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Ministry of Agriculture
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RADA INTEGRATED RURAL DEVELOPMENT PROJECT

Study into water resources in Al Bayda Province

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This report consists of 4 volumes:

Volume I - Main Report

Volume II - Annexes

Volume III - Maps

Volume IV - Appendices I, II, III

CONTENTS

CONTENTS (cont.)

CONTENTS (cont.)

LIST OF TABLES

CONTENTS (cont.)

LIST OF FIGURES

SUMMARY

In bilateral discussions between the Governments of the Yemen Arab Republic and the Netherlands in June 1982, it was decided that a study of water resources in the entire Al Bayda Province would be carried out by Ilaco. The study was to be done within the framework of the Rada Integrated Rural Development Project (RIRDP).

During the period March to April 1983 Ilaco carried out a reconnaissance survey in the project area in order to select areas for detailed studies of hydrogeological, water engineering and agronomic aspects, and to draw up work programmes and questionnaires for these studies. The general findings of the reconnaissance survey were reported in an inception report dated May 1983.

The detailed field surveys were carried out during the period April to October 1983. The compilation of the data collected, which already started in the field, was completed at Ilaco's head office in the Netherlands. Data analysis, including the drawing of maps and computer studies, and report writing were also done in the Netherlands.

This report presents the findings of the studies and makes recommendations for future activities to be undertaken within the framework of the RIRDP. In broad terms, the aim of the study has been to link the assessment of water resources directly to its main uses, water-supply for man and livestock, sanitation, and agriculture. To this end, an assessment has been of the irrigation potential in the areas investigated, and of the present and future water-supply and sanitation requirements; in addition the available water resources have been estimated.

As indicated by the figures below, there is considerable potential for further development in particular of groundwater resources (all surface water, except for extreme floods, is used) and irrigation, after reservations have been made for domestic water-supply. The study indicates that also in economic terms, expansion of irrigated agriculture is justified.

Estimated development potential for groundwater and irrigation in the investigated areas

Area	Water resources (m^3 × 1000)			Land resources (ha)		
	Total potential	Present abstraction	Development potential	Net irrigable land	Present irrigated area	Incremental irrigation potential
Rada Basin	33 288	20 605	12 683	6 207	1 443	993
Al Bayda North-East	5 450	2 976	2 474	827	177	> 127
Al Bayda West	3 600	2 106	1 494	361	107	> 57
Wadi Juban	3 458	1 953	1 505	818	202	115
Wadi Mansur	3 025	1 954	1 071	1 415	333	10
Wadi Dhi Na'im	4 550	3 545	1 005	772	175	113
Wadi Matar/Wadi Ar Rin	1 050	352	698	351	24	29
Abbas	680	337	343	373	22	28

The data show that the potential for further groundwater development in the eight investigated areas is in the order of 21.3 million cubic metres (MCM) per year. Of this, some 5.3 MCM is required for domestic water-supply in the coming 20 years and the remaining 16 MCM would be available for an increase in irrigation. This potential depends very much on local and hydrogeological conditions, present abstraction and water use, and is therefore strictly confined to the areas and sub-areas given in this report.

Drinking-water is a primary human need and it goes without saying that it should be available in sufficient quantities and be of good quality. Many villages surveyed have either a water shortage (ranging from 18-45 % in the areas investigated) or no adequate water-supply systems (ranging from 50-93 %, expect for the Al Bayda areas). There is thus a great need for the construction or improvement of water-supply systems, also in the larger villages with populations of 500 or more, all of which were included in the survey. In general, there is sufficient groundwater available but in certain sub-areas, particularly in the Rada Basin, overpumping occurs. In such areas, water management for the regulation of the number of wells, well distance and well abstraction is required in order to reserve groundwater for domestic water-supply. These areas are found around the larger towns such as Rada, Mallah, Al Bayda, and Juban. Ultimately, water management will be necessary in most areas in order to prevent overpumping and deterioration of water quality, and to ensure the optimum use of the scarce water resources.

All villages surveyed need improved sanitation facilities. However, there is at present no organized sanitation programme and therefore no base for planning. The most appropriate action is to initiate 'pilot projects' and monitor the progress of these projects so that experience can be gained for designing future sanitation schemes. This should be combined with a health education programme.

The study gives a basis for future development activities which should be undertaken by RIRDP in accordance with defined development objectives and strategies. Some of these activities are long-term in nature or even continuous, and aim at strengthening the data base for future planning; others should be implemented within the framework of the 1984/85 Operational Plan of the RIRDP. These include implementation of the second stage of the water resources study, site selection for boreholes, and pilot schemes for the development of sanitation systems. The proposed activities are summarized below.

1. Study into water resources in Al Bayda Province, Stage 2. (Continuation of the present study in areas not yet covered by the surveys, in particular Sabah/Ar Riashiyah and Wadi Arsard/Wadi Saru).
2. Expansion of monitoring network for the measurement of rainfall (15 meters), and water-levels and well abstraction (21-26 meters).
3. Setting up a system for monitoring of well drilling and water quality.
4. Preparation of a groundwater model for Rada Basin.
5. Site selection of boreholes for domestic water-supply for selected villages.

6. Construction of water-supply systems in accordance with the RIRDP programme.
7. Preparation and implementation of a programme for reducing the bacteriological pollution of drinking-water from shallow wells.
8. Preparation and implementation of pilot sanitation projects for:
   - the construction of modified baladiyah (traditional) toilets;
   - the construction of washing and excreta disposal facilities near a mosque;
   - the construction of treatment facilities for sewage and wastewater for a large village, together with agricultural re-use of effluent.
9. Implementation of a semi-detailed soil survey for the preparation of land suitability maps in areas with a high irrigation potential.
10. Setting up studies into optimum use of irrigation water, including:
    - irrigation trials;
    - farm management investigations;
    - crop feasibility studies.

1 INTRODUCTION

1.1 Background

Al Bayda Province lies in the south-eastern part of the Yemen Arab Republic (see Figure 1). It covers a mountainous area of approximately 11 000 km^2 and it has a resident population of about 268 000 (1981 census). The economy is based on, mainly rainfed, agriculture. There is no known mineral wealth in the area; industry has hardly developed. The province has a long history of migration dating back to the beginning of this century. Accessibility of the region has improved considerably since 1980 by the construction of the Dhamar-Rada-Al Bayda asphalt road, and a number of feeder roads connecting major population areas to the Dhamar-Rada-Al Bayda axis. However, large parts of the area are still only accessible by tracks with many bottlenecks.

The area is arid to semi-arid, the average annual rainfall being 200 to 350 mm. Surface water resources are very limited. There are no rivers, although there are a few small perennial streams in the south of Rada District. Small dams are found throughout the area; many have silted up and only a few are still in operation. Traditionally, water for the supply of drinking-water and for irrigation has come from numerous dug wells and a number of springs. In recent years, there has been a rapid increase in groundwater exploitation by deep tubewells.

Since 1977, the Rada Integrated Rural Development Project (RIRDP) has been active in the area with, for instance, activities in feeder road construction, domestic water-supply, livestock, agriculture and women participation programmes. The project is financed jointly by the Governments of the Yemen Arab Republic and the Netherlands. Up to 1983, the project covered only the district of Rada but today it deals with the entire Al Bayda Province.

In bilateral discussions between the Governments of the Yemen Arab Republic and the Netherlands in June 1982 it was decided that during 1983 a study of water resources in the entire Al Bayda Province would be carried out by Ilaco. The study was to be done within the framework of the Rada Integrated Rural Development Project.

In December 1982 the consultants presented a Research Outline giving their approach to implementation of the study. During the period March to April 1983 a reconnaissance survey was carried out in the project area in order to select areas for detailed studies of hydrogeological, water engineering and agronomic aspects, and to draw up work programmes and questionnaires for these studies. The general findings of the reconnaissance survey were reported in an inception report dated May 1983.

The detailed field surveys were carried out during the period April to October 1983. The compilation of the data collected, which already started in the field, was completed at Ilaco's head office in the Netherlands. Data analysis, including the drawing of maps and computer studies, and report writing were also done in the Netherlands.

YEMEN ARAB REPUBLIC

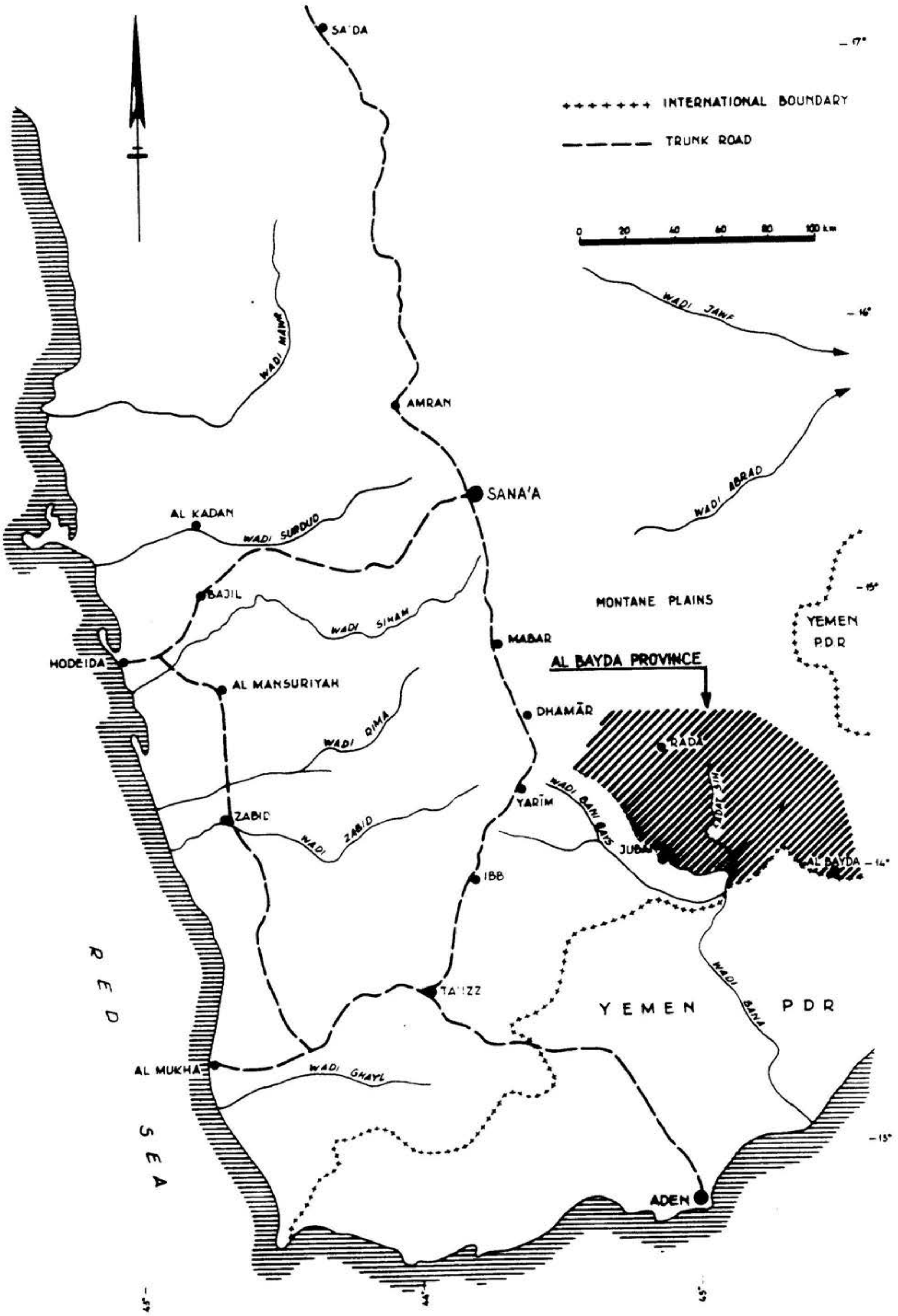


FIG. 1

In this report the consultants present the results of the surveys and their findings and views on the development possibilities of water resources in Al Bayda Province.

1.2 Objectives and scope of the study

The overall objectives of the study are:

- to provide information on available water resources to enable present and future water use to be assessed;
- to prepare a first framework for future development of water resources and water management.

More specifically, the objectives are the following:

- to identify geohydrological structures and their groundwater potentials related to present population distribution and land resources to be developed for irrigated agriculture;
- to select areas with groundwater potentials to be studied in more detail;
- to formulate recommendations for:
  - areas where because of limited availability of resources only recommendations will be formulated on the construction of new, or the improvement of existing, domestic water-supply systems;
  - areas where, in view of the available land and water resources, irrigated agriculture might be feasible;
  - additional investigations such as monitoring or geo-electrical and electromagnetic research for site selection of new deep and shallow wells.

Within a period of less than one year, as was available for the study, it is impossible to obtain a complete inventory of the water and land resources of the province. For one thing, continuous meteorological and hydrological observations including groundwater monitoring have just begun. However, long time series of climatological variables and water abstraction and recharge data are necessary to arrive at accurate estimates of water balances. This condition applies to groundwater and even more so to surface water, as perennial flows are virtually absent in the area. Since the surface water resources are also small relative to the groundwater resources, the emphasis in the study has been on assessing the potential of the latter.

Furthermore, it is impossible to cover the entire province as it is subdivided into a great number of separate groundwater catchments, many of which are small and have no sizeable water and land resources. As will be elaborated in Section 1.3, it has therefore been decided to concentrate from the very start of the study on those areas which either have a relatively large concentration of population, or groundwater and agricultural potential, or both. Most of these areas have been covered in the present study. In the second stage of the study the remaining areas should be covered.

