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RADA INTEGRATED RURAL DEVELOPMENT PROJECT

Study into water resources in Al Bayda Province

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Volume I - Main Report

<u>Volume II - Annexes</u>

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A.1 Introduction

A.1.1 General

This annex describes the results of the well survey carried out from April to September 1983 in 7 of the 12 areas with some scope for groundwater development. These areas, indicated on Fig. A.1, had been selected during a reconnaissance survey carried out during March/April 1983. More than 1600 wells have been mapped and data of these wells have been collected and recorded on questionnaires. All data of the survey have been compiled and stored in a computer data bank. The results are presented in maps, profiles, tables and a brief description in this annex.

Finally a first estimate of the groundwater potential of each of the investigated catchments has been made.

A.1.2 Methodology of the survey

During the survey, information on shallow wells, deep boreholes and springs was collected using a questionnaire and several instruments (Appendix A.I). In interviews with the owners or operators of wells the questionnaires were completed as accurately as possible, but in the absence of the owner no efforts were made to obtain lacking information by going back afterwards, in order to spend time as effectively as possible.

In the surveyed areas all wells were visited, but where density was high, information was gathered selectively. Not all selected areas could be covered because of the great number of wells encountered. The surveys are, however, still going on.

Table A.1 shows which areas were surveyed, as well as the percentage of wells visited in that area until now.

Table A.1 - Visited areas and percentage of wells covered

Rada Basin	100 %
Al Bayda N.E.	80 %
Al Bayda West	50 %
Wadi Juban	100 %
Wadi Mansur/Wadi Amad	70 %
Wadi Matar/Wadi Ar Rin	80 %
Wadi Dhi Na'im	70 %
Abbas	100 %

AREAS COVERED BY THE SURVEYS , AL BAYDA PROVINCE

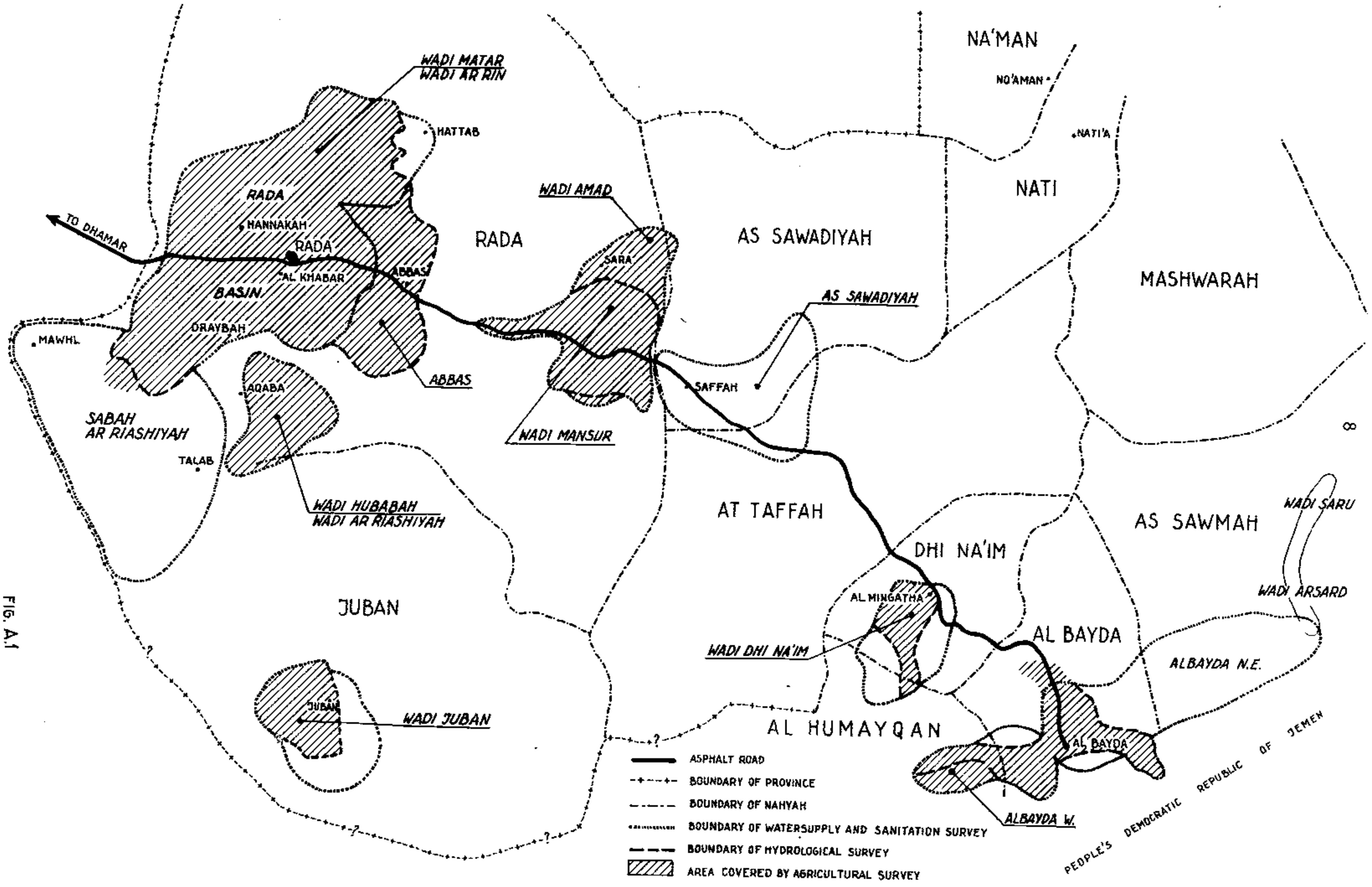


FIG. A.1

Information gained in this way was compiled and stored in a data base in Arnhem. The different items are described below.

Location of wells

In the field, wells were pinpointed on aerial photographs with a needle; then the number of the well was written on the back of the photo and painted on a visible place on the well or pump house. This is important, as it enables a future surveyor to compare measurements in later years, since information about all wells is always directly available on files at Rada headquarters. All well numbers have four digits, every selected area having a different initial digit.

Elevation

The elevation of each well was measured with a Thommen precision barometer. Every morning this barometer was adjusted at a reference point with a known or assumed elevation.

At the same time a barograph was started, to make it possible to correct the field measurements for changes in local air pressure. After return from the field both instruments were read again. After some time a correction factor of 10 m elevation reduction per millibar air pressure was derived empirically. The barograph stayed in Rada for surveys in the areas of Rada, Sabah, Mansur, Matar and Abbas.

For the surveys in Al Bayda, Juban and Dhi Na'im local benchmarks were used. In Al Bayda the platform in the middle of the town square was assumed to be 1955 m above MSL (mean sea level), in Juban the floor of the oldest mosque 2000 m above MSL. All elevations have been derived from the ground floor in the RIRDP-guesthouse, which was assumed at 2100 m above MSL. The accuracy of local benchmarks is approx. 10 m.

Apart from corrections necessary for calculating errors due to daily changes in air pressure, corrections had to be made for differences due to working on different days. It appeared that each working day showed some systematic over- or underestimation of the elevation of a few metres. The cause of this phenomenon is not known, but it gives rise to imaginary jumps in the wadi profile. The correction for each day can be estimated when all elevations in a wadi have been measured.

The corrected elevations in the field have the same accuracy as the benchmarks, approximately 10 m with respect to the Rada benchmark, but relative to each other aberrations will be smaller than approx. 2 m in most cases.

Water-table

The water-table was measured with a water-level meter. As a reference level mostly the beams of the pump were used, if present. In other cases the reference was always marked with a sign: <. As boreholes were closed in most cases, the depth to the water-table could not be measured there. Where possible also maximum and minimum water-levels were noted. If measurement of the water-level was possible, the top of the casing was always taken as the reference level.

Total depth of the wells

The total depth of the wells was usually derived from the number and length of pipes in the well, used for pumping. In other cases an estimation was given by the owner. It should be noted that such methods are not very accurate. Therefore sometimes the depth was measured with a rope and a lead, as a check.

Water quality

EC and pH were measured in the field throughout the survey, by taking a water sample with a bucket.

Chemical tests were intended to be taken from approx. 1 out of 10 wells. This density was not achieved, however, because of the large number of wells, delays in the supply of chemicals and reagents, and shortage of time to test the samples. As far as possible samples were taken from pumped water of productive wells.

The tests were carried out in a small laboratory set up on the compound in Al Khabar, employing a HACH kit.

Annual water abstraction from the wells

In interviews with farmers or owners of the wells information was gained about the hours of pumping throughout the year, both for the dry and the wet season. By measuring the discharge of the pump with a 90-litre drum and stopwatch, the annual abstraction per well was calculated. To correct for the period of harvesting, when abstraction is zero, the calculated abstractions were multiplied with a factor 11/12, assuming that no water is used during one month per year.

For various reasons the discharge could not always be measured. In such cases an estimation was made on the basis of discharges in surrounding wells with comparable installed engine-power and depth to water-table.

For wells visited both by the hydrogeological and the agricultural surveyor, annual abstractions could be calculated in two different ways. Unfortunately, large differences were found; the ratio of the calculated abstractions from the hydrogeological and the agricultural survey varies from -3 to +3. Therefore it was not justified to assume one overall factor to put these figures on a par with each other. In cases where differences were too large, a choice was made for either the abstraction calculated by the hydrogeological method or that calculated by the agricultural method (depending upon which of the two seemed most reliable), for further calculations.

Discharges of springs in the Rada area were measured with a portable RBC flume. Putting the flume in an upright and horizontal position proved to be time-consuming in the often rocky beds of the springs. It should be noted, however, that although the measured discharge is very accurate, variation over the year is large. Therefore these figures can merely give an impression of the order of magnitude of the annual spring flows.

Maps

Final maps were drawn from the aerial photographs with the aid of a stereoscope. The km-grid and degrees were copied from the YAR 1:250 000 topographical map (Directorate of Overseas Surveys, United Kingdom). The scale was checked with distances measured in the field.

Remarks

Especially in areas with high well density, the progress of the hydrogeological survey was rather slow. In the ongoing surveys it may therefore be better to skip a certain percentage of the wells, especially where measurements of well depth, EC and pH are concerned. For a good survey of the total number of wells present in the area and the calculation of the annual abstraction, however, it is necessary to pinpoint and number all wells. An interview with the owner will not always be necessary; in many cases an estimation of the pumping hours can be made with the help of neighbours or on the basis of the total area of irrigated land.

To obtain a good insight into the chemical properties of the water in different areas, a substantial amount of samples have to be taken and analysed. This takes a lot of time, at least one full day a week, and this time is hardly available. Problems in the supply of chemicals cause delays in analysing the samples, which affects the accuracy of the results, and leads to accumulation of work. It is therefore recommended that either no samples at all are taken or that this work is done thoroughly, because a few half-analysed samples give no information.

To deal with the difference in measured elevations between two days, as discussed in Section A.1.2, it is recommended that elevations be measured at a local benchmark when the survey continues.

Before the fieldwork starts, some time should always be spent on preparing a draft map by the surveyor him(her)self. This facilitates the field-work considerably.

A.2 Climate

A.2.1 The climate of the Yemen Arab Republic

Rainfall conditions are not uniform throughout the Yemen Arab Republic. The topography and the main wind directions are such that three rainfall zones can be distinguished: the zone influenced from the east, the zone influenced from the west, and the zone influenced from the south. The southern sector is under the influence of the Indian

Ocean and enjoys a relatively high rainfall. The western part of the country is the Tihama Plain. Rainfall is low, although relative humidity is very high. Temperatures often exceed 40 °C. Rainfall also varies considerably from year to year. In the Tihama Plain along the coast of the Red Sea, the average annual rainfall ranges from 100 to 200 mm. Further inland rainfall increases from 300 mm to 800 mm annually.

The eastern sector, in which Al Bayda Province is situated, is separated from the western sector by the main watershed of Central Yemen. In the more than 2300 m high Montane Plains just east of this main watershed the rainfall decreases north-eastward to less than 200 mm on the border with the Rub Al Khali. The highest recorded rainfall is near Ibb: more than 1000 mm annually. During the dry season from October to March, weather conditions are primarily determined by the Arabian high-pressure zone, resulting in a dry easterly to north-easterly air stream. Rainfall during this period is unusual, though occasional storms occur from February onwards. There are long periods of dry weather with few or no clouds. By March, however, a marked upper-air trough is often evident, the lower convergent winds ahead of the trough leading to a certain degree of convection. This in turn allows for the development of intermittent rainfall.

By July, Yemen has normally come under the influence of the intertropical low-pressure zone, leading to the convergence of warm dry air from the north and very moist south-westerlies originating from the Indian Ocean. Within the Yemen Highlands, this convergence gives rise to periodic but scattered rainfall. It is rare for rain to fall simultaneously throughout the entire catchment.

A.2.2 The climate of Al Bayda Province

A.2.2.1 Meteorological stations

An agro-meteorological station was set up in Al Khabar in 1978. Since then several climatological variables have been measured more or less continuously, i.e. the dry-bulb and wet-bulb temperatures, the evaporation of a class-A pan, the wind run and the wind direction, the total hours of sunshine per month, the cloudiness, and the precipitation rate.

For the project area two more meteorological stations are of special interest, the station in Rabat, south of Dhamar, and the one located in Ma'bar, north of Dhamar. From these stations data are available for the years 1975 and 1976, collected for the study of the Montane Plains and the Wadi Rima' Project. The data are comparable to the data of the Al Khabar station and are presented in Tables A.2 and A.3.

A.2.2.2 Precipitation

Rainfall is the main form of precipitation and varies annually, seasonally, and in its distribution over the survey area. Snowfall or hailstorms occur occasionally in December and January. In the mountains south of Rada there is a marked difference between the wetter south and

Table A.2 - Ma'bar weather-station[1] climatological data (1975-1976)

	J		F		M		A		M		J	
	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976
Sunshine hours/day												
recorded (n)	9.9		9.6		10.1		7.0		10.5		8.3	
Ma'bar		9.9		9.7	.	8.8		9.0		7.9		8.8
Possible (N)		11.3		11.7		12.1		12.5		12.8		13.0
n/N	0.88	0.87	0.82	0.83	0.84	0.73	0.56	0.72	0.82	0.62	0.64	0.68
Temperature (°C)												
Mean maximum	22.3	23.2	23.9	24.3	25.2	25.0	22.6	24.5	26.8	26.2	27.7	29.0
Mean minimum	0.3	-0.4	3.6	4.7	4.6	7.0	8.6	7.2	7.1	8.4	6.8	7.1
Mean[2]	11.3	11.4	13.8	14.5	14.9	16.0	15.6	15.8	17.0	17.3	17.2	18.1
Mean dewpoint (°C)	2.8	3.3	5.4	7.8	7.0	8.6	10.4	8.8	7.4	9.6	8.0	7.6
Wind run (km/day)	186	186	236	236	224	104	216	238	249	227	282	251
Mean relative humidity (%)												
06.00 hours	85	83	86	94	79	92	96	92	80	94	79	83
15.00 hours	27	32	32	37	42	38	52	41	31	41	34	31
Evaporation (mm/month)												
Penman E_o	131	130	150	144	180	173	155	176	210	184	191	196
Penman E_t	105	86	105	100	126	122	112	126	150	133	139	142
Class A pan	183	192	185	193	239	220	192	255	294	223	273	318
Rainfall (mm/month)	0	0	4	16	62	90	112	62	2	36	9	3

	J		A		S		O		N		D		Annual			
													Mean		Total	
	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976
Sunshine hours/day																
recorded (n)	6.6		6.6		7.7		10.7		10.8		9.9		9.0		3276	
Ma'bar		6.5		6.7		7.8		9.9		8.4		9.8		8.6		3139
Possible (N)		12.9		12.6		12.2		11.8		11.4		11.3				
n/N	0.51	0.50	0.52	0.53	0.63	0.64	0.91	0.84	0.94	0.73	0.88	0.87	0.75	0.71	-	-
Temperature (°C)																
Mean maximum	27.5	27.3	22.9	27.9	25.2	27.6	23.9	25.8	22.4	22.1	22.5	22.4	24.4	25.4	-	-
Mean minimum	8.7	9.4	11.9	8.8	9.6	5.9	1.1	2.3	1.1	2.2	0.1	-0.7	5.8	5.2	-	-
Mean[2]	18.1	18.3	17.4	18.4	17.4	16.7	12.5	14.1	11.8	12.1	11.3	10.9	14.9	15.3	-	-
Mean dewpoint (°C)	10.6	10.2	14.7	11.2	10.8	6.6	1.0	3.7	0.6	4.6	2.6	3.0	6.8	5.6	-	-
Wind run (km/day)	292	296	272	278	244	233	204	238	220	192	196	209	235	233	-	-
Mean relative humidity (%)																
06.00 hours	86	81	93	90	90	85	66	69	64	81	78	85	81	86	-	-
15.00 hours	44	44	72	46	45	30	25	29	25	37	31	31	38	36	-	-
Evaporation (mm/month)																
Penman E_o	183	188	153	189	169	176	167	175	144	127	126	134		-	1959	1992
Penman E_t	135	140	112	140	122	126	138	122	119	86	102	91	-	-	1465	1413
Class A pan	264	307	208	298	237	330[3]	254	356[3]	210	294[3]	177	360[3]	-	-	2716	-
Rainfall (mm/month)	61	46	192	66	13	0	0	0	0	37	0	14	-	-	455	370

[1] Position: 14° 50' N, 44° 20' E; elevation: 2350 m.

[2] Mean = $\frac{\text{Mean max. + mean min.}}{2}$

[3] Estimated data, awaiting verification.

Table A.3 - Rabat weather-station[1] climatological data (1975-1976)

	J		F		M		A		M		J		J		A		S		O		N		D		Annual			
																									Mean		Total	
	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976
Solar radiation (cal/cm²/day)	521	518	618	558	550	562	455	589	629	538	489	555	472	496	450	470	599	551	606	562	543	469	515	499	529	530	6347	6365
Temperature (°C)																												
Mean maximum	19.9	17.7	22.1	18.5	20.4	19.2	18.2	18.4	22.8	20.3	23.0	23.6	21.5	21.9	19.2	21.3	20.2	21.7	20.1	21.6	18.8	18.0	17.6	18.8	20.3	20.1	-	-
Mean minimum	-5.0	-3.0	-4.5	-1.3	0.9	1.6	4.7	4.0	3.0	5.8	2.7	3.2	6.8	7.2	8.9	7.5	5.7	3.7	-3.1	0.9	-3.5	1.5	-3.6	-3.5	1.1	2.3	-	-
Mean[2]	6.9	7.7	9.6	9.4	11.7	10.8	11.6	11.6	14.1	13.1	13.9	14.2	13.7	14.5	13.2	13.7	12.7	13.5	9.2	12.4	7.8	9.8	6.9	8.2	10.7	11.6	-	-
Mean dewpoint (°C)	-4.0	2	-0.2	4	5.7	5.5	7.5	6.5	5.2	7.5	5.7	5.0	9.1	10.0	10.7	10.5	7.5	8.0	-2.2	4.0	-3.0	4.5	-1.0	-1.5	3.8	5.5	-	-
Mean relative humidity (%)																												
06.00 hours	75	87	76	89	85	91	92	92	80	93	74	82	93	93	96	96	94	94	73	74	71	95	80	83	82	89	-	-
15.00 hours	43	55	46	56	55	57	63	51	39	53	48	39	67	63	81	73	54	56	24	42	35	53	47	40	50	53	-	-
Wind run (km/day)	158	189	177	210	201	198	173	199	201	183	230	218	211	250	188	204	175	175	160	190	165	153	177	175	184	195	-	-
Evaporation (mm/month)																												
Penman E_o	117	111	134	125	152	144	125	153	189	157	152	171	141	154	129	136	138	150	150	153	123	108	111	117	-	-	1661	1679
Penman E_t	75	73	89	85	107	100	90	115	134	119	111	122	102	112	95	99	98	106	99	104	80	72	72	75	-	-	1152	1182
Rainfall (mm/month)	0	1	0	8	36	88	99	141	23	98	6	32	139	99	221	108	73	18	0	4	2	46	16	0	-	-	615	643

[1] Position: 14° 12' N, 44° 19' E; elevation: 2550 m.

[2] Mean = $\frac{\text{Mean max.} + \text{mean min.}}{2}$

the drier north, and between the wetter west and the drier east. At Rabat the total annual rainfall was 615 mm in 1975 and 643 mm in 1976. Rainfall at Ma'bar was 455 mm in 1975 and 370 mm in 1976. The two stations east of Dhamar, in Al Khabar and Rada, show a significantly lower precipitation. Al Khabar rainfall data are available from 1978 to the present, and in Rada measuring started in 1977, resulting in continuous daily rainfall figures over a period of six years up to 1983 (see Table A.4).

In Al Khabar the annual rainfall has not exceeded 365 mm, with a mean of 269 mm, while for Rada the annual rainfall figures are even slightly lower: a maximum of 320 mm, with a mean of 204 mm.

In the figures the two wet seasons in the high plains are clearly visible: the first one is in March, sometimes April, and the second period falls mainly in August, though sometimes in July or September, lasting more than one or two months. Between April and July there is a short dry season, with mostly no rain at all in July only. Between September and February there is a long dry season, the months of October, November, December and January having zero precipitation most of the time. The data so far collected are not sufficient to indicate a significant difference between the total amount of rain falling in each year.

After 1979 attempts were made to extend the rainfall monitoring network in the Rada project area. Unfortunately, due to lack of co-operation from the local rain-gauge operators it proved to be difficult to obtain a set of continuous readings. At present most problems seem to be solved, however. From 1980 onwards more stations have become operational. In 1983, a total of eleven automatic stations were recording the daily rainfall rate. The stations are located in Rada, Al Khabar, Az Zuab, Al Manasa, Al Khadrah, Al Hajar, Al Qarry, Jauf Al Nugabah, Al Madhaf, Bayt Al Jabri, and Wadi Mansur. Since measuring at most of the stations did not start early enough to supply interpretable data, only the rainfall data are presented of Rada and Al Khabar. Rainfall is very variable within short distances. For example, in Az Zuab, located only 10 km north of Rada, the mean annual precipitation is much lower than in Rada, which in turn has less rainfall than Al Khabar, only 3 km south of Rada. The annual mean is about 140 mm in Az Zuab, 204 mm in Rada, and 269 mm in Al Khabar.

A.2.2.3 Temperature

In Ma'bar the daily temperature ranges from 11 °C to 18 °C; the mean annual temperature is 15 °C. For Rabat the daily temperature ranges from 7 °C in December to 14 °C in July; the mean annual temperature is about 11 °C. The mean minimum temperature in Ma'bar is never below freezing point, while in Rabat there are five months (from October to February) that have a minimum temperature below zero. Table A.5 shows the temperature data recorded at Al Khabar. Measuring started in 1978 and is still continuing. The mean temperature over the period of measurement is 17.6 °C, almost 6 °C higher than in Rabat, and 2.6 °C higher than in Ma'bar. The highest temperatures are reached in June,

Table A.4 - Rainfall data (in mm) from four weather-stations[1]

Station/year	J	F	M	A	M	J	J	A	S	O	N	D	Total
Al Khabar:													
1978	0	11.6	266	1.3	11.7	9.7	104	6.2	-	-	-	-	
1979	-	-	-	27.0	18.8	0	8.0	33.1	17.1	0.7	0	0.2	
1980	0	2.0	27.7	0	0	0	33.2	82.2	3.9	13.4	0	0	162.4
1981	0	3.6	149.6	10.6	34.4	0	27.7	139.9	0	0	0	0	365.0
1982	8.3	20.1	120.7	15.8	2.6	0	3.3	44.1	19.7	18.3	29.6	0	282.5
1983	42.6	23.9	31.0	142.8	28.7	0	11.2	46.4	0	0	0	0	326.6
Mean	10.2	12.2	119.0	32.9	16.0	1.6	31.2	58.7	8.1	6.5	7.4	0	270.0[2]
Rada:													
1977	10.0	0	0	20.6	41.1	0	0	33.4	0	31.3	0	0	136.4
1978	33.5	35.0	34.1	1.1	15.3	3.0	121.1	1.2	11.4	0	0	0	255.7
1979	5.6	0	69.8	14.0	21.7	0	10.1	12.6	39.4	0.7	0	0	173.9
1980	-	0.2	37.8	2.3	0.3	0	-	66.9	0	17.0	0	0	124.5
1981	0	0	126.7	8.4	0	0	23.3	54.9	0	0	0	0	213.3
1982	25.5	15.5	136.6	39.1	13.0	0	3.9	17.9	18.3	15.8	33.1	0	318.7
1983	40.7	15.0	50.5	71.1	34.0	0	0	34.2	0	0	0	0	245.5
Mean	19.2	9.4	65.1	22.4	17.9	0.4	26.4	31.6	9.9	9.3	5.5	0	204[3]
Ma'bar:													
1975	0	4	62	112	2	9	61	192	13	0	0	0	455
1976	0	16	90	62	36	3	46	66	0	0	37	14	370
Mean	0	10	76	87	19	6	54	129	7	0	19	7	413
Rabat:													
1975	0	0	36	99	23	6	139	221	73	0	2	16	615
1976	1	8	88	141	98	32	99	108	18	4	46	0	643
Mean	1	4	62	120	61	19	119	165	46	2	24	8	629

[1] Al Khabar : position: 14° 23' N, 44° 50' E; elevation 2100 m;
Rada : position: 14° 25' N, 44° 50' E; elevation 2080 m;
Ma'bar : position: 14° 50' N, 44° 14' E; elevation 2350 m;
Rabat : position: 14° 12' N, 44° 19' E; elevation 2550 m.

[2] Average 1980 to 1982.

[3] Average 1977 to 1982.

Table A.5 - Minimum, maximum and mean monthly temperatures* (in °C) at Al Khabar agro-meteorological station

		J	F	M	A	M	J	J	A	S	O	N	D	YEAR
1978	Min.	-	9.8	9.9	5.0	6.3	15.3	15.7	15.2	13.6	-	-	-	
	Max.	-	19.6	25.6	23.7	20.8	24.4	24.1	28.6	28.0	-	-	-	
	Mean	-	14.5	17.8	14.4	13.6	19.9	19.9	21.9	20.8	-	-	-	
1979	Min.	5.7	3.9	10.1	10.4	13.6	23.8	15.9	15.3	12.2	7.0	3.8	5.1	10.6
	Max.	7.8	5.5	11.8	-	-	30.6	30.4	30.0	26.7	24.6	21.5	23.6	21.3
	Mean	6.8	4.7	11.0	19.9	21.8	15.1	23.9	22.0	19.5	17.6	20.3	16.2	16.6
1980	Min.	5.9	7.4	10.7	-	12.2	13.8	14.3	13.8	10.4	7.4	3.6	1.1	9.2
	Max.	23.9	24.7	26.1	-	28.2	-	-	-	26.9	25.3	23.1	22.1	25.0
	Mean	16.1	18.0	19.7	-	21.7	24.2	23.5	21.8	21.5	17.9	16.0	14.3	19.5
1981	Min.	1.6	4.2	9.2	10.4	11.5	13.0	15.3	15.4	11.8	6.5	2.3	1.8	8.6
	Max.	23.9	25.0	23.4	-	-	29.1	30.1	29.7	25.2	23.5	-	-	26.2
	Mean	15.9	17.6	17.2	19.8	21.8	23.7	23.5	21.8	20.9	17.0	14.6	14.1	19.0
1982	Min.	8.1	9.9	13.1	12.5	13.8	13.9	16.9	15.2	11.8	8.3	9.6	6.1	11.6
	Max.	-	-	27.3	28.0	24.8	27.2	29.6	28.6	27.3	24.1	23.5	23.0	26.3
	Mean	15.9	17.7	18.5	18.3	20.5	22.8	22.5	21.0	19.2	16.2	16.6	14.3	18.6
1983	Min.	3.9	9.8	11.8	12.7	14.1	13.3	16.5	16.0	10.9				
	Max.	23.6	22.2	25.9	24.5	28.0	30.0	30.4	28.8	28.4				
	Mean	13.7	15.3	18.1	18.2	21.1	-	23.5	22.4	19.7				

* Calculated as an average of hourly measurements per day.

Notes: Mean of the minimum temperature over 1978-1983: 10.0 °C.
Mean of the maximum temperature over 1978-1983: 27.2 °C.
Mean temperature over 1978-1983: 18.4 °C.

July, and August; the highest mean monthly temperature recorded in Al Khabar so far is 31 °C. Mean monthly minimum temperatures are slightly above zero (about 1 °C). Occasionally daily temperatures fall below zero, mostly in November, December, and January, and sometimes even in February.

A.2.2.4 Humidity

Table A.6 shows the minimum, maximum and mean relative humidity recorded at the Al Khabar station in the period from April 1978 to September 1983. In contrast to the temperature there is no prominent seasonal fluctuation discernable, although figures tend to be lowest in July and in October, November, and December. The humidity figures show a close relationship with the monthly rainfall data: the wettest months show the highest humidity, the driest the lowest. The figure shows a large difference between the mean, maximum and minimum monthly relative

Table A.6 - Minimum, maximum and mean monthly relative humidity at Al Khabar agro-meteorological station (%)

Time		J	F	M	A	M	J	J	A	S	O	N	D
6.00	1979	-	-	-	78	79	58	61	72	-	59	64	74
12.00	1979				44	48	31	28	45	-	25	25	27
18.00	1979				47	54	34	40	66	-	26	24	37
Mean	1979				56	60	41	43	61	-	37	38	46
6.00	1980	72	69	71	-	53	49	56	77	63	63	63	59
12.00	1980	35	27	24	-	16	11	16	41	16	21	28	23
18.00	1980	38	35	36	-	17	13	31	52	21	23	32	33
Mean	1980	48	44	44	-	29	24	34	57	33	36	41	38
6.00	1981	64	68	86	82	74	60	70	74	66	72	76	95
12.00	1981	14	19	42	28	25	16	52	40	27	38	36	35
18.00	1981	23	27	58	37	29	21	51	56	27	37	38	37
Mean	1981	34	38	62	49	43	32	58	57	40	49	50	56
6.00	1982	76	-	-	-	-	-	58	71	68	82	88	-
12.00	1982	40	-	-	-	-	-	22	31	20	26	41	-
18.00	1982	42	-	-	-	-	-						-
Mean	1982	53	-	-	-	-	-	40	51	44	54	65	
6.00	1983	-	-	79	88	78	50	60	71	62			
15.00	1983	-	-	36	43	30	-	30	34	39			
Mean	1983	-	-	58	66	54	50	45	53	51			

humidity. Around 6 o'clock in the morning the relative humidity is highest, often reaching dewpoint, especially in the colder months. Lowest relative humidity is always early in the afternoon, just after noon. Mean monthly relative humidity is consistently lower in Al Khabar than in Ma'bar, which in turn has lower relative humidity figures than Rabat (46 % in Al Khabar against 60 % in Ma'bar and 69 % in Rabat).

A.2.2.5 Evaporation

Intense radiation, low relative humidity during the day, and constant wind result in a high potential evaporation.

Since mean monthly temperatures in Al Khabar are higher than in Rabat and Ma'bar and mean relative humidity figures are lower, evaporation is expected to be higher in Al Khabar. Table A.7 shows the evaporation data of a class A pan installed at the agro-meteorological station in Al Khabar, and the evaporation figures calculated according to the Penman method (FAO, 1979). The Penman method of calculating evaporation theoretically yields results about 20 % lower than figures obtained by measuring a class A pan. It may therefore be concluded that the two methods are in close agreement, minor differences being due to inevitable inaccuracies in the measurements. Monthly evaporation is highest in the months of April, May, and June, and lowest in the colder months of November, December, and January; seasonal fluctuation of the evaporation is only small (about 20-40 %).

The potential evaporation as calculated according to the Penman method is 2300-2400 mm/year, compared to 2000 mm in Ma'bar and only 1700 mm in Rabat.

A.3 Geology of Al Bayda Province

The following short description of the geology in Al Bayda Province is based on the BRGM geological survey carried out for Yominco in 1980, the geological study of the Rada Area by Ilaco carried out for the Ilaco (1981), and the work by Geukens (1966).

In the following stratigraphical synopsis the names and codes have been adopted from the geological maps by Grolier and Overstreet (1978) and the BRGM (1981) survey. The different formations are dealt with in chronological order. Figure A.2 shows the occurrence of the main stratigraphical units in Al Bayda province and Figure A.3 is the geological map.

A.3.1 Precambrian basement

Precambrian rock forms the basement of the whole of the YAR. It crops out in the part of the province east of Rada. The rock consists of grey-white and brownish gneisses and mica schists, intruded in many places by pink granites and pegmatites. The pegmatites are generally rich in feldspar and associated with quartz veins, which are sometimes mineralized. All basement rocks are highly metamorphized rocks of sedimentary, volcanic and plutonic origin (BRGM, 1981).

Table A.7 - Monthly evaporation (in mm) calculated at Al Khabar agro-meteorological station

Year	Calculation method*	J	F	M	A	M	J	J	A	S	O	N	D	Total
1979	A	-	-	-	198	228	247	164	162	-	212	187	193	-
1979	B	-	-	-	319	341	400	360	307	320	285	206	212	-
1980	A	193	193	203	-	253	235	230	181	209	220	191	179	2495
1980	B	226	288	282	-	366	345	323	282	297	284	218	201	3395
1981	A	188	187	170	198	219	267	230	208	188	185	178	174	2392
1981	B	241	258	180	249	288	339	310	280	310	273	225	205	3158
1982	A	173	185	-	-	-	-	226	189	191	183	162	-	
1982	B	170	170	186	180	186	189	356	313	-	226	174	171	2529
1983	A	-	-	209	-	-	-	197	177	171				
1983	B	202	244	267	-	282	-	-	251	282				
Mean	A	185	188	194	198	233	250	209	183	190	200	180	182	2386
Mean	B	210	240	229	284	293	318	337	287	302	267	206	197	3170

* A = Penman method; B = class A pan.

STRATIGRAPHICAL SCHEME

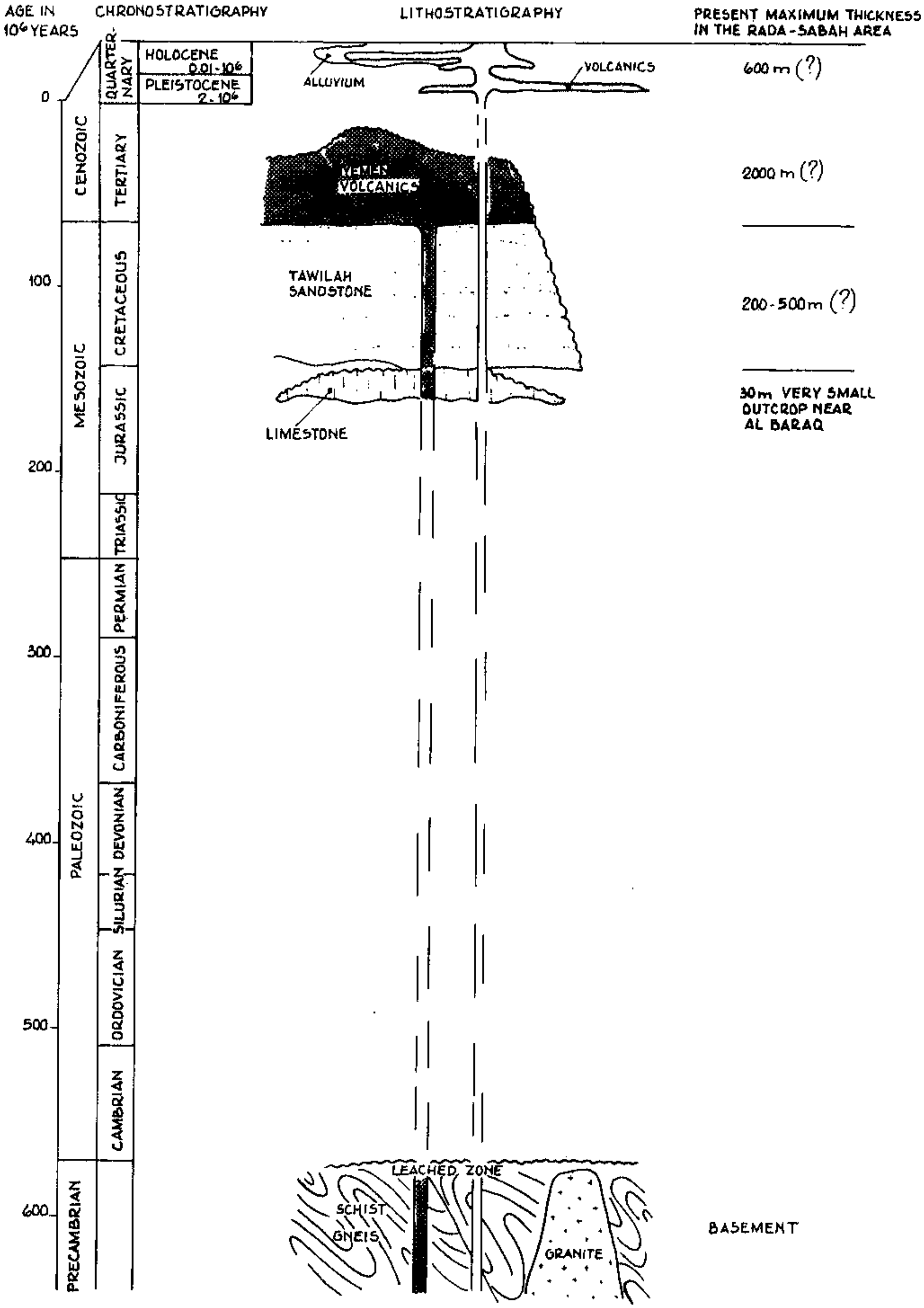
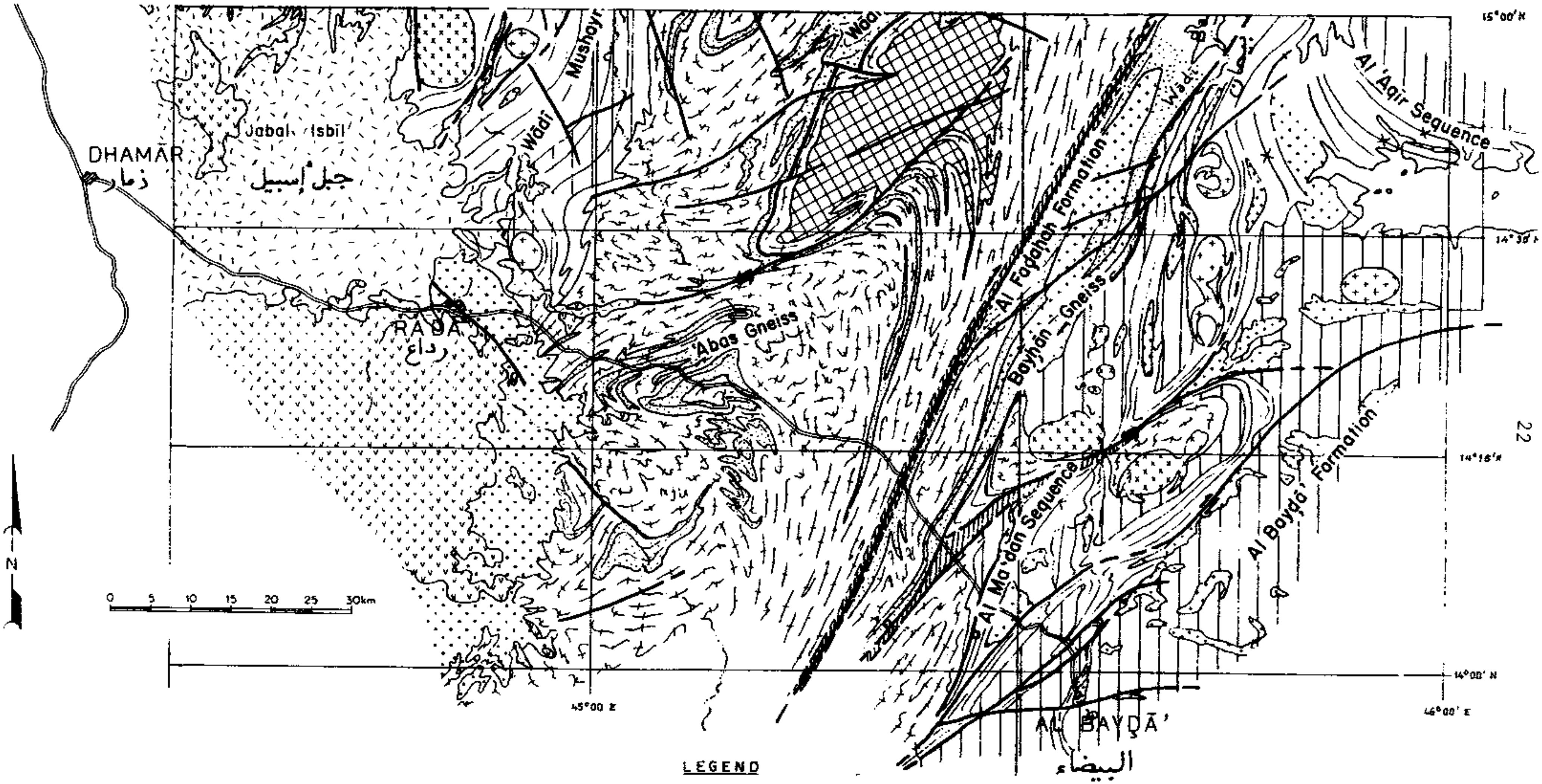


FIG. A.2

GEOLOGICAL MAP OF THE AL BAYDA PROVINCE

SOURCE: BUREAU DE RECHERCHES GEOLOGIQUES ET MINIERES



LEGEND

PRECAMBRIAN

- Recent alluvial and eolian deposits
- Quaternary volcanics
- Tertiary volcanics (Trapp Series) - (a) - Young alkali granites
- Tawilah sandstones (Cretaceous)
- Amran limestones (Jurassic)
- Diorite to norite — Post-tectonic intrusives
- Granite to tonalite — Post-tectonic intrusives
- Granite, monzonite (ante and syntectonic intrusives)
- Low to intermediate metamorphosed volcano-sedimentary formations (A, C and E units)
- Intermediate to high metamophosed volcano-sedimentary formations (C and E unit)
- Gneisses of 'Abas, Wādī 'Ablo' and Ghalil, Al Fadahah formation, Bayhān gneiss — B and D units
- Migmatites — B and D units
- Orthogneiss (D un

FIG. A.3

The Precambrian basement in the province is subdivided into three structural units separated by major north-east and south-west running faults. Each unit comprises series of highly metamorphic rocks folded into one or more synclinoria. Late orogenic granite intrusions are usually found along the axis of the synclinorium. The hill on which Al Bayda Town is situated forms a good example of such a granite intrusion. The structure of the synclinoria is complex as there are numerous folds with smaller amplitudes. Apart from the major faults separating the different structural units many more faults cut the area. The present wadi system usually follows major faults. The faults usually run in preferred directions and are of different age and origin. Very important NE-SW running faults are found especially in the south-eastern part of the province near Al Bayda where they form major wadi systems such as Wadi Az Zahir, Wadi Hazzah, and Wadi Nakhar. Numerous smaller wadis follow smaller NW-SE running faults and fractures.

