)
	*) 1=dug well 2=drilled 3=dug+drilled			**) 1=lineshaft pump 2=electro 3=centrifugal														
93	BAGEM	1924360	338230	2102	81	2	12	300		81	2	12				1200	22.0	336
94	BAGEM	1924160	337370	2110	86	2	12	70		89	1	14	7.5	1.3	1.3		23.0	380
95	BELAD ALMOAYED	1924600	337450	2100	85	2	12	100		85	1	10	7.5	7.5	1.3	100	24.0	418
96	BELAD ALMOAYED	1924500	337520	2100		1		8			1	6						
97	BELAD ALMOAYED	1924620	337500	2105		1		7			1	5						
98	BELAD ALMOAYED	1924600	337250	2110	89	2	12	100		88	1	12	5.0	2.0	2.0		23.6	366
99	GARAP ZAMPEL	1925100	336250	2130	91	2	12	91		91	1	17	7.5	2.5	1.5	10	23.0	265
100	BLAD ALMOAYED	1924800	337420	2110	82	2	12	104		80	1	12	5.0	1.3	0.5	10	22.0	272
101	BELAD ALMOAYED	1924720	337400	2110		1		16			1	14						
102	BELAD ALMOAYED	1803600	-370800	2110	80	2	12	120		80	1	13		2.5	2.5	150	17.0	422
103	BELAD ALMOAYED	1924750	337780	2108	85	2	12	100		85	1	10	6.8	2.5	2.0		24.0	360
104	BELAD ALMOAYED	1924550	337820	2105	84	2	12	100		84	1	8	7.5	2.0	2.0		22.5	930
105	BELAD ALMOAYED	1924700	337100	2110	84	2	12	100		84	1	15	7.5	2.5	1.5	150	16.5	390
106	BELAD ALMOAYED	1924850	337830	2110	85	2	12	80		85	1	20	10.7	0.8	0.5	60	19.5	328
107	ALMARAGA	1922700	337850	2110	78	1		6	6	78	3	3	9.4	1.0	1.0	15	17.0	775
108	DHA MASJAM	1921850	337950	2100	84	2	12	64		88	1	12	6.3	2.0	2.0	20	23.0	242
109	BAGEM	1924500	338100	2110	90	2	12	100		91	2	20			0.1	16	19.0	357
110	BAJEM	1924350	338100	2110	88	2	12	110		90	2	18				18	21.0	336
111	BAEGM	1924350	338220	2110	84	2	12	100		90	3	22					20	1530

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 Baqim Plain

The following SSHARDA engineers were involved in the well inventory:

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

Drivers

Ali Khorap
Abdullah Alyazidi
Ali Ahmed Al Montassar
Nasser Atef

Database entry was carried out by the SSHARDA engineers:

Samir Al Shamiri
Abdul Al Shamiri

Planning, supervision and reporting

W.J. Honijk (hydrogeologist)