In view of the limitations described above, the study should be considered as a first step towards preparing water management models for the various areas which have development potential, preparing a water management programme for the province, and formulating a regional policy on the development of water resources for domestic water-supply, sanitation and irrigated agriculture. It provides a general framework which will be filled in as more information becomes available.

1.3 Implementation and methodology of the study

In broad terms, the approach of the study has been to assess the availability of land and water resources in the province and to set this against the main uses at present, that is domestic water-supply and sanitation, livestock and agriculture. While a number of resource studies have been carried out before in Yemen, the present study is to our knowledge the first attempt at a regional level to link the assessment of resources directly to the main users in order to identify priority areas for development. The methodology that has been followed is described below.

The study has been conducted in two phases which partly overlapped:

- the reconnaissance phase;
- the phase of the detailed studies.

In the reconnaissance phase, the main areas in terms of water resources, cultivable land and population were selected. The following activities were carried out:

- a preliminary study of water resources aiming at the delineation of catchments;
- a rough identification of land resources and potentials for irrigation in various parts of the province;
- a review of the population and its distribution, and a preliminary study of the present water-supply and sanitation in the province;
- the assessment of the need for, and type and detail of subsequent field studies.

On the basis of the outcome of these activities in the reconnaissance phase, 12 areas were selected for further study.

In the second phase, detailed studies were carried out in the fields of hydrogeology, domestic water-supply and sanitation, and irrigated agriculture. Table 1 gives the selected areas and the areas included in each study (see also Figure 2). In addition, a broad study was undertaken into the cost and returns of irrigated agriculture, based on available data supplemented with information from interviews with farmers. The results of this study will provide some quantitative insight into the economics of production of individual crops as well as of a variety of cropping patterns found in the areas covered by the agricultural study.

AREAS COVERED BY THE SURVEYS, AL BAYDA PROVINCE

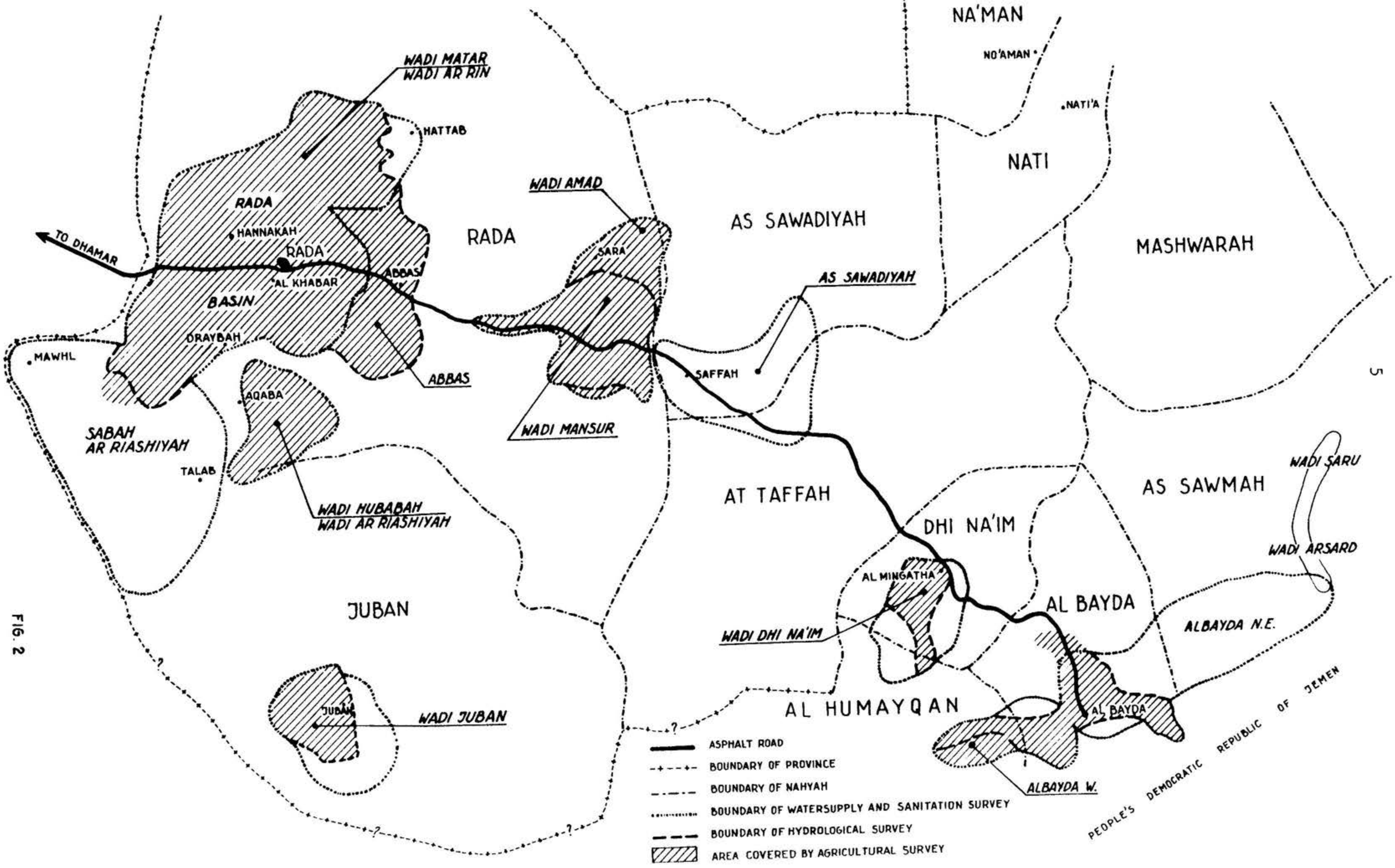


FIG. 2

Table 1 - Areas covered by the studies

Selected areas	Hydrogeological study	Water-supply and sanitation study	Agricultural study
1 Rada basin	x	x	x
2 Sabah/Ar Riashiyah	-	x	x
3 Al Bayda North-East	x	x	x
4 Al Bayda West	x	x	x
5 Wadi Juban	x	x	x
6 Wadi Mansur/Wadi Amad	x	x	x
7 Wadi Matar/Wadi Ar Rin	x	x	x
8 Wadi Hubabah/Wadi Ar Riashiyah	-	x	x
9 Wadi Arsard/Wadi Saru	-	-	-
10 Wadi Dhi Na'im	x	x	x
11 Abbas	x	x*	x
12 As Sawadiyah	-		-

Notes: * Comprises villages along the Rada-Al Bayda road including Abbas and As Sawadiyah.

The methodology and implementation of the three studies are described in detail in the Annexes, to which we refer. Here, the main aspects are summarized.

The hydrogeological study, which as its main part included a well inventory, provided information on the following aspects in the areas mentioned in Table 1:

- the geology;
- the geohydrology;
- the location and elevation of all shallow wells, boreholes and springs;
- the geographical distribution and depth of aquifers penetrated by the wells;
- yield and annual water abstraction of the wells;
- water quality (electrical conductivity);
- groundwater flow patterns;
- preliminary estimates on groundwater potentials;
- preliminary water balance (for Rada basin only);
- framework for setting up a monitoring network for the long-term observation of rainfall and water-levels.

On the basis of sample village and household surveys, the water-supply and sanitation study supplied information on the following aspects:

- existing water-supply and sanitation facilities in a range of villages and towns in the province, including engineering and operation and maintenance aspects;
- socio-economic conditions relating to water-supply and sanitation and the determination of basic parameters such as the per capita consumption and cost of water;

- present and projected total water demand from people and livestock in the various areas covered by the survey;
- standards for village water-supply and sanitation systems appropriate to various sizes of villages;
- chemical and bacteriological analyses.

The agricultural study, which comprised a sample survey of wells and their irrigated lands in the areas mentioned in Table 1, covered the following aspects:

- irrigation practices;
- cropping patterns per sample well, and typical cropping patterns for each of the areas;
- annual discharge and total irrigated area per well;
- average water application rates per crop;
- estimated total present irrigated area and total potential irrigation area for each of the areas;
- preliminary crop budgets and cost of pumping.

1.4 Acknowledgements

The study has been carried out under the responsibility of senior staff from Ilaco's headquarters in the Netherlands in co-ordination with Yemeni staff of the RIRDP and permanent expatriate staff in the Technical Assistance Unit. The consultants would especially like to mention the General Manager, Mr Abdullah Hobabi, the Heads of the various sections in the RIRDP, Mr Bert Carpay, water engineer, Mr Kees Peek, agricultural extension co-ordinator, and Mr Jaap Duys, hydrogeologist. Mr Duys also assisted in data analysis and report writing at Ilaco's headquarters in the Netherlands.

Many persons have contributed to the report. Special thanks are due to Mr Dan Bekkers, assistant water engineer, Mr Peter de Lange, assistant agronomist, and Mr Henno Nieuwenhuis, assistant hydrogeologist and their respective assistants/interpreters Mr Mohammed Abduwalli Oman, Mr Jamel as-Suwadih and Mr Ali Kalas. They have conducted, respectively, the water-supply and sanitation survey, the agricultural survey, and the hydrogeological survey. Mr Bekkers, Mr de Lange and Mr Nieuwenhuis also carried out the compilation of the data collected and assisted in data analysis, including the drawing of maps and computer studies. They were furthermore responsible for drafting major parts of the technical annexes.

We would like to thank Ms Loni Scheffers and Ms Nouria, who carried out a household survey among women in a number of villages in Al Bayda Province as part of the water-supply and sanitation study, and Mr Ron Bolmeyer, assistant hydrogeologist, who carried out a well inventory of part of Rada District prior to this study.

Finally, we wish to acknowledge the assistance rendered by staff of the Trans-Century Foundation, Mr Abdul-Kareen Al Kundi, Acting Director of Environmental Health, and his staff, and Mr Mohammed Ali Sharafadin and his staff of the Agricultural Office at Al Bayda.

2 THE PROJECT AREA

2.1 Physical environment

2.1.1 Topography and geomorphology

Al Bayda Province is situated in the south-east of the Yemen Arab Republic (between 44°30' and 46° E and between 14° and 15° N). From east to west it measures some 125 km at the most, and from north to south some 100 km; it covers an area of some 11 000 km^2. The province is bordered by the province of Mareb in the north, the Ibb Governorate in the west, and the Yemen Democratic Republic (YDR) in the south-east and north-east. The border with the YDR is not officially determined and therefore not exactly known. The province is subdivided into 10 nahiyah (sub-districts) indicated on Fig. 1. Rada in the west and Al Bayda in the south-east are the largest towns, situated in the most populated areas of the province. These two towns are connected by an all-weather road with Dhamar and the rest of the country.

Al Bayda Province forms part of a high plateau in the south-west corner of the Rub Al Khali at the southern tip of the Arab Peninsula. This highland area comprises a series of plains and valleys bounded by larger complexes of plateau mountains and volcanoes in the western part of the province; Jabal Isbil, a more than 3200 m high volcanic complex, and the older volcanic basalt plateau complex of Sabah and Agabah Riashiyah with elevations between 2500 m and 2800 m along the western border of the province, are the highest parts. The highlands are separated by an escarpment from the Rada Plain. This plain is a complex of alluvial plains and valleys bounded by ridges of older volcanoes and sandstones.

The rest of the province is part of a high plateau, with elevations of 2100 m in the north-west, 1950 m around Al Bayda, and 1800 m in the north-east. This plateau is a gently north-east sloping peneplain incised by numerous steep wadis forming the present drainage system. The resulting topography is a rough mountainous countryside with usually steeply incised valleys. The valley bottom usually lies 50 to 100 m below the watersheds of the surrounding hills. The wadis are mostly very narrow, locally widening to broader valley bottoms covered by alluvium. The rough terrain makes travelling difficult and slow.

2.1.2 Geology

Figure 3 gives the occurrence of the different geological formations as found in Al Bayda Province. The geological map is presented in Fig. 4

Precambrian rocks form the basement of the whole of the YAR and crop out at or near the surface of Al Bayda Province to the east of Rada. The Precambrian rocks are composed of highly metamorphic rocks, mainly intensely folded and fractured schists and gneisses with granite intrusions.