Also the strike of the folded metamorphic rocks is an important factor in determining the direction of wadis such as Wadi Mansur and Wadi Dhi Na'im.

Intrusive dikes and sometimes dike swarms, often associated with faulting, cut the Precambrian rocks in many places. A good example of dikes associated with a major fault is the dike swarm parallel to the east-west running fault just south of Al Bayda. Most of the dikes are of Precambrian age, but also many dikes of Tertiary age occur associated with the tectonical movements that formed the Red Sea Graben. Tertiary dikes occur especially in the western part of the province near areas with volcanic activity.

A.3.2 Tawilah Sandstone (probably Cretaceous age)

The Tawilah Sandstone is exposed in an elongated zone running from the north-north-west to the south-south-east through the western part of Al Bayda Province. Rada Town lies within this strip. The thickness of this formation may exceed 400 m. The sandstone forms a series of fluviatile (river-type) cross-bedded deposits. The grain size is in the range from coarse sand (1-2 mm) to fine gravel (2-5 mm). Sometimes much coarser, conglomeratic lenses are found. The colours are light-grey, purple, and yellow. In the lower part of this formation, well-stratified, thin shale layers are present south-east of Suar near Rada.

The Tawilah Sandstone rests discordantly on the basement rock. At some places faulting can be observed between this sandstone and the overlying Yemen Volcanics. The beds gently dip to the west. Major NW-SE running faults cut the sandstone near Rada. Vertical movements of more than 100 m have been observed in some cases. Dikes, sometimes forming dike swarms, cut the sandstone in many places.

A.3.3 Yemen Volcanics (probably Early Tertiary Volcanics)

The volcanics known as the Trapp series (Geukens, 1966) or the Yemen Volcanics (Grolier and Overstreet, 1978) are tentatively assigned to the Oligo-Miocene era. Volcanic rocks of this formation cover a large area of Yemen, including Sana'a, Dhamar, and Taizz. The Yemen Volcanics form the whole western part of Al Bayda Province, overlying the Tawilah Sandstone on top of a slightly marked erosion surface (BRGM, 1981). The volcanic series comprises piled-up flows and domes of lavas, tuffs sometimes alternating with alluvial sand and gravel deposits.

The rocks are of greatly varying chemical composition. Basalts, andesites, rhyolites, and basanites have been found. The colours are dark grey, green, and purple. There are numerous dikes, but with an irregular distribution, cutting the volcanic rocks as well as the neighbouring Tawilah Sandstone and sometimes the Precambrian basement. The numerous dikes crossing the basement in the As Sawadiyah region belong to the same volcanism (BRGM, 1981). Most of the dikes have a width of less than 10 m. Dikes several 100 m wide also occur, forming ridges in which eruption centres can be observed. Highly eroded volcanic cones occur frequently. Bedding occurs on a large scale and is either more or less horizontal or slightly dipping. In the high plateau area south of Rada, there is an alternation of hard and soft beds, with a bed thickness of up to 100 metres. Grolier and Overstreet (1978) estimate the thickness of the Yemen Volcanics to be at least 2000 metres.

A.3.4 Holocene and Upper Pleistocene basalt flows and dikes

The area north and west of Rada is one of the few scattered areas of recent volcanism in the YAR. There are numerous subrecent volcanoes, especially in the North-Western Quadrangle. During the earliest phase of this volcanism (Upper Pleistocene) a thin sheet of dark volcanic rock was formed over a large area. These beds are found at the base of the young volcanic rocks in the north-western part. Erosional remnants of these beds overlie Precambrian rock in the eastern part. The rock is dark greenish grey, of basaltic composition, and very hard.

The centre of volcanic activity was the Jabal Isbil in the north-west of the province; however, locally very small funnel-shaped occurrences of lava have been found.

The lava flows of Upper Pleistocene and/or Holocene age occurred in a younger phase of volcanism. These lavas determine the present landscape in the north-western part of the project area, with the main centre at Jabal Isbil. There are many very fresh-looking volcanic cones in this area. The rock is basaltic, sometimes trachytic, and is black. The lava has been rich in volatiles and has a characteristic vesicular structure with many cavities.

This formation is up to 1000 m thick near the Jabal Isbil. The lava flows are found interbedded in alluvial deposits in valleys at a considerable distance from this eruption centre.

A.3.5 Holocene alluvial deposits

Holocene alluvial deposits are found in many wadi beds in Al Bayda Province. The occurrence of valley-fill deposits around Rada is partly connected with the recent volcanism. Lava flows have blocked a number of erosion pathways, increasing the deposition of alluvium in the plains around Rada, Bani Ziad and Abbas. Other alluvial beds have been formed from stream deposits of the large watercourses in the north, and also where man has limited erosion by building dams and by making terraces.

The valley-fill deposits are silty, fine-grained sands, with some intercalations of gravel. The surface beds are loesses in the silt (2-50 µm) fraction. The beds are typically upto 30 m thick. The stream deposits are sand and gravel.

A.4 Water resources in the Rada Basin

A.4.1 Physical environment

Map A.1 shows that the Rada catchment is situated in the west of Al Bayda Province, extending north and south of the Dhamar-Al Bayda road. The southern boundary of this catchment follows the steep escarpment of the sometimes more than 2800 m high plateau mountains of Sabah and Agabah Riashiyah. The eastern boundary of the catchment is formed by the Precambrian basement hills, east of the Banin Ziad Plain. The northern boundary runs over the lava flows and the caldera of Jabal Isbil. The western catchment boundary is formed by the eastern boundary of the Dhamar Plains, 55 km west of Rada.

The Rada Plains investigated during this survey, occupy the eastern part of this catchment between Al Fugah and Bani Ziad and lie between longitude 44°40' and 44°57' east and between latitude 14°15' and 14°30' north. The area is 272 km^2, which is approximately 28 % of the total catchment (975 km^2). The exact area of the groundwater catchment is unknown because its northern boundary does not follow any topographical watershed, but follows rock structures buried under the younger lava flows of Jabal Isbil.

The Rada Plains are composed of:

- a central plain around Rada and the main road Dhamar-Rada-Al Bayda;
- a southward extension into a number of irregular intermontane plains and valleys surrounded by rugged hills and bounded in the south by the mountain range of the 2500-2800 m high escarpment of Sabah and Agabah Riashiyah;
- a northward extension into a number of irregular plains surrounded by plateau-like hills with elevations 20 to 150 m above the plains. The northern boundary of these plains is formed by the lava flows of the 3240 m high Jabal Isbil, and younger volcanoes east of this mountain.

A.4.2 Geology

The geology of the Rada catchment has been described first as part of an overall geological reconnaissance of Yemen by Geukens (1966), and Grolier (1977). The geology of the area is roughly indicated on the Geological Map of Yemen, based partly on Landsat-1 images published on a scale 1:500 000. Ilaco (1981) has published a geological map based on field surveys and geological photo interpretation. BRGM (1981) has mapped the Rada Basin as part of the Al Bayda-Marib Project. The present geological map (Map A.1) and geological profiles (Map A.2) have been based on the Ilaco geological map and a more detailed interpretation of aerial photos including mapping of faults, volcanic centres and intrusive dikes.

Table A.8 shows the succession and lithology of the different geological formations in the Rada catchment. A more detailed description is given in the description of the geological map by Ilaco (1981).

Map A.1 and the profiles in Map A.2 show that the Precambrian basement, which is composed of well-layered metamorphic schists and gneisses, occurs in the north-eastern and eastern part of the catchment.

The Tawilah Sandstone described in Section A.3.2 is present in the eastern part of the Rada Basin. Rada Town lies within this zone.

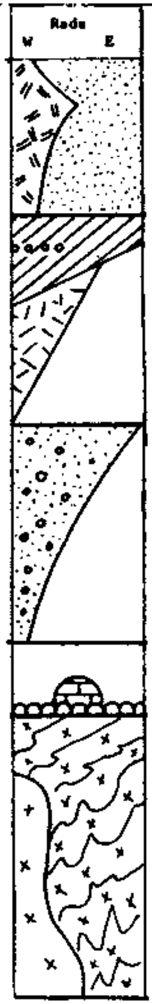
Numerous intrusive dolerite dikes cut the sandstone east of Rada. The width of these dikes is usually between 1 and 3 m. A 10 m wide north-south running dike cuts the Precambrian rock just east of Bani Ziad. All these dikes belong to the Yemen Volcanics of Tertiary age, as described below.

A.4.2.1 Tertiary and/or Cretaceous - Yemen Volcanics

The Yemen Volcanics described in Section A.3.3 form the whole south-western part of the project area. There are numerous dikes, but with an irregular distribution. Most dikes have a width of less than 10 m and occur as dike swarms. Dikes several 100 m wide also occur, forming ridges in which eruption centres can be seen. Bedding is on a large scale and more or less horizontal. In the south there is an alternation of hard and soft beds, with bed thicknesses of up to 100 metres. In the area around Ad Draybah there are numerous basalt volcanic cones. In addition there are important interbedded layers of coarse gravel, as shown by the borehole drilling results.

The Yemen Volcanics are reported to be at least 2000 metres thick (Grolier and Overstreet, 1978). In the Rada catchment the thickness increases stepwise, starting just west of Rada, over NW-SE running faults in a SW direction to probably more than 1000 m near Sudan, as indicated schematically on the geological sections of Map A.2.

Table A.8 - Stratigraphic succession and water-bearing properties of geological formations in the Rada catchment

System (Formation)	Formation log	Aproxi-mate thickness	Description	Water-bearing properties
QUATERNARY		0 > 300 m	Sandy clay with gravel and boulders to sandy loam and sand Volcanic cones and basalt lava flows	Generally moderate aquifers Moderate to probably high-yielding aquifers when fractured
TERTIARY (Yemen Volcanics)		0 > 500 m	Well-stratified basalt and tuffs with interbedded layers of clay, sand and gravel	Poor to moderate aquifer with inter-bedded aquicludes
		0 > 300 m	Basaltic and trachitic sub-volcanic rocks with dolerite dike swarms	Generally moderate aquifers due to fracturing or interbedded alluvium composed of clay, sand and gravel
CRETACEOUS (Tawilah Sandstone)		0 > 300 m	White and tan to reddish fine sandstone	Poor to excellent aquifer, especially when fractured
JURA (Amran Limestones)		0 - 30 m	Bluish-grey limestone, small reef facies near Bagarat only	Aquiclude
PRECAMBRIAN		unknown	Grey to tan and reddish well-stratified schists and gneisses with granite intrusions	Aquiclude - moderate aquifer when fractured or weathered

A.4.2.2 Holocene and Upper Pleistocene - Basalt flows and dikes

Around Rada there are numerous subrecent volcanoes, especially in the north-western quadrangle. During the oldest phase of this volcanism (Upper Pleistocene) a thin sheet of dark volcanic rock was formed over a large area. These beds are found at the base of the young volcanic rocks in the north-western part. Erosional remnants of these beds overlay Precambrian rock in the eastern part. The rock is dark green-grey, of basaltic composition, and very hard.

The centre of volcanic activity was the Jabal Isbil; however, in some places very small funnel-shaped occurrences of lava have been found from other sources.

The lava and volcanic ashes are up to 1000 m thick near the Jabal Isbil. The lava flows are found interbedded in alluvial deposits in the northern part of the Rada Plain around Dar Mas'ab.

A.4.2.3 Holocene alluvial deposits

The alluvial beds in the southern valleys have been formed from stream deposits of the large watercourses; they are usually coarse sand on gravel deposits, covered by finer deposits outside the main stream channels. These surface beds are loesses in the silt (2-50 µm) fraction. The valley-fill deposits are silty, fine-grained, with some intercalations of gravel. The beds are typically up to 30 m thick.

A.4.2.4 Faults

There are many faults to be found in the bottom of the Rada catchment. The geological map (Map A.1) shows a series of prominent NW-SE running normal faults or step faults, cutting the formation below the alluvial deposits in the Rada Plain and the young basalt flows of Jabal Isbil. These faults of Tertiary to Pleistocene age were formed during the opening of the Red Sea Graben. The Rada catchment lies on the eastern border of this graben with the Arabian Shield. The most north-eastern fault of this group, forming the NE border of the catchment with the Precambrian rocks, is partly buried under basalt flows of two Quaternary volcanoes formed on the fault. The second fault, approx. 3 km SE of these volcanoes, forms the boundary with the Tawilah Sandstone that has been lowered in respect of the Precambrian formations.

Going in a SW direction one finds three more step faults before crossing a very prominent NW-SE fault, running below the plain, under Rada Town, cutting into the mountains SE of the town where it forms the boundary between the Tawilah Sandstone and the Yemen Volcanics. NW-SE trending faults in the Volcanic rocks can be noted near Azzan, or their presence can be deduced from rows of volcanic centres and the positions of some of the valleys near Sawman and Ad Draybah. Large vertical displacements but hardly any horizontal displacement along the faults can be observed, and the vertical movements are usually unknown. We estimate vertical movements along the fault under Rada at more than

100 m, judging from the difference in elevation of the sandstone hills on both sides of the fault. However, it is impossible to determine the depth of the base of the Tawilah Sandstone with the Precambrian basement under the Rada Plains. We only know that this depth increases stepwise from zero NE of Dar Al Najd to several hundreds of metres SW of Rada, as indicated on the geological profiles of Map A.2.

Many of the major faults have been filled by sometimes more than 10 m wide dolerite intrusions. In some cases they are related to the location of the Tertiary and Quaternary volcanic centres, such as the young volcanoes on the fault in the NE corner of the Rada Plains and the Tertiary volcanic centres near Sawmah in the southern valleys.

A.4.3 Hydrogeology

Aquifers and aquicludes in the Rada catchment are described in Table A.8. From this description and the geological map the following can be deduced:

- The Precambrian basement forms an impermeable watershed in the north and east of the catchment and the impervious base underlying the alluvial deposits of the plain around Bani Ziad;
- The Precambrian basement forms the impervious base underlying all younger rock formations;
- The Tawilah Sandstone and the overlying Tertiary Volcanics form a moderately to highly permeable heterogeneous aquifer system of unknown thickness, cut into blocks by NW-SE trending faults. This aquifer system underlies the greater part of the groundwater catchment;
- The finer alluvium deposits occurring under the plains and valleys form a moderately permeable shallow aquifer;
- Coarse alluvium stream deposits form a usually shallow aquifer in the southern valleys of the catchment;
- The Quaternary volcanic rocks covering the northern part of the catchment around the Jabal Isbil form usually highly permeable aquifers on top of the older formations. The very deep water-levels and the consequently usually thin part of the formation saturated with water make it at least economically a less important aquifer.

The permeability of the aquifers is known from only 7 well tests. The average permeability of the sandstone and Tertiary Volcanics, calculated from 5 wells, is K = 2.67 m/d and varies between 1.13 m/d and 4.68 m/d.

Only 2 tests have been performed in the Precambrian rocks: the permeability is much lower, about 0.58 m/d including unproductive sections of solid granite. The weathered rock may be up to 10 times more permeable and the fractured rock even more than 100 times.

Flow-net analysis of the water-level elevation map (Map A.4) yields an average regional kD-value for the SW part of the catchment of about 1000-2000 m^2/d.

Thus far no pumping tests with observation wells have been carried out on wells in the Rada Basin. Therefore no storage coefficients are available.

A.4.3.1 Regional groundwater flow

Map A.5 shows the water-level depth contour map made from observations in 730 wells during June 1983. The map shows that:

- Water-levels deeper than 20 m down to 55 m occur in the area between Rada and Mallah, which is one of the most intensively pumped areas.
- Water-levels between 10 and 20 m occur in the southern valleys and northern plains, except in Wadi Tha where shallow water-levels occur of less than 5 m below the surface.

The water-level elevation map (Map A.4) shows a highest piezometric level of more than 2200 m above MSL in the SW extremity of the catchment around Sudan. From here the water-level elevation falls gradually in a NE direction to 2050 m above MSL around Rada and less than 2030 m above MSL NE of Rada. From this map we deduce that the general groundwater flow direction is from SW, W and NW directions eastwards to the Central Rada plain. From here the groundwater flow changes to a NE direction towards the NE corner of the catchment where shallow water-levels are less than 5 m and consequently groundwater losses occur by evapotranspiration. Heavy groundwater abstraction between Mallah and Rada causes a depression cone in the water-level, as is indicated by the 2060 m contour line.

A.4.3.2 Groundwater quality

Groundwater quality in the Rada catchment is known from more than 700 observations of the electrical conductivity (EC) in wells. Map A.6 shows the water quality as an EC-contour map based on these observations. Moreover, a chemical analysis of 27 water samples was made in the laboratory of the project.

The map shows that groundwater quality follows to a great extent the trends of groundwater flow. The best water with EC-values of 500-1000 µS (low to moderate salinity) is found in and close to recharge areas at the end of the wadis in the SW of the area and the springs of Wadi Tha. Water with higher salinity (1000-2000 µS) is found generally in the wadis and plains around Rada.

Groundwater quality deteriorates gradually in a NE direction and reaches its highest salinity of EC > 3000 µS in the plain between Dar al Najd and Dar Mas'ab. The higher salinity observed east of Wadi Tha is restricted to shallow groundwater. Near Hanaha Al Masud the water from the shallow wells in the alluvium and underlying basalt has an EC of 1500 to 2000 µS. Groundwater in the Tawilah Sandstone underlying the basalt at more than 100 m depth has a lower salinity of 1200 µS.

The chemical analyses of the 27 samples taken in the Rada catchment (see Volume IV, Part II) show that calcium and bicarbonate are dominant in the southern and western part of the catchment with fresh groundwater having its origin in volcanic rock aquifers. Water from the springs in Wadi Tha flowing from below the volcanic rocks of Jabal Isbil has similar characteristics. Water in the north-eastern part of the catchment shows higher sodium and sulphate concentration. This difference in groundwater chemistry is probably caused by the occurrence of sandstone, granites and metamorphic rocks with a completely different mineralogical and chemical composition than the volcanic basaltic rocks in the south and west of the catchment.

The higher salinity of the groundwater in the NE Rada plain and its evolution to sulphate-type groundwater is probably related to evaporation of groundwater under shallow water-table conditions as well as surface water flowing to and evaporating in this part of the plain after heavy rainstorms.

A.4.3.3 Groundwater discharge - recharge relation

Groundwater discharge in the Rada catchment occurs by:

- well abstraction in the plains and wadis around Rada;
- flow from springs in Wadi Tha and at the upstream ends of the southern valleys;
- direct evaporation of groundwater in areas of shallow water-tables in the eastern corner of Wadi Tha and near the NE outlet of the catchment.

All wells and springs are indicated with their well number on Map A.3. Allowing for a small percentage of wells overlooked during the well inventory and for wells drilled after August 1983, we estimate that there are around 800 wells in the Rada basin. An estimate of the annual groundwater abstraction of each well made during the well inventory is listed in Volume IV, Part I. Table A.9 summarizes well abstraction in the Rada Basin.

Before the construction of the Dhamar-Rada road in 1976 all wells were dug wells abstracting water from the alluvium in the Rada Plain and southern wadi beds, and the upper metres of the underlying rock. Between 1976 and 1983, 190 boreholes were drilled especially in the area between Rada and Azzan, which increased the water abstraction considerably. Also the introduction of pumps replacing many of the traditionally animal-powered water-lifting devices increased the water abstraction several times. Last year, drilling of new boreholes in the Rada Plains decreased considerably and is now estimated at less than 10 per year.

Apart from water abstraction by wells, water flows from a number of natural springs in Wadi Tha and some springs in the southern valleys. Annual water outflow in Wadi Tha is estimated at 1.6 MCM (million cubic metres). This figure is based on flow observations made in June 1983, and seasonal fluctuations are not taken into account. Well yields depend on the capacity of the pump installed, and are usually between 3 and 10 l/s.

Table A.9 - Present water abstraction and estimated future water availability, Rada Basin

Code of subcatchment	Catchment area (ha)	Alluvium (ha)	Water abstraction (x 1000 m^3/yr)			Present water-level depth (m)	Water availability (x 1000 m^3/yr)			Future water-level depth (m)
			Water-supply	Agriculture	Total		Total	Future water-supply	Available for irrigation	
RA-A	4709	195	25	640	665	5	1264[1]	66	1198	10
RA-B		37	0	0	0	N.A.	-	0	-	N.A.
RA-C		54	0	0	0	N.A.	-	0	-	N.A.
RA-D		60	0	135	135	N.A.	300	0	300	15
RA-E		190	26	675	701	10	1050	69	981	15
RB	1698	314	30	266	296	7	600	79	521	20
RC-A	2100	100	0	155	155	8	300	0	300	20
RC-B		76	0	67	67	8	150	0	150	20
RC-C		180	36	224	260	8	500	95	405	20
RD-A	3142	69	0	0	0	N.A.	50	0	50	20
RD-B		96	9	21	30	8	100	24	76	20
RD-C		300	0	131	131	13	750	0	750	25
RD-D		176	85	576	661	15	1000	224	776	25
RD-E		317	45	503	548	17	750	119	631	30
RE		189	31	673	704	8	1244[1]	82	1162	15
RF	1027	234	15	451	466	13	750	40	710	25
RG	1206	131	0	0	0	N.A.	206[1]	0	206	20
RH	925	215	0	0	0	N.A.	700	0	700	35
RI	958	600	29	899	928	27	1500	77	1423	40
RJ		182	40	79	119	27	150	106	44	40
RK	462	197	0	30	30	30	150	0	150	35
RL		58	32	136	168	15	300	84	216	30
RM		1042	190	2052	2242	17	3000	502	2498	30
RN		23	0	203	203	30	145[1]	0	145	30
RO		524	197	2389	2586	5	3751[1]	520	3231	10
RP		295	31	425	456	7	1000	82	918	15
RQ		89	0	94	94	5	250	0	250	25
RR		843	51	3305	3356	15-50	3800[2]	135	3665	30
RS		150	70	102	172	7	1357[1]	583[3]	774	20
RT-A		610	50	307	357	7	1000	132	868	20
RT-B		N.A.	8	79	87	N.A.	21[1]	21	N.A.	N.A.
RU-A		156	197	334	531	20	700[2]	700	0	35
RU-B		N.A.	0	3	3	27	3	0	3	40
RU-C		Urban	123	0	123	27	0	0	0	40
RV		88	180	1930	2110	20	2500	475	2025	35
RW		556	39	963	1002	12	1250[4]	103	1147	20
RX	1234	485	15	361	376	12	500	40	460	20
RY		728	16	360	376	10	418[5]	42	376	15
RZ-A		506	33	231	264	10	1000	87	913	20
RZ-B		N.A.	30	3	33	N.A.	79	79	N.A.	N.A.
ZA	2702	953	28	142	170	20	700	74	626	25
Total		11018	1661	18944	20605	0-50	33288	4640	28648	0-50

N.A. = not available.

[1] Not limited.
[2] In the northern part only.
[3] 500 for Rada.
[4] Western part only.
[5] Brackish water.

The annual abstractions of wells and springs have been estimated following the methodology described in Section A.1.2 and are listed in Volume IV, Part I. Map A.7 shows the estimated annual well abstraction and spring discharge in mm/yr. The highest abstraction of approximately 4.4 million cubic metres (MCM) per year occurs in the irrigation area between Rada and Mallah resulting in a sink in the water-level (see Map A.4 and Section A.4.4).

The total annual well abstraction and spring discharge in the Rada catchment is estimated at 21.8 MCM/yr. We estimate that 1.6 MCM of this water is used for domestic purposes. The remaining 20.2 MCM is used for irrigation, about 7 %.

The Rada catchment can be split up into two main recharge areas:

- the area north-west of the Rada Plains around Jabal Isbil, also called the northern basalt plateau, with a total area of 220 km^2; and
- the area between this basalt plateau and the southern mountains between Bab al Filak (Dhamar Governorate) and Bani Ziad with a total area of approximately 1200 km^2, including parts of the Dhamar Governorate.

In Wadi Tha north-west of Rada, a large number of springs yield a total of some 55 l/s or 1.6 MCM/year, not considering yet unknown seasonal fluctuations in spring flow from below the northern basalt plateau. This equals only 2.5 % of the annual rainfall estimated at some 300 mm on the high-lying northern basalt plateau.

Even during heavy rainstorms all the water falling on the lava flows and ash layers of Jabal Isbil infiltrates immediately into this highly permeable and porose volcanic rock. Also the coarse alluvial deposits in the wadi beds are very favourable for infiltration and may have infiltration rates of more than 10 % of the rainfall. Infiltration of rain-water is also increased by numerous earthen walls dividing the area into many infiltration basins preventing runoff.

Apart from spring flow in Wadi Tha there is probably a much larger natural groundwater flow from below the northern basalt plateau into the Rada Plain. This water, together with the underground inflow from western and southern directions and the direct infiltration of rain- and floodwater in the plains, forms the recharge of the groundwater.

Virtually no runoff water leaves the area even after heavy rainstorms. Storm water entering the Rada Plains through the southern wadis collects in the plain north of Rada and infiltrates in a few days' time.

Italconsult (1973) estimated the annual infiltration in the Sana'a and Dhamar basins at 3 % of the annual rainfall. This estimate is based on significant rainfall events, estimated evapotranspiration and an estimated soil moisture capacity of 50 mm in the plains. Recharge is particularly sensitive to the frequency of significant storms: minor storms only replenish soil moisture, except where they fall on bare rock. The great differences in annual rainfall indicate a high variability in the recharge of the groundwater.

More recent studies, however, have calculated higher recharge rates (one even up to 14 %). The "Bundes Anstalt für Geo-wissenschaften und Rohstoffe" (1975), for example, arrived at a figure of 5 %. Pratt (1976) calculated for the Dhamar plains 3.75 % in dry years, 5 % in average years and 5.5 % in wet years.

An accurate determination of the mean annual groundwater recharge is impossible because rainfall data and water-level and discharge observations cover only a few years. The great differences in annual rainfall in this semi-arid region necessitate a much longer rainfall period to make such calculations.

To illustrate this, Figure A.4 shows the water-level fluctuations and rainfall as observed at Al Khabar rainfall station over the period September 1980 to October 1983. During these years rainfall was between 162 and 365 mm, averaging 284 mm/year. The water-level hydrographs show a period of at least 8 months of declining water-levels, followed by a period of rising water-levels. This indicates that the enormous increase in water abstraction during the last 6 years caused by well drilling and installation of modern pumps on dug wells does not yet lead to overpumping on a regional scale and a permanent decline in the water-table. Only in the area between Rada and Mallah have water-levels been lowered to deeper than 50 m by heavy pumping of about 4.4 MCM per year (see Map A.5).

It is difficult to make a reliable estimate of the recharge because of the lack of sufficient hydrological data and information about the depth to the impermeable basement, especially in the sandstone area around Rada. The following estimate is based on a flow-net analysis of the water-level elevation (Map A.4) and the spring flow in Wadi Tha. From the results of this analysis, summarized in Table A.9, we estimate that the annual recharge is in the order of 30 MCM/year, which is 140 % of the annual abstraction by wells and springs. The rest of the infiltrating water is lost by direct evaporation of groundwater in the NE corner of the Rada Plains and some groundwater outflow.

A.5 Water resources in Al Bayda

A.5.1 Physical environment

Map A.8 shows that the investigated area around Al Bayda forms one catchment extending in the south into the People's Democratic Republic of Yemen north of a prominent escarpment. The catchment lies between 45° 20' and 45° 40' east and between 13° 55' and 14° 05' north, and has an area of 283 km^2. The major catchment boundaries are:

- the southern watershed formed by the prominent escarpment which is the southern edge of the high plateau of Yemen;
- the north-eastern watershed running in NW-SE direction just west of Awwayn;
- the north-western watershed on the western boundary of the map.

WATER-LEVEL FLUCTUATIONS

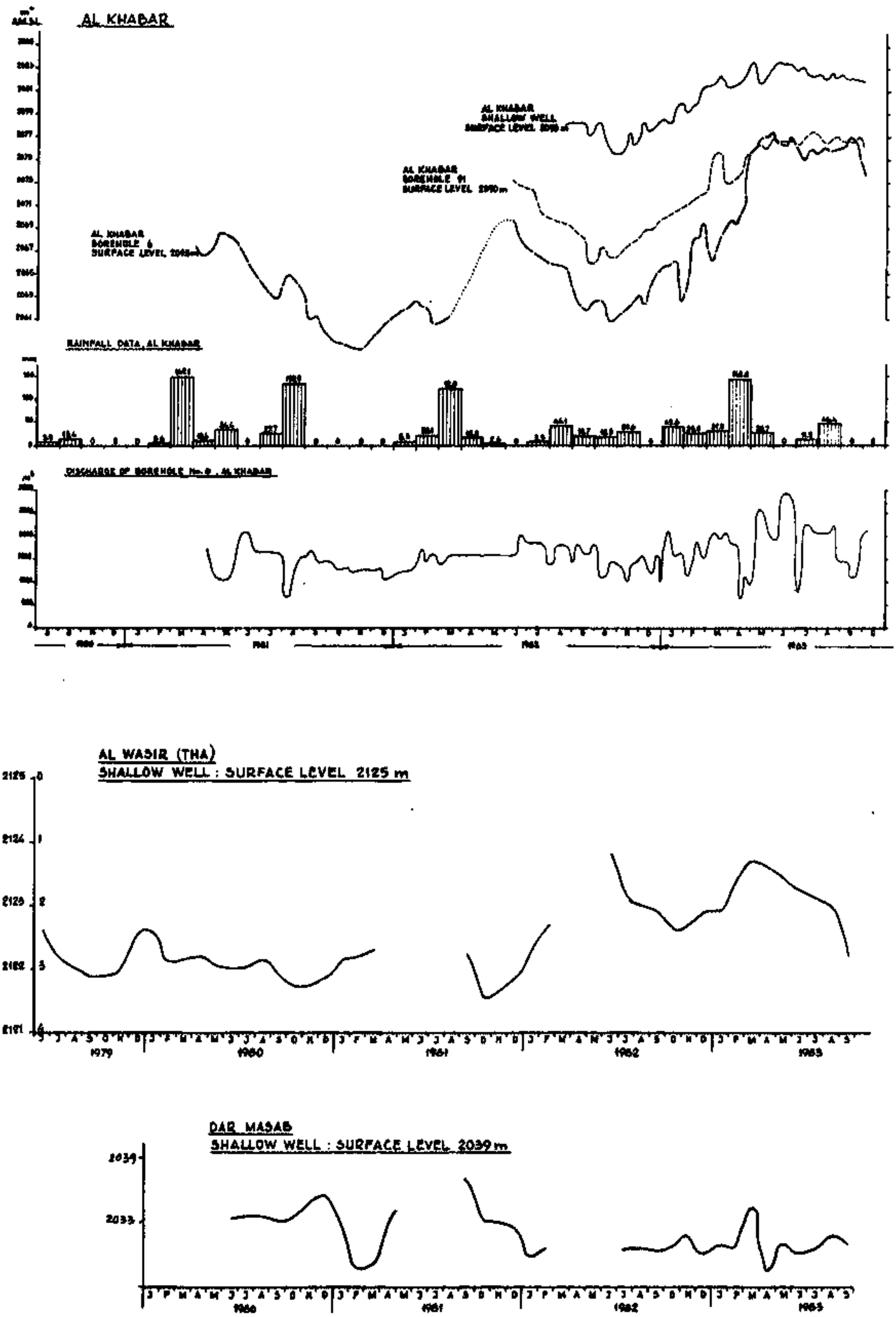


FIG. A.4

The outlet of this catchment lies north of Maradhim in a sharp bend of the Rada-Al Bayda road. The Al Bayda catchment can be divided into a number of smaller subcatchments related to the rather dense wadi system. The boundaries between these catchments are indicated by watersheds on Map A.8. Table A.10 gives the areas of the subcatchments and wadis indicated in Map A.8.

A.5.2 Geology

The Al Bayda catchment is underlain by Precambrian metamorphic rocks mainly composed of well-layered intensively folded gneisses and schists with some granite intrusions. Profiles PP1 and QQ1 in Map A.9. made by BRGM (1981) show the geological structure of the intensely folded rocks. The hill on which Al Bayda Town has been built is a good example of a granite intrusion in the otherwise highly metamorphic rocks.

A.5.2.1 Faults

There are many faults in the Precambrian basement of the Al Bayda catchment. Two major faults are:

- the east-west fault south of Al Bayda following from east to west Wadi Nakhar - Wadi Thihwahl and Wadi Az Zahir; and
- the NE-SW fault running along Mash'abah over Ghirran and north of Wadi Az Zahir.

Substantial horizontal displacements have occurred along both faults. The origin of the dike swarms south of Al Bayda is related to the E-W fault.

Apart from these major faults, numerous other mainly NE-SW and NW-SE trending faults cut the Precambrian basement.

Map A.8 shows that a prominent wadi system has developed by erosion in the Plateau around Al Bayda. Most of these wadis follow the strike direction of the folded Precambrian or major faults in the hard basement rocks.

A.5.2.2 Alluvium

Most of the wadis have been filled with usually 5 m to 15 m of generally finer alluvial deposits. In most cases river beds are absent. This does not necessarily mean that infiltration rates are high, because the profile of the wadi system is also of importance. It is not surprising, therefore, that in the steepest, upstream part of the wadis, south of the major E-W fault, river beds have occasionally developed.

A.5.3 Hydrogeology

The deeper Precambrian basement rocks can be considered impervious. Aquifers are confined to the wadi beds and the upper weathered zone of the bedrock and are entirely formed by:

- faults and major fractures in the rocks usually found in the subsurface of the wadis;
- the weathered upper 5-20 m of the rock;
- the alluvial deposits in the wadis.

The two major faults cutting the area are relatively important aquifers. The good water-supply of Al Bayda Town comes from wells tapping a fault connected to the major E-W fault running south of the town. The abundance of water in Wadi Nakhar, especially near Madhwagayn also indicates the importance of this fault as an aquifer. Yields of wells drilled in such faults are much higher than yields of wells drilled beside it.

The alluvium in most of the wadi beds and the weathered rock zone underlying the valleys form the groundwater reservoir storing the infiltrating rain-water and flood waters from the surrounding hills. Thickness of the alluvial deposits is usually no more than a few metres to 15 m at most. Most of the wells tap these last two aquifers. Only few of the wells tap faults. One of the wells tapping a fault is the water-supply well for Al Bayda Town.

The groundwater situation in the Al Bayda catchment has been presented in 4 profiles along wadi beds in Map A.9. The section lines can be found on Map A.10.

The profiles show that water-levels are shallow (0-3 m):

- in the vicinity of Al Bayda and in the wadi between Al Bayda Town and Mash'abah along the Al Bayda-Rada road;
- in the wadis south of Al Bayda called Wadi Thihwahl, Wadi Libanih and Wadi Nakhar;
- in Wadi Az Zahir south of Az Zahir, near Al Bayda;
- in Wadi Al Maynafahr near Al Quah.

Water-levels very near the surface are found in waterlogged areas near Al Bayda, Mash'abah and Madhwagayn. Depths of water-levels in other wadis or part of wadis generally do not exceed 10 m.

The water-level elevation shows a logical picture. Groundwater flows along the wadi beds fully follow the surface drainage pattern. Thus in the eastern half of the catchment water flows from all wadis to the main north-south wadi between Al Bayda and Mash'abah.

In Wadi Az Zahir water flows eastward to Wadi Al Adyah and further northward in the direction of Ghirran and finally Moradhim.

Groundwater quality is known from more than 268 observations in the surveyed wells of the areas. Vólume IV, Part II shows the chemical analysis of 27 water samples.

Map A.11 shows that water with EC between 500 and 1000 µS is generally found in all smaller wadis and upstream parts of the main wadis. Downstream the water quality increases in the main wadis to between 1500 and 2000 µS in:

- the wadi between Al Bayda and Mash'abah and the downstream parts of its side wadis;
- Wadi Togayoh until Wadi Makhar;
- Wadi Az Zahir downstream of the village Az Zahir.

The water-table in all these areas is at present less than 3 m below the surface, indicating that these higher EC-values are caused by direct evaporation of groundwater in sometimes waterlogged areas.

Groundwater discharge in the Al Bayda area occurs:

- by well abstraction;
- by seepage from faults for example near Al Bayda;
- by direct evaporation of groundwater in parts of wadis of shallow water-tables.

Of the wells in the different wadis with their branches in the Al Bayda area, approximately 80 % has been fully surveyed. All collected data, including the estimated well abstraction, are listed in Volume IV, Part I. Table A.10 summarizes well abstraction. This table also gives a first estimate of groundwater potential. Virtually all wells are shallow wells dug in the wadi beds. Deep boreholes like the well for the water-supply of Al Bayda Town are scarce.

Although not all the wells have been visited, it has been possible to extrapolate the figures for the investigated wadis. Map A.12 shows the estimated annual well abstraction in mm/yr. The total annual well abstraction was estimated at 5.1 MCM/yr. The main part of this amount is used for agricultural purposes. A relatively small fraction is used for the domestic water-supply. The quantity of water used for domestic purposes has been calculated from the total number of households in the investigated areas, as given by the CYDA census of 1981, and the average consumption per household per month. With these figures it has been estimated that about 0.84 MCM/year is used for domestic purpose. The rest, approximately 4.3 MCM/year, is used for irrigation.

The Al Bayda area can be split up in the following separate catchments:

- The Al Bayda catchment, comprising the main wadi between Al Bayda and Mash'abah and its side wadis including three larger wadis between the main road and the watershed near Awwayn. The area of this catchment is 140 km². Most of the wells in this area have been covered by the present survey.
- Wadi Ghirran and its tributaries including Wadi Az Zahir. The area of this catchment is 142 km². Only the upstream part of this catchment has been covered by the survey.

The watershed between the two catchments runs approximately north-south 2 km west of the Al Bayda-Rada road. The two catchments join each other at the town of Maradhim.

Estimating the recharge and thus the water potential of this area is very difficult because no rainfall data are available, and infiltration rates are unknown. From the figures around Rada it is estimated that the mean annual precipitation rate is no more than 250 mm. To estimate the water potential of the Al Bayda wadi system the present situation was investigated in more detail. Therefore the catchment was divided into a number of subcatchments (see Map A.8). For each subcatchment the abstraction was calculated, both in absolute terms and as a percentage of the annual rainfall. It was found that about 25 % of the water entering the catchment as rainfall was pumped up and used for irrigation. This figure is very high, and it is assumed that a portion of the pumped up water percolates back to the aquifer.

Tables A.10a and b contain the areas, annual water abstraction and other relevant data to arrive at a rough estimate of the groundwater potential of the catchments and the possibility of increasing water abstraction without exhausting the aquifer. The data in the table show that the extra water potential differs greatly from sub-area to sub-area. Considering the present situation, it can be concluded from the shallow water-tables indicating natural groundwater reservoirs at many places in the different wadis, that there is still scope for further development. Taking into account the location of the subcatchments and the thicknesses of the alluvium and the weathered zone (storing most of the groundwater), the water potential has been calculated for each subcatchment.

It should be noted, however, that the estimates are based upon figures obtained in 1983. This can give rise to large errors since most of the farmers claimed that about 2½ years ago the situation was substantially different. There seems to be much more water now. Before 1980 water-levels were said to be much lower, and in the dry season serious shortages occurred. Waterlogging, now a common phenomenon in most of the wadis, did not occur before 1977. Therefore it is advisable to treat the figures given in Tables A.10a and b for the water potential in Al Bayda with great care.

The lack of rainfall data and data about water-level fluctuations make the estimated figures unreliable. Monitoring of rainfall and groundwater levels is of utmost importance before groundwater development can be started on a large scale in the different wadis.

A.6 Water resources in Wadi Juban

A.6.1 Physical environment

The Juban area forms an isolated catchment in the south of Al Bayda Province 60 km south of Rada and just north of the border with the PDR of Yemen. The catchment extends from 44°47' to 44°58' east and from 13°55' to 14°05' north. The catchment comprises a series of valleys and plains at an elevation of approximately 2000 m above MSL. These

Table A.10a - Present water abstraction and estimated future water availability, Al Bayda North-East

Code of subcatchment	Catchment area (ha)	Alluvium (ha)	Water abstraction (x 1000 m^3/yr)			Present water-level depth (m)	Water availability (x 1000 m^3/yr)		
			Water-supply	Agriculture	Total		Total	Future water-supply	Available for irrigation
BA	765	159	0	40	40	3-5	200	0	200
BB	975	124	89	19	108	0-8	250	155	95
BC	716	147	40	559	599	0-9	900	75	825
BD	5047	N.A.	N.A.	N.A.	N.A.	N.A.	1000	N.A.	N.A.
BJ	1580	326	40	345	385	0-7	1000	130	870
BK	2125	384	81	657	738	3-15	1000	140	860
BL	783	179	8	480	488	2-5	600	15	585
BM	2039	550	400	218	618	0-6	1500	800	700
Total excl. BD	14030	1869	658	2318	2976	0-15	5450	1315	4135

N.A. = not available.

Table A.10b - Present water abstraction and estimated future water availability, Al Bayda West

Code of subcatchment	Catchment area (ha)	Alluvium (ha)	Water abstraction (x 1000 m^3/yr)			Present water-level depth (m)	Water availability (x 1000 m^3/yr)		
			Water-supply	Agriculture	Total		Total	Future water-supply	Available for irrigation
BE	2260	350	19	39	58	4-7	500	45	455
BF[1]	1608	159[2]	48	802	850[1]	0-5	1000	110	890
BG[1]	2093	204[2]	86	524	610[1]	3-15	1200	195	1005
BH	971	170	25	563	588	3-15	900	60	840
BI	7309	N.A.	73	N.A.	N.A.	N.A.	N.A.	165	N.A.
Total	14241	883	178	1928	2106	0-15	3600	410	3190

N.A. = not available.

[1] Abstraction figures extrapolated over the total catchment area.
[2] Measured area within available aerial photographs.

plains and valleys have eroded into a 2300 m to 2400 m high sandstone plateau. The 300 m high steep escarpment forms everywhere the boundary between the plains and the plateau. The total area of the catchment is 52.8 km^2.

The Juban area can be subdivided into the following three main catchments as also indicated on Map A.13.

- The catchments west of Juban, composed of five smaller valleys, and the plain east of Juban draining southward through a narrow wadi 2.5 km west of Nowah.
- The area around Nowah and R'sayan draining in the same direction as the above-mentioned catchment through a narrow wadi 1 km west of R'sayan.
- The plains around Al Ou'abbel draining southward in a narrow west-east wadi, formed along the prominent east-west fault running through the south of the Juban area.

A.6.2 Geology

The Juban plains and valleys have eroded nearly everywhere through the more than 300 m thick subhorizontal Tawilah Sandstone formation into the underlying Precambrian basement rocks, composed mainly of gneiss and granite. An up to 20 m thick sandstone layer underlies only the plains around Jahair and the wadis north of Mou'atha (Wadi Hanger and Wadi al Moffer). The sandstone is cut in many places by 2-4 m wide dolerite dikes sometimes occurring in dike swarms, related to tertiary and quaternary volcanic activity. The dikes are very difficult to follow in the underlying Precambrian rocks. Old volcanic centres are found in the eastern and western corners of the area. Sometimes these centres are located on intrusive dikes.

A.6.2.1 Faults

The east-west fault in the southern part of the area near Al Aggar and R'sayan is the most prominent fault cutting in the Precambrian basement rock. Other, less prominent faults are indicated on the geological map. Vertical displacements along the fault planes have been observed in the field and are indicated on the map. Many more faults and fractures than indicated on the map are found in the Precambrian gneiss and granite rocks.

A.6.2.2 Alluvium

Usually less than 10 m thick alluvial deposits underlie the plains around Juban. These usually sandy deposits originate from the Tawilah Sandstone and to a minor extent from the Precambrian metamorphic rocks and volcanic formations.

A.6.3 Hydrogeology

In the Juban area, aquifers are formed mainly by:

- sandy alluvials deposits;
- the underlying Tawilah Sandstone in the northern plains and valleys around Hanger and Jahair;
- the weathered zone of the Precambrian rocks;
- intrusive dikes, fractures and faults cutting the basement rocks.

The unweathered Precambrian granite and gneisses form an impervious floor under all these aquifers.

The alluvium in the plains and to a much lesser extent the weathered rock zone form the groundwater reservoir storing the infiltrating rain-water and flood water from the surrounding hills. Faults and intrusive dikes can be considered highly permeable conduits of low storage capacity. The thickness of the alluvial deposits is usually 5 to 10 m in the plains west of Juban and less than 5 m in the area east of the town, which limits the reservoir capacity of these formations. Fractures in the Precambrian rocks and intrusive dikes in the Tawilah Sandstone are probably important sometimes as highly permeable conduits for groundwater. One of the wells 1 km west of Juban taps a major fracture having an extremely high yield of 30 l/s in the wet season and 8 l/s in the dry season. The narrow zones of these fractures covered by alluvium makes accurate tracing and successful tapping by wells difficult without the use of the electromagnetic method. Therefore wells usually tap the alluvium and the underlying weathered rock aquifer, and the yields between 2 and 5 l/s.

The groundwater situation in the Juban catchment is presented on:

- the well location Map A.15;
- the water-level elevation Map A.16;
- hydrogeological sections along the wadi beds (Map A.14);
- the EC Map A.17.

Map A.15 shows the section lines and catchment boundaries. The hydrogeological cross-section Map A.14 show that water-levels deeper than 10 m below the surface occur in the northern extremities of the valleys. Southward water-levels become 5-10 m below the surface around Jahair and Juban, and in the area directly south of Hanger. Water-levels of less than 5 m occur in the wadis near Hanakah and in the south of Wadi Hanger. Near Nowah the water-level is 5 to 10 m below the surface, rising up to 3 m below the surface at the outlet of this catchment.

Map A.16 shows that the water-level contours of 1970 to 1980 m above MSL occur near the northern border of the catchment, and those of 2000 to 2010 m in the plain east of Juban Town. From here groundwater flows west and southward along Hanakah and Jahair. The groundwater flows through Wadi Hanger southwards into Wadi al Anab where it leaves the area. The similarity of the water-level elevations in Wadi al Moffer north of Moa'atha, in Wadi Hanger, and in the plains around Jahair may indicate that the groundwater flows under these wadis and plains are interconnected by way of the underlying thin sandstone aquifers. Groundwater in Wadi Juban east of the town may also be recharged by groundwater inflow from the sandstone rocks in the north. The north-south trending dikes of the dike swarm may play an important role in the groundwater inflow from the north. Groundwater in the plains around Nowah and Al Ou'abbel is not interconnected but is stored in isolated basins of alluvium and weathered rock aquifers; groundwater flows southward into the east-west fault of Wadi Al Aggar.

Groundwater quality is known from more than 170 observations in the surveyed wells. Volume IV, Part II shows the chemical analysis of the 21 samples taken in the Juban catchment. Map A.17 shows that groundwater in the Juban area is generally fresh with EC values less than 1000 µS. Brackish groundwater with EC between 1500 and 6000 µS occurs just west of Juban. This high salinity is mainly caused by local pollution of groundwater by wastewater of Juban Town. The isolated areas of slightly higher salinity near Hanaka, with EC up to 2100 µS, and south of Nowah, with EC up to 1400 µS, is caused by evaporation of shallow groundwater because shallow water-tables of less than 3 m below the surface have been observed at these places.

Groundwater discharge in the Juban catchment occurs at present mainly by well abstraction. Small springs occur only at the northern point of Wadi al Jahair just east of the road to Rada. Direct evaporation of groundwater is small and limited to the small areas of higher salinity near Hanakah and south of Nowah. All collected data including the estimated well abstractions are listed in Volume IV, Part I.

Table A.11 gives the well abstraction in the different wadis and plains in the Juban catchment as indicated on Map A.13. The table also gives a first estimate of groundwater potential deduced from examination of the different maps, the thickness of the alluvium and the sandstone in the wadis, groundwater flow, areas of subcatchments, estimated rainfall, etc.

Almost all wells are shallow wells dug in the wadis and plains. Drilling of boreholes has just started and three boreholes are in operation now. The depth of the shallow wells is usually between 10-20 m. Wells deeper than 20 m occur in Wadi Sa'id south-west of Juban Town. Map A.18 shows the estimated annual well abstraction in mm/yr. The total annual well abstraction in the Juban catchment is 1.95 MCM/yr, which is 8 % of the annual rainfall estimated at 400 mm/yr. The very high well abstraction in proportion to rainfall on the catchment may be partly explained by the sandy soils causing high infiltration rates. We expect that groundwater inflow from the sandstone area north of Juban is only of limited significance, as deeply incised wadis are found only one or two kilometres east, north and west of all the watersheds, preventing substantial groundwater inflow. Recharge of groundwater occurs also by infiltrating flood water flowing from the surrounding steep hills at great force after heavy rainfall. This and the generally sandy soils are favourable conditions for a higher than usual infiltration of rain-water under these low rainfall regimes. Estimating the recharge and thus the groundwater potential of the area is difficult because of

Table A.11 - Present water abstraction and estimated future water availability, Juban

Code of subcatchment	Catchment area (ha)	Alluvium (ha)	Water abstraction (x 1000 m^3/yr)			Present water-level depth (m)	Water availability (x 1000 m^3/yr)		
			Water-supply	Agriculture	Total		Total	Future water-supply	Available for irrigation
JA	444	105	27	271	298	9	400	65	335
JB	463	144	0	207	207	9	350	67	283
JC	377	111	0	40	40	6	250	0	250
JD	434	126	52	186	238	5-15	300	60	240
JE	181	55	0	0	0	15-20	100	0	100
JF	161	74	26	403	429	12	500	64	436
JG	88	28	0	72	72	7	100	0	100
JH	159	23	0	15	15	6	100	0	100
JI	327	66	17	106	123	6	250	42	208
JJ	520	90	17	118	135	6-13	250	41	209
JK	325	64	16	80	96	9	150	40	110
JL	608	115	10	92	102	9	200	25	175
JM	79	13	0	7	7	6	88	0	88
JN	195	89	12	4	16	11	50	37	13
JO-A	312	54	0	14	14	9			
JO-B		50	0	0	0	N.A.	50	0	50
JP	277	44	3	1	4	4-13	100	86	14
JQ	155	63	35	109	144	3-9	150	0	150
ALJR	50	21	0	0	0	N.A.	30	0	30
ALJS	100	52	0	0	0	N.A.	20	0	20
ALJT	25	8	0	13	13	4	20	0	20
Total	5280	1395	215	1738	1953	3-20	3458	527	2931

N.A. = not available.

lack of any rainfall data and water-level data. The usually thin aquifer and consequently small groundwater reservoir capacity limits the potential. From the water-level elevation map and the thickness of the sandstone aquifer in the northern part of the plain we estimate groundwater inflow at 0.5 MCM/yr.

We conclude from the limited size of the groundwater catchment, the thin aquifers and the consequent low groundwater reservoir capacity, and the already high abstraction rate that extra groundwater potential is limited.

Especially in the area south of Juban around Nowah and Al Ou'abbel groundwater storage in the weathered metamorphic rock aquifer is small and possibly only sufficient for drinking-water supply. Successful well drilling especially here depends on exact siting on fractures and faults in the subsurface. Tracing of such faults must be done using the electromagnetic method. Water for both villages can also be obtained from wells drilled in the prominent east-west fault in the south of the catchment. Groundwater occurrence and extra scope for development may be better in the northern part of the catchment north of the line Juban-Hanakah. We estimate the extra potential at 250 000 m^3/yr. Any increase in water abstraction in these areas proposed by this study should be made gradually, controlled by observation of rainfall and water-levels.

A.7 Water resources in Wadi Dhi Na'im

A.7.1 Physical environment

The Dhi Na'im catchment is the upper part of the catchment of a tributary of Wadi Al Ghayl, approximately 20 km NW of Al Bayda. The catchment of 10 × 7 km extends from 14°01' to 14°07' north and from 14°21' to 14°26' east.

The catchment comprises one broad north-south running wadi with some wide wadis, and smaller plains. The elevation of the valley bottom increases gradually from 1880 above MSL near Ar Rubat to approximately 1950 m in the south. The surrounding hills have elevations approximately 30 m higher than the wadi system. The main NNE-SSW trending valleys are parallel to the strike direction of the WNW-dipping well-bedded metamorphic rocks. Side valleys have developed along NW-SE trending faults. The wadi system drains from the southern watershed northward along one main outlet near Ar Rubat.

The western watershed is part of the main watershed between northward and southward draining wadis. It forms the watershed with Wadi Hamra, a tributary of Wadi Bana. The eastern catchment boundary is the watershed with another tributary of Wadi Al Ghayl. The total area of the investigated catchment is 58 km^2, which has been subdivided into a number of subcatchments.

A.7.2 Geology

Wadi Dhi Na'im and its tributary have eroded approximately 30 km into the intensely folded Precambrian basement rocks composed of well-bedded, steeply dipping gneisses and schists. The rocks are cut by at least two sets of faults.

The most prominent fault system has a WNW-ESE direction, practically perpendicular to the strike direction of the well-bedded metamorphic rocks and occurs over the whole area.

The second set of east-west trending faults occurs mainly in the eastern half of the catchment east of the main valley. A major shear fault of NNE-SSW direction runs just west of the catchment boundary. The valleys and plains are underlain by usually not more than 2 to 5 m of rather sandy alluvium.

A.7.3 Hydrogeology

In the Dhi Na'im catchment aquifers are formed by:
- the fracture system;
- the usually highly weathered, more than 10 m thick zone of weathered rocks;
- to a minor extent, by the usually thin sheet of alluvial deposits under the plains.

The fractured and weathered rocks probably form one aquifer system of moderate permeability.

All 111 wells but one (Well 18) are 5 to 22 m deep shallow wells dug through the alluvium often more than 10 m into the rather soft weathered rock. The yield of the wells is usually between 5 and 7 l/s.

The groundwater situation obtained from 111 wells in the catchment are presented in a:

- catchment map including the water-level elevations, Map A.19;
- well location Map A.21;
- water abstraction Map A.23;
- EC-Map A.22; and
- two hydrogeological sections, Map A.20.

The sections show that the water-level in the Dhi Na'im valleys is usually 3 to 5 m below the base of the alluvium in the weathered bedrock. Upstream the wadis have cut deeper into the rock, the alluvium is thicker, and the water-level is 1 to 2 m deep in the alluvium.

Map A.19 shows that the groundwater flows from south to north. The elevation of the water-level in the south is 1925 m above MSL and in the north around Ar Rubat it is 1875 m above MSL.

The EC-map (Map A.22) shows that water quality deteriorates with the direction of groundwater flow from EC = 600 µS in the south to EC = 6400 µS in the north near Ar Rubat. Brackish groundwater of EC > 1500 µS is found in the plains between Ar Rubat, Al Mingathah and Mash Khubah. Between Shashbih and Thomdjair lies another small area with groundwater of a somewhat higher salinity, up to EC = 2500 µS. The reason for the higher salinity of groundwater in these areas is natural losses of groundwater by evaporation under shallow water-table conditions in the past. Present water-levels are much deeper due to the great number of wells in these areas abstracting groundwater. Most of the rain-water infiltrating in the area is abstracted by wells. Minor quantities of water are lost by groundwater outflow in the north and evaporation in areas with shallow water-tables. The present water abstraction, extrapolated for all of the investigated catchments is 3.8 MCM/year, which is 27 % of the rainfall estimated at some 250 mm/year (see Table A.12 and Map A.23). Judging from the relatively high abstraction of groundwater in the Dhi Na'im catchment in proportion to the estimated annual rainfall, possibilities for further development should be considered low. Nowhere in the catchment, however, do farmers complain about water shortages in the past, not even in the dry seasons. It can therefore be assumed that a substantial part of the pumped-up irrigation water percolates back to the groundwater reservoirs.

In principle sufficient water for domestic water-supply can be abstracted from wells drilled at the right sites in faults. Boreholes yielding between 10 and 20 l/s must be possible if accurately sited on the faults. Only the electromagnetic method will be able to trace the faults with sufficient accuracy, i.e. within a few metres, as needed for a successful well. Especially in the north around the major towns Ar Rubat, Al Mingathan, Al Grain and Mash Khubah, site selection should take groundwater quality into account to avoid pumping up brackish to saline groundwater.

A.8 Water resources in Wadi Mansur

A.8.1 Physical environment

Wadi Mansur lies on the Rada-Al Bayda road 40 km east of Rada. The investigated area stretches from 45° to 45° 15' east and from 14° 15' to 14° 28' north. It has a total area of 228 km². A large part of the catchment lies in the Nahiya As Sawadiyah. The catchment is part of the upper tributaries of Wadi Adhanah just north of the main watershed with Wadi Husayniyah, a tributary of the southward draining Wadi Banah. The southern border of the catchment is formed by the main watershed between north and westward draining wadis. The other catchment boundaries are less prominent watersheds with other tributaries of Wadi Adhanah. The elevations in Wadi Mansur range from 1900 m above MSL in the south at the watershed to 1830 m above MSL near the northern outlet of the catchment. The surrounding hills of the wadis are generally 10 to 50 m higher than the plains.

Table A.12 - Present water abstraction and estimated future water availability, Dhi Na'im

Code of subcatchment	Catchment area (ha)	Alluvium (ha)	Water abstraction (x 1000 m^3/yr)			Present water-level depth (m)	Water availability (x 1000 m^3/yr)		
			Water-supply	Agriculture	Total		Total	Future water-supply	Available for irrigation
DA-A	1459	104	3	33	36	N.A.	100	11	89
DA-B		51	0	0	0	N.A.	50	0	50
DA-C		141	53	762	815	5	900	216	684
DB	482	165	33	601	634	4-10	700	132	568
DC	397	84	7	345	352	8	400	29	371
DD	311	125	10	233	243	7	300	40	260
DE	661	188	20	316	336	8	400	82	318
DF	116	85	3	227	230	6	250	0	250
DG	329	112	0	25	25	5-8	200	0	200
DH-A	1766	146	7	525	532	6	600	27	573
DH-B		53	18	41	59	N.A.	200	71	129
DH-C		29	0	0	0	N.A.	50	0	50
DH-D		43	0	0	0	N.A.	100	0	100
DH-E		43	0	0	0	N.A.	50	0	50
DH-F		69	51	71	122	6	250	206	44
DI	56	42	3	158	161	4	Saline	0	158
Total	5577	1480	208	3337	3545	3-10	4550	814	3736

N.A. = not available.

The wadi system has a dendritic pattern of 100-700 m wide SW-NE and SE-NW trending wadis. The main wadi is the SE-NW running wadi between M'gathuh in the south-east and Hatbah in the north-west of the area. Other major wadis with the same direction are found 5 km SW and NE of this wadi near Bayt Al Khama and Zanabah. All wadis drain in a northern direction through a single outlet, which is also the outlet of the Wadi Amad area east of Wadi Mansur.

Topographically the Wadi Mansur area can be subdivided into a number of smaller subcatchments draining on side wadis as indicated on Map A.24.

A.8.2 Geology

The wadis of this area have eroded 10 to 50 m into the underlying intensely folded Precambrian basement rocks of the slightly northward dipping peneplain. The Precambrian basement is formed by well-bedded, steeply dipping gneisses and schists with some granite intrusions. Many of the wadis developed along the well-developed system of NW-SE and NE-SW trending faults cutting the Precambrian rocks, as shown on the geological map A.24. In the SE corner of the catchment some of the NE-SW trending faults, and in the NE corner some of the NW-SE trending faults, have been filled with dolerite rock forming intrusive dikes.

The wadis and plains are filled with 5 to 10 m of the sandy alluvium with micas. Very coarse deposits of gravel and stones occur here and there in the wadi beds.

A.8.3 Hydrogeology

The Wadi Mansur catchment is underlain by impervious Precambrian basement rocks. Aquifers are formed by:

- faults underlying many of the wadis in a pattern of NW-SE and SW-NE directions;
- the usually thin zone of weathered rocks;
- the usually shallow alluvial deposits in the wadis.

Well abstraction takes place from approximately 250 dug wells and 4 boreholes, of which 180 have been surveyed.

Nearly all shallow wells tap the alluvium aquifer and the first metres of the underlying weathered rock. The depth of the wells is usually between 5 and 15 m, and yields are usually between 3 and 6 l/s. The groundwater situation obtained from the well inventory is presented in:

- well location map A.26;
- catchment and water-level elevation map A.24;
- annual abstraction map A.28;
- EC map A.27; and
- 2 cross-sections indicated on the well location map A.25.

Groundwater flows from south to north. The water-level elevation in the southern wadis is at maximum 1940 m above MSL near As Shariah, and 1900 m above MSL near Hakir. In a northern direction the water-level falls to 1845 m above MSL near the outlet north of Hatbah.

The water-level in the alluvial deposits is generally 3 to 10 m below the surface and only 0 to 3 m above the base of the alluvium. The water-level in many of the wells, especially in the south, was found to be in the weathered rock several metres below the base of the alluvium. For example, in the east-west wadi near As Shariah and Al Muqfari the water-level is found at depths of 10-13 m below the surface, 2 to 5 m below the base of the 6 to 11 m thick alluvium.

The EC map A.27 shows the water quality in the wadi system as found from 155 EC observations. Five water samples have been analysed chemically. Water quality of EC less than 1000 µS is found only in the southern wadis immediately north of the main watershed. In a northern direction, water quality deteriorates rapidly to EC values of more than 1000 µS within a few kilometres north of the watershed. Brackish to saline groundwater of EC values from 2000 to more than 5000 µS is common in the Wadi Mansur area. A local pocket of fresh groundwater is found in the areas of brackish groundwater west of Ad Dhra. Such pockets are of great value for drinking-water supply but have no importance for irrigation. The high salinity of the groundwater is a negative factor for the agricultural development of the area and is a major problem in the search for suitable drinking-water.

Groundwater discharge in the Wadi Mansur catchment occurs at present by well abstraction. Direct evaporation of groundwater does not occur because water-levels are everywhere more than 3 m below the surface. All collected data including the estimated annual well abstractions are listed in Volume IV, Part I.

Map A.28 shows the annual abstraction in mm as calculated for areas of 25 ha. Table A.13 gives the annual well abstraction as well as the number of wells and average well depth per subcatchment as indicated on Map A.24. We estimate the total annual well abstraction in the Wadi Mansur catchments at 2.0 MCM/yr, which is 7 % of the annual rainfall estimated at 200 mm/year. The net abstraction of water is probably lower due to the high salinity of the groundwater and the consequently higher leaching requirements. Recharge of groundwater occurs by infiltrating rain-water in the wadi beds. Infiltration occurs by direct infiltration of rainfall on the alluvium as well as by infiltration of runoff water from the surrounding hills into the wadi beds. Infiltration is enhanced by the numerous little retention dams built in the wadis by the farmers.

The scope for further development of groundwater is low because of the following factors:

- the occurrence of brackish to saline groundwater nearly everywhere north of the Rada-Al Bayda road;
- the relatively thin alluvium, so that especially in the south groundwater storage occurs only below the base of the alluvium in weathered metamorphic rocks of low storage capacities;
- the low rainfall, estimated at less than 200 mm per year.

Table A.13 - Present water abstraction and estimated future water availability, Wadi Mansur/Amad

Code of subcatchment	Catchment area (ha)	Alluvium (ha)	Water abstraction (x 1000 m^3/yr)			Present water-level depth (m)	Water availability (x 1000 m^3/yr)			Future water-level depth (m)
			Water-supply	Agriculture	Total		Total	Future water-supply	Available for irrigation	
MA	3 556	658	19	378	397	5-15	600	40	560	10-20
MB	1 746	461	12	62	74	3-10	200	25	175	10-15
MC	2 084	545	39	68	107	5-10	200	80	120	15-20
MD	1 042	396	77			2- 8		160		4-10
ME	932	310	17	132	149	2-10	200	35	165	5-15
MF	562	154	12	105	117	2-15	200	25	175	10-20
MG	8 044									
MH	1 425	378	7	113	120	7-15	300	15	285	10-20
MI	1 007	231	23	253	276	4- 8	350	50	300	8-15
MJ	193	41	10	44	54	3- 6	65	20	45	8-15
MK	337	83	6	84	90	7	130	12	118	12
ML	898	193	12	395	407	5-10	450	25	425	10-15
MM	1 313	359	23	49	72	3- 8	250	50	200	8-15
MN	403	110	5	45	50	3- 6	80	10	50	5-10
MO	315	202	11	30	41	3- 7	Saline	20		
Total	23 857									
Excl. MG MD :	14 771	3 725	196	1 758	1 954	2-15	3 025	407	2 618	

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The occurrence of local pockets of fresh groundwater in areas of brackish water or in small sidewaters may yield some scope for the development of drinking-water of reasonable quality.

Another positive point for groundwater abstraction is the occurrence of numerous faults and fractures, especially below the wadi beds. Exact drilling on the faults may give relatively highly productive boreholes. Tracing of these faults in the field can be done with the electromagnetic method in combination with the examination of aerial photographs. Tracing of pockets of better quality groundwater may be done with by the geo-electrical method as well as with the electromagnetic method.

A.9 Water resources in Wadi Matar/Wadi Ar Rin

A.9.1 Physical environment

Wadi Matar lies north of the Rada catchment north-east of Jabal Isbil. The investigated area stretches from 44° 49' to 44° 55' east and from 14° 27' to 14° 38' north. It has a total area of approximately 70 km^2. The area is part of the catchment of a tributary of Wadi Adhanah. The Rada area forms the upstream part of the same catchment but surface runoff from the Rada Plains hardly ever reaches the Wadi Matar area. The area can be roughly subdivided into two irregular plains with side wadis called Wadi Ar Rin and Wadi Matar at elevations of 1880-2000 m above MSL. The plains are connected by a narrow passage between plateau hills rising 50 to 100 metres above the plains. Wadi Ar Rin is bounded in the west by the lava flows of Jabal Isbil and in the north by steep hills composed of metamorphic Precambrian rocks.

Wadi Matar is bordered in the south by subrecent volcanoes in the NE corner of the Rada catchment. Wadi Matar is the outlet of the Rada catchment and runs from Ar Rubat along Al Khilaw northward into Wadi Ar Rin. Hardly any surface water from the Rada catchment ever reaches Wadi Matar. The Wadi Matar/Ar Rin catchment can be divided into a number of subcatchments related to the wadi system. Map A.29 shows the different subcatchments and their watersheds. A small perennial stream with a discharge of 10 to 20 l/s, of water with an EC of 1500 µS leaves the area at the northern wadi outlet.

A.9.2 Geology

Map A.29 shows the geology of the area. The whole Wadi Matar/Ar Rin area is underlain by Precambrian metamorphic rocks composed of highly metamorphic gneisses, schists and granite. The gneisses and schists have a well-developed schistosity dipping 10-30° in a westerly direction. A circular granite intrusion with a diameter of approximately 5 km occurs east of Wadi Matar. The Precambrian rocks have been covered by a sheet of 10 to 50 m upper Pleistocene basalt lavas. Later on, the present system of wadis and plains eroded into the Peneplain. Alluvial deposits have been deposited accordingly.

Subrecent basalt lava flows of sometimes more than 10 m thickness, originating from eruptions of Jabal Isbil on the south-east and from faults in the wadi beds, have flown out over the older alluvial deposits. At present the lava is covered in some places by several metres of recent alluvium.

Several prominent faults occur in the subsurface of the area. ENE-WSW and NW-SE are the most prominent directions of these faults. Neither horizontal nor vertical movements have been observed. Volcanic activity including basalt outflow occurs along many of the faults.

A.9.3 Hydrogeology

Wadi Matar as well as Wadi Ar Rin are underlain by impervious Precambrian basement rocks. Aquifers are formed by:

- faults cutting the Precambrian rocks and underlying plains and wadis as shown on Map A.29;
- the fractured and weathered upper 5 to 20 metres of weathered Precambrian rock;
- the alluvial deposits in the plains including the basalt lava sheets. The thickness of these alluvial deposits ranges from a few metres to 10 m at most.

Most wells in Wadi Matar tap the shallow alluvium and the weathered bedrock zone. More to the north in the plains around Ar Rawq and in Wadi Ar Rin near Dhigalib Al Asfal, wells tap the upper alluvial zone and a few metres of the underlying basalt lava, which is highly permeable. The yield of the wells is usually between 3 and 5 l/s, with the exception of a few wells with a yield between 7 and 8 l/s.

The well inventory covered only the southern part of the catchment of Wadi Matar. Some reconnaissance data are available from the northern part of the Wadi Ar Rin area.

The survey data are presented in:

- well location map A.30;
- EC map A.31;
- water-level elevation on the subcatchment map A.29;
- annual abstraction map A.32.

The water-level stands in Wadi Matar in the plain East of Ar Rawq approximately 20 m below the surface. The groundwater level is shallow in the plain near the northern outlet, north of Dighalib Al Asfal where a perennial stream and evaporation discharge the aquifer.

The EC map shows that the water quality is brackish, with EC values of 1500 to little less than 4000 μs in Wadi Matar between Ar Rubat and Al Khilaw and under the plain east of Ar Rawqi. Fresh groundwater occurs in the wadi east of Al Khilaw, with an EC up to 1000 μS.

Groundwater discharge occurs in Wadi Matar by well abstraction and evaporation of shallow groundwater between An Nubah and Ar Rubat:

- by well abstraction around Ar Rhawq;
- by surface outflow and evaporation near the northern outlet of the plains; and
- by well abstraction in Wadi Ar Rin NW of Dhigalib Al Asfal.

Up to 7 years ago a perennial flow also occurred in Wadi Matar south of Al Khilaw where water from the Rada Plain left that catchment. All collected data including the estimated well abstractions are listed in Volume IV, Part I. Map A.32 shows the annual abstraction in mm as calculated for areas of 25 ha.

Table A.14 gives the annual abstraction as well as the number of wells and average water-level depth per subcatchment as indicated on Map A.29. The well abstraction in Wadi Ar Rin is not yet known because the area has not yet been surveyed. The net abstraction in the Wadi Matar catchment is at present 0.5 MCM/year, which is 3 % of the annual rainfall estimated at 200 mm/year.

Recharge of groundwater occurs by:

- infiltration of rain-water and stormwater flows from the surrounding hills into the often sandy alluvial plains;
- inflow of groundwater from below the lava flows of Jabal Isbil in the south-west. The origin of this water is rain-water infiltrating into the very porous and permeable lavas on the northern slopes of Jabal Isbil;
- some inflow of brackish groundwater from the Rada Plains into Wadi Matar SW of Ar Rubat.

The net abstraction, especially in the northern plain, is lower than the water availability, as can be deduced from the perennial stream near the northern outlet and the low percentage of rainfall abstracted from wells. However, the occurrence of brackish water in the plain west of Ar Rawq reduces the potential for increasing groundwater abstraction.

Especially the infiltration of rain-water and surface runoff, and the inflow of groundwater from Jabal Isbil are important factors in determining the water potential of the area. Both factors are unknown but may give rise to a substantial extra potential of fresh groundwater in Wadi Ar Rin north of Dighalib Al Asfal where groundwater is fresh. This area should therefore be covered by the next survey.

Groundwater could be abstracted from wells tapping the alluvium and underlying basalt in the plain and from a NNW-SSE running fault near Najd Ash Showanah. Groundwater potential in Wadi Matar between Ar Rubat and Al Khilaw and in the plain west of Ar Rawq is unfortunately low because of the occurrence of brackish to saline groundwater.

Table A.14 - Present water abstraction and estimated future water availability, Wadi Matar

Code of subcatchment	Catchment area (ha)	Alluvium (ha)	Water abstraction (x 1000 m^3/yr)			Present water-level depth (m)	Water availability (x 1000 m^3/yr)		
			Water-supply	Agriculture	Total		Total	Future water-supply	Available for irrigation
TA	2568	435	0	33	33	10-15	300	0	300
TB	440	74	6	88	94	18-25	100	14	86
TC	1089	145	0	0	0	N.A.	200	0	200
TD		308	45	160	205	4-12	300	107	193
TE		180	0	10	10	25	100	0	100
TF		85	0	0	0	N.A.	0	0	0
TG		17	5	4	9	7-15	50	11	39
TH		421	0	1	1	N.A.	Depends on salinity		
TI		59	12	0	12	N.A.	50	29	21
TJ	565	125	0	0	0	N.A.	100	0	100
TK		233	0	0	0	N.A.	N.A.	0	N.A.
TL		39				N.A.			
TM		82				N.A.			
TN		151				N.A.			
TO		42				N.A.			
TP		68	9	N.A.	N.A.	N.A.			
TQ		23	0	0	0	N.A.	N.A.	0	N.A.
TR		74	0	0	0	N.A.	N.A.	0	N.A.
TS		36	5	91	94	17-22	150	10	140
TT		326	N.A.	N.A.	73	N.A.	N.A.	N.A.	N.A.
Total (TA to TH)	7770	1665	56	296	352	4-25	1050	132	918

N.A. = not available.

The selection of well sites by the geo-electrical and electromagnetic methods is very important for drilling on faults and to avoid areas of brackish and saline groundwater.

A.10 Water resources of the Abbas plain

A.10.1 Physical environment

Abbas is a small isolated catchment 12 km east of Rada. The investigated area stretches from 44° 55' to 45° east and from 14° 18' to 14° 25' north. It has a total area of 33 km^2. The area forms one catchment dewatering in the north through a tributary of Wadi Adhanah. The southern watershed is part of the main watershed between northward and southward draining wadis. The wadi outlets in the north have been blocked by Quaternary lava flows, but underground outflow remains possible. The Abbas catchment is composed of an irregular alluvial plain surrounded by high, sandstone-covered hills in the south, by lower hills east and west and by a subrecent volcano and its lava flows in the north. The catchment drains to the north through a wadi blocked by this lava flow. The rock of this basalt flow is so permeable that it is not necessarily a barrier to water flowing northward. South of the catchment lies a small catchment, Wadi Riam.

A.10.2 Geology

Map A.33 shows the division of the Abbas catchment in sub-areas, and the geology. Precambrian metamorphic gneisses and schists dipping in a NW direction underly the whole catchment. Gently westward dipping Tawilah Sandstone overlies the Precambrian basement discordantly in the hills forming the southern watershed of the catchment. Old Pleistocene volcanic rocks are found on top of the sandstone in the SW and SE corner of the catchment.

Several NW-SE to N-S running faults cut the area, as well as major dolerite dikes related to older and younger volcanism. An old 10 m wide prominent N-S running dolerite dike is found just east of the plain. Several other dolerite dikes are present in the Tawilah Sandstone and Precambrian rocks.

A.10.3 Hydrogeology

The alluvium, underlain by irregularly but usually moderately weathered Precambrian gneisses, forms the storage reservoir for groundwater. Permeability and thickness of this aquifer system is low to moderate. Faults under the plain form the permeable conduits. Wells drilled in these faults may be more productive. At least two wells tap the fault running N-S through the plain east of Abbas. Similarly, wells drilled south of the Rada-Al Bayda road are close to a NW-SE running fault crossing the plain parallel to the road. These two faults may well be the most important aquifers in the catchment. The thickness of the alluvium ranges from 7 to 20 m. Wells dug in the alluvium are failures or have a very low yield.

The well inventory covered 51 wells in the area. The survey data are presented on:

- well location map A.34;
- EC map A.35;
- water-level elevation on the catchment map A.33.

The water-level in Wadi Abbas is 15 to 30 m below the surface.

The EC map shows that water is fresh everywhere in the catchment, with EC ranging between less than 800 µS in the south to more than 1500 µS in the north.

Groundwater discharge in the Abbas plain occurs mainly by abstraction from 51 dug wells. There is one small spring with a yield of 3 l/s near Al Maklah. All collected data of the wells including the estimated annual abstraction are listed in Volume IV, Part I.

Map A.36 shows the annual well abstraction in mm calculated for areas of 10 ha. Table A.15 gives the annual abstraction in each sub-catchment. We estimate the well abstraction at 340 000 m^3/year, which is 5 % of the annual rainfall estimated at 200 mm/year. Recharge of groundwater occurs by infiltration of rain-water in the alluvial plain or in the surrounding hills. Stormwater never flows out of the plain but infiltrates in the alluvium of the Abbas plain.

We estimate that there is still some scope for water development in the Abbas plain. We consider a further increase of another 340 000 m^3 possible. Exploitation of this groundwater potential depends highly on successful wells. Well drilling in the plain cannot be successful due to the impervious rock underlying the shallow alluvium deposits. Only wells drilled on the faults crossing the plain may have acceptable yields. Site selection using the electro-magnetic method to trace these faults accurately in the field is therefore of utmost importance.

Table A.15 - Present water abstraction and estimated future water availability, Abbas

Code of subcatchment	Catchment area (ha)	Alluvium (ha)	Water abstraction (x 1000 m^3/yr)			Present water-level depth (m)	Water availability (x 1000 m^3/yr)		
			Water-supply	Agriculture	Total		Total	Future water-supply	Available for irrigation
AA	796	93	5	162	167	0-30	250	13	237
AB	707	123	0	0	0	N.A.	100	0	100
AC	1029	390	14	156	170	15-30	250	37	213
AD	199	26	0	0	0	N.A.	50	0	0
AE	544	34	0	0	0	N.A.	30	0	0
Total	3275	666	19	318	337	0-30	680	50	630

N.A. = not available.

APPENDICES

Ann. A

APPENDIX A.I
QUESTIONNAIRE USED IN THE WELL SURVEY

Ministry of Agriculture

RADA INTEGRATED RURAL DEVELOPMENT PROJECT
P.O. Box 816
SANA'A
Yemen Arab Republic

Date ....

1. Number .... Deep borehole number ....
   Village ....
   Owner ....
2. Aerial photograph number ....
3. Shallow well / deep borehole / spring
4. Reading barometer .... Temperature ....°C
   Time .... Calculated altitude .... m
5. Watertable Static level .... m
   Dynamic level .... m After .... hr
6. Total depth .... m Alluvium (soft material) .... m
   Hardrock starting at .... m
   Hardrock: sandstone / basaltic / granite colour ....
   Lithological log available: yes / no
7. Electric conductivity ....µS Wastersample: yes/no number.........
8. Highest water-level .... m Deepest water-level .... m
9. Water-level before 2 years ... m higher / lower
10. Pumping regime Dry season .... hrs/day ...... days/week
    Wet season .... hrs/day ...... days/week
    Capacity .... l/s
    Brand of the pump .... Brand of the engine .... Hp
11. Number of pipes .... Each pipe .... m
12. Wateruse domestic : number of persons ....
    irrigation : qat / sorghum / alfalfa / trees / others
13. Well was deepened out .... m in ....
14. Annual abstraction .... m^3/year (calculated)
15. Name drilling firm ....
16. Remarks ....
    ....
    ....

REFERENCES

BRGM, 1981.
Al Bayda Mar'ib Project; evaluation of mineral resources potential 1980 campaign YOMINCO.

Bundes Anstalt für Geo-wissenschaften und Rohstoffe, 1975.
Appraisal of groundwater occurrence in the Anwar Plain. Bundes Anstalt für Geo-wissenschaften und Rohstoffe.

DHV, 1983.
Water Resources Study Tichama Coastal Plain. DHV, Amersfoort, The Netherlands.

FAO, 1979.
Crop water requirements. Irrigation and Drainage Paper 24. FAO, Rome, Italy.

Geukens, F., 1966.
Geology of the Arabian Peninsula, Yemen.-U.S. Geological Survey, Prof. Paper 560-B.

Grolier, M.J., 1977.
Data from Geological Investigations in the Yemen Arab Republic during 1976. U.S. Department of the Interior, Geological Survey. Project Report (IR) Y-12.

Grolier, M.J. and Overstreet, W.C., 1978.
Geological Map of the Yemen Arab Republic (Sana). U.S. Department of the Interior, Geological Survey. Map I-1143-B.

Ilaco, 1977.
Report on the development and feasibility of upland dairy farms. Ilaco, Arnhem, The Netherlands.

Ilaco, 1981.
Geology of Nahiyah Rada. Rada Integrated Rural Development Project. Ilaco, Arnhem, The Netherlands.

Italconsult, 1973.
Water Supply for Sana'a and Hodeida: Sana Basin groundwater studies. Italconsult, Rome, for UNDP.

LRD, 1978.
Yemen Arab Republic Montane Plains and Wadi Rima' Project: a land and water resources survey, Vol. I. Project Report 18, Land Resources Division, England.

MOD, 1978.
The Montane Plains and Wadi Rima Project. Ministry of Overseas Project. Ministry of Overseas Development, London, U.K.

Pratt, D.J., 1976.
Initial Development prospects volume 1 The Montane Plains. MPWR Project Yemen Arab Republic.

ANNEX B
WATER-SUPPLY AND
SANITATION

ANNEX B - WATER-SUPPLY AND SANITATION

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ANNEX B
WATER-SUPPLY AND SANITATION

B.1 Introduction

This annex presents the results of the water-supply and sanitation survey conducted in the rural area of Al Bayda Province. Although drinking-water takes only an estimated 10 % of the total water-supply, it is a primary human need and, therefore, its future availability should be secured. The survey has gathered quantitative and qualitative information in order to prepare a phased programme for the future development of water resources. To our knowledge, this survey was the first of its kind in Yemen; therefore we could not rely upon prior studies, and a methodology had to be developed to gather the data.

The objectives of the survey were twofold:

(a) To provide information on the existing water-supply and sanitation facilities in the rural villages of the province.
(b) To prepare a phased programme for the future development of water-supply and sanitation facilities based on a priority ranking according to needs and potentials.

The water-supply and sanitation aspect of the water resources study included the following activities:

(a) An inventory of existing water-supply and sanitation facilities in the rural villages and Al Bayda Town, including those constructed under the responsibility of RIRDP.
(b) A socio-economic survey in representative villages to obtain basic water-supply and sanitation parameters as well as people's opinion regarding the water-supply and sanitation situation in their village.
(c) Determination of the actual total water demand from people for domestic purposes and livestock in the various catchments.
(d) Recommendations for improvements to village water-supply and sanitation systems and the levels of service appropriate to different villages.
(e) Determination of priorities for development of water-supply and sanitation facilities throughout the province.