GEOLOGICAL MAP OF THE AL BAYDA PROVINCE

SOURCE: BUREAU DE RECHERCHES GEOLOGIQUES ET MINIERES

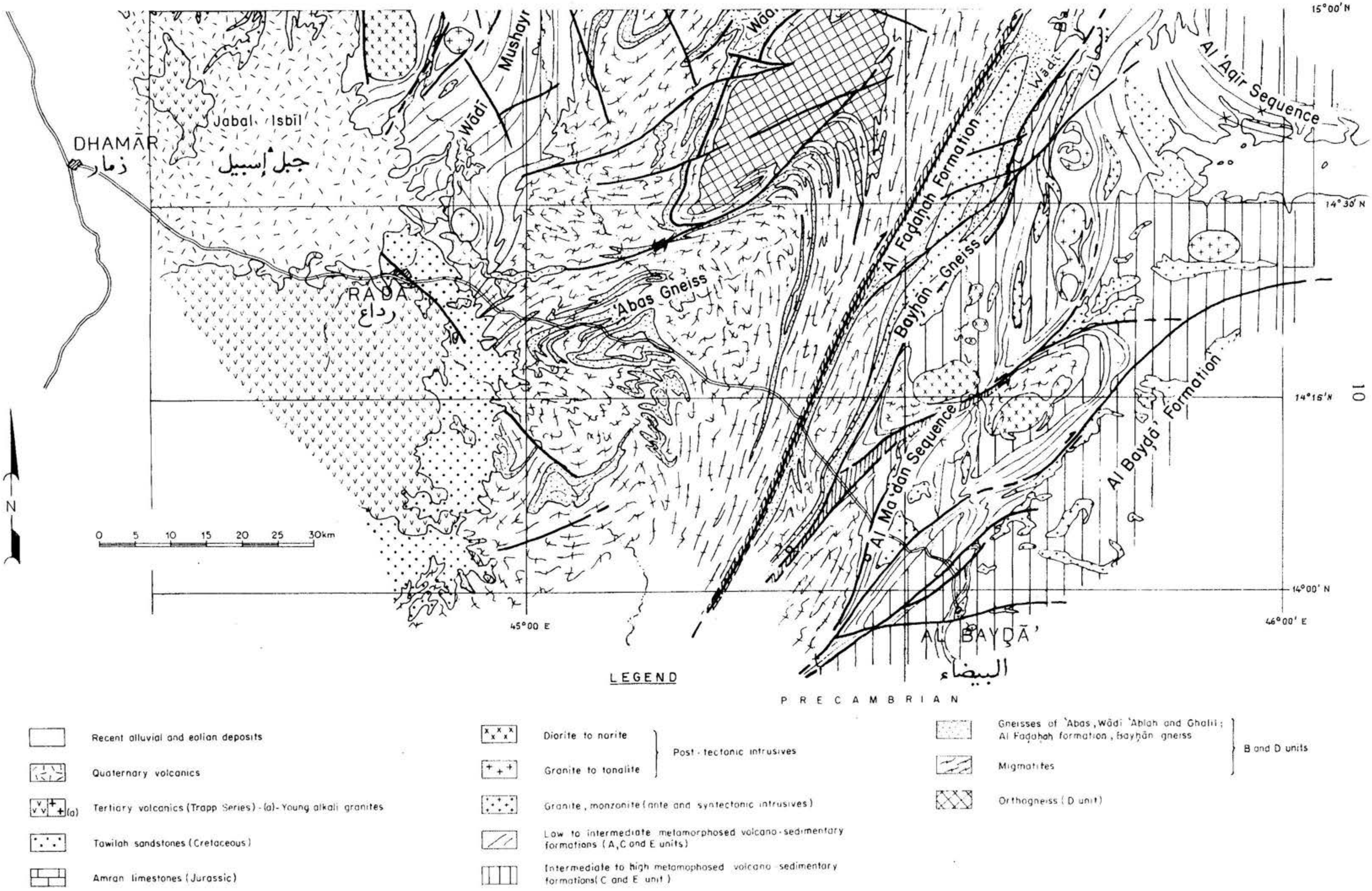


FIG. 4

The rocks have been eroded to a vast peneplain forming a high plateau at an elevation around 2000 m above MSL occupying the greater part of Al Bayda Province. The map shows that the Precambrian basement is subdivided into three structural units separated by major NE-SW running faults. Each unit comprises series of highly metamorphic rocks folded into one or more complex synclinoria. Late orogenic granite intrusions are usually found along the axis of the synclinorium. The metamorphic rocks are also cut by numerous smaller faults forming preferential directions for the wadis in the province.

Intrusive dikes often associated with faulting cut the Precambrian rocks at many places. Tawilah sandstone is exposed in an elongated zone running from north-north-west to south-south-east through the western part of Al Bayda Province. Rada Town lies within this strip. The sandstone forms a series of light-grey to yellow coloured fluviatile (river-type) cross-bedded deposits ranging from coarse sand to fine gravel. The Tawilah sandstone rests discordantly on the basement rock. NW-SE running faults related to the formation of the Red-Sea Graben cut the sandstone near Rada and Juban. The thickness of the Tawilah sandstone may be up to 500 metres.

Tertiary volcanic rocks overly the Tawilah sandstone along the western border of the province. These volcanic rocks known as the Yemen Volcanics cover a large area of Yemen including Sana'a, Dhamar, and Taiz.

The volcanic series comprises piled-up flows and domes of basalt lavas and tuffs sometimes alternating with alluvial sand and gravel deposits. Intrusive dikes, often occurring in swarms, cut the volcanic rocks and adjacent sandstones especially near volcanic centres. The thickness of the Yemen Volcanics is estimated to be at least 2000 metres.

Numerous sub-recent volcanoes, lava flows and volcanic ash deposits occur especially in the north-western corner of the province, with Jabal Isbil as centre of volcanic activity. The rock is basaltic and black. The lava has a characteristic vesicular structure with many cavities. The formation is up to 1000 metres thick.

Holocene alluvial deposits are found in many wadi beds in Al Bayda Province. Coarse sandy stream deposits with gravel underly especially major wadis. Finer valley fill deposits are found in the smaller wadis and plains around Rada and elsewhere in the province. The beds are up to 30 m thick.

2.1.3 Drainage patterns

(a) Groundwater

Groundwater flows from areas of recharge to areas of discharge. In Al Bayda Province, where there are no large regional aquifer complexes, flow of large quantities of groundwater over long distances does not occur.

In general, groundwater flow can be divided into the following two groups:

- groundwater flow in the Precambrian basement, and
- groundwater flow in the sandstone and volcanic rock areas in the western part of Al Bayda Province.

Groundwater flow in the Precambrian rock occurs below the wadi beds in the alluvium and underlying weathered and fractured rock. Here, the groundwater drainage pattern follows more or less the surface drainage system. The groundwater catchment boundaries practically always follow the topographical watershed of the wadis. Exceptions are those places where prominent faults serving as aquifers cut the watershed between two wadi systems. An example of such a fault is the east-west fault passing south of Al Bayda.

Usually the groundwater-transmitting capacity of a wadi bed is a product of the cross-section of the wadi bed, the permeability of the sand and weathered, permeable rock in the wadi, and the slope of the wadi bed. These factors differ greatly from place to place. Therefore the water-transmitting capacity may be sufficient for groundwater flow at one place, while it is too low at another point in the wadi. Thus it may occur in many wadi systems, because they are so long and their catchments are so large, that the groundwater-transmitting capacity of the wadi bed after several kilometres is smaller than the groundwater flow from upstream. As a result, groundwater levels rise to the surface and groundwater is lost by evapotranspiration or groundwater outflow in the form of springs and base flow. Further downstream the capacity may increase again and the water will again flow below the surface. Examples of groundwater discharge due to insufficient groundwater-transmitting capacity are the waterlogged area in the wadi near Nakhar east of Al Bayda, and the whole wadi north of Al Bayda along the main road to Rada from Al Bayda Town past Mash'abah.

Brackish to salty groundwater occurs generally in most of the wadi beds some distance downstream the catchment borders due to evapotranspiration of shallow groundwater and resulting salt accumulation. Thus, the waterlogged wadi bed north of Al Bayda contains brackish to saline groundwater, while the branch wadis contain fresh groundwater, with a water-table several metres below the surface.

Groundwater flow in the sandstone and volcanic rock areas in the western part of the province depends more on geological than topographical factors.

The main watershed is formed by the escarpment of Sabah and Ar Riashiyah. Here surface water and groundwater flow in a southern direction. Groundwater flow follows permeable layers in the volcanic rocks alternating with impermeable layers. The aquifers are recharged in outcrop areas in the mountains. Discharge of groundwater occurs mainly in the wadi beds, causing small streams during the greater part of the year in this high mountainous area.

Rain-water falling on the highly permeable young volcanic rock slopes of the Jabal Isbil north-west of Rada infiltrates to great depth into the underlying sandstone or onto the underlying basement rocks. This water flows for the greater part southward towards Wadi Tha where it discharges partly through a number of springs into the Rada Plain. Smaller quantities of water under this volcanic complex flow eastward and northward, discharging as smaller springs at the boundary of the lava flows with underlying rocks.

(b) Surface water

The south-west corner of the Arab Peninsula shown in Figure 5 can be divided into three main drainage basins:

- the western basin, draining on the Red Sea;
- the eastern basin, draining on the Rub Al Khali;
- the southern basin, draining on the Gulf of Aden.

Al Bayda Province is situated on the border between the southern and eastern basins, which means that it drains partly towards the Rub Al Khali and partly towards the Gulf of Aden.

The border between the eastern and southern basins in Al Bayda Province runs along the main escarpment south of the Rada Plain, then follows the main road from Rada to Al Bayda up to Wadi Dhi Na'im, where it bends south and follows the escarpment south of Al Bayda in the YDR. All the wadis in the southern catchment are upper tributaries of Wadi Al Bana. The catchment within Al Bayda Province comprises numerous deeply incised V-shaped wadis cutting through the escarpment forming the southern border of the high plateau. The numerous wadis in the eastern escarpment including the Rada Plain, the area north of the Rada-Al Bayda road, Wadi Dhi Na'im, and the wadis around Al Bayda drain northward. This drainage system forms a very complex wadi pattern belonging to at least three main wadi systems; these are from west to east:

- Wadi Sabah, draining water from the western part of the province including the Rada Plain;
- Wadi Harib, draining the central plains and northern part of the province;
- Wadi Bayhan, draining the eastern part of the province including Al Bayda and Wadi Dhi Na'im;
- Wadi Jifa, draining the north-east corner of the province.

The above wadi names are those found on the topographical map (scale 1:250 000) of the YAR near their inflow point into the Rub Al Khali. These names differ nearly always from the local names given to these wadi systems, which change every few kilometres.

Rain-water falling in and around the Rada Plains hardly ever reaches the northern wadis, as was demonstrated during heavy rainstorms lasting several days in March 1983, when water flooded the plain north of Rada, but did not leave the area. Another proof is the absence of a streambed in the northern part of the Rada Plain.

MAIN DRAINAGE BASINS OF THE YEMEN ARAB REPUBLIC

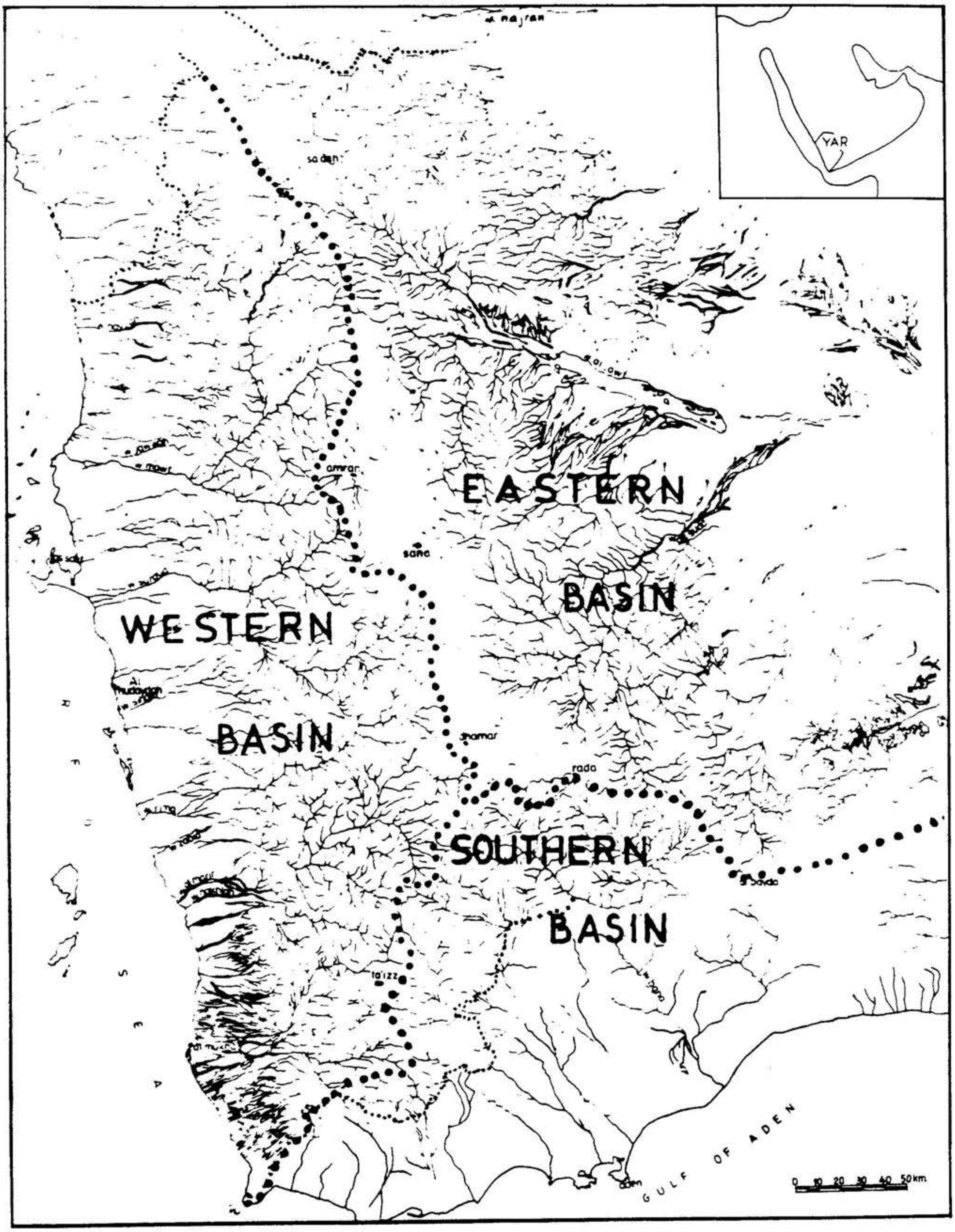


FIG. 5

The geological map of Figure 3 and the more detailed geological maps in Annex A show that the alignment of the wadis is determined geologically, especially in the area covered by Precambrian rocks. The wadis follow the strike of the well-layered rocks and the numerous smaller and larger faults in the intensely folded metamorphic rocks. For example, Wadi Bayhan follows major faults in the north-east of the province.