B.2 Survey method and field-work

B.2.1 Range

The Al Bayda Province covers about 11 000 km^2 with about 1300 villages and hamlets[1]) varying in size from 10 to 3000 inhabitants. There is only one asphalt road connecting Rada and Al Bayda Town. Because of this and the fact that the area is quite mountainous and

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[1]) Source: Census CYDA 1981.

capricious due to severe volcanic activity, a lot of regions are hardly accessible. Besides, quarrels between villages accompanied by shooting sometimes affected the survey programme.

Nevertheless the survey team succeeded in visiting 162 villages (12 % of the total number of villages in the province) in the period between May and October 1983. Emphasis was given to the larger villages (> 500 inhabitants) in the 12 selected areas, of which 10 areas were covered. The villages surveyed are indicated on Map B.1 (Volume III).

Below, the selected areas are listed. (These areas are somewhat different from the catchments that are discussed in the geohydrological and agricultural annexes):

Region 1 : Rada Basin
Region 2 : Sabah/Ar Riashiyah
Region 3 : Al Bayda North-East, including Al Bayda Town
Region 4 : Al Bayda West
Region 5 : Wadi Juban
Region 6 : Wadi Mansur/Wadi Amad
Region 7 : Wadi Matar/Wadi Ar Rin
Region 8 : Wadi Hubabah/Wadi Ar Riashiyah
Region 9 : Wadi Dhi Na'im
Region 10 : Villages along the Rada-Al Bayda road, including part of As Sawadiyah

These areas were chosen primarily on the basis of population density, and less on the basis of agricultural potential and groundwater resources as was done for the hydrogeological and agronomic surveys.

The following regions could not be visited:

(a) Al Jauf, because of the dangerous situation;
(b) Wadi Arsard/Wadi Saru, because of lack of time;
(c) a large part of As Sawadiyah, because of difficult accessibility and lack of time.

B.2.2 Transport and time schedule

The survey team used a Suzuki 4-wheel drive car which covered 15 000 km in 6 months. The team had their basis in Rada Town from where most of the visits were carried out; only for the Al Bayda regions (Regions 3 and 4 on Map B.1) and the Juban region was temporary accommodation arranged. During Ramadan the survey could not be carried out efficiently and during both the "Eets" (holidays) no work could be carried out at all. For the rest of the time available the team was able to carry out the work more or less according to the time schedule defined before the start of the study, although an average of two village visits per day proved to be unfeasible. On average the team managed to visit one village per day over the working days available, including days for laboratory and desk work.

B.2.3 Staff

The survey team on water-supply and sanitation consisted of Mr D. Bekker and Mr Mohammed Abduwalli Omar, who started as interpreter and ended up as trained counterpart able to carry out the tests as mentioned in Subsection B.2.4.

The special household survey among women as mentioned in Subsection B.2.4 under (c) was carried out by Ms Loni Scheffers, social worker, and Ms Nouria, assistant nurse in the Rada Mother and Child Health clinic.

B.2.4 Methodology and field work

(a) Before visiting any area the team prepared itself by means of aerial photographs (about 1:33 000) on which the (larger) villages were shown. For each region a topographical map was prepared, based upon oblique aerial photographs, which implies that distances were not very accurate. (Maps B.2 to B.10 in Volume III). Emphasis was given to villages larger then 500 inhabitants; other villages were randomly chosen in order to obtain an even distribution over the area.

(b) In 162 villages an "Operators Questionnaire" was completed by interviewing the water system operator or some other responsible person in the village (see Appendix B.I).

(c) In most of the villages at least one "Household Questionnaire" was completed by interviewing a randomly chosen householder (see Appendix B.II).

(d) In 3 villages about 30 % of the households were investigated using the same questionnaire as mentioned under (b), but in this case only women were interviewed (women's survey).

(e) Samples were taken from 93 water sources; the samples were chemically tested in a small laboratory at the RIRDP (see Appendix B.III).

(f) Thirty-four water sources were bacteriologically tested on Total and/or Fecal Coliforms. The bacteriological tests were carried out on the site using portable equipment.

(g) At each well pH and Electrical Conductivity (EC) were measured, as well as the depth of the (ground)water-table and the elevation of the ground level related to sea level. If applicable, the capacity of the water reservoir and its ground level were also measured.

(h) In some cases mosque "hammams" (washing and toilet facilities near the mosques) or special features, such as septic tanks, oxidation ponds, public toilets, etc. were visited.

(i) Where possible the survey team interviewed doctors or other health workers.

(j) Sometimes "qat" sessions (every afternoon the men come together to chew qat and to discuss "the problems of the day") were attended in order to get better insight into the problems concerning drinking-water and sanitation.

B.2.5 Reliability of results

There are two important matters to be mentioned as regards the reliability of the results. The first is the so-called "initial answer". This is a somewhat difficult problem to explain. The interviewers had the impression in many cases that it is quite common in Yemen that if somebody asks a (more or less private) question to a person (a man) not familiar to him, this man will answer such as to give the best impression of himself. He will never refuse an answer, but he may give a wrong answer, the initial answer. This fact has something to do with tradition, status, pride, and honour; it implies that some answers (especially those that are difficult to check) given to the interviewers were wrong, that is to say often too high or too positive, unless the survey team was able to become better acquainted with the respondent (as was the case during the qat sessions).

The second matter concerns the simple problem of just "not knowing the answer". For instance the question to an operator "how much water does a household consume per day" is difficult to answer if there are no water meters. Then the interviewee will also give some kind of answer in most of the cases - he will rarely say "I don't know" - but this answer cannot be more than a very rough estimate. Once alert to these problems the survey team tried to cross-check as much as possible, and engaged two female interviewers to carry out a special household survey in 3 villages, covering about 30 % of the households, and only interviewing women with whom the problem of the "initial answer" does not exist. (Apparently they have no status or pride to keep up and accordingly no reasons to give a better impression than the actual situation). It should be noted that it is (nearly) impossible in Yemen as a man to interview a woman who is unknown to you; it may even be very dangerous. Another reason to carry out this special household survey among women was the fact that women are supposed to have a more realistic judgement on domestic water consumption because they actually run the households.

It will be clear that the results from this survey are not 100 % reliable. However, the number of villages visited was large enough to form a representative sample, and the statistical approach to processing data in this report will at least result in very reasonable approximations of the actual figures.

B.3 Socio-economic aspects

B.3.1 Demographic data

Demographic data relating to household size, sex and age distribution was obtained from the following three sources:

(i) operators survey;
(ii) household survey;
(iii) women's survey in Al Ajma, Farasa and Al Khabar.

The results are summarized in Tables B.1 and B.2.

Table B.1 - Demographic data obtained from women's survey in Al Ajma, Farasa, and Al Khabar

Village	Inhabitants per household	Sex and age distribution per household					
		Males	Females	0-10	10-20	20-40	> 40
Al Ajma	6.1	3.0	3.1	2.4	1.3	1.5	1.0
Farasa	5.5	2.7	2.8	2.3	0.8	1.6	0.8
Al Khabar	5.9	3.0	2.9	2.4	1.2	1.4	0.8
Al Bayda Province (from 1981 CYDA census)	6.4	3.1	3.3	Not available for Al Bayda Province from 1981 census			

There is a clear discrepancy between the results obtained from the household survey and the other surveys including the CYDA 1981 census. In general, the household survey indicates small households, a lower percentage of females, and a disproportionately low representation of younger age groups. It must be concluded that for demographic data the household survey was not representative of the households in the province.

For this report therefore, the household sizes obtained from the operators questionnaire (based on census) and that obtained from the women's survey will be adopted.

No particular variation in demographic data between the regions can be derived from the survey, although in all areas there is a tendency that households are becoming smaller as young marrieds prefer to construct their own house rather than live in extended families.

B.3.2 Livestock

Livestock numbers in terms of cows, bulls, sheep, goats, donkeys, and camels were obtained from the household survey. An average household livestock population (in terms of equivalent sheep units) was enumerated. The results for each area are summarized in Table B.3.

Table B.2 - Demographic data from operators and household surveys

Region	Inhabitants per household		Sex and age distribution/per household (household survey)					
	Operators survey (based on census)	Household survey	Males	Females	0-10	10-20	20-40	> 40
1 Rada Basin	6.2	3.3	2.0	1.3	0.1	0.8	1.5	0.9
2 Sabah/Ar Riashiyah	6.7	2.8	1.6	1.2	0.3	0.2	1.1	0.7
3 Al Bayda North-East, including Al Bayda Town	5.3	4.9	2.8	2.1	1.3	1.2	1.3	1.4
4 Al Bayda West	4.7	4.0	2.5	1.5	1.2	0.4	1.3	1.2
5 Wadi Juban	6.6	3.0	1.7	1.3	0.3	0.2	1.2	0.7
6 Wadi Mansur/Wadi Amad	6.3	3.3	1.8	1.5	0.1	0.8	1.4	0.9
7 Wadi Matar/Wadi Ar Rin	6.7	5.3	3.0	2.3	2.0	0.7	2.0	0.7
8 Wadi Hubabah/Wadi Ar Riashiyah	5.7	3.7	2.6	1.1	0.4	0.9	0.9	1.6
9 Wadi Dhi Na'im	6.0	12.4	6.3	6.1		Incomplete		
10 Villages along Rada-Al Bayda road, including part of As Sawadiyah	6.0	2.4	1.2	1.2	0	0.6	1.4	0.4

Table B.3 - Livestock densities per area

Region	Number of households interviewed	Livestock numbers per type						Sheep units per household*
		cows	bulls	sheep	goats	donkeys	camels	
1 Rada Basin	33	33	5	493	12	6	4	29.8
2 Sabah/Ar Riashiyah	30	45	37	1472	49	1	17	73.3
3 Al Bayda N.E.	36	6	0	803	23	3	0	25.4
4 Al Bayda W.	12	9	0	135	3	3	0	16.5
5 Wadi Juban	24	32	9	338	1	2	0	76.9
6 Wadi Mansur/Wadi Amad	15	28	1	1200	16	0	6	95.4
7 Wadi Matar/Wadi Ar Rin	3	1	0	33	0	0	0	12.9
8 Wadi Hubabah/Wadi Ar Riashiyah	4	8	0	640	24	0	0	115.9
9 Wadi Dhi Na'im	12	18	7	896	42	0	2	94.5
10 Villages along Rada-Al Bayda road, including Abbas and part of As Sawadiyah	6	5	5	740	40	0	3	118.8
Total	175	185	64	6750	210	15	32	
Average per household		1.4		38.6	1.2	0.1	0.2	

* Sheep units are calculated on the basis of water consumption, see Subsection B.5.4.2. The figure for Rada Basin has been derived from the special women's survey.

B.3.3 Services

Much of Al Bayda Province suffers from inaccessibility and a lack of services, although the selected regions are somewhat above average in this respect, primarily due to the construction of the asphalt road between Rada and Al Bayda which is the only road of this standard in the province. Improved access roads are being constructed in Rada District by RIRDP and access to Juban will soon be improved by the construction of the Rada-Juban road. Elsewhere, particularly in the north of the province access is extremely difficult. School and health facilities were included in the operator's questionnaire and these are summarized in Table B.4 for each region.

Table B.4 - School and health facilities

Region	Population covered by each school	No. of health facilities (health centres and hospitals)
1 Rada Basin	950	2
2 Sabah/Ar Riashiyah	845	1
3 Al Bayda North-East, including Al Bayda Town	848 (excluding Al Bayda town)	4
4 Al Bayda West	417	-
5 Wadi Juban	1118	-
6 Wadi Mansur/Wadi Amad	738	1
7 Wadi Matar/Wadi Ar Rin	310	-
8 Wadi Hubabah/Wadi Ar Riashiyah	286	1
9 Wadi Dhi Na'im	2132	1
10 Villages along Rada-Al Bayda road, including part of As Sawadiyah	1463	2
Al Bayda Province	2043*	11* (in 1981)

* Source: Statistical Yearbook 1981.

The number of schools in the selected regions is above average for the province in all regions except Wadi Dhi Na'im. The most populated regions of Rada, Al Bayda and Sabah have about the same school density although it is not as great as in Hubabah and Mata. The latter results may however not be representative due to the small sample. According to the 1981 yearbook it would appear that most of the health facilities in the province are located within the selected regions.

B.3.4 Peoples' attitudes towards water-supply and sanitation systems

Peoples' attitudes towards water-supply systems can best be judged by the results of the household survey to questions on satisfaction with their existing systems and their willingness to pay for a new system. The survey data on these questions is contained in Appendix B.IV to this Annex and is summarized below in Table B.5.

Table B.5 - Attitudes to existing water-supply

Region	% satisfied with existing situation		% willing to pay for improved system	
	W.S.	No. W.S.	W.S.	No. W.S.
1 Rada Basin	50	5	58	74
(RIRDP Projects)	60	-	25	-
2 Sabah/Ar Riashiyah	67	7	100	96
3 Al Bayda North-East, including Al Bayda Town	68	-	75	-
4 Al Bayda West	45	0	55	100
5 Wadi Juban	38	13	100	93
6 Wadi Mansur/Wadi Amad	100	0	33	83
7 Wadi Matar/Wadi Ar Rin	100	0	0	100
8 Wadi Hubabah/Wadi Ar Riashiyah	75	0	100	100
9 Wadi Dhi Na'im	100	0	25	100
10 Villages along Rada-Al Bayda road, including part of As Sawadiyah	-	20	-	80

W.S. = water-supply system.

The table indicates a very low percentage of satisfaction amongst people without a water-supply system coupled with a high willingness to pay for a water-supply system.

Provision of a water-supply system has increased satisfaction considerably although in some regions, especially Rada and Al Bayda, many people were not satisfied with their systems and expressed a willingness to pay for improvements. For the RIRDP projects 60 % were satisfied with the system provided, indicating a need for some modification to the existing systems, and 60 % of these dissatisfied were prepared to pay for some improvements.

Attitudes of the people towards sanitation is revealed by their responses to question in the household questionnaire relating to their opinion of the healthiness of their existing facilities and their willingness to pay for improvements. The survey results are summarized in Table B.6.

The results indicate a strong desire and willingness to pay for improved sanitation facilities in all regions of the province. The most perceived need both in term of present unhealthiness and willingness to pay was in fact garbage disposal. Satisfaction with excreta disposal was the highest probably due to the existing use of the 'baladiyah' system. In Al Bayda West a high satisfaction was expressed with wastewater

Table B.6 - Attitudes to sanitation

Region	% people considering existing system healthy			% people willing to pay for improved system		
	Wastewater	Excreta disposal	Garbage disposal	Wastewater	Excreta disposal	Garbage disposal
1 Rada Basin	3	15	0	87	84	92
2 Sabah/Ar Riashiyah	3	17	3	97	96	100
3 Al Bayda North-East, including Al Bayda Town	0	11	6	94	96	100
4 Al Bayda West	25	0	0	67	67	80
5 Wadi Juban	4	8	4	96	90	95
6 Wadi Mansur/Wadi Amad	7	7	0	85	85	100
7 Wadi Matar/Wadi Ar Rin	0	0	0	100	100	100
8 Wadi Hubabah/Wadi Ar Riashiyah	0	0	0	100	100	100
9 Wadi Dhi Na'im	0	0	8	100	81	92
10 Villages along Rada-Al Bayda road, including part of As Sawadiyah	0	0	0	100	100	100
Al Bayda Town	84	15	33	76	33	85
Al Ajma (Women's survey)	0	9	9	92	88	88
Farasa (Women's survey)	0	0	0	79	75	75
Al Khabar (Women's survey)	0	0	0	70	65	76

facilities and this coincided with the villages which had some type of piped or channelled system. Surprisingly the same satisfaction was not expressed in Al Bayda North where some villages also have a form of wastewater system.

Less willingness to pay was expressed by the women in the Al Ajma, Farasa and Al Khabar survey, despite their emphatic replies regarding the unhealthiness of their present facilities. In Al Bayda town where existing wastewater, sewerage and garbage disposal facilities are available some dissatisfaction with excreta disposal and garbage disposal facilities was expressed and rather mixed reactions regarding willingness to pay. Many Al Bayda residents already find their water charges too high and this may affect their reaction to paying for sanitation.

B.3.5 Occupation and incomes

The household survey (generally asked of men) provided no significant data on incomes due to an unwillingness of the respondents to reveal this information. The women's survey in Al Ajma, Farasa and Al Khabar, however, did provide useful data which is included in Table B.7.

The percentages of self-employed farmers, employed people and emigrants in each of the region as obtained from the household survey is shown below in Table B.7.

It is considered that the percentage of emigrants was understated in the household survey, probably because in the households which were included there was a male present thus excluding the emigrant households. The women's survey in Al Ajma, Farasa and Al Khabar is considered to be more representative of the true situation. No particular regional variation is apparent from the results.

B.4 Public health

B.4.1 Health facilities

In Al Bayda Province there are the following health facilities:

In Rada:
- Hospital.
- Mother and Child Health Clinic.

In Al Bayda:
- Hospital (old).
- Hospital (new) (not in use during the survey).

In Mallah:
- Hospital (not in use during the survey).

In Awway, As Sawmah, Al Quah (As Sawadiyah), Mallah and some other villages:
- Doctors (and drugstores).

In most of the rural villages there are no health facilities at all. Although the Rada Clinic owns a mobile unit, it lacks the staff to use it. There are rumours that UNICEF will start some kind of mobile policlinic next year.

B.4.2 Diseases

In order to obtain an impression of the water-related diseases, the survey team inquired in all villages visited about the illnesses experienced. The answers are given in Table B.8. However, we cannot consider this information as very reliable, since health education scarcely exists. Only at schools are children taught a little bit on this subject; the physicians rarely tell their patients what kind of illness they have got. The survey team also has its doubts on the rural doctors it sometimes encountered in the field. Often they did not seem to be doctors at all, but rather drug sellers, as appeared during the interviews.

In our opinion the most reliable information comes from Dr Ahmed Al Azzi, who is working in Rada Hospital and as a general practitioner in Mallah. The following information comes from an interview with this doctor:

"Rada Hospital is visited by about 100 patients per day. The exact number is not known, because a filing system does not exist. The most common water-related diseases and the percentages of appearance are:

Helminthic diseases	: 60 %
Dysentry	: 30 %
Protozoal infections	: 10 %.

In areas with surface water (like Wadi Tha, near Rada) bilharziasis and malaria are most common. As far as malaria is concerned there is at least one case a day (other estimations are more than 1000 cases a year).

Another very common illness is kidney stones, even stone bleeding at children of 1 year age is not rare. This affection has something to do with the hardness (mineral content) of the water (without exception the water in Al Bayda Province is quite hard; see the chemical analysis in Volume IV Part II). Kidney stone cases appear in the hospital at least once a day.

Illnesses related to lack of personal hygiene and environmental pollution by garbage disposal, in which the numerous flies in Yemen play an important role, are: amoebiasis, typhoid, and eye infections.

Table B.8 - Occurrence of water-related diseases (% of appearance)

	1	2	3	4	5	6	7	8	9	10	11	12
1 Rada Basin	0	9.7	9.7	0	9.7	9.7	3.2	6.5	3.2	3.2	0	0
2 Sabah/Ar Riashiyah	0	0	5.6	0	0	16.7	5.6	16.7	0	0	0	5.6
3 Al Bayda North-East, including Al Bayda Town	4.5	32.1	9.1	4.5	9.1	22.7	0	0	4.5	0	4.5	0
4 Al Bayda West	11.1	0	0	11.1	0	11.1	0	33.3	0	0	0	0
5 Wadi Juban	8.3	16.7	8.3	8.3	0	0	0	16.7	0	16.7	0	25
6 Wadi Mansur/Wadi Amad	0	0	0	0	0	0	0	18.2	0	0	0	18.2
7 Wadi Matar/Wadi Ar Rin	0	0	0	0	0	0	0	75.0	0	0	0	0
8 Wadi Hubabah/Wadi Ar Riashiyah	0	22.2	22.2	0	0	0	0	0	0	0	0	0
9 Wadi Dhi Na'im	9.1	0	0	0	0	0	0	0	0	0	0	9.1
10 Villages along Rada-Al Bayda road, including part of As Sawadiyah	0	0	0	22.2	0	0	0	0	0	0	0	0

Code:
1 = Diarrhoea
2 = Malaria
3 = Bilharzia
4 = Skin infection
5 = Dehydration of babies
6 = Chickenpox
7 = Headaches
8 = Stomach aches
9 = Typhoid
10 = Measles
11 = Kidney stones
12 = Coughing (mainly children)

A disease not carried by flies, but mainly caused by handling cattle dung (women make "pancakes" out of cattle dung as fuel for their ovens) is viral hepatitis, of which again at least 1 case a day arises".

B.4.3 Health hazards

A lot of rural villages, if not all, are located in an extremely unhealthy environment. This is caused by:

Lack of garbage disposal facilities. Nearly everyone throws their domestic refuse out of the nearest window. After a while most of it is eaten by goats and dogs, but the tins remain and cause foot wounds with the children playing barefoot, which easily leads to infections.

Polluted drinking-water. The greater part of the shallow wells are uncovered, which makes them easily accessible for birds and other animals. Excreta of these animals and several kinds of insects are a severe health hazard. When the women fetch water with donkeys, these animals approach the well very closely, and litter the soil around the well with dung. Not so rarely a bucket or tin is placed in this mess before it is sunk into the well water. This, plus the seepage of the faecal material through the uncemented well lining, causes heavy contamination of the water.

In the case of a water distribution system contamination may also arise in an uncovered or badly covered reservoir that is never cleaned. Although a lot of interviewees assured the survey team that their reservoirs were cleaned once a month or even once a week, the surveyers have severe doubts about these answers. When checking these reservoirs, we found them to be heavily polluted in most of the cases.

Then there is the problem of leaking pipes going through wastewater pools. Any wastewater-related contamination can easily seep into these pipes at times when there is no pressure, as is often the case.

Excreta disposal system. Most of the households have the "baladiyah" excreta disposal system. Although this is in principle a good and safe composting system, the way in which it is presently laid out is a health hazard:

- the liquid excreta generally run on to the street out of a drain-pipe from the first floor;
- the solid excreta fall on the ground floor in a separate room that is accessible from outside through an open entrance and thus easily accessible for playing children and disease-carrying flies.

Mosque hammams. The basins near the mosques, meant to wash oneself before praying, not only contain algae, but all kinds of helminths and insects have an ideal habitat in these waters; even the bilharzia snail (although never observed by the survey team) seems to prosper here.

Personal hygiene. Only men are allowed to go to the mosque to pray. Before praying they have to wash themselves. Because women are not allowed to enter the washing facilities of the mosque, they have to wash themselves at home, where there is no shower and often not even a tap. As a result, women are often not very clean.

Cattle and dogs running free. Livestock and dogs excrete freely all over the place, resulting - especially in connection with wastewater - in a very unpleasant and unhealthy environment.

Emptying baladiyah rooms. The top layer of the excreta can never be completely composted at the time the room is emptied. This means that handling this stuff is a hazardous contact with feacal material that may carry contagious pathogens.

Cattle inside the house. Many houses have stables inside the house on the ground floor. This cattle is often free to walk in an out, relieving nature not only in the stable, but also in the hallway and right in front of the house. The cattle dung attracts flies that breed in this dung, resulting in millions of flies, each one a potential disease carrier.

B.5 Water-supply situation in the province

B.5.1 General

The main characteristics of the villages are indicated on the topographical maps made for each area (Maps B.2 to B.10 in Volume III). The main results of the survey are given in Table B.9.

Of all the villages visited, 96 % use groundwater as water source. In most of the cases (81 %) the water source is a shallow well, 10 % has a borehole, 5 % uses a spring. Surface water is only found as small streams in Al Bayda Province and these are used in the remaining cases.

There is some kind of water distribution system in 36 % of the villages. This means that in 64 % women and girls fetch water either with jerrycans or buckets on their heads or with donkeys carrying some kind of rubber water bag.

Provision of a piped water-supply system can, as well as improving health conditions, save these women many hours of time and effort in fetching water and thus provide time for them to engage in other productive or social activities. Table B.10 indicates the average time spent per day by women in each of the selected regions fetching water where there is no piped water-supply system.

Table B.9 - Water-supply situation in the province

Region	Total no. of villages (1)	No. of villages visited (2)	% covered (3)	% without water-supply (4)	% with water-shortage (5)	% compl. about quality (6)	No. of chem. anal. (7)	No.of bact. tests (8)
1. Rada Basin	172	30	17	50	20	30	27	13
2. Sabah/Ar Riashiyah	46	18	39	94	44	17	13	2
3. Al Bayda N.E.	102	20	20	5	25	15	27	2
4. Al Bayda W.	90	9	10	22	33	22		0
5. Wadi Juban	65	12	18	92	42	8	21	5
6. Wadi Mansur/Wadi Amad	72	27	38	93	45	0	5	5
7. Wadi Matar/Wadi Ar Rin	22	6	27	83	33	17	0	0
8. Wadi Hubabah/Wadi Ar Riashiyah	32	11	35	82	18	0	0	0
9. Wadi Dhi Na'im	44	11	25	36	45	0	0	2
10. Villages along Rada-Al Bayda road, including Abbas and part of As Sawadiyah	100	18	18	94	33	0	0	5

(1) : Total number of villages according to CYDA-census 1981.
Total number of villages in the selected areas: 745.
Selected regions cover 51 % of the total number of villages (1460) in the province.
Selected regions cover 58 % of the total number of inhabitants (327 539) in the province.
Survey covers 54 % of all the villages larger than 500 inhabitants.
(2) : Total number of villages visited by the survey team.
(3) : Percentage of villages covered.
(4) : Percentage of villages without water-supply systems.
(5) : Percentage of villages with water shortage.
(6) : Percentage of villages complaining about water quality.
(7) : Number of chemical analyses carried out.
(8) : Number of bacteriological tests carried out.

Table B.10 - Fetched-water supplies

Selected region	% of vill. where water is fetched	Av. time/day spent fetching water (h)	% people desiring system		
			Piped to connections	Piped to standpipe	No system
1 Rada Basin	50	3.1	93	7	0
2 Sabah/Ar Riashiyah	94	6.3	96	4	0
3 Al Bayda North-East, including Al Bayda Town	0	-	96	4	0
4 Al Bayda West	22	3.1	100	0	0
5 Wadi Juban	92	4.0	74	26	0
6 Wadi Mansur/Wadi Amad	85	5.6	100	0	0
7 Wadi Matar/Wadi Ar Rin	83	4.5	100	0	0
8 Wadi Hubabah/Wadi Ar Riashiyah	70	5.6	100	0	0
9 Wadi Dhi Na'im	36	6.4	100	0	0
10 Villages along Rada-Al Bayda road, including part of As Sawadiyah	90	4.2	100	0	0

B.5.2 Engineering aspects

B.5.2.1 Types of sources

As mentioned above, in most of the cases the village water source is either a shallow well or a borehole. This is indicated in Table B.11.

Table B.11 - Distribution of source types

Region	% source type			
	Borehole	Shallow well	Spring	Cistern/Stream
1 Rada Basin	43	47	0	10
2 Sabah/Ar Riashiyah	0	67	17	16
3 Al Bayda N.E.	10	90	0	0
4 Al Bayda West/Es Zahir	0	100	0	0
5 Wadi Juban	0	100	0	0
6 Wadi Mansur/Amad	7	93	0	0
7 Wadi Matar/Ar Rin	0	100	0	0
8 Wadi Hubabah/Ar Riashiyah	0	67	33	0
9 Wadi Dhi Na'im	0	100	0	0
10 Villages along Rada-Al Bayda road, including part of As Sawadiyah	0	100	0	0

(a) Shallow wells

In nearly all cases the shallow wells are circular (2.5-3 m diameter), dug and cut out by hand and lined with uncemented blocks. Usually they are not covered; often some kind of bush grows inside the well, attracting birds. In many cases the wells are hundreds of years old.

(b) Boreholes

Boreholes are a rather recent phenomenon; only since the construction of the Rada-Al Bayda asphalt road, which was completed in 1980, is it possible for a drilling rig to reach the sites at a reasonable cost. Nowadays there are four private drillers in the province (one of whom works in the Juban region only). They use Portadrill and Ingersoll Rand drilling equipment and mostly drill 8 to 10 inch diameter holes. Geo-electrical surveys or other investigations are never carried out (except for the RIRDP and Public Works boreholes) so that failures are quite common.

In a few areas the drinking-water source is a spring. Where the water comes out of a rock (Hawat in Sabah, Wadi Ar Riashiyah), people have somehow fitted a galvanized pipe (1-2 inches dia.) into the rock, out of which the water flows freely or is collected in a reservoir.

B.5.2.2 Pumps and engines

In places where there is a distribution system, the water is in general pumped up with a vertical turbine pump, out of shallow wells as well as boreholes. Submersible pumps are rarely used. The most common makes are Alta, Caprari, Desteco and Nemitsas. These pumps often have an optimum efficiency at about 1500 rpm. They are driven by a diesel engine, very often a Japanese Yanmar 16 or even 23 hp, with about 600 rpm at maximum. An approximately 1:2 belt drive connects pump and engine.

These pumps and engines are bought by private persons without any preliminary study of the required duties (except for the RIRDP schemes). Sometimes the result is satisfactory, but more often than not the engine is too powerful for too small a pump. This is not necessarily a problem, unless a discharge problem develops; then people tend to buy a new, more powerful - and more expensive - engine, because they think the problem is in the engine and not in the pump. Then of course a lot of money is wasted and the problem remains unsolved.

The age of pumps and engines varies from 8 months up to 15 years.

The capacities of the pumps range from 0.8 l/s to 6.3 l/s with heads varying from 6 m to 135 m.

The rising mains are often in good condition with 2.5 or 3 inch diameter as dominant sizes. Sometimes T-connections have been made in the rising main in order to use the water for irrigation as well.

B.5.2.3 Storage

In general there are two main types of storage reservoirs, one made out of rock blocks, the other made out of concrete, often on piles. The storage provided can range from 0.5 days up to 4 days, on average 2 days.

(a) Reservoirs made out of blocks

Because of the mountainous landscape, it is often possible to find a high location on the side or top of a hill or mountain suitable to build a reservoir. Yemeni people are accustomed to building with rock blocks; they traditionally build their houses that way. Most of these reservoirs built with rock blocks are square, waterproof cemented on the inside, and sometimes even on the outside. The roof is either made of corrugated steel plates or a cement cover on a wooden structure. Capacities range from 6 to 155 m^3. The thickness of the walls is 0.30-0.40 m.

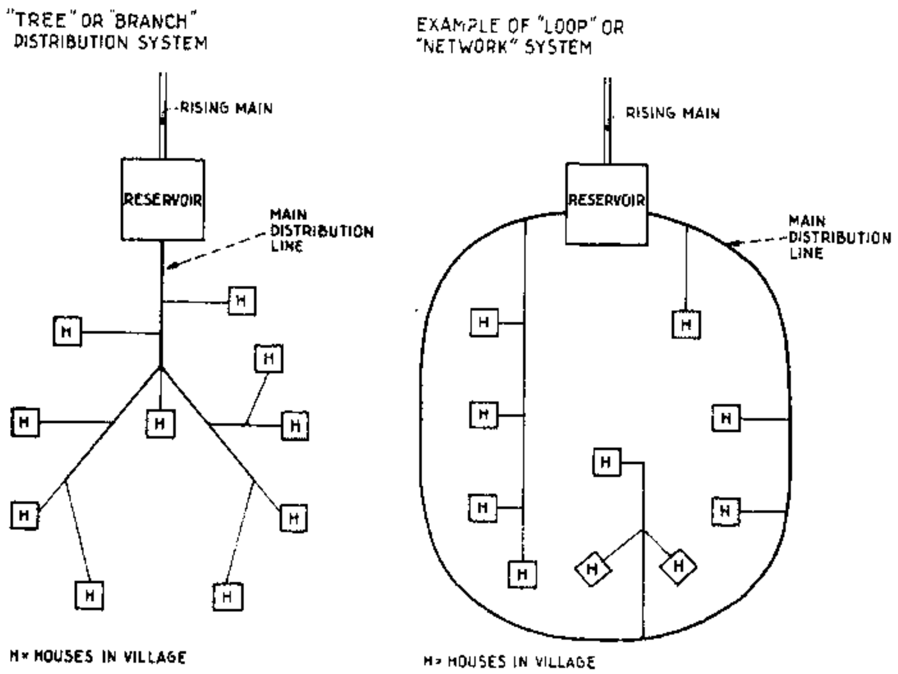
(b) Reservoirs made out of concrete

If a village is in a plain, there is no natural high site to build a reservoir. In these cases villages have reinforced concrete reservoirs on piles. These reservoirs are built by local contractors who have gained some knowledge about reinforced concrete in Saudi Arabia. The square constructions reach up to 8.5 m above ground level. Capacities range from 6 to 50 m^3. The thickness of the walls is 0.20-0.30 m.

B.5.2.4 Distribution systems

There are two main systems in Al Bayda Province: the loop network and the branch or tree system (see Fig. B.1), the latter being the most common in the province. However, a design is never made and a 0.5 inch pipe connected to a 3 inch main line that zigzags through a village for hundreds of metres is not rare. Hence capacities are often severely limited, and households towards the end of a pipeline suffer frequent water shortages. A water distribution system often looks more or less like a labyrinth, because house owners usually make their own house connections. Pipes are never placed underground, but lay on the surface. They go through wastewater pools and cross tracks. Trucks easily damage the pipes or cause leaking connections. In many villages the house connection ends up in a metal tank on the roof of the house that is filled up once per so many days. In general villagers use galvanized steel pipes ranging in diameter from 0.5 inch to 3 or, rarely, even 4 inches. Before screwing them together they paint the threads, which results in a watertight connection.

Figure B.1 - Water distribution systems



B.5.3 Operation and maintenance

B.5.3.1 Organization of operation and maintenance

At the moment the Ministry of Public Works is responsible for the operation and maintenance (O & M) of rural drinking-water supply systems on a national level. On a regional level the Local Development Authorities (LDAs) are responsible. However, no organizational structure as such exists to allow this responsibility to be exercised by the various authorities.

In practice in each village there is one or more responsible person, sometimes as members of some kind of organization, who turns on the engine and pump if necessary, looks after fuel and repairs of pump and engine, and collects the money from the households. Part of this money is a salary for the water system operator(s), about 500 to 1000 YR per month. In fact the whole "organization" remains restricted to village level.

B.5.3.2 Payments for O & M and cost of water

Two ways of payment for water can be distinguished in general:

(a) Villagers pay a fixed amount per person (including babies!) per month. This amount ranges from YR 2 to YR 20.
(b) Villagers pay a fixed amount per m^3 (or "barrel" or some other unit). This amount ranges from YR 2.50 to YR 7.50.

These amounts are based upon investment, operation and maintenance costs.

The above applies to villages in which there are house connections. In villages with stand-pipes only, people pay per m^3 or per household, both per month. In this case the price ranges from YR 2.5 to YR 4 per m^3 and from YR 20 to YR 100 per household. In a few villages people do not pay at all. The differences in cost for water between the several regions and villages are striking (see also Table B.12). These differences illustrate the lack of an overall responsible organization. Mainly in cases where the water source (or system) is a private matter (for instance in Hazzah, Region 3, Al Bayda North-East) and not owned by the village as a whole, people complain about the high price of the water, especially if on top of that the water quality is poor.

B.5.3.3 Maintenance and its problems

Preventive maintenance is something unknown to most, if not all, water system operators. If something breaks down, it is not always repaired, since a lot of water operators do not know very much about pumps and engines, and operator's manuals are never provided. Often they have no idea of what part of the machine has broken down, and the pump or engine is completely replaced, which demands an extra (high) contribution from the households. In rare cases, water system operators

Table B.12 - Mean payments for water per region

	Cost of house connection (YR)	House connection			Stand-pipe	
		YR/m^3	YR per capita per month	YR per household per month	YR per m^3	YR per household per month
1 Rada Basin	260	4	3.5	52.5	-	-
2 Sabah/Ar Riashiyah	-	-*	-	-	0	-
3 Al Bayda North-East, including Al Bayda Town	344	4.8	6.8	-	2.5	60
4 Al Bayda West	321	6	6.6	-	-	-
5 Wadi Juban	500	-	-	-	-	-
6 Wadi Mansur/Wadi Amad	400	-	-	-	-	0
7 Wadi Matar/Wadi Ar Rin	500	-	5	-	-	-
8 Wadi Hubabah/Wadi Ar Riashiyah	650	-	-	-	-	0
9 Wadi Dhi Na'im	371	4.8	2.7	50	-	-
10 Villages along Rada-Al Bayda road, including part of As Sawadiyah	-	-	0	-	-	-

* - is not available or not applicable.

have some mechanical knowledge, gathered during a temporary emigration, e.g. to Saudi Arabia, and this results in very neat equipment in a good condition.

In general there are no problems with the availability of fuel and spare parts in the market, although an exception to this rule should be made for pumps and engines from Eastern Europe or the USSR.

Reservoirs are not cleaned as often as the interviewees told the survey team, i.e. 12 times per year as was discussed in Subsection B.1.4.3.

Leakages in pipes and valves are often repaired in an improvised way using rubber from old inner tubes. Sometimes villages lack water for several days, e.g. when the rising main has broken down. Often there are no spare pipes or other parts available in the village itself and they have to be bought in one of the larger villages, which takes time and extra money.

B.5.4 Water consumption

B.5.4.1 Domestic water consumption

Each of the three surveys carried out during this study (operators, household and women's) provided data on water consumption, and a number of methods can therefore be adopted to calculate the present water consumption. These methods are discussed in Volume IV containing the computer print-outs. The results are summarized in Table B.13.

The value of water consumption based on storage tank capacity and time to fill the storage tank was rejected due to the high standard deviation of the results (Column 2). Water consumption calculated from the household questionnaire was also rejected: per capita values were found to be excessive (Columns 4 and 5) due to the small household sizes derived from the survey. Water consumption calculated from the household questionnaire (Column 3) was found to be less reliable than that calculated from the operators estimate of the village water consumption (Column 1). The latter values of per capita water consumption have therefore been adopted in this report for the determination of the total present domestic water consumption in each region.

As shown in Table B.13, the per capita water consumption from fetched supplies (Column 6) was not markedly less than that from villages with a water-supply system (Column 7), and in some cases even greater.

Per capita water consumption figures derived from the women's survey are shown in Table B.14 broken down for households with 1 tap, 2 taps and with 3 or more taps. The latter demonstrates quite clearly the increase in per capita water consumption which occurs once the number of water consuming facilities is raised or the standard of housing improves. A breakdown of water consumption into quantities used for cooking, washing, drinking and laundry is also incorporated.

Table B.13 - Per capita water consumption values calculated by various methods

Region	Per capita water consumption (l/capita/day)						
	Column*					Fetched supply	Water-supply system
	1	2	3	4	5	6	7
1 Rada Basin	51.5	42.7	47.0	156.5	110.6	56.9	43.4
2 Sabah/Ar Riashiyah	56.2	70.1	62.0	141.2	-	54.6	83.0
3 Al Bayda North-East, including Al Bayda Town	86.7	127.6	87.8	-	73.3	-	86.7
4 Al Bayda West	69.1	111.5	101.9	-	129.2	68.6	69.3
5 Wadi Juban	39.5	11.1	70.8	140.6	-	39.0	44.7
6 Wadi Mansur/Wadi Amad	58.6	75.9	122.8	206.7	150.0	61.7	50.3
7 Wadi Matar/Wadi Ar Rin	58.8	44.1	75.0	85.2	-	64.0	43.0
8 Wadi Hubabah/Wadi Ar Riashiyah	45.9	-	29.3	100.0	33.3	59.6	18.5
9 Wadi Dhi Na'im	76.4	95.7	105.6	93.1	22.5	100.8	62.5
10 Villages along Rada-Al Bayda road, including part of As Sawadiyah	54.4	17.4	65.9	160.5	-	55.2	48.1

* See text for explanation.

Table B.14 - Per capita water consumption in Al Ajma, Farasa and Al Khabar

Village	Per capita water consumption (l/capita/day)			Breakdown of water use (l/capita/day)			
	1 tap	2 taps	> 2 taps	Drinking	Cooking	Washing	Laundry
Al Ajma	39.8	48.2	79.9	6.0	10.4	16.0	24.1
Farasa	49.0	30.3*	68.0	4.9	16.1	12.4	12.5
Al Khabar	38.6	59.9	77.4	4.9	15.7	15.3	19.2
Mean	42.4	54.1*	75.1				

* Based on one observation only. Mean excludes the result from Farasa.

B.5.4.2 Livestock water consumption

Water consumption by livestock can be evaluated from the household survey by analyzing the quantity consumed by livestock who drink water supplied at the household. This was the only way of calculating consumption although many livestock also drink directly from the source.

An analysis of data from all regions and the survey in Al Ajma, Farasa and Al Bayda provides the following values:

- sheep consumption: 4.4 litres/sheep;
- cow consumption : 25 litres/cow.

These values are generally in accordance with those commonly accepted for sheep and cow water consumption.

Insufficient data regarding consumption from goats, donkeys and camels is available to make any definite conclusion from the survey. In order to calculate per capita livestock water consumption the following assumptions have been made.

1 sheep unit = 0.18 cow = 0.18 bull = 0.5 goat = 0.5 donkey = 0.18 camel.

Using these values and a water consumption of 4.4 l per sheep, the average water consumption per household has been calculated for each region. This is based upon the answers by respondents to the household survey. The results are summarized below in Table B.15.

The values for regions 1 to 5 are considered to be based upon sufficient data to be reasonably confident that they are representative of the situation in the region. Regions 6 to 10 however provided widely diverging results and are in general based upon small samples which may not be representative. The results from these regions have, therefore, been adjusted as follows:

Table B.15 - Livestock water consumption in 1/day

Region	Sheep units per household*	Livestock water consumption per household	Livestock water consumption per capita in household	
			From survey	Adjusted
1 Rada Basin	29.8	131.1	21.2	
2 Sabah/Ar Riashiyah	73.3	322.5	48.1	
3 Al Bayda North-East, including Al Bayda Town	25.4	111.8	21.1	
4 Al Bayda West	16.5	72.6	15.4	
5 Wadi Juban	76.9	338.4	51.1	
6 Wadi Mansur/Wadi Amad	95.4 (65.0)	419.8	66.7	45.3
7 Wadi Matar/Wadi Ar Rin	12.9 (32.2)	56.8	8.5	21.2
8 Wadi Hubabah/Wadi Ar Riashiyah	115.9 (62.3)	510.0	89.5	48.1
9 Wadi Dhi Na'im	94.5	415.8	69.3	
10 Villages along Rada-Al Bayda road, including part of As Sawadiyah	118.8 (61.8)	522.7	87.1	45.3

* See also Table B.3.

Wadi Mansur: a previous survey carried out in Wadi Mansur by RIRDP (Ilaco, 1983) included a larger sample and indicated a livestock population of 65 sheep units/household, equivalent to 45.3 litres/ capita/day. This is considered to be a more representative value.

Wadi Matar: this region has a low quantity of irrigated alfalfa which is often indicative of a low livestock population. There is no reason, however, to suggest that the livestock population is as low as indicated by the survey and the value for Rada Basin has been adopted in this report.

Wadi Hubabah: this region was found to be similar to Sabah with a relatively high livestock population and the same value has therefore been adopted for both regions.

Wadi Dhi Na'im: the survey indicated a high per capita livestock population and this was more or less confirmed by field observations. No adjustments have therefore been made.

As Sawadiyah: The region is quite similar to Wadi Mansur and therefore the value obtained from Ilaco (1983) for Wadi Mansur has also been adopted.

B.5.5 Water quality

Chemical analyses were carried out on water samples from the raw water-supply of 93 villages in Rada, Sabah, Al Bayda, Juban and Wadi Mansur and bacteriological analyses on samples from 34 supplies from villages in Rada, Al Bayda, Sabah, Juban, Wadi Mansur, Wadi Matar, Wadi Dhi Na'im and As Sawadiyah. The results are listed in Table B.16. A HACH was used for the chemical analyses and a MILLIPORE for the bacteriological analyses.

Table B.16 indicates the percentages of villages in each of the region where chemical or bacteriological test results exceeded the WHO maximum permissable levels for drinking-water supplies. While there is no maximum standard for EC, a higher than 1500 ppm was considered to be unacceptable.

The principal water quality problems highlighted by Table B.16 are as follows:

(a) Salinity: EC values above 1500 μS were found in the drinking-water supplies of Wadi Mansur, As Sawadiyah, Rada Basin and Al Bayda West. Furthermore in Wadi Matar, high salinity in the groundwater forces many people to purchase their drinking-water from sources outside the region.

(b) Hardness and calcium content: while high hardness of water is not always perceived as a health hazard, (although medical personnel in Rada attributed kidney stones to this) it is a characteristic which may be disliked by some people. Moreover, the lifetime of pipelines can be reduced due to encrustation of calcium compounds in the pipeline, thus reducing the internal diameter.

Table B.16 - Water quality characteristics

Region	pH	EC	% villages exceeding maximum permissible level Total hardness %	Ca++	Mg++	Cl-	F-	Mn++	Fe+/+++	SO_4^{--}	NO_3^-	Bacteriological
1 Rada Basin	0	7	7	0	0	0	33	0	0	0	7	90
2 Sabah/Ar Riashiyah	0	0	0	0	0	0	18	0	0	0	0	33
3 Al Bayda North-East, including Al Bayda Town	0	5	18	4	0	0	5	0	0	0	7	50 (2 samples only)
4 Al Bayda West	0	0	-	-	-	-	-	-	-	-	-	-
5 Wadi Juban	0	0	9	0	0	0	-	0	0	0	0	100
6 Wadi Mansur/Wadi Amad	0	18	0	0	0	0	-	0	0	0	0	80
7 Wadi Matar/Wadi Ar Rin	0	-	-	-	-	-	-	-	-	-	-	100
8 Wadi Hubabah/Wadi Ar Riashiyah	0	0	-	-	-	-	-	-	-	-	-	-
9 Wadi Dhi Na'im	0	0	-	-	-	-	-	-	-	-	-	-
10 Villages along Rada-Al Bayda road, including part of As Sawadiyah	0	22	-	-	-	-	-	-	-	-	-	60
WHO Max. permissible level (mg/l)	6.5-9.2	-	500	200	150	600	1.0	0.5	1.0	400	50	Total coliform : 10/100 ml Feacal coliform: 0

Extremely hard water is found in all parts of Al Bayda Province.

(c) Fluoride: fluoride above the maximum permissible value was found especially in the Rada and Sabah regions. Further analyses should be carried out in these regions to determine the reliability of these results, since confirmation of the high fluoride content should lead to a recommendation to choose a new source.

(d) Nitrates: a few water-supplies in Rada and Al Bayda were found to have nitrate content above the WHO maximum recommended level, although in general this does not appear to be a severe problem at present.

(e) Bacteriological pollution: this is a major health hazard throughout the entire province. Few bacteriologically safe water sources were encountered, except in Sabah and even the RIRDP projects which had a completely protected source had become polluted at some stage before reaching the consumer.

B.6 Sanitation facilities in the province

B.6.1 Inventory of systems

The baladiyah system is used as toilet facility (described in Section B.6.2) in 89 % of the villages. In nearly all these villages liquid excreta as well as the kitchen wastewater flow openly into streets and alleys. Only 20 % of the villages have drainage ditches or septic tanks, into which in most cases only the liquid excreta and kitchen wastewater flow (see Tables B.17 and B.18). Over 90 % of the people considered their existing sanitation systems unhealthy.

Table B.17 - Excreta, household and wastewater systems

System	Wastewater %	Liquid excreta %	Solid excreta %
Baladiyah	0	0	89
Throw to ground/street	80	78	1
Drain to ground/street	16	17	0
Pit latrine	0	1	2
Pour flush latrine	0	0	3
Flush toilet-septic tank	3	3	3
Flush toilet-sewerage system	1	0	1
Other	0	1	1

Table B.18 - Household garbage disposal systems

System	%
Throw to ground/street	97
Throw to garbage dump	1
Burn	2
Bury	0
Leave for animals	0

In a very few villages people have constructed some kind of sewerage system with 6 inch PVC pipes (e.g. Madhwagayn in Region 3: Al Bayda North-East), leading to an oxidation pond, but again only for liquid excreta and kitchen wastewater.

Al Bayda Town is the only place in the province that has a complete sewerage system, flowing out into (too small) oxidation ponds; it is also the only place with a privately organized garbage disposal system. In all other villages any kind of centralized system is lacking (see also Section B.3.3).

The Dutch consultancy firm DHV has carried out a survey and recently provided a report dealing with the water-supply and sanitation problems in Rada town.

B.6.2 Description of systems

B.6.2.1 Excreta and wastewater disposal

The baladiyah system can best be described by means of Figure B.2.

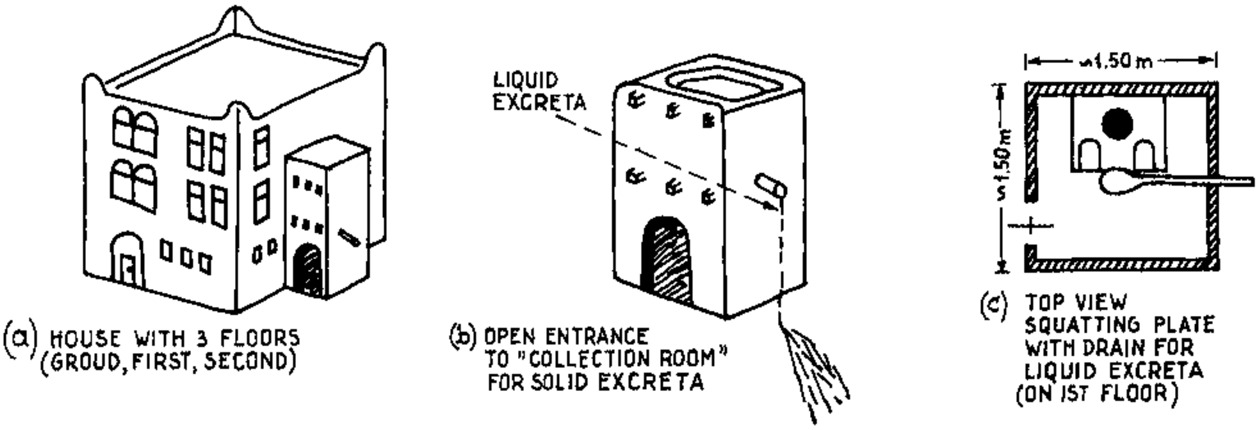
The actual toilet is on the first floor. Here one finds a squatting place as depicted in Fig. B.2. In this picture it can be seen that there is an uncovered hole in the floor through which solid excreta fall into the room below, on the ground floor; there are slightly raised foot supports; a small drain is cut out in the floor capturing the liquid excreta, which flow out of the building through a drain-pipe.

On the ground floor there is a room where the solid excreta pile up as well as the ashes from the kitchen ovens which are also thrown in. Here the excreta are supposed to compost, and they are taken out once per 6 months, once a year, or even after a longer period of time, depending on the size of the room and family. Then they are used in the fields as fertilizer.

In villages with drainage ditches or septic tanks, these are all covered and could therefore not be inspected by the survey team. It is certain, however, that none of these structures have been designed by professionals and most of them serve only 1 to 3 houses. The septic tanks are all fairly new and none of them has ever been cleaned; in fact the people do not even know how to clean these structures.

The rare sewerage systems are not properly designed either, although one system did have manholes. These systems are also quite new and clogging problems have not occurred yet.

Figure B.2 - Baladiyah system



B.6.2.2 Mosque "hammams"

The hammam, a washing facility found at most of the mosques, traditionnally consists of a square basin some 4 m long and wide and about 0.40 m to 0.80 m deep. Nowadays they are constructed in concrete. Often they are supplied from a source different from the drinking-water source by a separate rising main. Sometimes there is a (concrete) reservoir to which some 10 valves are connected. The wastewater is then led out of the mosque area through a gutter.

B.6.3 Operation and maintenance

There is no central responsible man or organization at the village level as far as sanitation is concerned, let alone at higher levels. All individual households are responsible for their own baladiyah, drainage ditch or septic tank. Usually Yemeni people never touch human stools, only the lowest class is involved with the cleaning of the baladiyah rooms. Apparently this system works rather well since the survey team never encountered a full baladiyah room except for a single public toilet in Juban. The survey team was not able to meet the persons responsible for the rare sewerage systems.

Usually there are persons responsible for mosque hammams, but they are ill-informed about the relationship between cleaning water and public health, and accordingly do not realise what a real health hazard a polluted basin means.

B.7 Possible development of new improved water-supply and sanitation systems

B.7.1 Water-supply systems

A programme of construction of water-supply systems is already well developed in Rada District through the RIRDP and it is not the intention of this report to recommend any significant changes to either the emphasis or the method of implementation of this programme. The approach is different to some other rural water-supply programmes in the country in that it provides complete, contractor-built water schemes as opposed to providing technical assistance to a community-built scheme. While this tends to result in more expensive projects, the experience of RIRDP has been that this approach is in general favoured by the people in Rada District.

Rather than change the approach then, this report will discuss the feedback received as a result of the survey in the villages with RIRDP water projects and recommend any modifications which now appear appropriate and which could be incorporated within the scope of the RIRDP water programme.

For practical use by the RIRDP, a set of tables has been prepared indicating for each of the villages surveyed the population, present and estimated future water consumption, present state of water-supply system and the availability and quality of water. The tables also indicate possible remedies and further investigations required. These tables are presented in Appendix B.IV at the end of this Annex.

B.7.1.1 Social aspects

The most important social implications on the development of new, improved water-supply systems are:

- social constraints on types of systems to be adopted;
- hygienic use of water in the household;
- community participation in planning, construction and operation of water systems.

Social constraints

While the activity of fetching water in Yemen is the responsibility of the women, it is usually the men who will decide whether or not to contribute to a water-supply system. Nevertheless an overwhelming majority of respondents in the survey (men and women) expressed a desire for a complete water-supply system indicating that the men also feel the need, and their lack of participation in water fetching is not a constraint to their desire for piped water in the house. For women, although water fetching can be a social activity, an opportunity to meet other women, this did not overcome their wish to have a private water-supply. It may be, however, that the women would still like public laundry facilities so that this social aspect of water use can be maintained.

While in many societies, traditional methods of water-supply may result in resistance to more modern technologies, in Yemen the 'complete system' presently provided by RIRDP seems to meet with universal approval. In fact expectations of the people are high and simple technologies such as hand pumps would not be readily accepted and, even if low incomes would imply such technologies, it is unlikely that they would be readily adopted. There is an overall feeling amongst the people that a 'borehole' is the panacea and even cheaper surface sources or shallow wells are not favoured.

It is, therefore, clear that through their previous experience with complete systems both in Rada through RIRDP and in Al Bayda through the LDA and RWD, the policy of providing piped water to individual connections will have to be maintained in most cases. Simple technologies could be considered if they are acceptable to the villagers.

In such systems with taps in the houses, care must be taken with the structural condition of the mud houses which can be jeopardised by continuous exposure to running-water.

Hygienic water use in the household

Water use in the household is discussed in detail in RIRDP Technical Note No. 10 (Ilaco, 1983). Clearly there are a number of measures which can be taken to improve the hygienic aspect of water use and this should be undertaken through an extensive health education programme.

While women were generally found to be fairly careful with water wastage, this should be monitored and if considered to be excessive such water-saving measures as constant volume discharge taps should be used on any public supply. It is not considered that a policy of discouraging individual connections in order to save water should be adopted since this would alienate many of the people who have come to expect piped water in the house. Moreover, the water availability situation is not considered to be sufficiently critical as to justify such an action.

Community participation

In the present RIRDP project, the community are involved in the initiation of a project and contribute up to 30 % of the construction cost. Construction is carried out by a contractor. The history of RIRDP water projects suggests that the people prefer this arrangement and discussion with the village representation always forms part of the design process. The survey did, however, unearth certain criticisms of either the design or operation of some of the RIRDP schemes which might have been resolved through more adequate discussion between RIRDP and the village representatives concerned. It is therefore recommended that a 'complaint desk' be initiated at RIRDP such that villagers are able to discuss any shortcomings they may feel exist with their scheme and any action (if necessary) can be taken to satisfy the consumers.

B.7.1.2 Economic aspects

Table B.19 gives the costs of complete water-supply systems constructed by RIRDP in a number villages during the period 1977 to 1983. The total costs depend on the design capacity of the system and on the location as this affects the costs of boreholes and piping. Nufan, for example, is located high up in the mountains and consequently has a very deep water-level, which explains the high cost of the borehole.

Although the investment costs vary to some degree with the capacity installed, there is a large overhead component. This is reflected in the cost per household or per capita; in larger villages such as Draybah or Al Khabar the cost per capita is some 3 to 4 times less than in the smaller villages.

The decision whether or not to install a water-supply system depends on the one hand on the villagers' willingness to pay for the investment costs and operating expenses and, on the other hand, on their ability to pay. Both aspects were covered in the water-supply and sanitation survey. However, except perhaps for the women's survey, the data on incomes proved to be unreliable, whereas respondents' opinions as to a reasonable level of payment (willingness to pay) varied too widely to obtain a consistent picture (see also Sections B.3.5 and B.5.3.2). No economic price can be established and it is therefore impossible to determine with respect to village size a cut-off point below which a water-supply system would not be feasible in economic terms.

In order to provide a greater coverage with the same funds and manpower it will be necessary to either construct lower cost schemes or to introduce simple measures to cover the most basic needs such as a clean water source. Low cost schemes are not always possible for the reasons outlined under 'social aspects', but a programme of simple measures to improve water quality carried out concurrently with the water-supply programme would at least assist the smaller villages for which construction of a complete system is at present not feasible. The details of such a programme will be discussed below under engineering aspects.

B.7.1.3 Engineering aspects

Source: Improvement of water quality at the source can provide a measure which will enable rapid improvement to the water-supply of a number of villages. The following measures can be considered:

Table B.19 - RIRDP water-supply project costs

Village	Year of construction	Design population		Design demand (m^3/day)	Borehole	Pump + engine	Pumphouse	Reservoir	Piping	Total cost of RIRDP project	Total adjusted cost of scheme*	Adjusted cost (YR)	
		People	Households									Per capita	Per household
Draybah	1980	1 200	250	96	158 390	64 358	35 840	112 141	169 281	540 010	540 010	450	2 160
Al Khabar	1982	1 150	235	69	120 000**	93 231	25 390	98 327	102 335	312 783	432 783	376	1 842
Al Khadrah	1977	672	120	54	41 435	55 000**	30 000	128 035	40 000**	207 620	302 620	450	2 522
Al Ajma	1980	450	100	36	185 890	53 400	32 000	113 317	41 386	436 685	436 685	970	4 367
Qarn Attah	1981	420	90	25	49 747	40 000**	10 529	102 823	40 000**	194 940	243 099	579	2 701
Al Khilaw	1983	325	65	20	70 000	35 242	28 000	45 000	66 228	244 470	244 470	752	3 761
Al Wajar	1983	250	45	15	150 000	80 885	29 138	75 000	49 091	384 114	384 114	1 536	8 536
Nufan	1983	240	45	15	214 050	90 569	21 000	57 500	42 558	425 797	425 797	1 774	9 462
Aischama	1982	140	30	10	20 000**	35 000**	20 000**	35 000**	60 000**	171 570	171 570	1 225	5 719
Qawl Addhra	1981	365	70	22	120 000**	50 095	30 284	133 337	35 578	249 294	369 294	1 011	5 276

* Includes contribution by villages.
** Estimated.

- lining of shallow wells;
- covering of shallow wells;
- provision of drainage facilities at shallow wells;
- source protection of springs;
- simple treatment of spring source;
- protection of cistern from pollution and simple treatment;
- chlorination of polluted supplies.

The lining, covering and provision of drainage facilities for shallow wells are simple measures which could be carried out by the villagers on the basis of a standard design produced by RIRDP and with the provision of materials by the project. Spring source protection requires an individual design and would need input from the project in the construction. It need not however be undertaken by a contractor.

With regard to treatment, the water quality survey revealed the following aspects requiring attention:

(i) bacteriological pollution;
(ii) high hardness;
(iii) high fluorides;
(iv) high nitrates;
(v) high salinity.

At present the most serious of these is the bacteriological pollution. This can be contributed to a number of reasons, namely pollution of the groundwater itself by wastewater infiltration, pollution at source by inadequate source protection, pollution within the distribution system and reservoirs, or pollution in the household.

In general for bacteriological pollution of groundwater sources adequate source protection, wastewater disposal facilities and suitable personal hygiene should eradicate the problem, and therefore the necessity of disinfection measures is marginal. Moreover disinfection requires careful operation to ensure correct dosage of the disinfectant, as well as a reliable supply of the raw material. Nevertheless if a village has a persistant bacteriological problem in the water-supply, which cannot be removed by the measures described above, simple chlorination should be provided. There are a number of simple chlorination devices that can be designed if the supply of solid chlorine is assured. Gas chloration should not be considered for village supply.

Areas of high salinity (i.e. greater than 1500 µS) were measured in Wadi Mansur and Wadi Matar where shallow wells are utilized for water-supply. People recognize the unacceptable quality of this water and will not use it. In such areas it may be necessary to replace the shallow wells with boreholes as the deeper aquifer should have a lower salinity.

High fluorides (greater than 1.0 ppm) were encountered in Rada and Sabah. While this level can probably be tolerated it is approaching the range which can be dangerous to health. It is not feasible to treat such a source to reduce fluorides, and in these cases new sources should be investigated.

High nitrates were encountered in Rada and Al Bayda. For such areas care should be taken with wastewater disposal and fertilizer use. The water quality should be monitored and if nitrate values over 50 mg/l persist a new source should be investigated and protected very carefully from possible wastewater pollution.

Pumping facilities

The energy source for all pumping facilities investigated was diesel power. It is not considered appropriate at present to attempt to utilize any alternative energy source such as solar or wind power. Solar pumps are not yet competitive and are still in any case easily damaged and therefore not suitable for remote Yemeni villages. Wind power is not really suitable for any but very small villages where only a small storage is required to overcome periods with insufficient wind. Moreover people are used to working with diesel machinery and at present the fuel cost does not appear to be an undue burden.

With the existing diesel pumps and engines, repairs do not generally take excessive time, except in the case of an unusual make for which spare parts are difficult to obtain. Standardization of machinery should be attempted although it is recognized that this is difficult in a competitive market. Attention should in any case be paid to the availability of spares before a particular make is purchased. Most engines are presently too powerful for the pump and do not appear to be purchased with the duty requirements in mind. This involves unnecessary fuel costs and here advice could be given to villages either through RIRDP or RWD on the correct engine size.

Distribution systems

In setting up a village water-supply distribution system the following aspects should be taken into account:

- reduction of leakage;
- avoidance of a labyrinth of pipeline structures;
- prevention of pollution in pipelines by stagnant wastewater;
- prevention of damage to above-ground pipelines from vehicles;
- provision of sufficient valves to allow isolation of sections of the system;
- provision of a plan of the village distribution system, pipe signs, location of valves etc.

The above improvements are all generally necessary in most villages with a water-supply system, but do not take precedence over the provision of a clean supply and thus source development and improvement. Advice on the above matters could be given to villagers for their own implementation, but it is not recommended that a programme for the improvement of distribution systems be adopted until after the implementation of a programme to improve water quality. Pollution in pipelines from stagnant wastewater is an important health issue but it is unlikely that the continuous supply necessary to prevent this occurring will be adopted in most villages, and so the problem is best solved by the provision of adequate wastewater disposal facilities.

B.7.1.4 Organization and management

That the present situation with regard to the organization and management of rural water-supplies is far from ideal is clear from Section B.5. Not only is there a lack of co-ordination in the initiation and implementation of projects, but no one authority is responsible for operation and maintenance which is consequently left in the hands of the individual village operators.

For the initiation and implementation of water-supply schemes, it is considered that only one authority should be responsible for each of these activities.

The Co-ordinating Council, presided over by the Provincial Government, and of whom the Local Development Association (LDA) chairmen are all members, is the most appropriate body to co-ordinate the planning of water-supply schemes in the province. The LDAs are well informed about activities in their region and often requests for village water-supplies are channelled through the LDA to the CYDA (Confederation of Yemen Development Associations) and then to the RWD (Rural Water Department). It is recommended that all future requests for village water-supplies be received by the Co-ordinating Council. The priority for implementation of village water-supply schemes will then be decided upon through discussions between the Co-ordinating Council and the implementing authority.

The RIRDP is a well regarded organization in the Rada District, has its project base there, and has considerable local experience in the construction of rural water-supply schemes. The Ministry of Public Works (RWD) is the national authority responsible for rural water-supply and therefore develops design, construction and operational standards throughout the country. Consideration should be given to the possibility of reinforcing the staff of the RIRDP with suitable manpower from the Ministry of Public Works, including the necessary budget, and making the RIRDP the sole organization responsible for the design and implementation of water-supply projects in the province. Similarly operation and maintenance responsibilities should be under the RIRDP, but assisted by staff from the Ministry of Public Works. Some control can then be exerted over village operators who can also seek advice from RIRDP when necessary. Regular training courses should be available for village operators. It is considered, however, that the responsibility for the collection of money for operation and maintenance and operators' salaries be left with the village, as this system appears to work satisfactorily.

A suggested organization chart is given in the main report.

B.7.2 Sanitation

The primary benefits of provision of a water-supply system are an expected health benefit and a reduction in the arduous and time-consuming work of fetching water. In fact provision of a clean, potable water-supply should realize some reduction in disease, but paradoxically an increase in certain diseases may be experienced due to the increasing quantities of wastewater, resulting from a higher water consumption. Moreover indiscriminate disposal of wastewater may pollute the groundwater and even, under certain conditions, piped supplies.

In order to realize substantial health benefits, three aspects must be considered in conjunction. These are water-supply, sanitation and personal hygiene. Table B.20 indicates the effect on control of excreted infections of each of these three aspects.

Table B.20 - Effect of water-supply, sanitation, and personal hygiene on control of excreted infections

Category	Infection	Water-supply alone	Sanitation alone	Personal hygiene alone
1	Enterobiasis, Enteroviral infections, Ameobiasis etc.	Moderate	Negligible	Great
2	Typhoid, Cholera, Shigellosis	Moderate	Slight/moderate	Moderate
3	Ascariasis, Trichuriases, Hookworm	Negligible	Great	Negligible
4	Taeniasis	Negligible	Great	Negligible
5	Schistosamiasis, etc.		Moderate	Negligible
6	Filariasis and other diseases where flies and cockroads are vectors	Negligible	Slight/moderate	Negligible

It can be seen from Section B.4 that a number of these categories of infections are highly prevalent in Al Bayda Province. The main difference between Categories 1 and 2 and other categories is the strong dependence upon personal and domestic hygiene, and thus these infections are much more likely to be controlled if water availability is improved concurrently with sanitation and if an effective and sustained programme of hygiene education is organized. For other categories an improvement in sanitation on water-supply alone may be sufficient, but will not control the wide range of infections.

It has been stated in the past that Yemeni villages do not have a sanitation problem as their location on the tops of mountains provides for easy and safe disposal of wastewater. While this may to some extent be true for the smaller villages, the prevalence of excreta-related diseases in the province and the overwhelming desire of the people as expressed in the survey for an improved sanitation system would seem to belie this belief. Moreover during the progress of the survey many villages with a serious wastewater problem were visited.

From Section B.6 it can be seen that very few rural villages have any form of wastewater or garbage disposal facilities and that for excreta disposal use is largely made of individual baladiyah installations. Consequently there is very little precedent in Al Bayda, or for that matter in Yemen, for a sanitation programme. In order to develop systems which are acceptable to the public, it is necessary to investigate the social and economic aspects which may affect the choice of the system.

B.7.2.1 Social aspects

The social aspects which influence the choice of sanitation technology to be adopted can be summarized as follows:

- existing defecation practices;
- differences between tribes or sexes;
- cleansing and ablution materials;
- important taboos due to custom and religions;
- latrine emptying and sludge re-use practices;
- opinions on public toilets;
- attitudes to different possible systems.

The systems recommended in this section are based upon these considerations,

B.7.2.2 Economic aspects

The survey results indicate that the majority of people claimed a willingness to pay for an improved sanitation system as well as a desire for it. The estimated present incomes suggest an ability for most people to pay for any of the possible options, although their willingness to pay for such an expensive option as sewerage is questionable.

The selection of a sanitation technology on economic grounds is not very satisfactory due to the numerous social criteria involved and the difficulty in enumerating the non-economic benefits. It is perhaps best to consider the possible technologies in terms of their mean annual cost and then to discuss them in terms of the most promising options selected for social and environmental reasons.

While costs will obviously vary according to the location, site condition, material costs etc. Kalbermatter et al, (1980) do give a guide to the relative costs of various possible technologies. These costs are shown in Table B.21. The most expensive option, sewerage, has been set as base of 100 and the other technologies are expressed as a percentage of the mean annual cost of sewerage.

Table B.21 - Relative annual costs of different sanitation systems (%)

Technology	Mean cost*	Investment cost	Recurrent cost
Pour flush toilets	4.7	3.3	1.4
Pit latrine	7.1	7.0	0.1
Vacuum-truck cartage	9.4	4.5	4.9
Composting toilet	13.7	12.7	1.0
Bucket cartage	16.2	9.2	7.0
Aquaprivy	42.0	40.4	1.6
Septic tank	92.2	56.8	35.4
Sewerage	100	67.4	32.6

* Mean annual cost of sewerage as base of 100.
Source: Kalbermatten et al., 1980.

B.7.2.3 Engineering aspects

(a) Choice of technology for household latrine

The primary reason for the provision of sanitation facilities is to improve community health through the reduction of pathogens responsible for disease transmission. This requires the selection of an appropriate system with the criteria of pathogen rather than BOD reduction, the latter being the criterion often adopted for effluent disposal in watercourses. Another criterion is that, where possible, systems which require large quantities of water should be avoided due to the scarcity of water resources in the province and the consequent production of additional wastewater requiring treatment. Sewerage is, therefore, an inappropriate and expensive technology, at least for the medium/small rural villages.

Of the technologies listed in Table B.21 in the lower cost category, only pour flush toilets and composting toilets appear appropriate for rural Yemen villages. The use of water for anal cleansing rules out pit latrines while communal toilets cannot be considered for social reasons. Bucket and vacuum truck cartage require a degree of organization and maintenance which is unlikely to be achieved at the present stage. Moreover, the recurrent costs of both the pour flush and the composting toilets is low, indicating minimal operation and maintenance requirements. The more expensive aquaprivies have no real advantage over the pour flush latrine unless solid anal cleansing materials are used which may block the water seal. This is not the case in Yemen so aquaprivies need not be considered.

The high-cost septic tanks and sewerage systems are only really applicable where a large amount of water is used as in flush toilets, and where possible these systems should be avoided.

The recommended technology for rural village household sanitation is therefore either a composting toilet or a pour flush latrine. Due to the tendency of the Yemeni's to separate solid and liquid excreta and their practice of using composted solid excreta as fertilizer, a dry composting toilet is considered to be the most appropriate waste disposal system. Moreover, the baladiyah system described in Section B.6 is currently used in 89 % of the households and, with certain modifications, can easily be converted into safe, healthy composting toilets.

The composting toilet cannot be used to dispose of liquid excreta and wastewater and, therefore, a separate system is required for this. Where sufficient space is available and ground conditions permit, individual soakaways can be constructed. Otherwise liquid excreta and wastewater from groups of houses can be transported by open channels or pipelines to common soakaways, or, where soakaways are not feasible due to ground conditions, to stabilization ponds.

While it is considered that flush toilets should not be encouraged, they will undoubtedly be installed by some households and indeed have already been. It is a matter of personal preference and where sufficient water is available and can be afforded, undoubtedly a number of different types of systems will be installed in a village. However, the installation of flush toilets should not be financed. With a flush toilet fixture, the composting toilet is no longer applicable and either a septic tank or sewerage system must be adopted. A village with a minority of houses with flush toilets will require individual septic tanks and soakaways for those houses, and a large village with many houses with flush toilets will require a sewerage system and stabilization ponds. These should not be considered initially. A project should therefore be initiated which will promote the installation of composting toilets in the households of rural villagers.

The installation of composting toilets is the most justifiable of the possible sanitation technologies, all of which in conjunction with water-supply and health education can be expected to improve community health. The following advantages can be identified:

- it is appropriate to the prevailing, traditional practices;
- no water is used;
- there is no need for expensive sewerage systems and no effluent problem;
- easy operation and maintenance, and little institutional infrastructure required;
- local materials and labour can be used;
- 90-95 % of pathogens are destroyed after one year of aging;
- production of fertilizer which has an economic value;
- precedence in Yemen of human excreta as fertilizer;
- the poorest families will benefit from the project.

(b) Proposed details of composting toilet

Details of the existing baladiyah toilets are shown in Fig. B.2. In order to convert this into a safe composting toilet certain modifications are required:

(i) Two separate vaults should be provided to allow for complete composting inside the vaults before removal. This is favoured above the continuous composting type toilet, the efficiency of which has been found to be extremely sensitive to the degree of user care.
(ii) The vaults should be sealed from the open and provided with an access hatch to remove compost.
(iii) A screened vent pipe should be provided to allow the decomposition gases and odours to escape.
(iv) A cover should be placed on the squatting hole to seal the vault from the house and to prevent flies from breeding in the vault.
(v) The access hatches should be of a transparent material so that sunlight and temperature effects can improve the rate of digestion.
(vi) The drain for liquid excreta near the squatting hole should be located in such a way as to allow for the collection of urine from women.
(vii) Two separate squatting holes will be required.
(viii) The pit should be designed for one year composting.
(ix) Depending upon the groundwater level, a permeable base can be provided in the vault which will allow for infiltration and percolation of urine and wastewater.

These recommended modification are illustrated in Fig. B.3.

Where ground conditions permit, liquid excreta and wastewater should be piped to on-site soakaways for individual houses or to a soakaway serving a group of houses. The soakaway design will depend upon soil percolation tests carried out in each village.

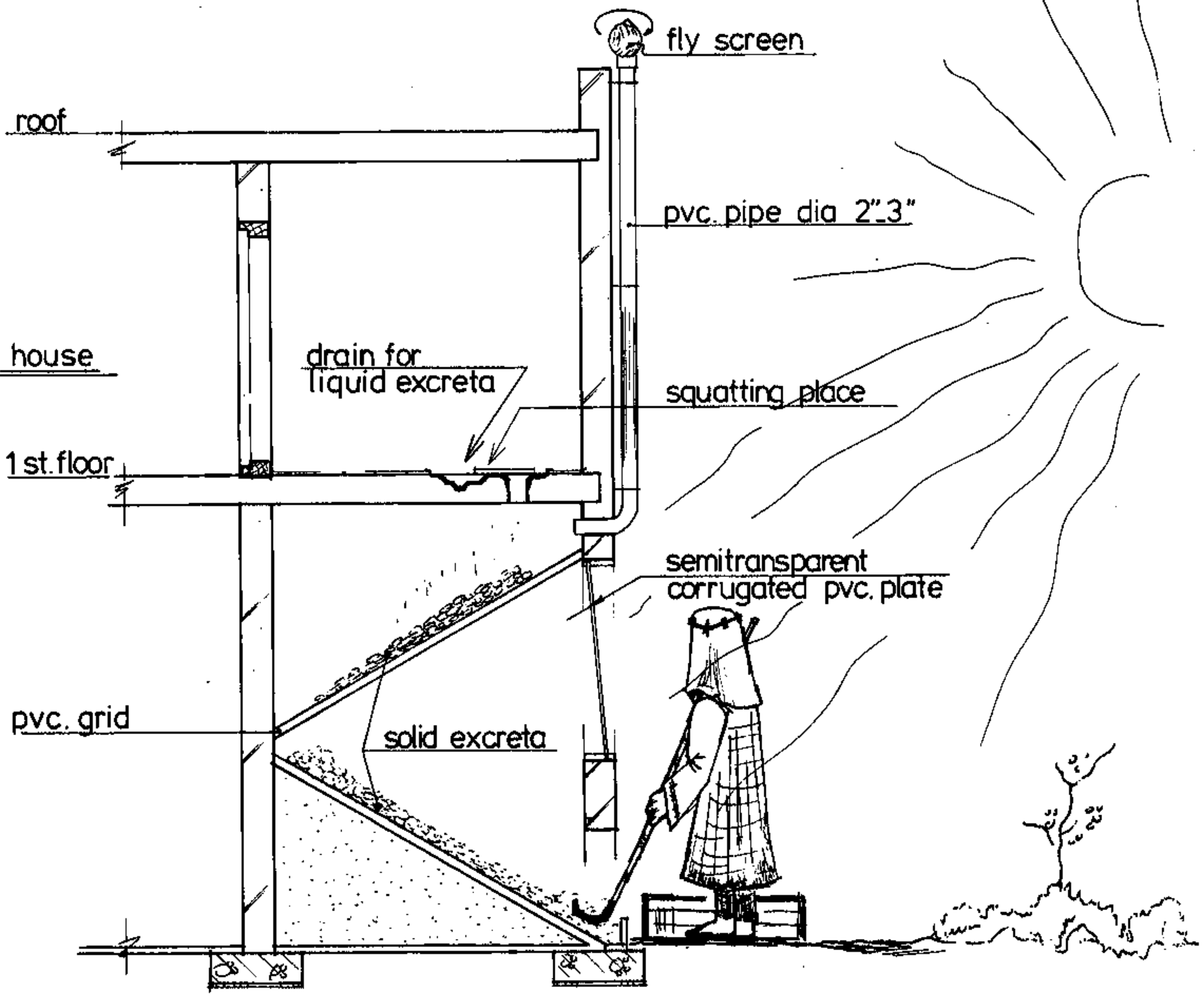
(c) Communal sanitary facilities

Communal sanitary facilities were observed in Juban and appeared to be in use, although no maintenance had been carried out for some time. In discussions with the Ministry of Municipalities it was suggested that communal facilities be avoided, primarily because men find it distasteful to see women using them. While there may be a need for communal facilities for women, since unlike men they cannot use the mosque facilities, the basic traditional fact that women are not to be seen in public places would probably render communal facilities useless for this group of the population, which most needs them.

(d) Mosques

As discussed in Section B.6 the sanitary situation in mosques deserves particular attention. The ritual washing before prayer is at present often undertaken in basins of heavily polluted water. Since the

ADJUSTED MULTRUM COMPOSTING TOILET



CROSS-SECTION

TOP VIEW

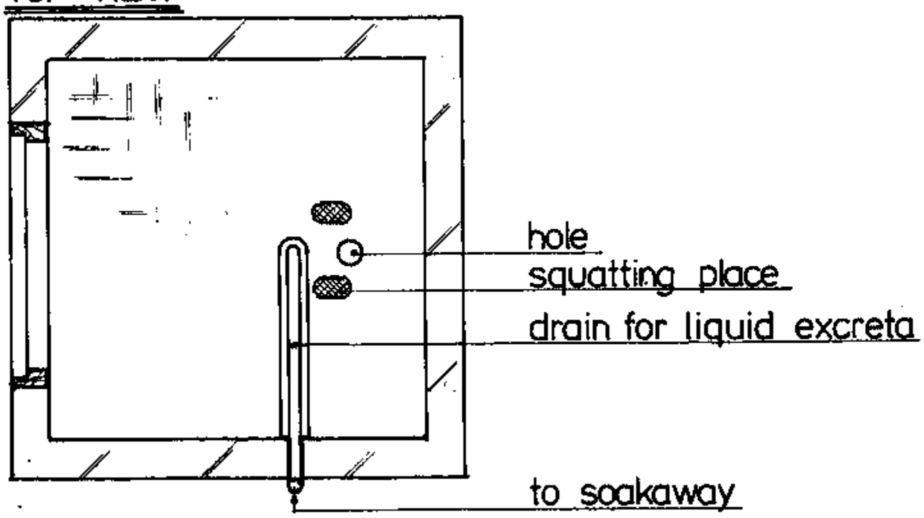
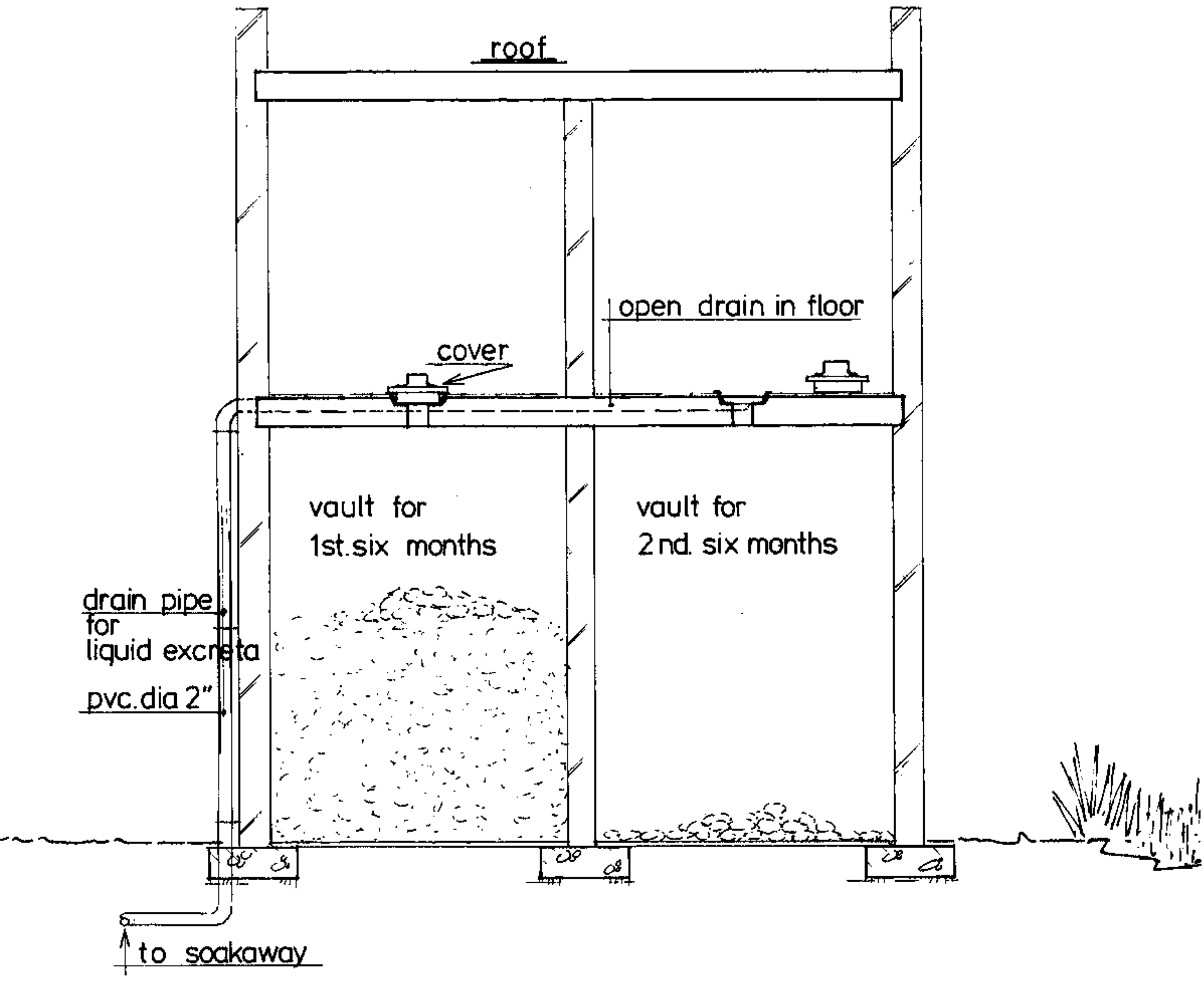


Fig. 3a

ADJUSTED MULTRUM COMPOSTING TOILET

2 VAULT



CROSS - SECTION

Fig. 3b

majority of the male population uses these basins, any disease originating from them may be transmitted to a large part of the population. The improvement of conditions in the mosque, in particular the provision of taps or showers and excreta facilities should therefore be given a high priority. It is difficult to envisage a reliable method of continuously circulating water in the basin which, if possible, should be abandoned. Dry solid excreta facilities should be provided and shower water and urine could be piped to soakaways.