The wadi systems near the main watershed end up in flat areas like the Rada Plain where the inflowing run-off water infiltrates into the permeable alluvial deposits.

2.1.4 Soils

To date no systematic soil survey has been carried out in Al Bayda Province. Thus, no detailed information can be given on the soil conditions in the area. For a correct determination of the irrigation potential, which depends on the availability of suitable land as well as irrigation water, a (semi-)detailed soil survey is a prerequisite.

As far as conditions allowed, the Assistant Agronomist dedicated some of his attention to the soil conditions in the selected areas, but this provided hardly more than a superficial impression. In some areas, soil moisture content was measured at field capacity, while also a few infiltration rates were measured. The latter varied between 38 and 72 cm per day.

In general, soils are of an alluvial nature and comprise loam and sandy loam. Soils in Wadi Mansur, Wadi Juban and Wadi Dhi Na'im appeared to be the lighter ones in the selected areas. This is more or less confirmed by the water-holding capacities (soil moisture at field capacity as a percentage of dry matter), which are no more than 15 to 20 % for Wadis Mansur, Juban and Dhi Na'im, as compared to percentages between 20 and 25 % for the remaining areas, both for the topmost 25 cm soil layer.

2.2 Climate

2.2.1 General

In Al Bayda Province, 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. In addition, there are number of stations in Al Bayda Province which record rainfall only. Of these, Rada station has the longest time series.

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.

This section summarizes the main climatological data of Al Bayda Province. Further details of Al Khabar, Rada and other stations in the province as well as data from Rabat and Ma'bar are given in Annex 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 the drier north, and between the wetter west and the drier east. Al Khabar rainfall data are available from 1978 to the present, while in Rada measuring started in 1977, resulting in continuous daily rainfall figures over a period of six years up to 1983 (see Figures 6 and 7).

In Al Khabar the annual rainfall is never more than 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.

2.2.3 Temperature

Figure 8 shows the temperature data recorded at Al Khabar. The mean temperature over the period of measurement is 17.6 °C. Highest temperatures are reached in June, 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. The figure shows the marked seasonal fluctuation of the mean, minimum and maximum monthly temperatures and the daily range.

2.2.4 Humidity

Figure 9 shows the minimum, maximum and mean relative humidity recorded at Al Khabar station from April 1978 to September 1983. In contrast to the temperature there is no prominent seasonal fluctuation discernable, although the figures tend to be lowest in July and in October, November, and December. The figure shows large differences between the mean, maximum and minimum monthly relative 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.

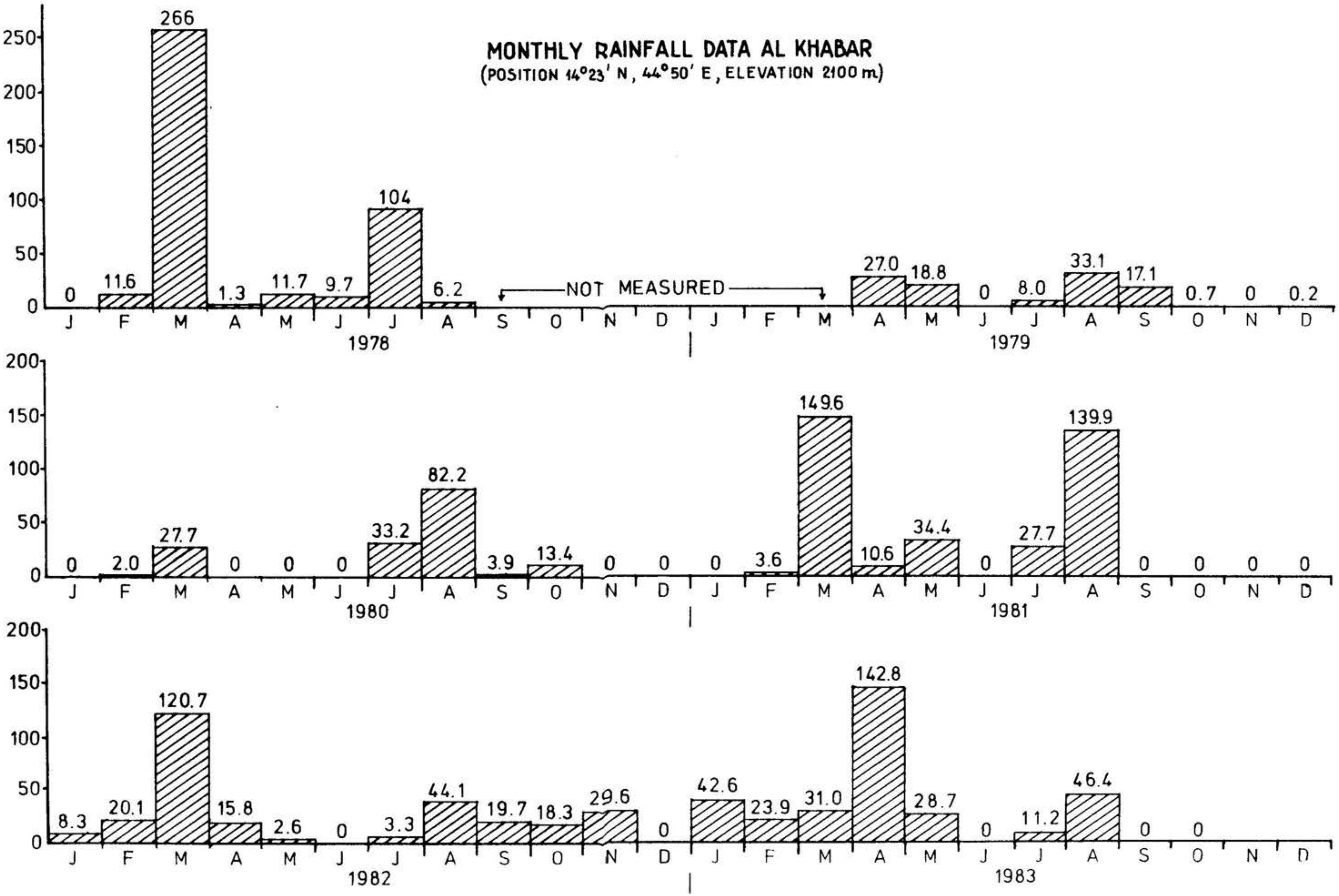

MONTHLY RAINFALL DATA AL KHABAR
(POSITION 14°23' N, 44°50' E, ELEVATION 2100 m)
NOT MEASURED
1978
1979
1980
1981
1982
1983

FIG. 6

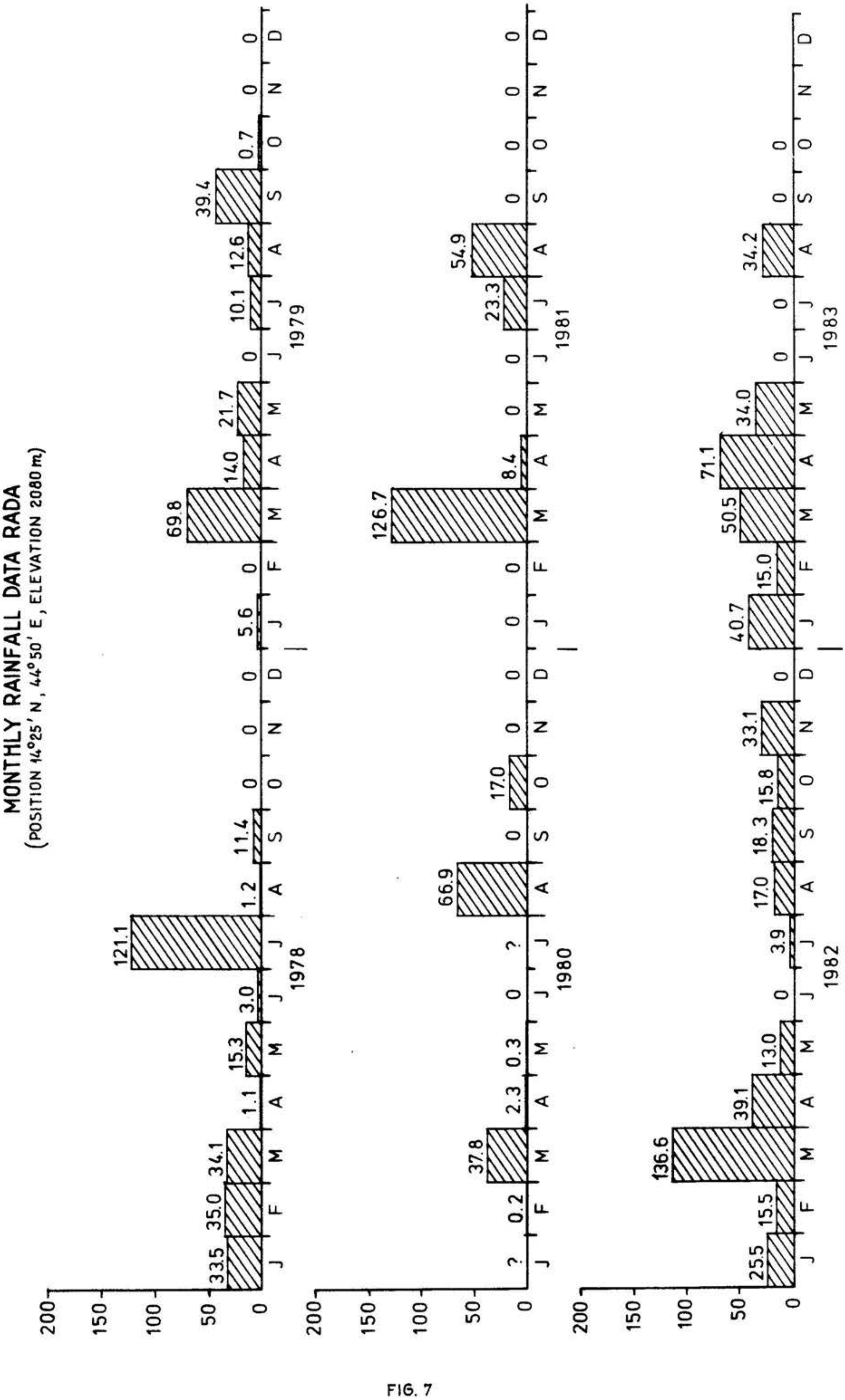

MONTHLY RAINFALL DATA RADA
(POSITION 14°25' N, 44°50' E, ELEVATION 2080 m)
1978: J 33.5, F 35.0, M 34.1, A 1.1, M 15.3, J 3.0, J 121.1, A 1.2, S 11.4, O 0, N 0, D 0
1979: J 5.6, F 0, M 69.8, A 14.0, M 21.7, J 0, J 10.1, A 12.6, S 39.4, O 0.7, N 0, D 0
1980: J ?, F 0.2, M 37.8, A 2.3, M 0.3, J 0, J ?, A 66.9, S 0, O 17.0, N 0, D 0
1981: J 0, F 0, M 126.7, A 8.4, M 0, J 0, J 23.3, A 54.9, S 0, O 0, N 0, D 0
1982: J 25.5, F 15.5, M 136.6, A 39.1, M 13.0, J 0, J 3.9, A 17.0, S 18.3, O 15.8, N 33.1, D 0
1983: J 40.7, F 15.0, M 50.5, A 71.1, M 34.0, J 0, J 0, A 34.2, S 0, O 0
0
50
100
150
200