(e) Re-use of effluent

The benefits of a sanitation system are not always immediately obvious to either the population or governments. If some visual or economic benefit could be demonstrated, this would be of assistance in the development of a sanitation programme. Hopefully a visual indication of the benefit will be the improved health conditions in the community. Likewise if the effluent can be shown to have economic value then the people will see its benefit.

The digested excreta from the composting toilet will provide useful crop fertilizer as described above, provided that basic rules are adhered to in the composting of waste. Re-use of liquid effluent will require some modifications to the systems proposed above:

- some elements of the wastewater (shower, laundry) can be diverted on a household basis or from mosques for irrigating crops;
- effluent from septic tanks or stabilization ponds can be used to grow certain crops on an evapotranspiration bed;
- effluent from a stabilization ponds can be used for direct application to certain crops.

The types of crops which can be grown depend on the particular situation with regard to the treatment process adopted and the standard of effluent achieved; general recommendations should not be given.

(f) Groundwater pollution

At present there are few villages which have constructed excreta and wastewater disposal facilities, so evidence of groundwater pollution from these sources is scarce. However, it is a potential problem for shallow aquifers and, especially if soakaways, stabilization ponds or agricultural re-use are envisaged, care must be taken with the location of these treatment facilities. Once an aquifer is polluted, it is very difficult to restore its purity.

The following conditions may lead to groundwater pollution:

- if only a thin cover (less than 3 m) of unconsolidated strata overlies a fissured non-porous bedrock aquifer;
- if the groundwater table is seasonally or perennially shallow (less than 3 m depth);
- under a high hydraulic loading of wastewater (e.g. greater than 30 mm/day).

With regard to fecal pollution, the unsaturated zone is far more active in eliminating excreted pathogens than the saturated zone. In dry conditions with hydraulic loadings less than 30 mm/day, 3 m of unsaturated zone is sufficient to allow a gross reduction of fecal pathogens. If any of the above three conditions exist, according to current practice, water-supply boreholes should be at least 15 m from the soakaway or latrine. This recommended distance, however, is still subject to review and a recent paper (Foster, 1983) suggests a considerably greater distance.

The buildup of nitrates in groundwater represents a less immediate hazard than pathogens but higher concentrations have been found to be a health hazard, especially for children. Some areas of high nitrates were found during the water quality survey, although these cannot at present be realistically related to groundwater pollution from excreta disposal. On-site excreta disposal units can result in high concentrations of nitrates in the groundwater, especially under conditions of low regional groundwater flow. This effect, however, will be reduced by the use of the composting toilets and the dilution in soakaways of the liquid excreta by wastewater. Stabilized wastewater effluent, when used for irrigation, can also result in an increase in nitrates in the groundwater through leaching of the non-plant nutrients.

The following measures are recommended to reduce pollution due to pathogens and nitrates caused by sanitation facilities:

- ensured emptying of latrines when contents are stabilized;
- reduction of hydraulic loading as much as possible;
- minimum distance between groundwater supply borehole and soakaways of at least 15 m, but prefarably considerably greater;
- where necessary extension of the depth of lining of boreholes to a considerable depth below the pumping level, thus ensuring longer groundwater flow paths;
- control of the location of stabilization ponds with respect to hydrogeological conditions and groundwater supply installations;
- possible lining of lagoon base to reduce seepage;
- control of irrigation schedule to maximize soil denitrification.

(h) Resource recovery

Possible methods of resource recovery from excreta effluent and wastewater encompass:

(a) agricultural re-use;
(b) aquacultural re-use;
(c) biogas production.

Agricultural re-use has been discussed above and is already practised in terms of the use of digested solid excreta as fertilizer. It is proposed to extend this practice to include the use of wastewater for household irrigation, stabilized effluent for larger-scale irrigation purposes, and possibly for the adoption of evapotranspiration beds. For the composted excreta it is suggested that a minimum of 12 months composting is required. With regard to irrigation with effluent from stabilization ponds on evapotranspiration beds it is possible that without tertiary treatment some pathogens may survive although provided the retention of at least 30 days is maintained, the risk is low. Kalbermatten et al. (1980) suggest standards of < 100 fecal coliform bacteria per 100 ml, and if effluent is used for irrigation regular monitoring of effluent standards should be maintained.

Biogas is used extensively in the Far East and to some extent in India. In principle it should have some potential in Yemen, particularly in the larger villages where there is a tradition of re-use of human and animal wastes. However, there is no background in Yemen in biogas technology and it is felt that in the present stage basic sanitation facilities should be developed rather than complicating the situation with more risky ventures. Moreover, the Yemeni villages do not appear to have a serious energy problem at present which of course is the major justification for a biogas project.

Biogas projects could only really be considered suitable for centralized facilities such as schools, industries etc., but there is no evidence yet of a demand for the gas generated or any desire by either the authorities or the population for such a project.

(i) Garbage disposal

The problems of garbage disposal in Yemeni towns and villages has been documented by Ilaco Technical Note No. 10 (1983) and DHV (1983). The report of the latter, which was concerned with Rada and environs recommended a number of short-term improvements including a health education programme on the hygienic aspects of proper waste handling and the risks to public health. The issue of health education is probably the key to the garbage disposal problem as without a proper understanding of the implications for public health of the present situation it is unlikely that the villagers will be motivated to support a collection and disposal system. The survey indicated a strong support for garbage collection facilities, but to date few villages have shown much inclination to initiate any measures.

It is not considered appropriate at this stage to consider garbage collection services organized by either the LDA or the municipalities: there is no existing infrastructural base from which to initiate such a programme. Rather the health education programme should be commenced and than hopefully initiatives will develop on a village basis for collection and disposal services. Advice, and possibly funds, for such services should be made available from the project.

APPENDICES

Ann. B

APPENDIX B.I
OPERATORS QUESTIONNAIRE
AL BAYDA WATER RESOURCES STUDY
QUESTIONNAIRE ON EXISTING WATER-SUPPLY AND SANITATION FACILITIES

Village	....	Nahiyat	....
No. of houses	....	Estimated Population	....
Well No.	....		
Co-ordinates x	.... km	y	.... km
Elevation	.... m		
Aerial Photo No.	....		
Date	....		
School(s)	....	No. of pupils	....
Health facilities	....		
No. of patients	....		

Water Source

1.

Source *)	Dry Season	Wet Season	Elevation				Domestic	Domestic + Agric.	Owner-ship
			m (read)	°C	time	m adjusted			
Borehole									
Shallow Well									
Spring									
Cistern									
Pool									
Stream									
Other (specify)									

*) All sources to be indicated

If there is no distribution system,otherwise step to Q4)

2. (a) Distance of source from village .... km
   (b) How long does a round trip to fetch water take .... hrs
   (c) How many times per day is water fetched .... times/day

3. (a) Is there sometimes a water shortage .... yes/no
   (b) If yes, when and for what duration ? ....
   (c) From where does village get water during shortage ? ....

4. (a) Source - borehole or well

Static Level	.... m		
Dynamic Level	.... m		
Depth	.... m		
Depth where water struck	.... m	.... m	.... m
Yield capacity	.... 1/sec.		.... m^3/hr
Depth in soft material	.... m	Hard Material .... m	

   (b) Source - cistern or spring

Capacity/Discharge .... m^3

.... 1/sec.

5. How long does it take to fill the storage reservoir .... hrs

6. Quantity of water pumped

Dry Season	.... hrs/day	.... days/week
Wet Season	.... hrs/day	.... days/week

7. Well lining material — unlined/stones/concrete

8. (a) Is well covered — yes/no
   (b) Type of covering — concrete/steel/other (specify)

9. How often is well cleaned — .... per ....

10. Is water quality satisfactory (Opinion of operator) — ....

11. Take sample (min. 3 litres)
    EC .... S

Pumping facilities

12. (a) Make of pump — ....
    (b) Make of engine — ....

13. Pump duty : capacity — .... m^3/hr
    head — .... m
    HP — .... HP
    Depth of pump setting — .... m

14. Age of pump and engine — Pump .... years
    Engine .... years

15. (a) Fuel type — Diesel/other (specify) ....
    (b) Fuel consumption — ....

16. (a) Does pump deliver water to reservoir without problems — yes/no
    (b) If no, state problems — ....

Pumping Main

17. Length .... m
18. Material .... G.S./PVC
19. Diameter .... ins.
20. Capacity .... m^3/hr (Assume 1 m/sec in pipe)
21. Condition ....
22. Are there any tees in pumping main (indicating multipurpose use) yes/no

Storage Reservoirs

23. No. of reservoirs ....
24. Ground Elevation .... m
25. Height .... m
26. Capacity .... m^3 (Dimensions .... m x .... m x .... m
27. Material .... R.C./blocks/ other
28. Condition ....
29. Leakage ....
30. How often is reservoir cleaned .... per ....
31. Does reservoir have overflow .... washout ....
    vent pipes on roof ....

Distribution System

32. Extent of system .... % of village covered
33. Pipe material G.S./PVC
34. Diameters .... ins. to .... ins.
35. Estimated capacity of system .... m^3/hr (Assume 1 m/sec. in main pipes)
36. (a) What is extent of leakage in system .... % of connections leaking
    (b) Are there particular connection types where leakage is greatest e.g. valves, tees, etc. ....

37. (a) How often is reservoir pumped full .... times/day
    (b) Estimated water consumption in village .... m^3/day
    (c) Estimated water consumption/person .... litres/day

38. Are there water meters yes/no
39. Are there public taps yes/no
    public laundries yes/no
    cattle troughs yes/no

Level of service

40. Standpipes .... % served
41. Individual connections .... % served
42. No distribution .... %
43. (a) Does each person make his own house connection yes/no
    (b) How much does this cost .... YR

Operation and Maintenance

44. Who is responsible for O & M of pumps, reservoirs and pipelines ....
45. (a) Do repairs often take a long time yes/no
    (b) If yes, why ....
46. Are fuel supplies reliable yes/no
47. Are spare parts readily available yes/no
48. Who pays for fuel, repairs, etc. ....
49. Payments for water supply Connection .... /month
    Standpipe .... /month
50. Payment made to whom ....

Sanitation

51. Waste water collection system in village ....

52. Excretion collection system in village ....

53. Garbage disposal facilities in village

54. Drainage from public standpipes, public laundries, cattle throughs

55. If hospital or health centre, any common sickness in village ....

56. To operator : Are there any suggestions you could make to improve your water sanitation system.
57. Ground conditions rocky/sandy/clayey/ other (specify)
58. Permeability high/average/low/impermeable

<u>General comments by interviewer</u>

Source

Reservoirs

Distribution System

Operation & Maintenance

Need for sewerage system, drainage system or garbage disposal system in village.

<u>Additional questions (if RIRDP project)</u>

(A) Did the village make improvements to the well/borehole after RIRDP completed the work.

(B) Did the village extend the pipework system after the RIRDP completed the work.

(c) Did the village make any other alteration to the system after the RIRDP completed the work.

APPENDIX B.II
HOUSEHOLD QUESTIONNAIRE
AL BAYDA WATER RESOURCES STUDY
QUESTIONNAIRE ON WATER SUPPLY AND WASTEWATER AND EXCRETA DISPOSAL

This questionnaire is intended to assess the opinion of people about their present water supply and sanitation facilities and to determine their future response to possible improvements in these facilities such that they can participate in the decision making process. In addition, their ability and willingness to pay for improved facilities will be determined.

Date	....	Co-ordinates x ...... km	y .... km
Village	....	Nahiyat	....
Elevation	....	Air photo ref.	....
No. of houses in village	....		
Estimated population of village		....	
Position in household of person interviewed		....	

QUESTION	ANSWER

Demographic and socio-economic

1. (a) How many people (men, women and children) are living permanently in your household ? What are their ages and relation to person interviewed. (List all persons if necessary).	See Table 1A
(b) List the members of your household who are presently living outside the country.	See Table 1B

TABLE 1A - PEOPLE LIVING IN HOUSEHOLD

	Name	Age	Relation to interviewer			Naam	Age	Relation to interviewer
1					11			
2					12			
3					13			
4					14			
5					15			
6					16			
7					17			
8					18			
9					19			
10					20			

TABLE 1B - MEMBERS OF HOUSEHOLD LIVING ABROAD

	Name	Age	Relation to interviewer
1			
2			
3			
4			
5			

QUESTION		ANSWER
2. (a) What material is your house built of ?	walls	
	roof	
(b) How old is your house ?		.... years
3. What is the occupation of the head of the household ? (Tick more than one if necessary)		( ) farmer
		( ) shopkeeper
		( ) contractor
		( ) grain grinder
		( ) firewood seller
		( ) tractor operator
		( ) militia
		( ) teacher
		( ) government official
		( ) mechanic
		( ) other (specify)
4. What is the total income of the household ?		
(a) From selling crops	Winter	.... YR per year
	Summer	.... YR per year
(b) From occupation (contractor, shop-keeper, miller, etc. etc.)		.... YR per month
(c) From remittances from abroad		.... YR per month
5. How many and which livestock do you keep ?		
(a) Milk cows		No. ....
(b) Bulls		No. ....
(c) Sheep		No. ....
(d) Goats		No. ....
(e) Camels		No. ....

QUESTION ANSWER

Existing water supplies

6 (a) From where do you obtain most of your water ? If more than one source, place in order of importance.

(b) What is the distance from house to water source ? See Table 2

(c) How long does it take for a round trip to fetch water ?

(d) For what purpose do you use this water ?

Table 2

Source	dry season	wet season	Dist.to house	Time spent to and from source	Drinking	Cooking	Bathing	Laundry	Animals
Spring									
Shallow Well									
Deep Well									
Public tap									
Tap in house									
Tap at neighbour									
Rainwater									
Stream									
Cistern									
Other(specify)									

QUESTION ANSWER

7. If you fetch water from outside house

(a) Who brings water to house ?

(b) In what container, of what capacity and how many containers per trip ? See Table 3

(c) How many trips per day are made to fetch water ?

Table 3

Family member	Container used for carrying water	No. of containers used per trip	Estimated capacity of container (state unit)	Daily trips for water

QUESTION — ANSWER

8. (a) If you have a tap in your house, please state number and location of taps. — .... taps
   ( ) kitchen
   ( ) laundry
   ( ) bathroom
   ( ) toilet

   (b) How much water do you use per day
   If metered — .... litres/day
   If not metered, how much water do you use per day for :
   a) washing — .... buckets
   b) cooking — .... buckets
   c) laundry — .... buckets
   d) drinking — .... buckets
   e) for animals — .... buckets

9. (a) Do you take animals to drink at the water source ? — yes/no
   (b) If not, how much water do you give them at your house — .... buckets
   (c) Do you give them fresh water or wastewater — fresh water/waste water

10. Do you consider the water quality good for
   (i) drinking — yes/no
   (ii) cooking — yes/no
   (iii) washing — yes/no
   (iv) animals — yes/no

   Do you boil water for drinking ? — yes/no

11. (a) Do you consider your existing water supply satisfactory — yes/no

QUESTION	ANSWER
12. Do you believe that time and effort employed in obtaining water is	( ) too much ( ) normal ( ) little
13. Do you sometimes have a shortage of water.	yes/no
If yes, what time of the year and for how long	....
14. Is water stored in house ?	yes/no
If yes,	
(a) Where in the house is it stored ?	....
(b) In what type of container ?	....
(c) Is the container covered or uncovered ?	....
(d) Is container cleaned before refilling ?	yes/no
(e) Is drinking water stored separately ?	yes/no
15. (a) Do you pay for water ?	yes/no
(b) If yes, how much and to whom ?	.... YR per year .... YR per month Pay to ....
(c) Do you think the cost of water is high, normal or low	( ) high ( ) normal ( ) low
16. (a) Would you be willing to spend more money in order to obtain a closer or cleaner source ?	yes/no
(b) If yes, little more or much more	little/much
(c) If no, why ?	....
17. What type of service would you prefer ?	Service / Cost Walk to source Standpipe in village Tap in house
18. (a) Do you have any idea of what could be done in order to help you obtain a better quality of water ?	yes/no
(b) If yes, what is your idea ?	....

QUESTION | ANSWER

<u>Wastewater and excreta disposal</u>

19. How do you dispose of wastewater ?
    - ( ) throw it on ground or street
    - ( ) drainpipe from house to street
    - ( ) throw it into drainage ditch
    - ( ) use it for animals
    - ( ) septic tank
    - ( ) sewerage system
    - ( ) other (specify)

20. Does wastewater remain close to your house ? yes/no

21. (a) Would you like to see a wastewater disposal system in your village ? yes/no

    (b) Would you be willing to pay for a wastewater disposal system ? yes/no

22. What system do you use to dispose of excreta.

    Liquid excreta

    - ( ) drain from house to ground or street
    - ( ) drain from house to drainage ditch
    - ( ) bucket-night soil collection
    - ( ) latrine (pit or pour flush)
    - ( ) septic tank with flush toilet
    - ( ) sewerage system with flush toilet
    - ( ) other (specify)

    Solid excreta

    - ( ) pit latrine (no collection)
    - ( ) pour-flush latrine
    - ( ) vault with collector
    - ( ) leave it on ground or street
    - ( ) leave it for animals
    - ( ) aqua-privy
    - ( ) septic tank with flush toilet
    - ( ) sewerage system with flush toilet
    - ( ) other (specify)

QUESTION	ANSWER
23. (a) Do you think this is the healthiest method of disposal ?	yes/no/don't know
(b) If yes, why ?	....
(c) If no, would you be willing to pay for an improved method of disposal ?	yes/no
24. How do you dispose of your garbage ?	( ) throw it onto street or ground ( ) throw it onto special garbage dump ( ) burn it ( ) bury it ( ) leave it for animals ( ) other (specify)
25. (a) Do you think this is the healthiest method of disposal ?	yes/no/don't know
(b) If yes, why ?	
(c) If no, would you be willing to pay for an improved method of disposal ?	yes/no
26. Would you like to see a health education programme carried out in the village regarding the disposal of wastewater, excreta and garbage ?	yes/no
<u>Community Participation</u>	
27. (a) Do you sometimes work with other people in	( ) building houses ( ) building roads ( ) agricultural work ( ) marketing crops or goods ( ) other (specify)
(b) Is the work paid or voluntary	....
28. (a) Do you think you could work with other people to improve water supply or excreta disposal ?	yes/perhaps/no
(b) Under what conditions would you work ?	( ) voluntary work ( ) exchange work ( ) paid work

EXISTING WATER SUPPLIES (1)

Quest.							1			2			3		4a							4b	
															BOREHOLE/WELL							CIST/SPRING	
Village	Pop.	Well No.	Coordinates x y	Aerial photo No.	Schools No.	Pupils No.	Source Dry S. (1-7)	Source Wet S. (1-7)	El. (m)	Dist. (km)	Time (hrs)	Freq. time/day	Shortage (Y/N)	Duration mon./yr.	Static level (m)	Dyn. Level (m)	Depth (m)	Depth water struck (m)	Cap. (l/s)	Soft Rock (m)	Hard Rock (m)	Cap. (m^3)	Disch (l/s)

Ann. B

EXISTING WATER SUPPLIES (2)

Quest	5	6						7	8	9	10	11	12	14	13	12	14	13		17	19	20	21
VILLAGE	WATER CONSUMPTION							Well lined	Well covered	Well Cleaned	Quality Sortis	EC	ENGINE			PUMP				PUMPING MAIN			
	Time to fill res.	Water pumped dry season		Water pumped wet season		Dry S.	Wet S.			times/ year	Satis		Make	Age	HP	Make	Age	Cap	Head	Length	Dia	Cap.	Cond.
	(hrs)	(hrs/d)	(d/week)	(hrs/d)	(d/week)	(m^3/d)	(m^3/d)	(Y/N)	(Y/N)		(Y/N)	S		(years)			(years)	(m^3/hr)	(m)	(m)	(ms)	(m^3/hr)	(G/B)

EXISTING WATER SUPPLIES (3)

Quest	23	25	26	24	28	30	32	34	35	36	37			40	41	42	43	44	45 47	49		51	52	53
VILLAGE	STORAGE RESERVOIR						DISTRIBUTION SYSTEM				WATER CONS.			LEVEL OF SERVICE				O+M		COST OF WATER		SANITATION		
	No	Height (m)	Cap. (m^3)	G.L. (m)	Cond. (G/B)	Cleared Times/ year	Extent % cov.	Dia. range	Cap.	Leakage (Y/N)	Freq. res pumped full (times/ day	Village water cons. (m^3/d)	per capita cons. (l/p/d)	Stand pipe %	I.C. %	No dist. %	Cost of conn (YR)	Resp org. (Y/N)	Prob. with O+M (Y/N)	Conn. (YR/m)	Stand pipe (YR/m)	Waste water syst. (Y/N)	Excreta Coll. syst. (Y/N)	Garbage disp. syst. (Y/N)

SOCIO ECONOMIC QUESTIONNAIRE - sheet 1

Question	1							3	4				5					6			7	8	9	10				
VILLAGE	POPULATION (Nos)			AGE GROUP (Nos)				OCC	INCOME (YR per annum)				LIVESTOCK (Nos)					WATER CONSUMPTION						WATER QUALITY				
	Male	Female	Overseas	0-10	10-20	20-40	40+	(1-9)	Crops	Occ.	Remit.	Total	Cows	Bulls	Sheep	Goats	Camels	Type (1-10)	Dist. (km)	Time (hrs)	Fetched (1/p/d)	Tap (1/p/d	Lives. cons. (1/a/d)	Drink G/B	Cook G/B	Wash G/B	Anim. G/B	Boil Y/N

SOCIO-ECONOMIC QUESTIONNAIRE - Sheet 2

Question:	11	13	15		16	17			19			22		23		24	25		26
VILLAGE	EXISTING W.S.				DESIRED W.S.				WASTE WATER			EXCRETA				GARBAGE			HEALTH EDUCATION
	Satis. (y/N)	Short. (Y/N)	Payment (YR/an.)	Water cost (H/N/L)	Willing to pay (Y/N)	Service Walk	SP	Tap	Type (1-7)	Des. Syst. (Y/N)	Pay (Y/N)	Type LE (1-7)	Type SE (1-9)	Healthy (Y/N)	Pay (Y/N)	Type (1-6)	Healthy (Y/N)	Pav (Y/N)	(Y/N)

APPENDIX B.III
AL BAYDA WATER RESOURCES STUDY
PHYSICAL, CHEMICAL AND BACTERIOLOGICAL WATER ANALYSES

Village	....	Nahiyat	....
Owner	....	Source	....
Date of sampling	....	Date of analysis	....
Analyst	....	Analysis method	....

RESULTS		W.H.O. Standard	
		Highest Desirable	Maximum Permissible
Conductivity	.... uS	1500	
Temperature	.... °C		
pH	....	7.0 - 8.5	6.5 - 9.2
Colour	.... units	5 units	50 units
Turbidity	.... units	5 units	25 units
Total Hardness(as $CaCO_3$)	.... mg/l	100 mg/l $CaCO_3$	500 mg/l $CaCO_3$
Alkalinity (P)	.... mg/l		
Alkalinity (T)	.... mg/l		
Bicarbonates	.... mg/l		
Calcium	.... mg/l	75 mg/l	200 mg/l
Magnesium	.... mg/l	30 mg/l (if 250 mg/l sulphate)	150 mg/l
Chloride	.... mg/l	250 mg/l	600 mg/l
Fluorides	.... mg/l	10°C 0.9 mg/l 20°C 0.7 mg/l (lower limit) 30°C 0.6 mg/l	1.7 mg/l 1.2 mg/l (upper limit) 0.8 mg/l
Sodium	.... mg/l	-	-
Manganese	.... mg/l	0.05 mg/l	0.5 mg/l
Iron (total)	.... mg/l	0.1 mg/l	1.0 mg/l
Sulphates	.... mg/l	200 mg/l	400 mg/l
Nitrate	.... mg/l	50 mg/l	100 mg/l
Potassium	.... mg/l	-	-
Phosphate (orthophosphate)	.... mg/l		
BACTERIOLOGICAL			
Total Coliform	....		10/100 ml.
Fecal Coliform	....		0

Remarks : ....

....

....

APPENDIX B.IV - WATER SUPPLY SITUATION AND POSSIBLE REMEDIES; AND INVESTIGATIONS REQUIRED

Table B.IV.1 - Water-supply situation

Village*	Population	Present water consumption (m^3/day)		Estimated future water consumption (m^3/day) (2003)	No water supply system	Water shortage	Excessive salinity	Excessive fluorides	Bacteriological pollution	O + M problems	Water quality considered unsatisfactory
		According to survey	Calculated present requirements								
Rada Basin											
Rada Town + Mosallah	16 500	-	1 230.9	3 240.9							
Mallah	3 231	134.5	243.3	634.6		x				x	
Qarn al Asad	2 591	110.9	193.3	508.9		x					
Draybah	1 072	87.5	80.0	210.6							
Hannakah	1 062	30.6	79.2	207.3							
Farasa	906	63.7	67.6	178.0	x				TC = TNTC		
Khaber	876	56.8	65.3	172.1							
Sudan	735	31.0	54.8	144.4	x	x			TC = 256/100 ml		x
Mawr	655	66.7	48.9	128.7	x				TC = 250/100 ml		
Hamaydah	557	28.2	41.6	109.4	x				FC = TNTC		x
Khadra	489				x						x
Haban	480									x	
Beni Ziad	471				x	x			TC = 65/100 ml		
Al Asba	450										
Q. Zubaydih	400				x						
S. Shadadih	420				x						x
Wathbah	400				x						
Qusair	400										
Al Hamrah	384				x			2.10			
Ghawl Dhra	360								TC = TNTC		
Ajma	332								TC = 27/100 ml		
Q. Sawdah	330				x						x
Nadhim	300				x				FC = TNTC		
Wadi Sir	250				x		1 800 mg/l		TC = 46/100 ml		x
Nuffan	200									x	
Al Qawl	92					x	1 700 mg/l				x
Qurayshiya	400					x				x	x
Sawman	284				x						
Sabah											
Hawat	1 372	204.0	146.3	307.0	x						
Zakham	1 056	87.6	92.8	236.3				1.12			
Suraymih	1 032	191.0	110.0	231.0	x						x
Shirganih	900	42.0	95.9	201.4	x			1.28			
Talab	698	23.8	74.4	156.2	x	x					
Al Abi	694	90.9	74.0	155.3	x	x					
Al Hajar	549	30.2	58.5	122.9	x	x					
Qarab	523	28.8	55.8	117.0	x				FC = TNTC		x
Nuwayrah	457				x						x

* Villages which have a satisfactory water-supply situation are not mentioned.

Table B.IV.1 - Water-supply situation (continued)

Village	Population	Present water consumption (m³/day)		Estimated future water consumption (m³/day) (2003)	No water-supply system	Water shortage	Excessive salinity	Excessive fluorides	Bacteriological pollution	O + M problems	Water quality considered unsatisfactory
		Presently used	Calculated present requirements								
Sabah (cont.)											
Jubayr	460				x	x					
Nuwayrah	457				x						
Hassan	439				x	x					
Agabah	437				x						
Mudhur	300				x	x					
Al Bayda	272				x	x					
Ash Sharaf	296				x						
Al Zarar	294				x						
Shahr	250				x						
El Hanek	119				x	x					
Al Bayda North-East											
Al Bayda Town	12 913	900	1 424.0	2 536.4							
Hazzah	1 693	148.1	186.7	332.5			1 650 mg/l			x	x
Madhwagayn	1 338	255.0	147.6	262.8							
Awwayu	1 479	135.5	163.1	290.5							x
As Sawmaah	1 448	172.0	159.7	284.4		x					
Al Uglah	858	107.6	64.5	168.5		x					
Ad Dahaki	844	37.2	93.1	165.8		x			FC = TNTC		
Mashrah Ji	418					x					
El Adph	174									x	
Murth	63									x	
Al Bayda West											
Es Zahir	661	25.4	57.6	126.6							x
Al Quah	651	26.4	56.7	124.7							x
Al Isa	400					x					
Dougee	294					x					
Al Quah	190				x						
Hayd Moh	100				x						
Wadi Juban									TC = 180/100 ml		
Juban	2 313	103.4	214.0	525.0					FC = 3/100 ml	x	
Nowah	932	83.2	86.2	211.6	x				FC = TNTC		
Bani Gaysh	594	7.9	54.9	134.8	x	x					
Hannakah	510	11.6	47.2	115.8	x	x					
Al Aggar	504	16.2	46.6	114.4	x				TC = 140/100 ml		
Jahair	791	57.6	73.2	179.6	x	x					
Hangar	500	12.2	46.3	113.5	x						x

Table B.IV.1 - Water-supply situation (continued)

Village	Population	Present water consumption (m^3/day)		Estimated future water consumption (m^3/day) (2003)	No water-supply system	Water shortage	Excessive salinity	Excessive fluorides	Bacteriological pollution	O + M problems	Water quality considered unsatisfactory
		Presently used	Calculated present requirements								
Wadi Juban (cont.)											
Monatha	479				x						
Al Ouabbal	442				x	x					
Glayah	302				x						
Boakita	251				x				TC = 155/100 ml		
R'zayn	211				x	x			TC = 267/100 ml		
Wadi Mansur											
Safiah	1 500	59.1	159.3	330.9							
Abbas	616	17.0	65.4	135.9	x	x					
Sara/Ghan	400				x	x					
Zanabah	394					x	1 850 mg/1		FC = 84/100 ml		
Guraisha	342				x				FC = TNTC		
Razqiah	314				x						
Wagah	312									x	
Sumadah	175					x			FC = TNTC		
Jabar	167				x	x					
Ath Thra	104				x		1 900 mg/1		FC = 68/100 ml		
Mansam	104										
Wadi Matar											
Dhig Asfal	394				x						
Nubah	106				x	x					x
Ar Rayshah	92				x	x					
Wadi Hubabah											
Salama	267				x	x					
Al Col	242				x						
Suar	316				x						
Khulan	226					x					
Za'am	191				x						
Qahara	116				x						
Mahaba	88				x						

Table B.IV.1 - Water-supply situation (continued)

Village	Population	Present water consumption (m^3/day)		Estimated future water consumption (m^3/day) (2003)	No water-supply system	Water shortage	Excessive salinity	Excessive fluorides	Bacteriological pollution	O + M problems	Water quality considered unsatisfactory
		Presently used	Calculated present requirements								
Wadi Dhi Na'im											
Nasfan	2 760	120.0	408.5	675.4	x	x					
Rubat	1 400	14.0	207.2	342.6							
Nasrin	1 000	90.0	148.0	244.7	x	x					
Mingathb	929	35.0	137.5	227.3							
Hammas	600	16.8	88.8	146.8						x	
Grain	600	19.0	88.8	146.8	x					x	
Yaf'an	396					x					
Salwah	250					x					
Gasheb	128				x	x					
As Sawadiyah											
Quah	750	30.0	76.4	164.4	x	x	2 300 mg/l		FC = TNTC		
Quah	480				x				FC = 25/100 ml	x	
Afar	403								FC = 1/100 ml		
Madbaran	397				x				FC = 3/100 ml		
Sarawil	300				x	x					
M'gathuh	160				x						
Salam	157				x						
Safah	157				x	x					
Jahdri	121				x		2 000 mg/l				

TC = Total coliform.
FC = Fecal coliform.
TNTC = Too numerous to count.

Table B.IV.2 - Remedies and investigations required

Town/village	Water shortage Present (m³/d)	Future (m³/d)	Water quality problem	Remedy	Required investigations
		Rada Basin			
Rada	?	3000		7 to 10 boreholes of 150 m in areas ALRUA and ALRS	Geo-el. survey + model study
Mallah	110	500		2 boreholes in ALRM	Geo-el. survey
Qarn Al Assad	90	400		2 boreholes in ALRDD	Geo-el. survey
Draybah	0	130		1 borehole ALRCC	EM survey
Hanakah	50	180		Sufficient water from project borehole near wel No. 260 yield 10 l/s	
Al Faraza	0	120		1 borehole	
Khabar	?	120		1 borehole	
Sudan	24	115		Sufficient water in existing borehole	
Mawr	0	80		Sufficient water from borehole 625	
Hamaydah	13.4	80		1 borehole 150 m probably existing	
Bani Ziad	X			1 borehole	Geo-el. + EM survey
Al Hamrah			F = 2.1 mg/l	Other well after testing quality	
Wadi Sir			1800 mg/l	Borehole in ALRX	Geo-el. + EM survey
Al Qawl	X		1700 mg/l	Borehole in ALRX	Geo-el. + EM survey
Qurayshiya	X			Sufficient water from existing wells social problem.	
		Al Bayda North			
Al Bayda	525	1636		At present increase in pumping from existing wells; in future 2 new boreholes on fault	EM survey
Hazzah	38.6	184.4	1650 mg/l	1 borehole in area BL on fault	EM survey
Awwayn	27.5	155		1 borehole	Geo-el. + EM survey
As Sawmah	0	112.4		1 borehole	Geo-el. + EM
Al Uglah	0	61		1 borehole	Geo-el. + EM
Ad Dahaki	56	129		1 borehole	Geo-el. + EM
Mashra Ji	X			1 borehole	Geo-el. + EM

Table B.IV.2 - Remedies and investigations required (continued)

Town/village	Water shortage Present (m³/d)	Water shortage Future (m³/d)	Water quality problem	Remedy	Required investigations
		Al Bayda West			
Es Zahir	32	101		1 borehole	EM + geo-el.
Al Quah	30	98		1 borehole	EM + geo-el.
Al Isa	X			shallow well	EM + geo-el.
Dougee	X			1 borehole	EM + geo-el.
Al Quah	X			1 borehole	EM + geo-el.
Hayd al Moh.	X			1 borehole	EM + geo-el.
		Juban			
Juban	114	425		1 borehole in JB.	EM + geo-el.
Nowah	0	130		1 borehole	EM
Bani Gaysh	47	127		1 borehole	EM
Hannakah	36	104		1 borehole	EM
Al Aggar	31	98		1 shallow well	
Jahair	16	122		1 borehole	
Hangar	34	101		1 borehole	Geo-el. + EM
Al Ouabbel	X			1 borehole	EM + geo-el.
R'Zyan	X			1 borehole	EM
		Wadi Mansur			
Safiah	100	272		1 borehole	EM + geo-el.
Abbas	49	119		1 borehole	EM + geo-el.
Sena/Ghan	X			1 shallow well of borehole east of village	Geo-el. + EM
Zanabah	X		1850 mg/1	Other well	Geo-el. + EM
Sumadah	X			1 borehole	EM
Jabar	X			1 well in side wadi	
Ath Thra			1900 mg/1	1 borehole in side wadi (MN)	EM + geo-el.
		Wadi Matar			
Nubah	X			Borehole in valley east or west of main wadi (brackish)	EM + geo-el.

Table B.IV.2 - Remedies and investigations required (continued)

Town/village	Water shortage		Water quality problem	Remedy	Required investigations
	Present (m^3/d)	Future (m^3/d)			
		Dhi Naim			
Nasfan	289	556		?	
Rubat	163	300		1 borehole east of town	EM + geo-el.
Nasrin	58	155		1 borehole	EM
Mingatha	103	190		Existing borehole?	
Hammas	72	130		1 borehole	EM
Yaf'an	X			1 shallow well?	EM + geo-el.
Salwah	X			1 borehole	EM
Gasheb	X			?	

* X = water shortage.

REFERENCES

DHV, 1983.
Rada Urban Development Project, 11 volumes. DHV Consulting Engineers, Amersfoort, The Netherlands.

Foster, S.S.D., 1983.
Potable groundwater supplies and low-cost sanitary engineering -How compatible?

Ilaco, 1983.
Household water use in Al Bayda Province, Rada Integrated Rural Development Project, Technical Note No. 10. Ilaco, Arnhem, The Netherlands.

Kalbermatten, J.M., D.S. Julius, and C.G. Gunnerson, 1980.
Appropriate technology for water-supply and sanitation. A sanitation field manual. World Bank, Washington D.C., USA.

YAR, 1982.
Statistical Yearbook 1981. Prime Minister's Office, CPO, Statistics Department. Yemen Arab Republic.

ANNEX C
AGRICULTURE

ANNEX C - AGRICULTURE

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ANNEX C
AGRICULTURE

C.1 Introduction

C.1.1 General

This annex presents the detailed results of the agronomic survey conducted in Al Bayda Province. The survey started at the end of April and went on till mid-October 1983. From November 1983 to the end of January 1984 compilation of all data and drawing of the different maps took place.

The method of data collection is described and the compiled data and other field data are presented. The areas covered by the agricultural survey are briefly described and some general remarks are made about cropping patterns and irrigation practices and efficiencies.

C.1.2 Methodology of the survey

C.1.2.1 Objectives and scope of survey

The objectives of the agricultural survey are:

- to determine the total amount of water presently used within the surveyed areas for irrigated agriculture;
- to identify areas potentially suited for expansion of irrigated agriculture in view of both quantity and quality of available land and water.

As crop irrigation makes the highest demand on water, as exact as possible an assessment of water quantities used to this end is essential. The survey therefore concentrated on the irrigated areas around operational wells. The areas covered are given below plus the number of surveyed wells:

Rada Basin	18
Sabah/Ar Riashiyah	4
Al Bayda North-East	13
Al Bayda West	12
Wadi Juban	7
Wadi Mansur/Wadi Amad	4
Wadi Matar/Wadi Ar Rin	5
Wadi Hubabah/Wadi Ar Riashiyah	6
Wadi Dhi Na'im	5
Abbas	8
Total	82

The following basic data have been collected:

- actual discharges of shallow wells/boreholes;
- the total irrigated areas in the areas covered;

- the typical cropping patterns within each of the areas;
- the average irrigation dosages for the crops grown;
- irrigation water losses through seepage (infiltration measurements) or surface waste water;
- potential irrigation expansion areas, as far as soil quality is concerned.

C.1.2.2 Survey method and field-work

The field staff consisted of an assistant agronomist and an interpreter. The survey was carried out on the basis of a questionnaire (see Appendix C.I) and a field form.

Before going into the field a selection was made of the subareas to be visited by means of aerial photographs and/or on the indication of other team members. In each subarea it was tried to locate a - in terms of cropping pattern practised - representative farmer, which was not always an easy task: especially farmers with unusual crops were usually eager for an interview, and it was not always possible to refuse their invitation. However, the surveyed sample can generally be considered a representative one.

Each farmer was first informed by the interpreter of the background of the survey. After this explanation the questions 1, 2, 4, 5 (for rough indication), 6, 7 and 8 were asked. Questions 6 and 8B were sometimes a problem; if a farmer seemed slightly wary, it was better not to upset him by those questions.

After this introduction the pump irrigation discharge was measured (if not already done by the hydrological section), either by means of a 20- or 90-litre drum, or, if the outflow of the pump was near the surface, by using a constructed linear BCR-flume. The latter is a discharge measurement profile, which has to be put level into an irrigation ditch; after a steady state of the water-level upstream has been reached, the discharge is read from the water-table in the flume at an indicated point. Also a water sample was taken for the EC-value and the pH-value. After those measurements, the farmer was asked to show all the separate plots irrigated by the well. Per plot the following data were asked;

- the crop(s) grown during winter and summer;
- the hours of irrigation;
- the time between two applications (the interval);
- the growing season of the crops (planting date and harvesting date);
- application before planting (pre-irrigation).

After all the plots had been visited, the farmer was asked what kind of problems he had in growing his crops; if these seemed easy to solve the RIRDP project was informed to assist. (In case of severe diseases an extension co-ordinator of the RIRDP solved those problems often a few days later). Finally, the separate plots were measured by means of a 50-m measuring-tape.

On a working-day (7.00 a.m. to 1.00 p.m.) normally one or two wells were visited. The interviews took quite a long time, especially getting the permission for and the actual measuring of the separate plots.

The Rada Basin area was reserved for the period of Ramadan. During this period sometimes the surveying of one well took more than one day, as no farmers were available in the field or they were not willing to co-operate, and the working-days were shorter (from 6.00 a.m. to 10.00 a.m.).

Sometimes additional measurements were carried out. If a farmer had irrigated the previous day, a soil sample was often taken at 25 cm and/or 50 cm with a soil auger. The moist soil sample (including the container) was weighed at Al Khabar and put into the oven (105 °C). After 24 hours the dry soil sample as well as the empty container were weighed again for determining the water content at field-capacity (weight percentage). Measurement of the basic infiltration rate (i.e. the infiltration rate which has reached the steady state) of the soil was only possible if the farmer had stopped irrigating just before and the water-level in the separate basins of a plot was steady; in those cases a wooden stick was marked and put into a basin (preferably in the centre of the plot), and after about 30 minutes the falling of the water surface was measured.

C.1.2.3 Reliability of results

The results of the survey are used to calculate the total water dosages given to a crop per unit of area in the growing season of the crop.

The number of applications (Appl.) multiplied by the hours irrigated (h) and the discharge (Q) gives the water abstraction (W.A. in m^3) per crop:

$$W.A. = Appl. \times h \times Q \times 3.6 \text{ (conversion factor)}.$$

The water abstraction divided by the cropped area (area in m^2) gives the total water dosage (W.D.):

$$W.D. = \frac{W.A.}{area}$$

The answers given by the farmers were reliable most of the time. It should be realized that the field survey was implemented in a relatively short period. In fact the visits to individual farms or selected areas constitute an instantaneous view only of the situation, while for the remainder of the year one has to rely on the farmers' information with the inherent risk of misunderstanding.