FIG. 7

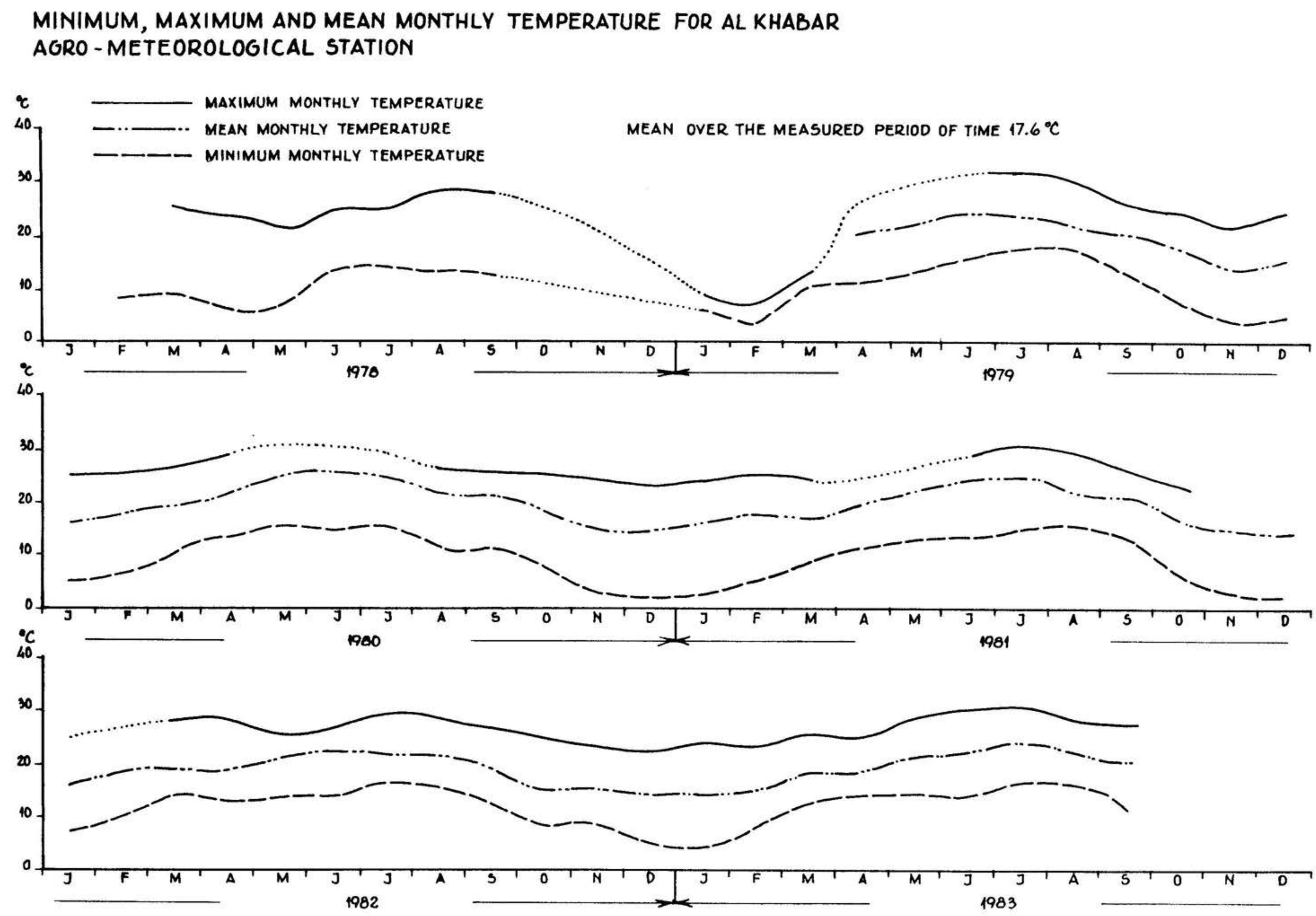

MINIMUM, MAXIMUM AND MEAN MONTHLY TEMPERATURE FOR AL KHABAR
AGRO-METEOROLOGICAL STATION
MAXIMUM MONTHLY TEMPERATURE
MEAN MONTHLY TEMPERATURE
MINIMUM MONTHLY TEMPERATURE
MEAN OVER THE MEASURED PERIOD OF TIME 17.6 °C
°C
40
30
20
10
0
J F M A M J J A S O N D J F M A M J J A S O N D
1978
1979
1980
1981
1982
1983

FIG. 8

MINIMUM, MAXIMUM AND MEAN MONTHLY RELATIVE HUMIDITY FOR AL KHABAR AGRO-METEOROLOGICAL STATION

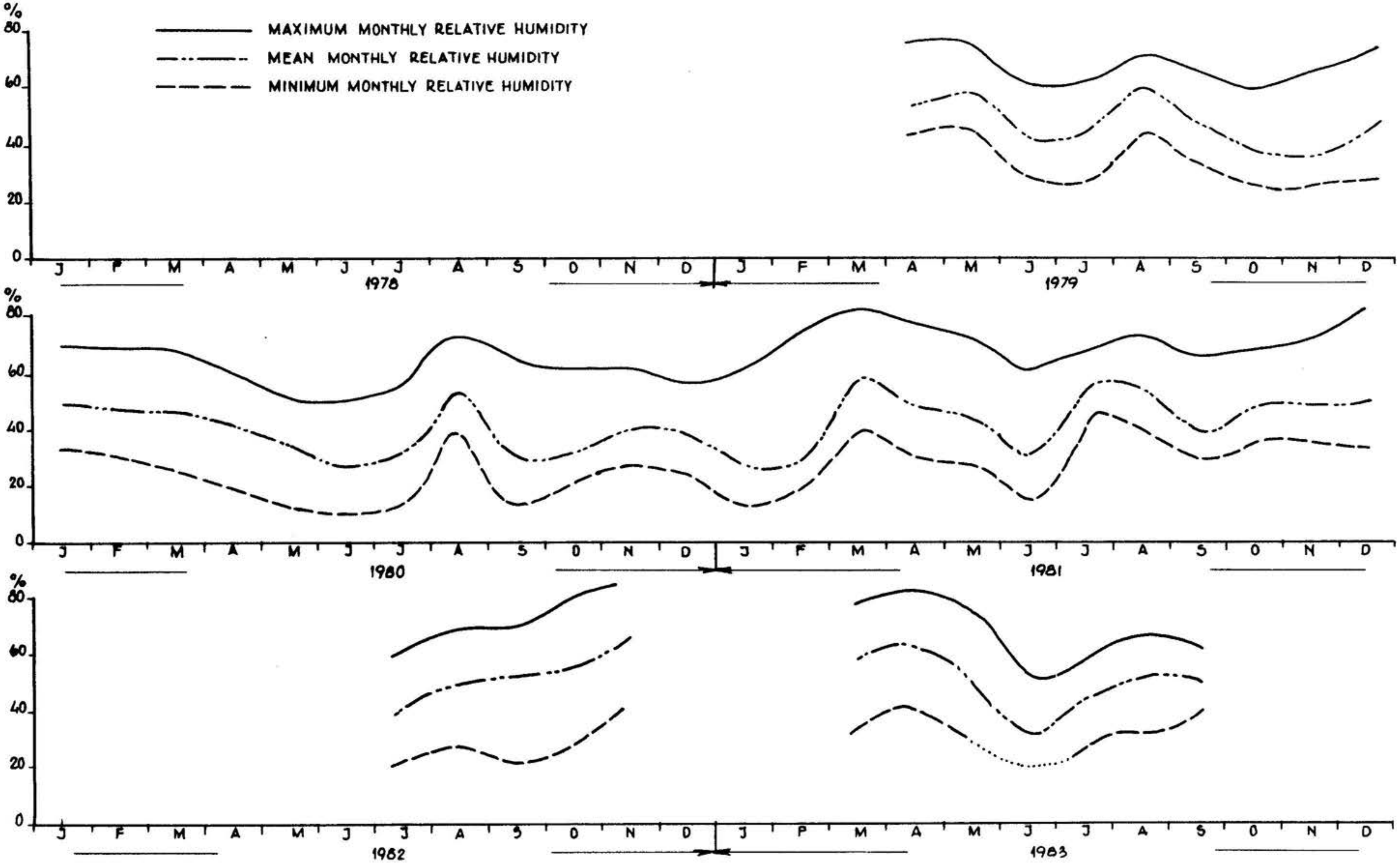


FIG. 9

2.2.5 Evaporation

Intense radiation, low relative humidity during the day and constant wind result in a high potential evaporation. Figure 10 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, which are theoretically about 20 % lower than class-A pan measurements.

Monthly evaporation is highest in 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 %).

2.3 Population

2.3.1 Present population and growth

The first modern population census in the Yemen Arab Republic was carried out in February 1975, followed by a second census in February 1981. Prior to that, population figures were based on the records of the zakat (local tax) administration; these estimates are shown in Table 2 together with results from the two censuses. For a more detailed discussion of demographic data in the Yemen Arab Republic, and Rada District in particular, reference is made to the RIRDP Technical Note No. 7 - Demographic Data on the Yemen Arab Republic and the Rada District (Ilaco, 1982a).

It was expected that comparison of the 1975 and 1981 census results would provide the most satisfactory basis for an estimate of the national population growth. These data, presented in Table 3, show an annual growth rate of 8.3 % for the de jure population (including emigrants) and 7.2 % for the de facto population (excluding emigrants). However, an analysis of the birth and death rates based on an age group distribution from the 1975 census results in a predicted growth rate of 2.4 %, which corresponds with that indicated by the <u>zakat</u> results between 1965 and 1974 shown in Table 2. Doubts must therefore be cast upon the results of either the 1975 or the 1981 census. Ilaco (1982a) considers that the 1981 results are suspect, and certainly the estimate of the number of emigrants appears to be overstated at 1 395 123, i.e. 33 % of the male population or 75 % of the male population in the age group 15-54. The results also indicate an increase in emigration ratio since 1975, which is contrary to what is generally believed. Adjustments such as made in the Final Report of the 1975 census, which significantly reduced the number of emigrants and the estimate of the number of people not enumerated, may produce a more acceptable growth rate between 1975 and 1981.

MONTHLY EVAPORATION FOR THE AL KHABAR AGRO-METEOROLOGICAL STATION

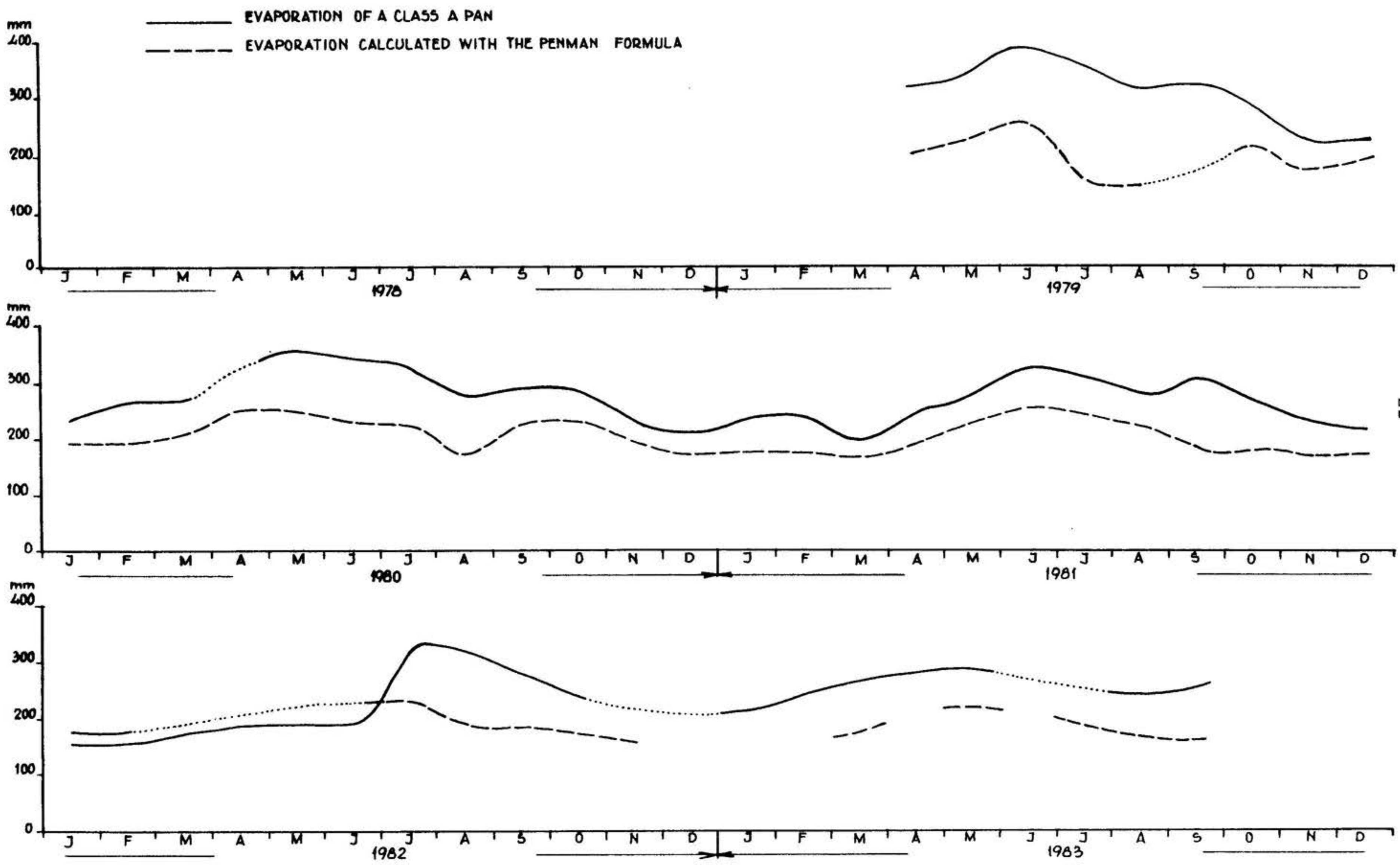


FIG. 10

Table 2 - Population estimates for the Yemen Arab Republic

	Population (× 1000)			Annual growth rate (%)
	Male	Female	Total	
1965[1]	2700	2434	5134	-
1966[1]	2762	2488	5250	2.3
1967[1]	2825	2546	5371	2.3
1968[1]	2891	2606	5497	2.3
1969[1]	2961	2668	5629	2.3
1970[1]	3033	2733	5766	2.4
1971[1]	3109	2802	5911	2.5
1972[1]	3189	2873	6062	2.6
1973[1]	3271	2946	6217	2.6
1974[1]	3356	3023	6379	2.6
1975 (Feb.)[2]	3405	3067	6472	-[4]
1975 (Feb.-adjusted)[2]	2743	2564	5307	-[4]
1981 (Feb.)[3]	4753	3803	8557	-[4]

[1] Based on poll zakat tax returns.
[2] Estimates for 1975 based on adjusted results of the Housing and Population Census (February 1975) as presented in the Final Report (1978) on the Airphoto Interpretation Project of the Swiss Technical Co-operation Service.
[3] 1981 Census.
[4] See Table 3.

Table 3 - Results of population censuses in February 1975 and February 1981 for the Yemen Arab Republic

	Feb. 1975 (× 1000)	Feb. 1975 (adjusted) (× 1000)	Feb. 1981 (× 1000)	% Increase per year	
				Unadjusted	Adjusted
De jure	6472	5307	8540	4.8	8.3
De facto	5238	4705	7145	5.3	7.2

The 1975 and 1981 census results for Al Bayda Province are reproduced in Table 4 and in common with the national figures, high growth rates of 7.6 % and 8.5 % per annum are indicated for the de facto and de jure population, respectively. The most significant of the discrepancies between the censuses is for the more sparsely populated nahiyah (sub-districts) such as Sawadiyah, Nati'a, Maswarah, and Markha, where growth rates of between 14 % and 25 % p.a. are found. The population densities of these areas are still low, however, and neither the 1975 nor the 1981 results can really be verified in the field.

Table 4 - Al Bayda Province: 1975 and 1981 census results

	Inhabitants			Emigrants		Total population			Emigration ratio		Area (km^2)	Population density	
	1975 (adjusted)	1981	% Incr.	1975	1981	1975 (adjusted)	1981	% Incr.	1975	1981		1975	1981
Al Bayda Town	6 154	10 724	9.7	968**	2 264	7 122**	12 988	10.5	13.6	17.4	-	-	-
Az Zahir	8 500	12 012	5.9	1 111	2 316	9 611	14 328	6.9	11.5	16.2	210	40.5	68
As Sawma'ah	19 903	24 408	3.5	2 382	4 454	22 285	28 978	4.5	10.6	15.4	440	45.2	66
Al Bayda	15 305	21 131	5.5	2 411	4 767	17 716	25 898	6.5	13.6	18.4	570	37.6	45
Juban	15 442	20 157	4.5	2 477	4 231	17 919	24 388	5.3	13.8	17.4	560	27.6	44
Dhi Na'im	6 866	10 304	7.0	981	2 019	7 847	12 323	7.8	12.5	16.4	370	18.6	33
Rada	69 363	101 334	6.5	9 530	17 589	78 893	118 923	7.1	12.0	14.8	3 970	17.5	30
As Sawadiyah	11 148	24 524	14.0	841	4 454	11 989	28 978	15.9	7.0	15.4	1 270	8.8	23
At Taffah	10 801	17 665	8.5	1 121	3 273	11 922	20 938	9.8	9.4	15.6	960	11.3	22
Nati'a	3 039	6 060	12.2	230	1 348	3 269	7 408	14.6	7.0	18.2	570	5.3	13
Markha	2 499	9 407	24.7	242	1 660	2 741	11 067	26.2	8.8	15.0	1 040	2.4	11
Maswara	3 853	10 384	18.0	137	1 769	3 990	12 153	20.4	3.4	14.6	1 210	3.2	10
No'aman*	-	7 391				-	8 702						
Total*	172 873	268 110	7.6	22 431	50 727	195 304	318 837	8.5	11.5	15.9	11 170	17.5	29

* No'aman was not mentioned in the 1975 census. In order to facilitate comparison between the two censuses the totals do not include results from No'aman.

** Estimated.

It is thus probable that the 1981 census figures are overestimated to some extent, and for the purpose of detailed design of a village water-supply system, it is recommended that an independent census of the village population be taken prior to the design. The objective of this report, however, is to provide an estimate of the water requirements in the province and as such, some overestimation of the present population will at least err on the side of safety. Moreover, village population figures for the entire province are available for 1981, which will allow a more detailed analysis of the water requirements. For the purposes of this report, therefore, it is proposed to use the 1981 census results. The consultants further considered that water demand figures should take into account the emigrated population, as it is not possible to say that they will not return to the village within the 20 year time span considered in this report.

The scarcity of reliable population data can make the estimation of population parameters such as growth rate hazardous. Due to the apparent discrepancy between the 1975 and 1981 census results the calculated growth rate of 8 % p.a. should be ignored. For present RIRDP designs, a growth rate of 2.4 % p.a. is assumed, which is the rate calculated from the present birth and death rates. In order to make a prediction about future growth rates, certain assumptions must be made regarding future birth and death rates. While it can be expected that the death rate will drop with improved health facilities, water-supply and sanitation, the future birth rate is less predictable. It is therefore considered appropriate to adopt a growth rate of 2.4 % p.a. for the 20 year time span considered in this report as there is no evidence at present to support any change in the assumptions from which this value was derived.

2.3.2 Distribution of population and settlement pattern

The population is concentrated in the Rada Basin and around Al Bayda Town, along the Rada-Al Bayda road, in the wadis north and west of Al Bayda, in Juban, and in Sabah/Ar Riashiyah. The 1981 census results indicate little change in the pattern except for an increase in settlement in the more sparsely populated northern regions of the province. This is however still questionable as mentioned in Subsection 2.3.1. The areas outside the selected areas contain many small, scattered villages, as is evidenced by the distribution of village sizes shown in Table 5. Little agricultural activities are carried out in these regions, livestock husbandry being the main occupation.

As can be expected, settlement is generally adjacent to wadis where some agricultural activities can be sustained. Although not evident from the 1975 and 1981 census results, there does appear to be an increasing concentration of population around the major towns of Al Bayda and Rada, where, in general, water resources are less scarce than elsewhere. The population increase in these areas is reflected more in the villages adjacent to Rada and Al Bayda than in the towns themselves, where growth is to some extent restricted by the town boundaries. In many villages the number of households is increasing at a rate much

Table 5 - Distribution of village sizes in Al Bayda Province
(according to 1981 census results)

		No. of villages with population:			
		0-250	250-500	> 500	Total
Al Bayda District					
Nahiyah					
As Sawmah		107 (10)*	8 (2)	5 (3)	120 (15)
Al Suwadia		324 (13)	6 (4)	2 (1)	332 (18)
Al Bayda		69 (1)	18 (4)	6 (4)	93 (9)
Az Zahir		44 (3)	12 (2)	3 (2)	59 (7)
Dhi Na'im		34 (2)	6 (5)	4 (2)	44 (9)
Markha		23 (0)	9 (0)	2 (0)	34 (0)
Mashwarah		98 (0)	3 (0)	0 (0)	101 (0)
No'aman		87 (0)	1 (0)	0 (0)	88 (0)
At Taffah		115 (0)	14 (0)	0 (0)	129 (0)
Nati'a		49 (0)	2 (0)	0 (0)	51 (0)
Rada District					
Nahiya	**Ozla**				
Rada	Rada'a	1 (0)	2 (0)	4 (2)	7 (2)
	Al Arsh	14 (1)	15 (12)	10 (5)	39 (18)
	Sabah	15 (2)	5 (4)	9 (5)	29 (11)
	Jabal al Riashiyah	0 (0)	4 (3)	1 (1)	5 (4)
	Al Thumood Riashiyah	7 (0)	2 (1)	3 (2)	12 (3)
	Wadi Al Riashiyah	9 (8)	7 (3)	0 (0)	16 (11)
	Qaifah				
	Walad Rabia	26 (0)	10 (0)	1 (0)	37 (0)
	Al Ghonain	62 (20)	8 (5)	2 (2)	72 (27)
	Al Mohsin Yazid	97 (7)	12 (7)	3 (2)	112 (16)
	Al Mahdy	11 (0)	4 (0)	0 (0)	15 (0)
Juban		45 (5)	16 (3)	4 (4)	65 (12)
Total		1227 (72)	172 (55)	61 (35)	1460 (162)

* ( ) No. of villages covered by survey.

greater than the population increase, due to the tendency for young marrieds to construct their own house rather than live with extended families.

The population concentrations generally coincide with the areas selected for this study. The population in each of these areas is indicated in Table 6; this represents just over half of the total provincial population.

Table 6 - Estimated population in selected areas

	Estimated population	Size distribution of villages		
		0-250	250-500	> 500
1 Rada Basin	59 000	130	28	14
2 Sabah/Ar Riashiyah	23 000	22	11	13
3 Al Bayda North-East (incl. Al Bayda Town)	32 000	91	5	6
4 Al Bayda West	22 000	82	5	3
5 Wadi Juban	12 000	57	4	4
6 Wadi Mansur/Wadi Amad	12 000	65	5	2
7 Wadi Matar/Wadi Ar Rin	6 000	20	2	0
8 Wadi Hubabah/Wadi Ar Riashiyah	8 000	25	7	0
9 Wadi Dhi Na'im	8 000	36	6	2
10 Villages along Rada-Al Bayda road incl. Abbas and As Sawadiyah	7 000	95	4	1
Total	189 000	623	77	45

Sources: 1981 Census; figures include emigrants.

All villages with a population greater than 500 and those with a population between 250 and 500 are listed in Annex B. The location of the larger villages is shown in Figure 2.

2.4 Economic base

Agriculture is the principal economic activity in Al Bayda Province, engaging an estimated 80 % of the resident population. Mining and industry are insignificant, but since the early seventies the construction, trade and transport sectors have grown substantially, mainly as a result of the infusion of cash through remittances from emigrants.

The economy is heavily dependent on these remittances, which come from workers who have emigrated mainly towards neighbouring Gulf states. According to census figures, 11 to 16 % of the Al Bayda population have nowadays emigrated. Their remittances, estimated to be in the order of YR 10 000 to YR 20 000 per worker per year, form a substantial part of the region's income.

The cash incomes from remittances, together with the income from the production of qat, has led to a vast growth in the consumption of, mainly imported, foodstuffs and clothing as well as luxury goods such as televisions, and to a rapid increase in the construction of houses and in the purchase of motor vehicles. This in turn has led to an increasing number of modern stores, mechanical workshops and wood and metal workshops in the private sector. By comparison, the provision of public services in for example health, education and sanitation has lagged behind.

The effects of migration on agriculture are twofold. Like in other parts of Yemen, labour shortage and rapid escalation of wages have resulted in a reduction in the area planted under rainfed farming and abandonment of marginal lands. Mechanization has not really compensated for this trend because of its high cost and inefficiency: the tractors used are often too large for the small plots and many drivers are inexperienced. On the other hand, investments resulting from remittances combined with the opening of the area by new roads have led to a tremendous increase in the number of boreholes (deep tubewells) which, although primarily used for qat production, have enabled a shift from rainfed farming of food crops to irrigated farming.

Data on the present state of agriculture and livestock are provided by the agricultural census conducted by the Ministry of Agriculture. The Al Bayda census, which is actually a survey among 2 % of the holdings in the province, was held in the 1980/81 agricultural season. According to this census, the total cultivable land in Al Bayda is about 52 400 ha, with the major part rainfed. Almost 17 000 ha is irrigated, mainly from wells (see Table 7). The census estimated that there are about 23 400 agricultural holdings in the area, ranging in size from less than 0.5 ha to 5 ha and over. More than half of the holdings fall in the range 0.5 to 2 ha (see Table 8). The average farm size is 2.2 ha, which includes both rainfed and irrigated land as well as fallow land. Average irrigated area per holding is roughly 1 ha.

Table 7 - Total cultivable area in Al Bayda

	ha	%
Rainfed	32 377	61.8
Irrigated by springs	1 049	2.0
Irrigated by pumps	15 851	30.2
Uncultivated	3 165	6.0
Total	52 442	100.0

Source: YAR Ministry of Agriculture and Fisheries, 1983.

Table 8 - Distribution of holdings and area by farm size, Al Bayda

Farm size (ha)	% of holdings	% of area
Less than 0.5	15.9	2.2
0.5 and less than 1	27.9	9.2
1 and less than 2	26.8	17.3
2 and less than 3	10.0	11.0
3 and less than 5	9.2	15.7
5 and over	10.2	44.6
Total	100.0 (23 416)	100.0 (52 442 ha)

Source: YAR Ministry of Agriculture and Fisheries, 1983.

Fragmentation is very common in Al Bayda, as it is in other parts of Yemen. The number of parcels per holding ranges from 1 to 19. On average, the number of parcels per holding is about 5.

Private land ownership is predominant in Al Bayda. About 88 % of the holders own the land they cultivate; 2 % are share-croppers and 10 % of the holdings are a mixture of ownership, share-cropping or rented land.

The production is strongly subsistence-oriented, with sorghum and other grains such as wheat, barley and maize prevailing. Only small surpluses, if any, are sold in the local market or off the farm. Also alfalfa and livestock products such as milk, ghee and meat are mainly produced for home consumption. Vegetables, e.g. tomatoes, water-melons, potatoes and onions are grown for the market in certain areas but mostly they are grown in small plots for home consumption. Qat is the main commercial crop. The estimated areas by crop are given in Table 9.

Statistics of the number of livestock are bound to be approximations only, as no complete count has ever been taken in Al Bayda. The census has estimated the number of livestock in the province as given in Table 10. Most of the holdings own some livestock, be it cattle, sheep, goats, camels, donkeys or chickens. Camels and donkeys are used as draught animals and for transport of products and water.

Table 9 - Estimated area by crop in Al Bayda

Crop	ha	%
Sorghum	43 843	89.0
Wheat	945	1.9
Other grains*	781	1.6
Alfalfa	883	1.8
Vegetables and pulses	864	1.8
Other annual crops*	145	0.3
Qat	1 791	3.6
Other permanent crops	25	-
Total	49 277	100.0

Source: YAR Ministry of Agriculture and Fisheries, 1983.

* Including mixed crops.

Table 10 - Livestock, total number and averages per holding, in Al Bayda

	Total number	% of holdings reporting ownership of livestock	Average no. of livestock per holding reporting	Average no. of livestock in all holdings
Cattle	25 235	61	1.8	1.1
Sheep	299 841	65	19.8	12.8
Goats	136 153	38	15.2	5.8
Camels	5 226	16	1.4	0.2
Donkeys	23 207	79	1.3	1.0

Source: YAR Ministry of Agriculture and Fisheries, 1983.