Often the farmers declared that the discharges vary with the season or even during one day, especially in areas with water shortage. If a farmer has not been told to operate the pump at normal irrigation discharge, he tends to let the pump work at full capacity. Especially in the beginning of the survey the mistake was made to measure under such conditions.

Sometimes farmers irrigate with reduced discharges, since fields on a higher level are supplied by narrow pipes. The calculated water abstractions had to be adjusted in those cases. The results of the household water consumption were also adjusted afterwards.

Sometimes the farmers change the irrigation intervals in accordance with the different growing stages of a crop, which makes it difficult to find out the real number of applications. The total number of applications may also be effected by rainfall.

It was not always possible to measure all the plots irrigated from one and the same well, because some of the plots belonged to other farmers and the interviewed farmers did not allow measuring of those plots. In those cases an extrapolation was made from the already collected data, which was checked afterwards by counting steps and on aerial photographs.

The reliability of the results can be increased by monitoring farms throughout the seasons, together with rainfall measurements. Of course this takes a lot of time, but it will give a complete picture about farm operations. A negative aspect is the small number of wells which can be handled this way.

C.2 Survey results

C.2.1 Cropping patterns

Since the present study concerns the water resources and their present and future application, the agricultural survey has focused on irrigated agriculture supplied with water from shallow wells, boreholes and springs. Rainfed agriculture, which covers an area twice as large, has not been considered as it plays a negligible role in the whole water cycle.

During the agricultural survey 82 wells were visited and in principle the related irrigated plots measured. Before processing the cropped areas into cropping patterns, a number of wells were eliminated because their related cropped areas were considered to produce unreliable figures, on account of the areas having to be estimated instead of measured because of absence or non-cooperation of the owners of the wells.

For each of the selected areas visited (Wadi Arsard/Wadi Saru and As Sawadiyah were not covered by the agricultural survey) the cropped areas per crop were totalled and a cropping pattern was derived by dividing them by the total area cropped either in summer or winter, whichever was the largest. Usually this is the summer area, but an exception is formed in case of water-melon for which the cropped area in winter is larger (Abbas and Wadi Amad). The cropping patterns for the individual selected areas as well as the overall average cropping pattern (approximating the one for the whole of Al Bayda Province) are represented in Table C.1.

The patterns for Rada Basin and Wadi Mansur/Wadi Amad were composed by weighting (for acreage) partial patterns of areas which have a clearly discernible difference in cropping pattern. Thus, Rada Basin can be divided into a qat area between Al Jayf and Mawr, a water-melon area in Qa'Rada, and the remainder, while in the Wadi Mansur/Amad area, Wadi Amad clearly distinguishes itself by its vast area under water-melon. Although Al Bayda North-East can be clearly split up into Wadi Nakhar and Wadi Mash'abah, there is no sufficient reason to use a weighted average pattern here: the former contains relatively much alfalfa and vegetables and is more plentiful in irrigation water, while the latter has more qat. The partial patterns are represented in Table C.2.

Table C.2 also shows separate cropping patterns calculated for the Rada Basin subareas supplied by shallow wells and those irrigated from boreholes (excluding the qat and water-melon areas with their distorted cropping patterns) so as to study a possible influence of the cost of water on the composition of the cropping pattern (see also Annex D).

From Table C.1 it can be observed that total cropping intensities vary generally between 158 and 170 %, with an extreme figure of 198 % for Sabah which must be due to the high rainfall, which is about double the rainfall of for instance the Rada Basin.

Both in the summer and winter season a certain area remains fallow for a while. Farming systems research in Wadi Tha and Wadi Mansur has shown the extent to be 25 and 17 % of the irrigated area during the summer and winter season respectively (Ilaco, 1982 and 1983). When the area covered by infrastructure (roads, villages, and canals), for which a figure of 15 % is adopted in this report, is included as well, one arrives at the gross irrigated area (see also Section C.4).

The cropping patterns show extensive areas under qat, which could be expected because of its high returns and good market prospects. The area under alfalfa appears to be rather variable with an extreme figure of (on average) 40 % for Wadi Matar/Ar Rin. It has been studied whether this has anything to do with a high livestock density in the area: this was found to be extremely low, but it should be noted that the sample of households studied was very small.

From the comparison of cropping patterns for shallow-well-irrigated and borehole-irrigated farms it can be concluded that boreholes serve the more commercially profitable crops such as qat and vegetables, while the shallow wells serve a relatively high percentage of alfalfa and cereals, except wheat. It must, however, not be forgotten that a time factor may play a role as well: the absence of fruit in the figures for boreholes is possibly an illustration of this aspect, as fruit planting has only recently started.

In Table C.3 the average annual abstraction per well covered by the agricultural survey and the average electrical conductivity (EC)

Table C.1 - Cropping patterns and intensities per area (%)[1]

Area	Winter 1982/83[2]											
	Alfalfa	Sorghum	Wheat	Barley	Potato	Maize	Qat	Onion	Melon	Fruit	Veg. + others	Total
1 Rada Basin[3]	12.9	-	2.9	1.0	0.1	0.2	40.8	0.5	4.4	0.4	3.1	66.3
2 Sabah/Ar Riashiyah	12.7	-	48.3	-	30.0	0.7	3.2	1.0	-	-	1.8	97.7
3 Al Bayda North-East	12.3	-	21.8	24.0	1.5	0.5	7.6	0.4	1.2	-	1.5	70.8
4 Al Bayda West	4.6	2.0	9.6	15.7	3.4	-	12.4	0.9	-	2.2	7.2	58.2
5 Wadi Juban	6.5	-	-	-	-	11.4	50.6	-	-	-	-	68.5
6 Wadi Mansur/ Wadi Amad[3]	13.9	-	20.6	-	-	6.2	5.3	1.0	11.7	-	-	58.7
7 Wadi Matar/ Wadi Ar Rin	46.2	-	12.8	-	-	-	5.8	-	-	-	-	64.8
8 Wadi Hubabah/ Wadi Ar Riashiyah	4.4	-	6.5	5.6	-	12.4	31.7	-	-	0.5	-	61.1
9 Wadi Arsard/ Wadi Saru							not available					
10 Wadi Dhi Na'im	13.1	-	22.4	19.1	-	4.1	3.6	-	0.3	3.6	-	66.2
11 Abbas	3.2	-	-	-	8.4	-	46.5	-	32.1	-	9.8	100.0
12 As Suwadiyah							not available					
Overall average	10.4	0.3	9.9	8.2	1.9	2.4	27.6	0.4	8.7	1.0	2.8	73.6

Area	Summer 1983[2]												Annual total
	Alfalfa	Sorghum	Wheat	Barley	Potato	Maize	Qat	Onion	Melon	Fruit	Veg. + others	Total	
1 Rada Basin[3]	11.3	35.0	6.7	0.2	1.0	-	40.9	0.7	0.7	1.2	2.3	100	166.3
2 Sabah/Ar Riashiyah	11.7	9.2	39.1	-	23.6	5.4	3.1	0.3	-	-	7.6	100	197.7
3 Al Bayda North-East	10.4	74.7	-	-	4.6	-	8.7	-	-	-	1.6	100	170.8
4 Al Bayda West	6.2	57.9	-	-	2.8	-	15.7	3.7	3.0	5.9	4.8	100[4]	158.2
5 Wadi Juban	6.5	32.8	3.6	-	5.1	0.6	50.6	0.1	-	0.1	0.6	100	168.5
6 Wadi Mansur/ Wadi Amad[3]	13.9	61.3	-	1.0	5.1	3.1	4.3	-	9.2	-	2.1	100	158.7
7 Wadi Matar/ Wadi Ar Rin	36.4	39.4	18.4	-	-	-	5.8	-	-	-	-	100	164.8
8 Wadi Hubabah/ Wadi Ar Riashiyah	4.4	63.3	-	-	-	4.1	27.7	-	-	0.5	-	100	161.1
9 Wadi Arsard/ Wadi Saru													
10 Wadi Dhi Na'im	13.1	74.9	-	-	-	1.5	3.6	2.5	-	3.6	0.8	100	166.2
11 Abbas	3.2	-	-	0.9	-	-	41.3	6.6	-	5.3	11.9	69.2	169.2
12 As Suwadiyah													
Overall average	9.4	43.9	6.4	0.1	3.2	0.9	27.5	1.3	0.8	4.0	2.5	100	173.6

[1] Percentages calculated over total cropped area in summer (which is usually larger than the one in winter, except for Abbas).
[2] The field survey was mainly done during the summer season of 1983; of the 1982/83 winter season only the end was observed.
[3] The figures for Rada Basin and Wadi Mansur are weighted averages derived from Table C.2.
[4] Some figures for the summer season for Al Bayda West were arbitrarily changed because of a non-representative sample: the area under fruit was reduced, while the ones for alfalfa, sorghum and qat were equally increased. The fruits are mostly recently planted.

Table C.2 - Partial cropping patterns (%)

Selected area	Winter 1982/83												Summer 1983												Annual total
	Alfalfa	Sorghum	Wheat	Barley	Potato	Maize	Qat	Onion	Melon	Fruit	Vegetables and others	Total	Alfalfa	Sorghum	Wheat	Barley	Potato	Maize	Qat	Onion	Melon	Fruit	Vegetables and others	Total	
Rada basin[1]:																									
Qat area	5.0	-	2.0	-	-	-	75.0	-	-	-	-	82.0	5.0	15.0	3.0	-	2.0	-	75.0	-	-	-	-	100	182.0
Water-melon	1.1	-	2.4	-	-	-	22.7	-	69.9	3.5	0.4	100.0	2.2	6.8	-	-	-	-	22.7	-	-	16.8	-	48.5	148.5
Remainder	19.6	-	3.4	1.8	0.1	0.4	14.4	0.9	-	0.3	5.6	46.5	16.4	51.2	10.0	0.3	0.4	-	14.4	1.4	1.4	0.3	4.2	100	146.5
Weighted average	12.9	-	2.9	1.0	0.1	0.2	40.8	0.5	4.4	0.4	3.1	66.3	11.3	35.0	6.7	0.2	1.0	-	40.9	0.7	0.7	1.2	2.3	100	166.3
Shallow wells[2]	20.6	-	12.8	3.5	0.2	1.7	6.4	2.3	-	1.1	0.2	58.8	23.3	41.3	23.8	1.0	1.7	-	6.4	1.2	-	1.1	0.2	100	158.8
Boreholes	15.6	-	-	1.2	-	-	17.4	0.4	-	-	7.5	42.1	13.9	33.4	26.2	-	-	-	17.4	1.5	1.9	-	5.7	100	142.1
Wadi Mansur/Amad[3]:																									
Wadi Amad	15.7	-	-	-	-	-	9.8	-	37.4	-	-	62.9	15.7	48.0	-	-	13.1	13.4	9.8	-	-	-	-	100	162.9
Wadi Mansur	13.3	-	26.7	-	-	8.0	4.0	1.3	4.0	-	-	57.3	13.3	65.3	-	1.3	2.7	-	2.7	-	12.0	-	2.7	100	157.3
Weighted average	13.9	-	20.6	-	-	6.2	5.3	1.0	11.7	-	-	58.7	13.9	61.3	-	1.0	5.1	3.1	4.3	-	9.2	-	2.1	100	158.7
Al Bayda North-East[4]:																									
Wadi Nakhar	25.1	-	25.8	23.3	4.1	-	3.0	-	-	-	1.9	83.2	19.8	70.4	-	-	4.4	-	3.0	-	-	-	2.4	100	183.2
Wadi Mash'abah	4.8	-	19.3	24.4	-	0.8	10.3	0.7	1.9	-	1.3	63.5	4.8	77.3	-	-	4.7	-	12.0	-	-	-	1.2	100	163.5
Average	12.3	-	21.8	24.0	1.5	0.5	7.6	0.4	1.2	-	1.5	70.8	10.4	74.7	-	-	4.6	-	8.7	-	-	-	1.6	100	170.8

[1] The Rada Basin can be roughly divided into a 'qat area' (1062 ha) situated south-west of Rada Town, between the villages of Al Jayf and Mawr, a 'water-melon area' (124 ha) situated south of Qa'Rada, and 'remainder area' (1062 ha). The cropping pattern for the qat area was arbitrarily changed as the visited farms did not constitute a representative sample and resulted in too high a percentage for qat. In the case of the water-melon area the percentage for summer wheat was reduced in favour of sorghum.

[2] Individual cropping patterns were calculated for shallow-well-fed farms and borehole-fed farms in the Rada Basin excluding the qat and water-melon areas.

[3] The cropping pattern for Wadi Mansur in Table C.1 is a weighted average for the ones of Wadi Mansur (gross irrigated area 137 ha) and of Wadi Amad (gross irrigated area 459 ha). For Wadi Mansur the cropping pattern was adopted from the farming systems research survey (see Ilaco, 1983).

[4] Al Bayda North-East consists of two main wadis (Wadi Nakhar and Wadi Mash'abah), which are of about equal size.

of the well water, calculated for each of the selected areas, are indicated: the former figures reflect the relative abundance of irrigation water, while high EC figures point to poor-quality irrigation water. These figures were calculated to find out whether there is a correlation between these factors and the prevalent cropping patterns. Abundance of irrigation water would probably induce relatively high total cropping intensities, while poor-quality irrigation water would limit the area under crops sensitive to saline water (such as alfalfa, onion, and potato). The figures are, however, not consistent in the sense: the selected areas with the highest annual abstraction per well (Rada Basin and Wadi Dhi Na'im) have a lower total cropping intensity than Abbas, which has the lowest abstraction, and similarly Wadi Mansur/Wadi Amad and Wadi Matar/Wadi Ar Rin, in spite of having by far the highest average EC, show high percentages of (summer) potatoes and alfalfa, respectively.

Table C.3 - Water abstraction and areas irrigated

Selected area	Average annual abstraction per well[1] (m^3)	Maximum area irrigated per well[2] (ha)	Average EC of well water[3] (μS)
1. Rada Basin	35 340	3.26	896
2. Sabah	18 170	0.92	415
3. Al Bayda North-East	21 490	1.67	1 057
4. Al Bayda West	16 990	1.52	1 365
5. Wadi Juban	11 100	1.55	707
6. Wadi Mansur/Wadi Amad	16 860	1.69	2 037
7. Wadi Matar/Wadi Ar Rin	15 170	0.67	2 325
8. Wadi Hubabah	12 100	1.44	-
9. Wadi Arsard/Wadi Saru		not available	
10. Wadi Dhi Na'im	41 900	1.60	1 370
11. Abbas	6 200	0.70	854
12. As Sawadiyah		not available	
Overall average	21 310	1.72	-

[1] Excluding water abstracted for domestic use.
[2] These figures indicate the average areas irrigated/cropped per well for the summer season, which are usually the largest, except for Abbas where the area cropped is larger during winter due to the extensive cropping of water-melon.
[3] For wells included in the agricultural survey only.

C.2.2 Characteristics of the selected areas

C.2.2.1 Rada Basin (Map C.1)

This area can roughly be divided into three subareas: a qat area (between Al Jayf and Mawr), a water-melon area (south of Qa'Rada), and the remainder.

(i) Qat area

The area is characterized by more than 50 % qat in the cropping pattern. This area has a lot of boreholes, which all supply other plots in addition to those of the borehole owner. The water quality is always good. In certain areas a genuine maze of all kinds of pipes is found. In frosty winter-nights the crop is protected by a framework covered by colourful patchwork quilts. The qat is sometimes intercropped with fruit-trees and/or grapes and onions (the last are thought to protect the qat against disease attacks). A special feature of this area is that there are always labourers working in the qat-fields (cutting watershoots, picking qat, irrigating, etc.). There are not many crop diseases in this area, and if there are the farmers use insecticides bought on the Rada suq. They are not always familiar with those insecticides and accidents occur, especially when the sprayed qat is picked too early. During the survey one harvest was destroyed by a severe hailstorm.

(ii) Water-melon area

This area is characterized by enterprising farmers. They try out new crops (especially fruit-trees) and the outcome is very satisfactory from an economic point of view. The emphasis lies on water-melon, which is grown from the end of January till June/July, after which the produce is sold at Rada suq. The crop is very profitable and other farmers follow this example. Qat is also important, but does not expand in this area.

(iii) Remainder area

A few visited wells provided water for a wheat crop in summer, which normally should have been sorghum. At the beginning of the growing season of sorghum the wells did not work properly, so wheat was sown six weeks later. The water quality is the limiting factor in the cropping pattern. The plain north-east of Rada is almost only suitable for cereals and alfalfa because of too saline irrigation water.

The farmers in the remainder area are more inclined to practise subsistence farming; only a few cash-crops are grown. Crop diseases occur frequently, and most farmers are not familiar with insecticides. The local wheat (Samrah, Balladih) lodges during winter.

C.2.2.2 Sabah

Only a part of this large area was visited, so that the cropping pattern is valid for this part only. Most crops are rainfed because rainfall is relatively high. During the last years new wells have been built or the existing ones deepened out.

As can be seen from Table C.1, Sabah has a cropping pattern that is quite different from the ones practised in the other areas surveyed, mainly because of its altitude of about 2500 m above sea-level.

Sorghum and qat cannot stand frost and can only be grown in the lower parts of Sabah Plain. The irrigated crops are mostly grown for the markets (local market and Rada suq).

The high potato percentage in the cropping pattern is remarkable. Three years ago this crop was introduced in this area and it does well. The farmer do not use seed-potatoes for planting, but they split harvested potatoes into about four parts. However, in the Sabah area the potatoes always occupy the same field: as potatoes are very sensitive to diseases, failures may occur if the farmers continue with this practice. At first sight Sabah Plain has possibilities for expanding irrigation and/or supplemental irrigation, because of higher rainfall, suitable flat areas, and better access in future.

C.2.2.3 Al Bayda North-East (Map C.2)

This area comprises Wadi Nakhar (east of Al Bayda Town) and Wadi Mash'abah (north of Al Bayda Town).

In this area there are several large waterlogged areas. Most wells in those areas are abandoned. With an efficient drainage system those areas can be made suitable again for agriculture. During the 1982/83 winter season floods destroyed a lot of cropped fields, especially in Wadi Libanih, Wadi Mash'abah, and Wadi Arthul Hoseisj. Most irrigated produce is for home consumption. Only in the north farmers try out different cash crops; because of their unfamiliarity with those new crops there are a lot of failures. Besides, there are a lot of crop diseases, and insecticides are difficult to get: farmers have to go to Rada or even up to Sana'a to buy them. The farmers in the area around Maradhim are very eager for information. Extension in this area will be very effective on agriculture.

C.2.2.4 Al Bayda West (Map C.2)

The main irrigated areas are situated around Al Quah and As-Zahair, and most farmers in those areas are very familiar with irrigated agriculture, so that extension officers can hardly improve agriculture in those areas.

The qat is generally thought to be of an excellent quality and is the most important source of income. Therefore, a lot of farmers can experiment with new crops, and large areas are planted with all kinds of fruit-trees. There is no night-frost in those areas and the quality of irrigation water is good to reasonable, so there are no limitations for those new crops.

C.2.2.5 Wadi Juban (Map C.3)

The most important limiting factor in this area is the overall shortage of irrigation water. Even drinking-water for home consumption is not everywhere available. During the survey there was a shortage of rain, so farmers had to irrigate part of their normally rainfed sorghum. This can be considered supplemental irrigation, so the figure for sorghum in 'normal' years in the cropping patterns (see Table C.1) is even lower. A very important crop (over 50 % of the irrigated crops) in this area is qat, which is the main source of income. (Another major source of income is derived from labourers working abroad because of the small scope in agriculture; a lot of these speak English very well.) Several farmers are trying out new crops (coffee, bananas, fruit-trees, vegetables), but because of the limiting factor of water availability it is only on a small scale. The farmers are very eager for information on those new crops, as they lack experience in growing them.

C.2.2.6 Wadi Mansur/Wadi Amad (Map C.4)

This area can be divided into two subareas:

- Wadi Mansur;
- Wadi Amad (area MD on Map C.4).

Water quality in the greater part of Wadi Mansur varies from reasonable to very poor. Only in the west of this subarea, south of Al Muqfuri, water quality is good and here the main crop grown is qat. In the remaining area sorghum is the main crop, which gets in most cases supplemental irrigation.

Farmers are trying out other crops (tomato, water-melon, onion, potato), but the water quality is so poor that a lot of failures occur. Besides, there are a lot of diseases which attack those new crops (e.g. blacknose rot in water-melon). There is a water shortage in this area: most wells can only pump for a few hours with a low discharge. Unfortunately, there is not much scope for expanding agriculture or introducing new crops in this area; extension should focus on improvement of the already existing crops (plant protection) and assist in trials of new crops.

Agriculture in Wadi Amad is quite different. A very important crop in this area is water-melon, which is why this subarea is also called Wadi Hab-Hab (water-melon wadi). This crop was introduced three years ago and nowadays almost every farmer in this wadi grows water-melons; for profitable marketing at the Rada suq the farmers co-operate. The total acreage under irrigated sorghum has decreased because its growing season and the one for water-melon overlap: harvesting of water-melon is in June/July, while sowing of sorghum is in the beginning of June. For this reason maize and potatoes were introduced three years ago, as they can be sown later and their growing seasons are shorter (3½ -4 months). The qat area is reducing, because water-melons are more profitable in this area. The farmers are very enterprising, but lack information about new crops like fruit-trees. Extension can be very valuable in this area.

C.2.2.7 Wadi Matar/Wadi Ar Rin (Map C.5)

Almost all agriculture in Wadi Matar is rainfed. The irrigation water in Wadi Matar is in most cases of a poor to very poor quality, being only in the side wadis good to reasonable. Farmers give an overdosage in case of saline irrigation water to delay salinization of the soil. Large areas are unsuitable because of saline soils and the only way to develop those is by leaching.

As can be seen from Table C.1, only traditional crops are irrigated (alfalfa, wheat, barley, sorghum, qat). There are some trials supported by the RIRDP extension officers near Ar Rawk. Remarkable is the high percentage of alfalfa in the cropping pattern, probably the result of other crops (cereals) being mostly rainfed.

In Wadi Ar Rin itself there are no irrigation wells. The only irrigated crop in this wadi is alfalfa, which is supplied by small springs from the mountains. There is a perennial stream draining from this wadi, but the water is not used for irrigation, probably because the low population density in this area.

C.2.2.8 Wadi Hubabah/Wadi Ar Riashiyah (Map C.6)

Wadi Hubabah is mainly irrigated by small perennial streams, Wadi Ar Riashiyah by wells. The streams are divided among the villages according to an old local tradition.

The water quality is good and farmers are trying out new crops. The acreage under maize is expanding: as reasons the local people mention the duration of the growing season, the taste, and the high market price. Wadi Hubabah suffers from termites, which not only attack the crops (especially sorghum), but also the houses; there were a lot of termitaries. The people in Wadi Hubabah dislike interference; they want to be left on their own.

The total gross irrigated area in both wadis is 108 ha, which can be expanded, as far as soil quality is concerned, to 154 ha (see also Map C.6).

C.2.2.9 Wadi Dhi Na'im (Map C.7)

The water quality for agriculture is in most areas very good to reasonable. West of Al Mingatah there are saline soils, which are not cultivable; desalinization may be effected by applying sufficient quantities of good-quality irrigation water. Also the water availability per well is good; water shortage occurs very seldom. This water availability and the fact that the soil is more sandy than in most other areas are probably the reasons why the total irrigation water dosage per crop is generally the highest of all areas (see also Table 23 of the Main Report). Irrigated agriculture produces good-quality crops, especially the traditional ones (alfalfa, wheat, barley, and sorghum).

Several farmers started with fruit-trees four years ago. Last summer the first fruits were picked and everybody was quite enthusiastic. Unfortunately those farmers lack experience and information is scarce, so that not everyone was successful.

C.2.2.10 Abbas (Map C.8)

The water quality of the wells is always very good in this area. As can be seen from Table C.1 this area has quite a different cropping pattern: cereals are never irrigated, almost all irrigated crops being cash crops produced for the Rada suq.

Irrigated agriculture is very recent. Most wells have been constructed during the last five years, the main motive being qat cultivation. Trials have been made with other crops. Very remarkable is the cultivation of tobacco: the growing season lasts nine months (including seed setting and seed ripening); during seed ripening irrigation is stopped. The tobacco was generally thought to be of excellent quality.

Onions, water-melons, sweet peppers and potatoes are also doing very well in this area. The qat is of not so excellent quality and the acreage is being reduced in favour of fruit-trees.

There are some crop diseases, but only very local: the farmers are familiar with plant protection measures and in case of serious problems they call in the assistance of the RIRDP project in Rada.

C.3 Irrigation practices

C.3.1 Irrigation water supply

In Table C.4 the irrigation water distribution systems prevailing in the areas surveyed are presented. Shallow wells combined with either pipelines plus earthen ditches or earthen ditches only are the most common feature.

C.3.2 Irrigation systems

In Al Bayda Province two main irrigation systems can be distinguished: basin irrigation and furrow irrigation.

(i) Basin irrigation

The irrigated plots are usually subdivided in small, flat basins. The size of those basins differs, but is usually about 4 x 4 m. The separate basins are supplied by furrows which cross the plots.

Table C.4 - Irrigation water-supply in the areas covered by the agricultural survey

Source of supply	Method of water conveyance	Distribution system	Examples
Surface water:			
Springs	Gravitational	Earthen ditches	Wadi Tha (Rada Basin)
	Pumped	Earthen ditches	
Perennial streams	Gravitational	Earthen ditches	Wadi Hubabah
	Pumped	Earthen ditches	
		Pipelines + earthen ditches	
Groundwater:			
Shallow wells	Pumped	Earthen ditches	Rada
		Pipelines + earthen ditches	Al Bayda North-East
		Pipelines	Sabah
Deep boreholes	Pumped	Earthen ditches	Rada
		Pipelines + earthen ditches	Qat area near Al Jayf
		Pipelines	

The basins may be irrigated separately, but also in clusters. After a basin has got its dosage of irrigation water, i.e. a certain water-level has been reached in the basin(s), the inlet is closed with soil and the farmer continues with the next basin(s).

This method of irrigation is very suitable for small discharges and easy to manage for farmers who have little experience with irrigation. This is the main method of irrigation in Al Bayda Province. Predominantly basin-irrigated crops are alfalfa, qat, sorghum, wheat, barley, onion, and fruit-trees.

(ii) Furrow irrigation

The irrigated plots are subdivided by furrows of about 50 cm width at an interval of about 1 m. The crops are planted on both sides of the furrows or sometimes in the furrows. The length of the furrows differs (depending on plot size and discharge), but is normally about 35 m. Each furrow is irrigated individually. Generally the discharge is a little higher than for basin irrigation.

This method of irrigation requires more skill from the farmer, as it is more difficult to distribute the irrigation water evenly over the plot. Predominantly furrow-irrigated crops are water-melon, tomato, potato, tobacco, and sweet pepper.

Intermediate forms of the two systems also occur.

C.3.3 Irrigation frequency

In Table C.5 the average intervals of irrigation applications and the prevailing range in those intervals for the crops grown are given. If the average intervals are compared with the intervals used in Wadi Dhi Na'im and Abbas (see Volume IV, Appendix III, Tables III.17-20) there is a remarkable difference: in the latter areas the intervals are generally shorter (except for fruit-trees in Abbas and alfalfa in Wadi Dhi Na'im) and, consequently, the irrigation frequency is higher.

Table C.5 - Irrigation intervals and their range in the areas covered by the agricultural survey

Crop	Average interval (days)	Interval range (days)
Alfalfa	9	7-14
Sorghum	20	14-30
Wheat	16	14-30
Barley	16	14-30
Potato	20	14-30
Maize	17	14-30
Qat	41	30-60[1]
Onion	9	7-14
Melon	10	7-14
Fruit-trees	25	14-60[1]
Vegetables + other crops	9	5-30[2]

[1] When only recently planted, the root system has not fully developed yet, and so requires shorter irrigation intervals.
[2] This range is so wide because of the variety of crops which are included under this common denominator (e.g. tomato, tobacco, sweet pepper, lentil), which all have different intervals.

C.3.4 Irrigation efficiency

The irrigation efficiencies of the areas covered by the agricultural survey are studied on the basis of the alfalfa figures, because:

- alfalfa is a perennial crop; there is no problem in determining the exact growing season: harvesting and irrigation take place year-round. Besides, there are experimental data available about the crop factors of alfalfa which can be averaged to one crop factor for the whole year;
- most farmers grow alfalfa and the crop occurs in all the areas covered by the survey.

In Table C.6 the net requirements of alfalfa are given, calculated from the Penman evapotranspiration figures of Al Khabar multiplied by the overall crop factor of alfalfa (0.90) (Doorenbos & Pruitt, 1977). Rainfall data are not considered because the rainy season is excluded from the irrigation period.

For the study of the irrigation efficiencies of alfalfa only the cases where wells are reliable and water dosages are exceeding the net requirements are included. In case of underirrigation the effect of water saving through underirrigation is contrary to the amount of water wasted through deep percolation losses: to be able to determine irrigation efficiency in such a case more data would have to be collected, e.g. on

Table C.6 - Net requirements of alfalfa

	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Penman evapotranspiration ETo (mm)	185	188	194	192	233	250	209	183	190	200	180	182	2386
Crop factor K_c	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	
Net requirements (mm)	167	169	175	173	210	225	188	165	171	180	162	164	2149

the well discharge, the discharge at field inlet and how evenly the water is distributed over the plots; however, such data were not collected during the survey.

In Table C.7 the calculated irrigation efficiencies and their range are presented for the areas covered by the survey. For the wells considered the efficiency rates are low to moderate. There seems to be scope for improvement of irrigation practices by reducing deep percolation losses.

Table C.7 - Irrigation efficiencies of alfalfa and their range (%)

Area	Wells included[1]	Average irrigation efficiency	Range of irrigation efficiencies
Rada Basin	67	62	46-89[2]
Sabah/Ar Riashiyah	50	66	56-80
Al Bayda North-East	56	66	43-95[2]
Al Bayda West	71	49	43-78
Wadi Juban	60	56	48-67
Wadi Mansur/Wadi Amad	100	77	69-87[2]
Wadi Matar/Wadi Ar Rin	67	42	41-44
Wadi Hubabah/Wadi Ar Riashiyah	75	54	47-63
Wadi Dhi Na'im	50	42	36-52
Abbas	100	69	55-87[2]

[1] Water dosages > 2149 mm and reliable supply.
[2] The high efficiencies are probably the result of underirrigation.

C.3.5 Additional measurements

In some areas additional measurements regarding soil water availability and infiltration rates were carried out. In Table C.8 the average water availability (in weight percentage of dry soil) and the range are given.

Table C.8 - Soil water availability in some areas surveyed (in weight percentage)

Area	Average water availability	Range	Number of samples
Rada Basin	24.9	22.3-30.0	5
Wadi Juban	17.1	12.8-19.5	8
Wadi Mansur	14.6	8.7-19.5	4
Wadi Matar	24.1	22.3-25.8	2
Wadi Ar Riashiyah	26.4	24.3-28.5	2
Wadi Dhi Na'im	18.2	-	1

The water availability in the areas Wadi Juban, Wadi Mansur, and Wadi Dhi Na'im is clearly less, which might have been expected because of their light-textured soils. For determination of water availability in volume percentage additional measurements would have to be carried out.

In Rada Basin a soil sample was taken out of an alfalfa field just before irrigation, and another one of the same plot, but in another basin which had been irrigated the day before. The 'dry' soil sample had a water availability of 11.4 %, while the 'wet' soil sample had a water availability of 23.4 %, so the soil was depleted by 12 %, which is 51 % of the total water availability.

In the areas Wadi Mansur, Wadi Matar and Rada Basin also a single infiltration measurement was carried out. The basic infiltration rates measured were 384 mm/day, 640 mm/day, and 720 mm/day, respectively. Since the number of measurements is so small, they form a rough indication only; more infiltration measurements would have to be carried out (preferably with a (single) ring-infiltrometer) for a complete picture of the infiltration rates of the soils in the different areas.

Summarizing, for more exact data about irrigation practices additional measurements are required. Especially a thorough soil survey in Al Bayda Province would be very valuable.

C.4 Land resources

By means of aerial photographs and field observations the gross irrigated areas were plotted on maps with the same scale as the aerial photographs. Those maps were subsequently enlarged to a proper scale (1:20 000 or 1:25 000) by means of a photographic procedure and epidiascope. On the maps a division was made into subareas: a subarea was chosen in such a way that it formed a unity (a side wadi or a part of a main wadi), for each of which the acreages of the catchments, alluvium, and gross irrigated areas were determined with the aid of a Digitizer.

In Tables C.9 to C.16 the net irrigated areas are calculated by multiplying the figures of the gross irrigated areas by a factor. This factor takes into account the infrastructure (which is assumed to be 15 %) and short-term fallow (which is also assumed to be 15 %).

The net irrigable land of a subarea is determined by the acreage of the alluvium multiplied by a reduction factor. This reduction factor takes into account an estimated proportion of the alluvium considered suitable for cultivation (saline soils, too shallow alluvium, and relatively high elevated alluvium are considered non-suitable) and the infrastructure.

The irrigation requirements are calculated with the figures of the net irrigable land and the figures giving the crop water requirements per hectare for the selected areas (see Table 29 of the Main Report).

The column 'available for irrigation' was calculated by the hydrological section (see Annex B).

The 'water available for irrigation' in relation to the 'water requirements' (both per subarea) provides the proportion of irrigable land which can actually be irrigated. After deduction of the 'net irrigated area' at present, the 'incremental irrigation potential' is arrived at.

Table C.9 - Irrigation potential Rada Basin

Subarea	Alluvium (ha)	Presently irrigated		Net irrigable land (ha)	Irrigation requirement[2] ('000 m^3)	Available for irrigation ('000 m^3)	Incremental irrigation potential (ha)
		Gross (ha)	Net[1] (ha)				
RA-A	195	32	23	99	1 198	> 1 198	76
-B	38	0	0	0	0	0	0
-C	54	0	0	0	0	0	0
-D	60	11	8	23	278	300	15
-E	190	57	41	81	980	981	40
RB	314	41	29	107	1 295	521	14
RC-A	100	14	10	59	714	300	15
-B	76	7	5	32	387	150	7
-C	180	29	21	107	1 295	405	12
RD-A	69	0	0	15	182	50	4
-B	96	6	4	25	303	76	2
-C	300	13	10	178	2 154	750	52
-D	176	37	27	90	1 089	776	37
-E	317	39	28	135	1 634	631	24
RE	189	68	49	96	1 162	> 1 162	47
RF	234	39	28	99	1 198	710	31
RG	131	0	0	17	206	> 206	17
RH	215	0	0	110	1 331	700	58
RI	600	124	89	408	4 937	1 423	29
RJ	182	7	5	77	932	44	0
RK	197	3	2	117	1 416	150	10
RL	58	16	11	35	424	216	7
RM	1 042	220	159	664	8 034	2 498	47
RN	23	14	10	12	145	> 145	2
RO	524	183	132	267	3 231	> 3 231	135
RP	295	39	28	201	2 432	918	48
RQ	89	5	4	38	460	250	17
RR	843	350	253	609	7 369	3 665	50
RS	150	7	6	64	774	> 774	58
RT-A	611	60	43	311	3 763	868	29
-B	n.a.	3	2	4	48	> 0	0
RU-A	156	45	32	106	1 283	0	0
-B	n.a.	4	3	4	48	3	0
-C	urban	0	0	0	0	0	0
RV	881	249	180	600	7 260	2 025	0
RW	556	113	82	236	2 856	1 147	13
RX	485	41	30	206	2 493	460	8
RY	728	70	51	155	1 876	376	0
RZ-A	506	31	22	172	2 081	913	53
-B	n.a.	0	0	0	0	0	0
ZA	953	22	16	648	7 841	626	36
Total	11 813	1 995	1 443	6 207	75 119	> 28 648	993

n.a. = not available.

[1] Gross area reduced by 15 % for infrastructure and another 15 % for short-term follow.

[2] On the basis of Table 29 of the Main Report an average of 1210 mm per hectare has been adopted as irrigation over a full year in Rada Basin.

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Table C.10 - Irrigation potential Al Bayda North-East[1]

Subarea	Alluvium (ha)	Presently irrigated		Net irrigable land (ha)	Irrigation requirements[3] ('000 m^3)	Available for irrigation ('000 m^3)	Incremental irrigation potential (ha)
		Gross (ha)	Net[2] (ha)				
BA	159	6	4	40	554	200	10
BB	124	16	12	26	360	95	0
BC	147	37	27	94	1 303	825	33
BD	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
BJ	326	42	31	139	1 927	870	32
BK	384	60	44	163	2 259	860	18
BL	179	39	28	84	1 164	585	14
BM	550	44	31	281	3 895	> 700	20
Total	1 869	245	177	827	11 462	> 4 135	> 127

n.a. = not available.
1 As far as covered by the aerial photographs.
2 Gross area reduced by 15 % for infrastructure and another 15 % for short-term fallow.
3 On the basis of Table 29 of the Main Report an average of 1386 mm per hectare has been adopted as irrigation over a full year in Al Bayda North-East.

Table C.11 - Irrigation potential Al Bayda West[1]

Subarea	Alluvium (ha)	Presently irrigated		Net irrigable land (ha)	Irrigation requirements[3] ('000 m^3)	Available for irrigation ('000 m^3)	Incremental irrigation potential (ha)
		Gross (ha)	Net[2] (ha)				
BE	350	9	6	253	3 054	455	37
BF[1]	(159)	(36)	(26)	n.a.	n.a.	(890)	n.a.
BG[1]	(204)	(25)	(18)	n.a.	n.a.	(1 005)	n.a.
BH	170	69	50	108	1 304	840	20
BI	n.a.	10	7	n.a.	n.a.	n.a.	n.a.
Total	883	149	107	361	4 358	3 190	> 57

n.a. = not available.
1 As as far as covered by the aerial photographs.
2 Gross area reduced by 15 % for infrastructure and another 15 % for short-term fallow.
3 On the basis of Table 29 of the Main Report an average of 1207 mm per hectare has been adopted as irrigation over a full year in Al Bayda West.

Table C.12 - Irrigation potential Juban

Subarea	Alluvium (ha)	Presently irrigated		Net irrigable land (ha)	Irrigation requirements ('000 m^3)	Available for irrigation[2] ('000 m^3)	Incremental irrigation potential (ha)
		Gross (ha)	Net[1] (ha)				
JA	105	27	19	67	659	335	15
JB	144	30	22	92	905	283	7
JC	111	8	6	71	699	250	19
JD	127	55	40	81	797	240	0
JE	55	0	0	35	344	100	10
JF	74	30	22	44	433	436	22
JG	28	8	5	18	177	100	5
JH	24	2	1	12	118	100	9
JI	66	24	17	42	413	208	4
JJ	90	25	18	46	453	209	3
JK	64	18	13	41	403	110	-
JL	115	19	13	59	581	175	5
JM	14	2	1	9	89	> 89	8
JN	89	2	1	46	453	13	0
JO-A	54	3	2	46	453	50	3
-B	50	0	0	21	207	0	0
JP	45	1	1	23	226	14	0
JQ	63	24	18	32	315	150	0
JR	21	0	0	7	69	30	3
JS	52	0	0	22	216	20	2
JT	8	4	3	4	39	20	0
Total	1 395	280	202	818	8 049	> 2 932	115

[1] Gross area reduced by 15 % for infrastructure and another 15 % for short-term fallow.
[2] On the basis of Table 29 of the Main Report an average of 984 mm per hectare has been adopted as irrigation over a full year in Juban.

Table C.13 - Irrigation potential Wadi Mansur/Wadi Amad[1]

Subarea	Alluvium (ha)	Presently irrigated		Net irrigable land (ha)	Irrigation requirements[3] ('000 m^3)	Available for irrigation ('000 m^3)	Incremental irrigation potential (ha)
		Gross (ha)	Net[2] (ha)				
MA	658	85	62	224	3 364	560	0
MB	461	16	11	157	2 358	175	1
MC	545	16	12	185	2 779	120	0
MD (Wadi Amad)	(396)	(137)	(99)	(269)	(4 040)	-	-
ME	310	46	33	105	1 577	165	0
MF	154	58	42	52	781	175	0
MG	-	-	-	-	-	-	-
MH	378	38	28	128	1 923	285	0
MI	231	43	31	78	1 172	300	0
MJ	41	14	10	17	255	45	0
MK	83	28	20	35	526	118	0
ML	193	27	19	74	1 111	425	9
MM	359	36	26	122	1 832	200	0
MN	110	19	14	65	976		0
MO	202	34	25	173	2 598	50	0
Total (Wadi Mansur only)	3 725	460	333	1 415	21 252	2 618	10

[1] In fact Wadi Mansur only, since the survey of Wadi Amad was incomplete.
[2] Gross area reduced by 15 % for infrastructure and another 15 % for short-term fallow.
[3] On the basis of Table 29 of the Main Report an average of 1487 mm per hectare has been adopted as irrigation over a full year in Wadi Mansur.

Table C.14 - Irrigation potential Wadi Matar/Wadi Ar Rin[1]

Subarea	Alluvium (ha)	Presently irrigated		Net irrigable land (ha)	Irrigation requirements[3] ('000 m^3)	Available for irrigation ('000 m^3)	Incremental irrigation potential (ha)
		Gross (ha)	Net[2] (ha)				
TA*	435	3	2	129	2 461	300	14
TB*	74	9	7	22	420	86	0
TC*	145	0	0	43	820	200	10
TD*	308	19	13	79	1 507	193	0
TE*	180	2	1	46	878	100	4
TF*	85	0	0	25	477	0	0
TG*	17	1	1	7	134	39	1
TH*	421	0	0	n.a.	n.a.	0	n.a.
TI	59	0	0	15	286	21	1
TJ	125	0	0	53	1 011	100	5
TK	233	0	0	99	1 889	0	0
TL	39	14	10	26	496	n.a.	n.a.
TM	82	0	0	24	458	n.a.	n.a.
TN	151	n.a.	n.a.	38	725	n.a.	n.a.
TO	42	0	0	n.a.	n.a.	n.a.	n.a.
TP	68	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
TQ	23	0	0	n.a.	n.a.	0	n.a.
R	74	0	0	22	420	n.a.	n.a.
S	36	n.a.	n.a.	11	210	140	8
T	326	n.a.	n.a.	139	2 652	n.a.	n.a.
Total (Wadi Matar only)	1 665	34	24	351	6 697	918	29

* Belonging to Wadi Matar. Other subareas belong to Wadi Ar Rin.
n.a. = not available.