There are very few data available on economic sectors other than the agricultural one. To date, no systematic survey has been carried out. However, short socio-economic village surveys conducted in the context of the Water-Supply and Sanitation Study and by the RIRDP have indicated that a substantial proportion of the male labour force (in some villages up to 70 % of the heads of households) finds employment, often besides farming, in non-agricultural sectors, particularly in construction. Next to off-farm employment and commercial crop production (mainly qat), migration and the related remittances are an important source of income for the rural households. In some of the villages covered by the surveys, up to 50 % of the households had one or more men abroad.

3 PRESENT WATER RESOURCES AND WATER USE

3.1 Groundwater resources

3.1.1 Aquifers and aquicludes

The following aquifer units can be distinguished in Al Bayda Province:

- volcanic rock aquifers of:
  . the highly permeable Quaternary Basalts; and
  . the moderately permeable Tertiary Yemen Volcanics;
- sandstone aquifer of the Tawilah sandstone;
- alluvium aquifer under plains and wadis composed of unconsolidated sand and gravels, often underlain by rock aquifers as mentioned below;
- weathered and fractured rock aquifers in the Precambrian basement.

Table 11 contains the main water-bearing characteristics of these different geological formations.

3.1.2 Groundwater catchments

The geology of Al Bayda Province prevents the occurrence of large continuous aquifer systems. Especially in the impervious Precambrian rocks, surface water as well as groundwater catchments are small and confined to the wadi bed and adjacent slopes up to the hill crests. The valley slopes up to the watershed serve as catchment for rainwater, which infiltrates in the wadi bottoms. Somewhat larger catchments, less depending on the topography and surface watersheds, occur in the western part of the province.

In the present study, the very large number of separate groundwater catchments in the province made it necessary to select a number of areas for more detailed studies. Eight catchments/wadis (or cluster of catchment wadis) were selected for the well inventory (see Table 12). Not all wells have been investigated in each area. However, the coverage is sufficient to allow for an assessment of the water resources at this stage. The main characteristics of these areas are summarized in the following paragraphs. Average values of pump discharge and annual water abstraction for shallow wells and deep wells for each area are given in Table 13. Details are provided in Annex A.

a) Rada basin

The basin is composed of a number of irregularly shaped intermontane plains and valleys at elevations of 2040-2200 m surrounded by hills and mountains. It lies at the western border of Al Bayda Province, bounded in the south by the Basalt plateau mountains of Agabah Riashiyah and Sabah, and in the north by Jabal Isbil. Its area is 272 km^2, which is approximately 28 % of the total catchment of 975 km^2.

Table 11 - Hydrogeological characteristics of the different geological formations in Al Bayda Province

System	Rock type	Aquifer/aquiclude	Well performance	Water quality
QUATERNARY	Volcanics Volcanic cones basalt lava flows volcanic ashes - 600 m	Highly permeable aquifer but usually deep water-levels, sometimes high-yielding springs (Wadi Tha)	High-yielding wells. Usually moderate yield due to great depth to water table	Fresh
	Alluvium Sandy clay with gravel and boulders to sandy loam and sand 0-20 m	Low to moderately permeable aquifers in wadi beds, where of sufficient thickness Important as groundwater reservoir	Low to moderate yields due to shallow to moderate thickness. important aquifers in wadis and plains	Fresh to saline
TERTIARY Yemen Volcanics	Chaotic and stratified rocks Well-stratified basalt and tuffs with interbedded layers of clay, sand and gravel 0-1500 m	Poor to moderate aquifer with interbedded aquicludes	Low to moderate yield, sometimes failures when clay and tuff occur frequent	Fresh
	Sub-volcanic rocks Basaltic and trachitic sub-volcanic rocks with dolerite dike swarms and interbedded layers of clay, sand and gravel 0 - > 300 m	Generally moderate aquifers due to fracturing or inter-bedded alluvium	Usually moderate yield 5-10 l/s	Fresh
CRETACEOUS Tawilah sandstone	White and tan to reddish firm sandstone with thin fine conglomerate layers 0-500 m	Poor to excellent aquifer especially when fractured	Usually moderate yield 3-10 l/s high yield > 10 l/s when fractured	Fresh
	In the vicinity of the Yemen Volcanics often cut by deeply weathered and fractured intrusive dikes 1 to 5 m wide	Moderate to excellent aquifer some springs originate from dikes and wells dug into dikes near Juban	Probably moderate to high yield	Fresh
PRECAMBRIAN	Well-stratified schists and gneisses with granite intrusions	Aquiclude	Failure	
	Weathered and fractured rock zone 0-20 m	Low to moderate aquifer	Low to moderate yield (1 to 5 l/s)	Fresh to saline
	Faults	Moderate to highly productive aquifer under wadi beds in combination with overlying alluvium	Moderate to very high yield 5 - > 30 l/s	Fresh to saline

Table 12 - Percentage of wells surveyed

Area	Percentage
Rada basin	100
Al Bayda North-East	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

Table 13 - Average pump discharges and annual abstraction of wells*

Area	Boreholes			Shallow wells		
	No.	Pump discharge (l/s)	Annual abstraction (m^3)	No.	Pump discharge (l/s)	Annual abstraction (m^3)
Rada basin	143	8.1	60 284	413	5.9	28 644
Al Bayda	4	3.3	47 400	207	5.3	23 951
Wadi Juban	-	-	-	153	3.6	12 426
Wadi Mansur/Wadi Amad	3	4.0	14 600	140	3.6	12 726
Wadi Matar/Wadi Ar Rin	4	7.0	20 662	30	4.0	12 174
Wadi Dhi Na'im	-	-	-	84	5.7	30 062
Abbas	3	9.0	24 183	52	4.5	12 170

Note: * Wells in operation only.

The main hydro(geo)logical characteristics are:

- The main aquifers are formed by Tawilah sandstone in the east and north and the overlying Tertiary and Quaternary volcanic rocks in the west and north of the area.
- Groundwater is abstracted at a rate of approximately 20 MCM (million cubic metres) per year from about 600 dug wells and 190 boreholes.
- Additional spring flow in Wadi Tha is estimated at 1.6 MCM/year; most of this water is used for irrigation.
- Water-levels are 30-55 m deep in the plain between Rada and Malah and generally 10-20 m deep under the rest of the plains and valleys. Very deep water-levels occur on the southern slopes of Jabal Isbil.
- Water quality is generally reasonable to good. Brackish water of EC > 2000 µS occurs mainly in the northern extremity of the Rada Plains near its natural outlet.

- Groundwater recharge occurs by:
  . lateral inflow of groundwater from south-western, western and north-western directions;
  . infiltration of rain-water and runoff water in the hills and plains; the average rainfall over the last 5 years amounts to 272 m^3/yr.

b) Al Bayda

The Al Bayda area forms one catchment composed of a number of usually narrow wadis and side wadis of a dendritic pattern with one single outlet in the north. The wadi bottoms range in elevation between 1880 m in the north to 2030 m in the south. The wadis are surrounded by 90 to 200 m higher bare ridges and hills. The investigated area of 283 km^2 is bounded in the south by a prominent escarpment forming the southern border of the high plateau of Yemen. The town of Al Bayda lies in the centre of the area. The main hydro(geo)logical characteristics are:

- Faults under the wadis and alluvium and the underlying weathered rock zone form aquifers of high to low permeability in the otherwise impervious Precambrian rocks composed of gneiss, schists and granites.
- Groundwater abstraction takes place from a great number of dug wells at an estimated rate of 5.1 MCM per year in the investigated half of the area.
- Water-levels are generally less than 15 m deep. Some artesian wells occur in a fault just south of Al Bayda Town. Water quality is generally good with the exception of the main wadi along the main road from Al Bayda.

c) Wadi Juban

The Juban catchment is a series of irregular plains and valleys at an elevation of around 2000 m above MSL (mean sea level) eroded 300 m deep into a high sandstone plateau of 2300 m above MSL. It lies in the south-eastern corner of Al Bayda Province and has an area of 53 km^2. The main hydro(geo)logical characteristics are:

- Aquifers of generally low to moderate productivity are formed by:
  . usually less than 20 m thick Tawilah sandstone in a 1 to 2 km wide strip under the northern plains and valleys of the catchment
  . weathered Precambrian gneiss and granite
  . the usually 5 to 15 m thick alluvium under the plains.
- Faults and dolerite dikes cross the area.
- Annual groundwater abstraction is estimated at 1.95 MCM/year, from around 200 dug wells.
- Water-levels are usually between 5-10 m. Deeper water-levels occur in the northern extremities of the valleys.
- Water quality is reasonable to good with an exception for small areas west of Juban Town near Al Hajar and at some places in the south where groundwater leaves the area along a narrow valley.

- Groundwater recharge occurs by
  - infiltration of rainfall in the sandy soils
  - infiltration of water running from the mountain slopes into the plains
  - some unknown groundwater inflow through the Tawilah sandstone from the north.

d) Wadi Mansur/Wadi Amad

Wadi Mansur forms one catchment composed of a number of broader wadis and side wadis in a dendritic pattern with one single outlet in the north. The wadi bottom elevation ranges from 1950 m above MSL at the south-western watershed to 1840 m near the northern outlet. Wadi Mansur lies 40 km east of Rada on the main road to Al Bayda, just north of the main watershed which forms its southern boundary. The catchment has an area of 228 km^2. Main hydro(geo)logical characteristics:

- Aquifers of generally low to moderate productivity are formed by
  - usually less than 10 m thick alluvium under the wadi
  - weathered Precambrian gneiss and schists

  Aquifers of good productivity are probably formed by the great number of faults underlying and crossing the wadis. So far, no boreholes have been sited on them.
- Annual groundwater abstraction is estimated at 2 MCM/year (not including the part of the catchment situated in nahiya As Sawadiyah) which is 7 % of the annual rainfall estimated at some 200 mm/year.
- Water-levels are usually between 7 and 15 m below the surface.
- Reasonable water quality is found only in the upstream sections of the main wadis and side wadis. Brackish water of EC > 3000 µS occurs mainly in the downstream parts of the main wadis in the north.
- Groundwater recharge occurs by infiltration of rainfall and runoff water from the surrounding hills into the wadi beds; infiltration is enhanced by numerous retention dams built by the farmers.

e) Wadi Matar/Wadi Ar Rin

Wadi Matar forms with Wadi Ar Rin a depression of two irregular plains with side wadis eroded into the Precambrian basement north of the Rada basin and Jabal Isbil. The area of Wadi Matar is approximately 78 km^2 and the elevation of the plains is 1880 to 2040 m above MSL. The main hydro(geo)logical characteristics are given below.

- Aquifers of generally moderate permeability are formed by
  - sandy alluvium and interbedded Quaternary basalt lavas;
  - weathered metamorphic rocks;
  - faults in the metamorphic rocks.
- Groundwater abstraction in Wadi Matar is around 8.5 MCM/year, which is about 3 % of the annual rainfall estimated at 200 mm/yr.
- Water quality is generally poor, with EC > 1500 µS up to 4000 µS in the plains and in Wadi Matar. Fresh groundwater occurs in the wadi east of Al Khilaw and in the plains adjacent to Jabal Isbil.
- Water-levels are less than 5 m in Wadi Matar and near the northern outlet of the catchment, but range between 15 m and 25 m in the upper reaches of wadis and plains.

- Groundwater recharge occurs by infiltration of rainfall and runoff water from the surrounding hills and by underground flow from below the northern slopes of Jabal Isbil.

f) Wadi Dhi Na'im

Wadi Dhi Na'im forms one catchment of some 70 km^2 composed of two NNE-SSW running broad main wadis and a number of side wadis developed parallel to the strike direction of the folded rock and along main fractures. The wadi system has one outlet in the north. The wadi bottoms range in elevation from 1950 m near the southern main watershed to 1880 m above MSL at its northern outlet. Wadi Dhi Na'im lies 20 km NW of Al Bayda just south of the main road to Rada and is bounded in the south and west by the main watershed with Wadi Al Bana. The main hydro(geo)logic characteristics are:

- Aquifers of generally moderate productivity are formed by
  . usually more than 10 m thick weathered Precambrian metamorphic rocks
  . the fracture system
  . to a minor extent, the thin sheet of alluvial deposits in the wadis and plains.
- Annual groundwater abstraction (by about 160 wells) is 3.6 MCM/yr, which is a very high percentage of the annual rainfall estimated at 250 mm/yr.
- Water quality is generally good but at some places brackish water of EC > 1500 to 6400 µS occurs in some parts of the main wadis especially near its northern outlet at Al Rubat. Water-levels are generally less than 5 m deep.
- Groundwater recharge occurs by infiltration of rainwater and runoff water from the surrounding hills.

g) Abbas

Wadi Abbas is an isolated catchment of 33 km^2, 12 km east of Rada just north of the main watershed. It is composed of an irregular alluvial plain with some side wadis at an elevation of 2010 m to 2075 m. Main hydro(geo)logic characteristics:

- Aquifers are formed by
  . 5 - 20 m alluvium underlying only parts of the plain
  . weathered metamorphic rock
  . faults tapped by some of the wells.
- Water quality in Wadi Abbas and Wadi Riam is good.
- The EC ranges from less than 800 µS in the south to more than 1500 µS near its northern outlet.
- We estimate present groundwater abstraction at 340 000 m^3/year, which is about 5 % of the rainfall estimated at 200 mm/year.
- Water-levels are 15-30 m below the surface.
- Groundwater recharge occurs by infiltration of rainfall and runoff water from the surrounding hills.