1 In fact Wadi Matar only, since the survey of Wadi Ar Rin was incomplete.
2 Gross area reduced by 15 % for infrastructure and another 15 % for short-term fallow.
3 On the basis of Table 29 of the Main Report an average of 1908 mm per hectare has been adopted as irrigation over a full year in Wadi Matar.

Table C.15 - Irrigation potential Wadi Dhi Na'im

Subarea	Alluvium (ha)	Presently irrigated		Net irrigable land (ha)	Irrigation requirements[2] ('000 m^3)	Available for irrigation ('000 m^3)	Incremental irrigation potential (ha)
		Gross (ha)	Net[1] (ha)				
DA-A	104	2	2	35	494	89	4
-B	51	0	0	17	240	50	4
-C	141	53	38	84	1 184	684	11
DB	165	40	29	105	1 481	568	11
DC	84	19	14	46	649	371	12
DD	125	14	10	85	1 199	260	8
DE	188	20	15	104	1 466	318	8
DF	85	24	17	58	818	250	1
DG	112	2	1	57	804	200	13
DH-A	146	31	22	68	959	573	19
-B	53	3	2	14	197	129	7
-C	29	0	0	10	141	50	4
-D	43	0	0	11	155	100	7
-E	43	0	0	11	155	50	4
-F	69	8	5	38	536	44	0
DI	42	27	20	29	409	saline	0
Total	1 480	241	175	772	10 887	3 736	113

1 Gross area reduced by 15 % for infrastructure and another 15 % for short-term fallow.
2 On the basis of Table 29 of the Main Report an average of 1410 mm per hectare has been adopted as irrigation over a full year in Wadi Dhi Na'im.

Table C.16 - Irrigation potential Abbas

Subarea	Alluvium (ha)	Presently irrigated		Net irrigable land (ha)	Irrigation requirements[2] ('000 m^3)	Available for irrigation ('000 m^3)	Incremental irrigation potential (ha)
		Gross (ha)	Net[1] (ha)				
AA	93	10	8	40	510	237	11
AB	123	0	0	52	662	100	8
AC	390	20	14	265	3 376	213	3
AD	26	0	0	7	89	50	4
AE	34	0	0	9	115	30	2
Total	666	30	22	373	4 752	630	28

[1] Gross area reduced by 15 % for infrastructure and another 15 % for short-term fallow.
[2] On the basis of Table 29 of the Main Report an average of 1274 mm per hectare has been adopted as irrigation over a full year in Abbas.

APPENDICES

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APPENDIX C.I
WATER RESOURCES SURVEY IN THE GOVERNORATE OF AL BAYDA

1) Well number ____ Date ___________, 1983.
2) Village ______________ Wadi ______________ Catchment __________
   Distance to village _____ m Direction to village ____ °
3) Agricultural characteristic of the wadi _________________________

4) Observations on wadi concerned:
   - Halophytic vegetation or other signs of salinity? yes/no
   - Signs of waterlogging? yes/no
   - Soil quality otherwise (sandy?) _____________________
5) Presently irrigated in wadi as compared to aerial photo ____ %
   Reason for change _____________________________
6) Farmer is tenant/owner of the land. Owner of the well yes/no
7) Water measurements: Pump capacity _____ l/sec. EC _____ Ph _______
   Limitation in pumping? yes/no
8) Water use:
   - Water pumped also for domestic use? yes/no ___ hours; interval ___ days.
   - Water also pumped for irrigation by others? yes/no
9) Irrigation water use:

Crop	Winter 1982/'83			Summer 1983		
	Area (in m^2)	Irrigation		Area (in m^2)	Irrigation	
		Hours per time	Interval[1] (days)		Hours per time	Interval[1] (days)
Alfalfa (berseem)						
Sorghum						
Wheat						
Barley						
Maize						
Qat						
Onions						
Melons						
Others[1]						
Others[2]						

[1]) Interval in absence of rains.

10) <u>Irrigation water losses</u>:
- infiltration rate __________ mm/day (measured)
- surface water losses __________ l/sec measured/estimated

Rada, 14 April 1983

REFERENCES

Doorenbos, J., and Pruitt, W.O., 1977.
Guidelines for predicting crop water requirements (revised). FAO Irrigation and drainage paper no. 24. Rome, Italy.

Ilaco, 1982.
Report on farming systems research survey in Wadi Tha. Rada' Integrated Rural Development Project, Technical Note No. 9. Arnhem, The Netherlands.

Ilaco, 1983.
Report on farming systems research survey in Wadi Mansur. Rada' Integrated Rural Development Project, Technical Note No. 13. Arnhem, The Netherlands.

ANNEX D
ECONOMICS
OF IRRIGATED
CROP PRODUCTION

ANNEX D - ECONOMICS OF IRRIGATED CROP PRODUCTION

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ANNEX D
ECONOMICS OF IRRIGATED CROP PRODUCTION

D.1 Introduction

D.1.1 General

There are three sources of irrigation water in Al Bayda, viz. surface water, springs, and wells. Both surface water resources and springs are limited, and the main source of water for irrigation has always been groundwater exploitation. Traditionally, groundwater was abstracted from numerous dug shallow wells spread throughout the province. In recent years, however, groundwater development has been largely dependent on the construction of boreholes or deep tubewells.

This annex provides an analysis of the economics of groundwater exploitation for irrigation by shallow wells and boreholes. It investigates the returns to irrigation per crop and per cropping pattern prevailing in the various areas selected for the study. By setting the returns against the cost of pumping, an indication can be given of the economics of irrigated agriculture in Al Bayda Province.

To our knowledge, this analysis is the first attempt undertaken in Al Bayda Province and probably in all Yemen to quantify the cost and returns to irrigation. Especially with respect to returns, there are hardly any data available. Irrigation water can be valued in terms of crop returns, that is the net values from irrigated crop production which are obtained by deducting from the product's gross proceeds the cost for mechanization, materials, labour etc. To obtain information on these aspects systematic studies need to be undertaken of farm economics, yield and input levels, and prices of products and inputs, resulting, for instance, in the computation of crop budgets. The RIRDP has recently made a start with farming system research and production economics surveys, but establishment of a reliable data base takes years and the information presently available is therefore limited.

The figures on crop returns presented in this report are based on these surveys, complemented with information from interviews held in the course of this study with agricultural extension staff and farmers. We do not claim accuracy but we believe that the figures presented are at least of the right order of magnitude. With respect to the cost of irrigation, the RIRDP has a wide experience in the construction of boreholes and the cost estimates of tubewells are believed to be reliable.

D.1.2 Basic assumptions

By analysing the cost of and returns to irrigation it will be possible to give an indication in economic terms of the scope for development of irrigated agriculture in Al Bayda Province. An attempt will also be made to assess a critical pumping depth below which pumping becomes unprofitable. The analysis will be done in financial terms.

using average values. It is important that the consequences of this method be stated clearly at the outset.

Firstly, the use of average values instead of marginal values means that no attempt has been made to introduce crops or design cropping patterns which will maximize agricultural benefits. Such an exercise requires a much more detailed knowledge of crop production potentials, input-output coefficients, prices, markets and development constraints than is currently available. We also believe that cropping patterns will not drastically change in the short run. This study is therefore limited to an analysis of the present situation using the very rough data provided by the RIRDP and obtained from interviews with farmers and extension agents as mentioned above.

A second consideration concerns the use of financial prices in the analysis. Financial prices rarely reflect the real scarcity of goods and resources and almost certainly do not reflect the socio-economic development goals of the country. It is therefore conceivable that irrigated agricultural production may seem financially attractive, while from the economic point of view of the society as a whole or in terms of the country's employment, income distribution and regional development objectives, it will be unacceptable or vice versa. It is, however, beyond the scope of this study to try to assess appropriate weights and development criteria which incorporate the economic conditions and socio-economic goals of the country. With the assessment of financial efficiency at least a start is made with evaluating the scope for irrigation development in Al Bayda. When more data become available, the method can be refined in follow-up studies.

One more aspect should be mentioned in this respect. The rural economy of Al Bayda, as in many other parts of Yemen, is still strongly subsistence-oriented, especially with respect to the production of staple grains and livestock products. The purpose of production is not sale but own use, and farmers are willing to spend quite a large amount (in cash) on producing crops for their own consumption. In this analysis, subsistence crops have been valued at prevailing market prices; their social values might be different, but to what extent is not known and would require further research.

We have elaborated on the above issues so as to make it clear that the results of the present economic analysis should not be regarded as the last word in judging whether or not and to what extent there is economic potential for irrigation development in Al Bayda. The results, however, help establish a base for the assessment of development possibilities and help indicate the direction future studies and research in economics and agriculture should take.

D.2 Returns to irrigation

The most direct measure of the value of irrigation water is its selling price. In most cases, irrigation water is used by the well owner himself or paid for in kind through share-cropping arrangements in which the land/well owner and the farmer take - usually equal -

shares of the yield. However, selling of water for agriculture does take place, and in Al Bayda water prices have been reported to range from YR 10 to YR 50 per hour. For certain crops such as qat the price may go up to YR 100 per hour.

These wide variations are explained by one or a combination of the following aspects: kinship or tenure relationships between seller and buyer, the type of crops (cash crop or food crop), the source of water (spring, shallow well or tubewell), and the number of wells, that is the availability of irrigation water. Because of these distortions, we believe that the selling price of water does not accurately reflect its actual value. In this report, the value of irrigation water is measured in terms of net crop returns. Crop budgets of the main crops are calculated, which are then set against the crop water requirements and weighted for the prevailing cropping patterns to obtain an average value per unit of water.

D.2.1 Yields and farm inputs

Table D.1 summarizes the estimated yields and input levels for the main crops. These are average figures for Al Bayda Province, estimated on the basis of interviews with farmers and extension personnel and on the basis of results of the Al Khabar research farm and farmers' demonstration plots. Furthermore, the estimates have been cross-checked with the results of the farming system research surveys in Wadi Tha (Ilaco, 1982) and Wadi Mansur (Ilaco, 1983) and the sorghum production survey in Wadi Tha (RIRDP, 1983).

Table D.1 - Yields and input levels by crop

	Alfalfa	Sorghum	Wheat/ Barley	Maize	Qat	Water- melon	Potato
Yield (t/ha)							
main product	60	2.5	2.5	3.5	[1]	20	15
by-product		[2]	3	[2]			
Seed (kg/ha)	[3]	16	120	16	[4]	[5]	3000
Fertilizer (kg/ha)		25	25	25	200	50	50
Agro-chemicals (YR/ha)						300	
Labour (days/ha)	350	100	80	100	500[6]	150	250
Tractor (h/ha)[7]	6	18	18	18	11	18	18
Animal (days/ha)		11	8	11			

Notes: [1] 20 000 bundles.
[2] 1500 bundles of stalk and leaves.
[3] YR 100/ha.
[4] YR 30 000/ha.
[5] YR 100/ha.
[6] 2 permanent labourers.
[7] Alfalfa and qat are perennial crops and tractor hours as well as seed requirements are average annual figures for a period of respectively 3 and 5 years.

The main activities include land preparation, sowing, cultivation (weeding, application of fertilizer and agro-chemicals, and irrigation) and harvesting and post-harvesting operations. Farming practices are dealt with in Annex C and only some salient points will be mentioned here. In most parts of Al Bayda, tractors have replaced draught animals for the preparation of land, which usually includes one ploughing and two harrowings. The number of tractor hours is very high due to the small size of the plot and the inexperience of the drivers. Draught animals (camels, oxen or donkeys) are used for the sowing of sorghum and wheat and for weeding, which is usually combined with ridging. The use of fertilizer for wheat and sorghum production varies widely, ranging from no application to some 8 bags/ha. Qat and vegetables use more fertilizer than cereals, which is reflected in the average figures in Table D.1. In addition, manure is given but this could not be quantified.

There are no records whatsoever on farm labour input, and the data presented here should be regarded as indicative only. Migration has affected both the availability of farm labour and its price. The shortage of manpower has increased the participation of women in crop production. Typical women's tasks include harvesting and post-harvesting operations. Typical men's tasks are land preparation, planting, irrigation, and ridging, although the men may also help in other activities.

Hired labour is difficult to obtain and expensive, with wages varying from YR 40 to YR 70 per day over the year. For the report, an average wage of YR 50 has been adopted. In addition to availability and price of labour, there are of course other factors influencing the extent of employment of hired labour, e.g. size of the holding, size and composition of the household, and socio-economic factors such as level of cash income from non-farm activities. It has been observed that in food and fodder crop production most work is done by the family. If employed, hired labour is used mainly for land preparation, sowing and ridging in combination with the use of tractors or draught animals. In vegetable cash crops such as onion and water-melon, the contribution of hired labour in the total farm labour input is usually higher, while for the production of qat nearly all work is done by hired labour, with the farmer having a supervisory task. In order to indicate the actual labour cost paid by the farmer, it has been roughly calculated that for the production of alfalfa, sorghum and wheat, hired labour constitutes 20 % of the total farm labour input. For onion, potato and water-melon, this proportion is in the order of 50 %; for qat, it has been assumed that all farm work is done by hired labour.

The yields have been derived from a variety of sources, including the results of agricultural research, demonstration plots, interviews with farmers, and the consultants' own observations. They have furthermore been cross-checked with the average crop water dosages found in the agricultural survey (see Annex C) and while no accuracy can be claimed, they are considered to reflect reasonably well the present levels obtained in the province.

In Table D.2, the yield estimates used in this study are compared with the 1980/81 yield levels for Al Bayda Province found in the Agricultural Census (Ministry of Agriculture, 1983). In addition to grains, sorghum and maize produce stalks and leaves for fodder, which are harvested separately. Wheat straw is locally used in brick-making.

Table D.2 - Comparison of yield levels in Al Bayda Province (t/ha)

Crop	Consultants (1982/83)	Agricultural Census (1980/81)
Alfalfa	60	33.1
Sorghum (grain)	2.5	2.7
Wheat (grain)	2.5	2.4
Barley	2.5	1.6
Maize	3.5	3.9
Qat, bundles	20 000	-
Water-melon	20	34.7
Potato	15	20.8

D.2.2 Prices and crop budgets

The prices of the major farm inputs and outputs are summarized in Table D.3. The prices have been derived from information collected in the Rada and Al Bayda markets and from interviews with farmers. If the basis is a market price for produce, a reduction of 20-25 % has been applied to arrive at farmgate prices. The consumer preference for locally grown products explains the high prices that can be obtained. For example, the market price of local wheat is about 50 % higher than that of imported North American wheat. For qat, a conservation price estimate has been adopted. If the produce is of high quality, or sold in the off-season, prices may be considerably higher.

On the basis of Tables D.1 and D.3, crop budgets have been calculated. The results are given in Table D.4. The figures represent total production values. As discussed in Section D.1.2, these values are not identical to cash incomes because of the large proportion of home consumption.

Net values have been calculated with and without labour costs, and with hired-labour costs only. The latter will be used as the basis for further calculations as they include the costs which are actually incurred by the farmer.

As can be expected, qat is the most profitable crop. The traditional staple food crops are the least profitable. Table D.5 gives the net returns per labour day. It is shown that for all crops the net returns per labour day (before deduction of water costs) are higher than the prevailing rate of YR 50 per day.

Table D.3 - Farmgate prices of agricultural products and inputs

Products/inputs	Unit	Unit price (YR)
Alfalfa	bundle (1.5 kg)	0.8
Sorghum - grain	kg	2.5
Sorghum/maize - stalks and leaves	bundle	2
Wheat/barley - grain	kg	3
Wheat/barley - straw	kg	0.3
Maize - grain	kg	2.5
Qat	bundle	15
Potato	kg	3
Water-melon	kg	2
Sorghum seed	kg	3
Wheat/barley seed	kg	3.5
Maize seed	kg	3.0
Potato seed	kg	4
Fertilizer (urea)	50 kg	70
Labour	man-day	50
Tractor	hour	70
Animal traction	day	150

Table D.4 - Crop budgets (YR/ha)*

	Alfalfa	Sorghum	Wheat/ Barley	Maize	Qat	Water-melon	Potato
Gross value:							
Main product	32 000	6 250	7 500	8 750	300 000	40 000	45 000
By-product	-	3 000	900	3 000	-	-	-
Total gross value	32 000	9 250	8 400	11 750	300 000	40 000	45 000
Costs:							
Seed	100	50	420	50	30 000	100	12 000
Fertilizer		40	40	40	280	70	70
Agro-chemicals							300
Labour	17 500	5 000	4 000	5 000	60 000	7 500	12 500
Tractor	420	1 260	1 260	1 260	770	1 260	1 260
Animal		1 650	1 200	1 650			
Other					9 000***		
Total costs	18 020	8 000	6 920	8 000	100 050	9 230	25 830
Net value, incl. labour cost	13 980	1 250	1 730	3 750	199 950	30 770	19 170
Net value, excl. labour cost	31 480	6 250	5 730	8 750	259 950	38 270	31 670
Net value, incl. hired labour costs**	27 980	5 250	4 930	7 750	199 950	34 520	25 420

Notes: * Figures rounded off to nearest YR 10.
** Estimated percentage hired labour of total labour input:
alfalfa, sorghum, wheat, barley and maize - 20 %
qat - 100 %
water-melon, potato - 50 %.
*** Depreciation of pipes, fence and watch-tower.

Table D.5 - Net returns per labour day

	Alfalfa	Sorghum	Wheat/ Barley	Maize	Qat	Water-melon	Potato
Net returns per ha (YR)	31 480	6 250	5 730	8 750	259 950	38 270	31 670
Labour days per ha (man-days)	350	100	80	100	500	150	250
Net returns per labour day (YR)	90	63	72	88	520	255	127

D.2.3 Returns to cropping patterns

Average cropping patterns for each of the selected areas are given in Annex C. In Tables D.6 and D.7 the crop net returns are weighted for these cropping patterns. The net returns per ha thus obtained range from about YR 20 500 in Wadi Dhi Na'im to about YR 113 000 in Abbas and YR 153 000 in the qat area of Rada Basin. For the province as a whole, the average value is of the order of YR 70 000 per ha.

This very high value, as well as the variations between the areas, is largely explained by the proportion of qat in the cropping pattern. Qat, which has net returns of nearly YR 200 000 per ha as shown in Table D.4, is prominent in Rada Basin, Wadi Juban, Wadi Hubabah/ Wadi Ar Riashiyah and Abbas but less so in the other areas.

Set against irrigation requirements, the net returns of each crop and cropping pattern can be calculated per m^3 of water. This will be done in Section D.4.

D.3 Costs of irrigation

D.3.1 Investment costs

The investment costs of wells consist of two components, viz. well construction, and pump, engine, ancillary structures, and equipment. The unit costs are presented in Table D.8; these are based on RIRDP contracts and quotations of local agencies. The distribution system generally consists of simple, hand-made, earthen field channels and bunds which need restoration every year as part of the farm labour input; their cost has not been taken into account. Qat is often irrigated by pipes and these costs as well as those for the fence and watch-tower are included in the production costs (see Table D.4).

The economic lives of a deep well (borehole) and a shallow well have been established at 30 years. For civil structures, such as the pump house, the same period has been taken. For pump, engine and ancillary equipment (pumphead and shaft) an average economic life of 10 years has been assumed.

Table D.6 - Calculation of returns per ha for the average cropping patterns

	Crop returns per ha (YR)	Rada Basin		Sabah/Ar Riashiyah		Al Bayda N.E.		Al Bayda W.		Wadi Juban		Wadi Mansur/ Wadi Amad		Wadi Matar/ Wadi Ar Rin		Wadi Hubabah/ Wadi Ar Riashiyah		Wadi Dhi Na'im		Abbas		Total	
		CI[1] (%)	Returns[2] (YR)	CI (%)	Returns (YR)	CI (%)	Returns (YR)	CI (%)	Returns (YR)	CI (%)	Returns (YR)	CI (%)	Returns (YR)	CI (%)	Returns (YR)	CI (%)	Returns (YR)	CI (%)	Returns (YR)	CI (%)	Returns (YR)	CI (%)	Returns (YR)
Alfalfa	27 980	12	3 358	12	3 358	11	3 078	5	1 399	7	1 959	14	3 917	41	11 472	4	1 119	13	3 637	3	839	10	2 798
Sorghum	5 250	35	1 838	9	473	75	3 938	60	3 150	33	1 733	39	2 048	39	2 048	63	3 308	75	3 938	-	-	44	2 310
Wheat	4 930	10	493	87	4 289	22	1 085	10	493	4	197	21	1 035	31	1 528	7	345	22	1 085	-	-	16	789
Barley	4 930	1	49	-	-	24	1 183	16	789	-	-	1	49	-	-	6	296	19	937	1	49	8	394
Maize	7 750	-	-	6	465	1	78	-	-	12	930	9	698	-	-	17	1 318	6	465	-	-	3	233
Qat	199 950	41	81 980	3	5 999	8	15 996	14	27 993	51	101 975	5	9 998	6	11 997	30	59 985	4	7 998	44	87 978	28	55 986
Potato	25 420	1	254	54	13 727	6	1 525	6	1 525	5	1 271	5	1 271	-	-	-	-	-	-	8	2 034	5	1 271
Others[3]	34 520	13	4 488	11	3 797	5	1 726	24	8 285	1	345	24	8 285	-	-	1	345	7	2 416	63	21 748	19	6 558
Total/ha			92 460		32 108		28 609		43 634		108 410		28 456		27 045		66 716		20 476		112 648		70 339

Notes: [1] CI is cropping intensity in %, rounded to nearest 1 %.
[2] Returns weighted for cropping pattern.
[3] Includes water-melon, onion, fruits, vegetables and other crops.

Table D.7 - Calculation of returns per ha cropping pattern, Rada Basin sub-areas

	Qat area		Water-melon area		Remaining area			
					Boreholes		Shallow wells	
	CI (%)	Returns (YR)	CI (%)	Returns (YR)	CI (%)	Returns (YR)	CI (%)	Returns (YR)
Alfalfa	5	1 399	2	560	15	4 197	22	6 156
Sorghum	15	788	7	368	33	1 733	41	2 153
Wheat	5	247	2	99	26	1 282	37	1 824
Barley	-	-	-	-	1	49	5	247
Maize	-	-	-	-	-	-	2	155
Qat	75	149 963	23	45 989	17	33 992	6	11 997
Potato	2	508	-	-	-	-	2	508
Others	-	-	80	27 616	17	5 868	5	1 726
Total/ha		152 905		74 632		47 121		24 766

Table D.8 - Unit costs of a well (YR)

1. Borehole	
Mobilization and de-mobilization	10 000
Drilling costs incl. development, 0-150 m	600/m
" " " " , over 150 m	850/m
Casing 10-12 inch	225/m
Cement slab	1 000
Cementation (10 m)	1 000
Testing (24 hours)	7 200
2. Shallow well	
Unconsolidated (soft) soil	500/m
Soft rock	2 000/m
Hard rock	5 000/m
Concrete lining	3 000/m
3. Pump and engine	
Pump, discharge 3- 5 l/s, head 25 m	3 000
" " " , head 50 m	5 000
" " " , head 100 m	8 000
Pump, discharge 7-10 l/s, head 25 m	3 000
" " " , head 50 m	6 000
" " " , head 100 m	12 000
Flexible shaft	700/3 m
Pumphead	3 000
Pump house	25 000
Engine incl. installation, 7 hp	7 000
" " " , 15 hp	13 000
" " " , 22 hp	17 500
" " " , 35 hp	29 000

Tables D.9 and D.10 give the investment costs of respectively boreholes and shallow wells at different well depths and water-depths. The pump discharge is kept constant at average provincial levels. While this does not affect the well construction costs, the size of pump and engine does vary with different pump discharges. However, the cost implications are minor relative to the total investment costs.

Table D.9 - Borehole investment costs ('000 YR)

Well depth (m)	Head (m)						
	10	15	20	30	40	50	60
Well construction*							
50	78	79	80	82	-	-	-
75	93	94	95	97	99	102	-
100	108	109	110	112	114	117	119
150	138	139	140	142	144	147	149
200	180	181	182	185	187	189	191
250	223	224	225	227	229	232	234
Pump and engine**	16	21	26	34	42	49	59

* Includes cost of pump house.

** At a pump discharge of 8 l/s; costs apply to all well depths and include pumphead and flexible shaft.

D.3.2 Recurrent costs

Recurrent costs include maintenance (repairs and spare parts) and fuel consumption. The cost of a pump operator has been excluded as this function is usually performed by the farmer; his labour cost is included in the farm labour input given in Table D.1. Annual maintenance costs have been estimated at 10 % of the initial investment in pump, engine and ancillary equipment (see Table D.11). This rate seems acceptable in view of the economic life assumed for the machinery. Inadequate maintenance would result in a shorter life, as is borne out by the findings of the water-supply and sanitation survey.

Fuel consumption has been estimated at 0.25 litre diesel per hour per actual horsepower (hp) used (see Table D.11). The latter is the required horsepower calculated on the basis of pump discharge and water-level (head). As shown by the hydrogeological and water-supply and sanitation surveys, the most common types of engine have capacities of 16 or 24 hp, which is generally higher than required. Farmers, therefore, overinvest in pump and engine, which is caused partly by the absence of a suitable type in the local shops and partly by the people's belief that a stronger engine will abstract more water irrespective of the well characteristics.

D.4 Costs and returns per unit of irrigation water

Table D.12 summarizes the average pump discharges and annual abstraction of wells as found by the hydrogeological survey. Nearly

Table D.10 - Shallow well investment cost ('000 YR)

Well depth (m)	Head (m)				
	5	10	15	20	30
Well construction*					
10	75	-	-	-	-
20	125	125	125	-	-
30	-	-	-	175	-
40	-	-	-	-	225
Pump and engine**					
10	8	-	-	-	-
20	10	12	14	-	-
30	-	-	-	19	-
40	-	-	-	-	24

* Includes cost of pump house.
** At a pump discharge of 5 l/s; includes costs of pumphead and flexible shaft.

Table D.11 - Maintenance and fuel costs

	Head							
	5	10	15	20	30	40	50	60
Boreholes:								
Maintenance (YR)	-	1 600	2 100	2 600	3 400	4 200	4 900	5 900
Diesel (l)[1]	-	1 570	2 616	3 663	5 233	6 802	8 372	10 465
Diesel (YR)[2]	-	2 920	4 866	6 813	9 733	12 652	15 572	19 465
Shallow wells:								
Maintenance (YR)	800-1 000	1 200	1 400	1 900	2 400	-	-	-
Diesel (l)[3]	309	618	927	1 236	1 854	-	-	-
Diesel (YR)[2]	575	1 150	1 724	2 299	3 448	-	-	-

[1] Based on 2093 hours, i.e. a pump discharge of 8 l/s and an average annual water abstraction of 60 284 m^3 (see Table D.12).
[2] At a cost of YR 1.86/l (YR 1.55/l for diesel plus 20 % for lubrication).
[3] Based on 1236 hours, i.e. a pump discharge of 5 l/s and an average annual water abstraction of 22 240 m^3 (see Table D.12).

Table D.12 - Average pump discharges, water-level depth (head) and annual abstraction of wells*

Area	Boreholes				Shallow wells			
	No.	Pump discharge (l/s)	Head (m)	Annual abstraction (m^3)	No.	Pump discharge (l/s)	Head (m)	Annual abstraction (m^3)
Rada Basin	143	8.1	32	60 284	413	5.9	14	28 644
Al Bayda	4	3.3	8	47 400	207	5.3	7	23 951
Wadi Juban	-	-	-	-	153	3.6	9	12 426
Wadi Mansur/W. Amad	3	4.0	14	14 600	140	3.6	8	12 726
Wadi Matar/W. Ar Rin	4	7.0	54	20 662	30	4.0	16	12 174
Wadi Dhi Na'im	-	-	-	-	84	5.7	10	30 062
Abbas	3	9.0	33	24 183	52	4.5	15	12 170
Weighted average	-	-	-	-	-	5.0	-	22 240

* Wells in operation only.

all boreholes are located in the Rada Basin and the average annual abstraction of 60 284 m^3 has therefore been used for calculating the costs of pumping per m^3 irrigation water. These costs are given in Table D.13 and include capital recovery - calculated as an annual annuity at 10 % over a period of 30 years for well construction costs and pump house and over a period of 10 years for pump, engine and ancillary equipment -, maintenance costs and fuel costs.

Table D.13 - Cost of irrigation water pumped from boreholes (YR/m^3)*

Well depth	Head (m)						
	10	15	20	30	40	50	60
50	0.25	0.31	0.36	0.45	-	-	-
75	0.28	0.34	0.39	0.48	0.57	0.66	-
100	0.31	0.36	0.42	0.51	0.59	0.68	0.79
150	0.36	0.42	0.47	0.56	0.65	0.73	0.84
200	0.44	0.49	0.55	0.63	0.72	0.81	0.91
250	0.51	0.57	0.62	0.71	0.80	0.89	0.99

* At an annual discharge of 60 284 m^3 (see Table D.12).

It is shown that the costs rise as either the well depth or the depth of the water-level (i.e. pumping depth or head) increase. Of course, the cost per m^3 water pumped also varies with the annual abstraction or, in other words, the number of hours pumped. An increase in pumping would lower the fixed costs and thus the total cost per m^3 of water.

The costs of water per m³ for shallow wells are given in Table D.14. The average annual abstraction of shallow wells varies considerably between areas, as shown in Table D.12. Therefore, the costs per m³ water have been calculated at different abstraction rates, assuming however a constant pump discharge. The table shows that pumping costs per m³ water decrease drastically as the annual abstraction increases due to a relative drop in the fixed cost. Fuel costs per m³ water, on the other hand, fluctuate only with the head and are not influenced by the total amount of water abstracted.

Table D.14 - Cost of irrigation water pumped from shallow wells (YR/m³)

Well depth (m)	Head (m)	Annual abstraction (m³)*			
		10 000	15 000	22 240**	30 000
10	5	1.02	0.69	0.48	0.36
20	5	1.62	1.09	0.75	0.56
20	10	1.66	1.13	0.79	0.59
20	15	1.77	1.21	0.85	0.64
30	20	2.45	1.67	1.17	0.88
40	30	3.18	2.18	1.53	1.17

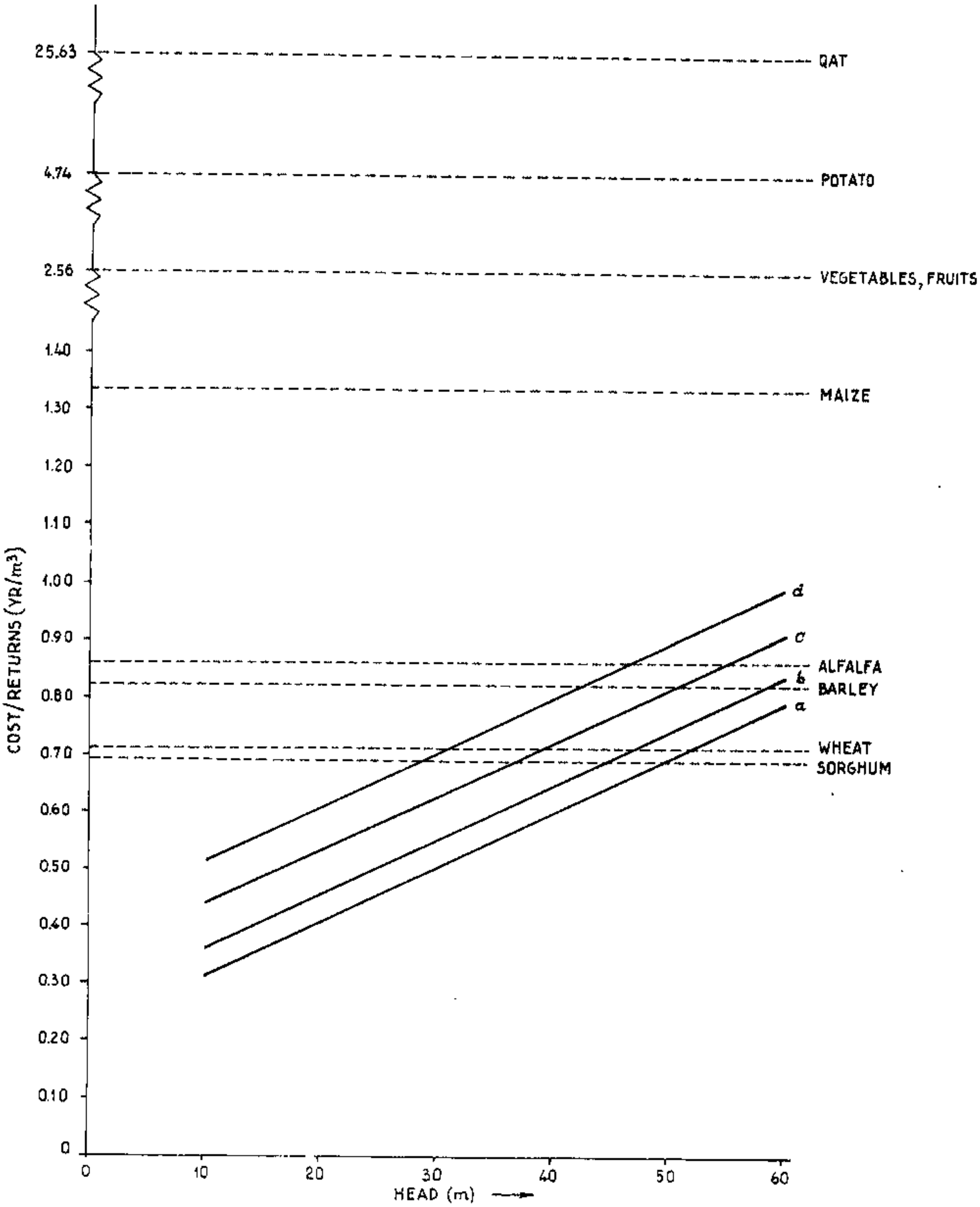
* At a pump discharge of 5 l/s.
** Average annual discharge for the selected areas (see Table D.12).

Generally, the unit cost of water pumped from shallow wells is higher than that pumped from boreholes which is due mainly to the difference in annual abstraction. The unit costs for boreholes are graphically shown in Figure D.1. For the present report, the costs have been calculated for only one average annual abstraction and for a limited number of well depths and water-level depths. However, for practical use in the field, a series of graphs covering a wide range of annual abstractions, well depths, and water-level depths should be drawn, which is possible with the cost data available.

The returns per m³ water for individual crops are given in Table D.15. The unit values are obtained by dividing the net returns per ha by the irrigation dosages as derived from the agronomic survey.

The unit net returns per crop, which are average values for all areas covered by the survey and are believed to be fairly representative for the province as a whole, can now be compared with the unit costs given in Tables D.13 and D.14.

COST AND RETURNS OF IRRIGATION WATER PUMPED FROM BOREHOLES AT AN ANNUAL ABSTRACTION OF 60284 m^3



a - WELL DEPTH AT 100 m
b - WELL DEPTH AT 150 m
c - WELL DEPTH AT 200 m
d - WELL DEPTH AT 250 m

FIG. D1

Table D.15 - Returns to irrigation water, per crop

	Net returns per ha (YR)[1]	Irrigation dosages per ha (m^3)[2]	Returns per m^3 irrigation water (YR)
Alfalfa	27 980	32 640	0.86
Sorghum	5 250	7 560	0.69
Wheat	4 930	6 970	0.71
Barley	4 930	6 010	0.82
Maize	7 750	5 820	1.33
Qat	199 950	7 800	25.63
Potato	25 420	5 360	4.74
Others	34 520	13 500	2.56

Notes: [1] See Table D.4.
[2] Derived from the agronomic survey.

Qat and potato production and the production of other (commercial) crops such as vegetables and fruits seem economically viable at most well depths and water-level depths. Alfalfa and food crops are more marginal, particularly when irrigated from shallow wells. The critical well depth and water-level depth below which the net returns no longer cover the cost of pumping can be read from Figure D.1. For example, for sorghum, which has an average net return of YR 0.69 per m^3 water, cultivation becomes economically unattractive when water-level depths exceed approximately the following values:

- 60 m at a well depth of 100 m;
- 45 m " " " " " 150 m;
- 37 m " " " " " 200 m;
- 30 m " " " " " 250 m.

For shallow wells it can be seen that at the average annual discharge of 22 240 m^3 only a well depth of between 10 and 20 m and a water-level depth of 5 m would allow for profitable irrigated production of sorghum. With higher annual abstractions, say of 30 000 m^3, well depth and head could increase to over 20 m and 15 m respectively (see Table D.14). The same exercise can be done for other crops.

The net returns per m^3 water for the average cropping patterns in the selected areas are given in Table D.16. As mentioned in Section D.2.3, the high values in the Rada Basin, Wadi Juban, Wadi Hubabah/Wadi Ar Riashiyah and Abbas are caused by the high proportion of qat in the cropping pattern. The influence of qat on the returns per m^3 water is also evident when comparing the Rada Basin sub-areas: in the qat area the returns are more than 3 times higher than in the other sub-areas.

Table D.16 - Returns to irrigation water, per cropping pattern

	Net returns per ha (YR)[1]	Irrigation dosages per ha (m^3)[2]	Returns per m^3 irrigation water (YR)
Rada Basin (total)	92 460	12 100	7.6
Qat area	152 905	9 190	16.6
Water-melon area	74 632	13 670	5.5
Remainder			
- boreholes	47 121	12 510	3.8
- shallow wells	24 766	14 440	1.7
Sabah/Ar Riashiyah	32 108	15 410	2.1
Al Bayda N.E.	28 609	13 860	2.1
Al Bayda W.	43 634	12 070	3.6
Wadi Juban	108 410	9 840	11.0
Wadi Mansur/Wadi Amad	28 456	15 020	1.9
Wadi Matar/Wadi Ar Rin	27 045	19 080	1.4
Wadi Hubabah/Wadi Ar Riashiyah	66 716	10 360	6.4
Wadi Dhi Na'im	20 476	14 100	1.5
Abbas	112 648	12 740	8.8
Total	70 339	13 170	5.3

Notes: [1] See Table D.6 and D.7.
[2] Derived from the agronomic survey.

Comparison of the net returns per m^3 water of the cropping patterns with the unit cost given in Table D.13 and Figure D.1 indicates that all cropping patterns are economically viable for the various boreholes considered.

The same does not hold true when water is pumped from shallow wells, which are at present the major source of groundwater in areas outside the Rada Basin. In areas where returns per m^3 water are low and at the same time the water-level is deep and annual abstraction low, the cropping patterns are marginal. This holds true particularly for Wadi Matar/Wadi Ar Rin where, at an average abstraction of about 12 000 m^3 and an average head of 16 m, the unit cost per m^3 water pumped is approximately between YR 1.7 and YR 2.5, as against an average return of YR 1.4 per m^3 water. For Wadi Mansur/Wadi Amad, the average net return is YR 1.9 per m^3 water which is just sufficient to cover the cost of pumping which is roughly YR 1.7 per m^3 water.

It should be realized, of course, that many shallow wells have been dug more than a generation ago and are past their economic life. In economic terms, they are written off and the only costs the farmer incurs are for maintenance or replacement of pump and engine and for fuel consumption. The relevance of the analysis, however, is that it provides a basis for future decisions on well construction. The farmer is becoming cost-conscious, as is indicated by a comparison of the cropping patterns in the Rada Basin: areas with a high incidence of boreholes (qat area, water-melon area and "remainder borehole area") have more high-value crops, resulting in a higher return per m^3 water, than the area with shallow wells. In recent years, groundwater has been exploited mainly through boreholes. The results of analyses indicate that boreholes are indeed more economic than shallow wells.

D.5 Conclusions and recommendations

We believe that there is scope for further irrigation development in Al Bayda. Annexes A and C show that more groundwater and land are available. It is economic to develop these resources. Of course, the speed by which and the extent to which they will be actually developed depend also on other factors such as the availability of capital and labour.

In the long run, agricultural development should be supported by the formulation of programmes and advice on crops and cropping patterns as well as on the use of modern irrigation techniques to maximize agricultural benefits and the use of irrigation water. However, extension work in Al Bayda has just begun and it will take some years before sufficient experience has been built up to adopt an integrated approach as suggested above. Moreover, for this type of farm planning to be realistic and effective, it should be backed up by proper (applied) research and trials and by farm management surveys.

The graphical presentation of unit pump costs provides a simple way of assessing the average profitability of irrigated crop production for a variety of well types. However, the method should be refined before it can become a practical tool for extension. In the first place, a range of unit cost graphs should be designed which would reflect in detail the variations of the local conditions of groundwater availability and water quality. Secondly, farm management research, that is a study of the entirety of the farm and not only of its separate activities, should be carried out to assess more accurately than was possible in this study the net returns of crops and cropping patterns and irrigation requirements under various soil and management conditions.

REFERENCES

Ilaco, 1982.
Report on farming systems research survey in Wadi Tha. Rada Integrated Rural Development Project, Technical Note No. 9. Ilaco, Arnhem, The Netherlands.

Ilaco, 1983.
Report on farming systems research survey in Wadi Mansur. Rada Integrated Rural Development Project, Technical Note No. 13. Ilaco, Arnhem, The Netherlands.

RIRDP, 1983.
Economic study of sorghum production in Wadi Tha-Rada area. Ministry of Agriculture and Fisheries, Rada Integrated Rural Development Project, Rada, Yemen Arab Republic.