3.2 Surface water resources

There are no rivers in Al Bayda Province. Although there are some small perennial streams in the volcanic highlands south of Rada, where rainfall is higher than in the rest of the province, surface water is mainly runoff water from steep slopes immediately after heavy rainstorms, causing wadis to run during a few hours to several days. Most of the runoff water is diverted by the farmers to their cultivated land on the plains, in the wadis, and on terraces which are widely developed throughout the province. This runoff water supplements direct rainfall and may multiply by several times the water available to the cultivated land. This water is very important for the success of dry-land farming, especially the cultivation of sorghum.

At many places, water in the wadis is retained by dams. These structures are used primarily as diversion structures to bring water to cultivated land. They are not large or strong enough to dam and store the water flowing through the wadis after the occasional heavy rainstorm.

The narrow wadi beds and steep V-shaped valley profiles limit the storage capacity of dams. Dam sites for the storage of sufficient surface water for irrigation are therefore very scarce, if not absent. Sites for retention and flood protection are more readily available. A study made by the Ministry of Agriculture in 1983 indicates such a site in a narrow wadi passage south of Al Bayda for protection of the town. In conclusion, all surface water, except for extreme floods, is used. Retention of extreme floods, however, will be necessary in certain areas to protect population and property.

3.3 Water use for domestic consumption

3.3.1 Households

Data on present domestic water consumption per capita and per household were obtained from the village and household surveys of 162 villages throughout the province. A further survey of household water use was conducted in February 1983 and the results are outlined in RIRDP Technical Note No. 10 (Ilaco, 1983a). This survey was extended in September/October 1983 by interviews with women in the villages of Al Ajma, Al Farasa and Al Khabar of Rada District. The results of each of these surveys are compared and discussed in Annex B.

It has been concluded that it is not possible to derive a value for the present per capita water consumption that is representative for the entire province, since each area has reached a different level of development with regard to the number of water-supply systems and the type of water consuming facilities. Therefore values have been produced for each area, as indicated in Table 14.

Table 14 - Per capita water consumption in selected areas

Area	Per capita water consumption l/cap./day	% of villages with water-supply systems
1 Rada Basin	51.5	50
2 Sabah/Ar Riashiyah	56.2	6
3 Al Bayda N.E.	86.7	95
4 Al Bayda West	69.1	78
5 Wadi Juban	39.5	8
6 Wadi Mansur/Wadi Amad	58.6	7
7 Wadi Matar/Wadi Ar Rin	58.8	17
8 Wadi Hubabah/Wadi Ar Riashiyah	45.9	18
9 Wadi Dhi Na'im	76.4	64
10 Villages along Rada-Al Bayda road incl. part of As Sawadiyah	54.4	6

The results shown in Table 14 are illustrated in Figure 11, which clearly indicates the increase in water consumption occurring as a result of the provision of water-supply systems and the consequent increase in water consuming facilities. The latter effect is also supported by the results of the survey in Al Ajma, Al Farasa and Al Khabar where a greater number of taps in the house produced a significant increase in per capita water consumption (see Annex B, Table B.14).

Fig. 11 indicates that the value for fetched supplies should be of the order of 45 l/capita/day. This is a higher value than is often considered in the literature for fetched supplies, but this may be due to the fact that donkeys are used for water collection in Yemen, which increases the water quantity that can be collected.

The 1981 population of each of the selected areas was indicated in Chapter 2. In the basis of the results of the village survey in these areas and the estimated population in 1983, an estimate of the present domestic water consumption is given in Table 15.

3.3.2 Other users

In addition to the household consumption, water is required for schools, health facilities, mosques and industries. The numbers of school pupils and health facilities in the selected areas obtained from the operators survey is indicated in Annex B, Table B.4.

A number of schools have been constructed in recent years, and many of these are provided with flush toilets although often they are neither correctly used nor supplied with adequate water. While the daily water consumption of a school with flush toilets can be of the order of 15 l/pupil/day it is probably correct to assume that the

VARIATION OF PER CAPITA WATER CONSUMPTION WITH % OF VILLAGES WITH WATER-SUPPLY SYSTEMS
(BASED ON SURVEY RESULTS)

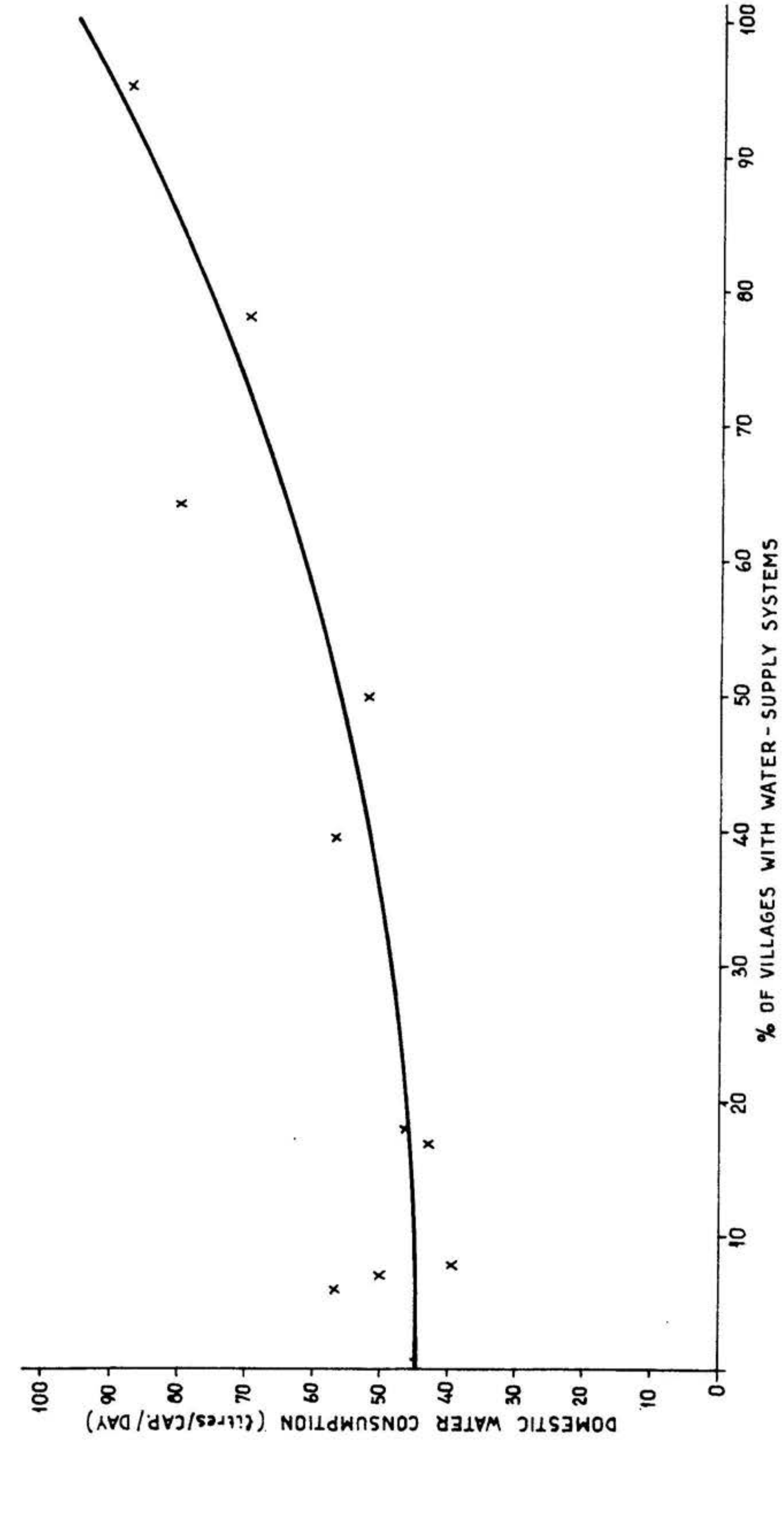


FIG. 11

present school water consumption is no more than 50 % of this value or 7.5 l/pupil/day. Health facilities are no significant water users, but it is important that a water-supply be provided in villages where permanent health facilities are available.

Table 15 - Present domestic water consumption in selected areas (estimated)

Area	Population 1983*	Per capita water consumption (l/cap./day)	Total present domestic water consumption (m^3/day)
1 Rada Basin	62 600	51.5	3 224
2 Sabah/Ar Riashiyah	24 400	56.2	1 371
3 Al Bayda N.E.	34 000	86.7	2 948
4 Al Bayda West	23 300	69.1	1 610
5 Wadi Juban	12 700	39.5	502
6 Wadi Mansur/Wadi Amad	12 700	58.6	744
7 Wadi Matar/Wadi Ar Rin	6 400	58.8	376
8 Wadi Hubabah/Wadi Ar Riashiyah	8 500	45.9	390
9 Wadi Dhi Na'im	8 500	76.4	649
10 Villages along Rada-Al Bayda road incl. part of As Sawadiyah	7 400	54.4	402

* Derived from the 1981 census in applying a growth rate of 2.4 % p.a.

An important water consumer is the mosque, where according to moslem tradition one must wash before praying. If taps are provided for washing in the mosques, it is estimated that a mosque could require 1.5 l/person/day.

There are no significant industries at present in the rural areas of Al Bayda Province, so no water consumption for this purpose has been considered. The present estimated water consumption for schools and mosques, which are the main consumers outside the households, is indicated in Table 16.

3.3.3 Livestock consumption

An analysis of the livestock water consumption is made in Annex B, and the unit values considered representative of the existing situation in Al Bayda Province are given in Table 17.

Table 16 - Estimated present water consumption of schools and mosques

Selected area	Population 1983	Estimated no. of pupils	Water consumption (m^3/day)		
			Schools	Mosques	Total
1 Rada Basin	62 600	4 100	31	89	120
2 Sabah/Ar Riashiyah	24 400	2 500	19	35	54
3 Al Bayda N.E.	34 000	4 900	37	48	85
4 Al Bayda West	23 300	3 300	25	33	58
5 Wadi Juban	12 700	500	4	18	22
6 Wadi Mansur/Wadi Amad	12 700	1 200	9	18	27
7 Wadi Matar/Wadi Ar Rin	6 400	400	3	9	12
8 Wadi Hubabah/Wadi Ar Riashiyah	8 500	700	5	12	17
9 Wadi Dhi Na'im	8 500	1 000	8	12	20
10 Villages along Rada-Al Bayda road incl. part of As Sawadiyah	7 400	700	5	11	16

Table 17 - Present water consumption per head of livestock

	Present water consumption (litres/animal/day)
Cow, Bull	25
Sheep	4.4
Goat	8.8
Donkey	8.8
Camel	25

The values obtained from the household survey have been adjusted slightly so that the above consumption figures conform reasonably with what could be expected from livestock under the conditions existing in Al Bayda Province.

The livestock water consumption values derived above are based upon household consumption, as it was not possible to obtain estimates of livestock water use at the source. However, the quantity consumed per animal should not vary significantly in either case. Since surface water sources are relatively rare, it can be assumed that most of the water consumed by livestock originates from groundwater, irrespective of where it is consumed. Consequently, the consumption by all livestock within the selected area is relevant to the estimation of water requirements.

Based upon the livestock population in the selected areas determined in Section 2.4 and the unit values derived above, the present livestock water consumption in the selected regions was calculated, based on a sheep unit consumption of 4.4 litres/day (see Table 18).

Table 18 - Total livestock water consumption

Selected region	No. of households 1983	No. of sheep units per household*	Estimated total no. of sheep units	Livestock water consumption (m^3/day)
1 Rada Basin	10 097	29.8	300 883	1 324
2 Sabah/Ar Riashiyah	3 642	73.3	266 948	1 175
3 Al Bayda N.E.	6 407	25.4	162 728	716
4 Al Bayda West	4 967	16.5	81 948	361
5 Wadi Juban	1 927	76.9	148 361	653
6 Wadi Mansur/Wadi Amad	2 021	65.0	131 373	578
7 Wadi Matar/Wadi Ar Rin	950	32.2	30 602	135
8 Wadi Hubabah/Wadi Ar Riashiyah	1 489	62.3	92 781	408
9 Wadi Dhi Na'im	1 415	94.5	133 697	588
10 Villages Rada-Al Bayda road incl. part of As Sawadiyah	1 238	61.8	76 504	337

* Derived from Water-supply and Sanitation Survey, see Annex B.

3.3.4 Total water consumption for non-agricultural purposes

Table 19 indicates the total present water consumption in the selected regions, other than for agricultural purposes.

Table 19 - Estimated total present water consumption for non-agricultural purposes

Selected region	Estimated water consumption (m^3/day)				Equivalent total per capita consumption (l/cap./d)
	Domestic	Livestock	Schools + mosques	Total	
1 Rada Basin	3224	1324	120	4668	74.6
2 Sabah/Ar Riashiyah	1371	1175	54	2600	106.6
3 Al Bayda N.E.	2948	716	85	3749	110.3
4 Al Bayda West	1610	361	58	2029	87.1
5 Wadi Juban	502	653	22	1177	92.5
6 Wadi Mansur/Wadi Amad	744	578	27	1349	106.2
7 Wadi Matar/Wadi Ar Rin	376	135	12	523	81.9
8 Wadi Hubabah/Wadi Ar Riashiyah	390	408	17	815	96.0
9 Wadi Dhi Na'im	649	588	20	1257	148.0
10 Villages Rada-Al Bayda road incl. part of As Sawadiyah	402	337	16	755	101.9

3.4 Water use for irrigated agriculture

3.4.1 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 unreliable. This was mostly due to the fact that areas had 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/Saru and As Sawadiyah were not covered by the agricultural survey) the cropped areas per crop were totalled and made into a cropping pattern 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 by water-melon areas where the cropped area in winter is larger (Wadi 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 Annex C, Table C.1.

The cropping pattern forms the basis for the explanation of differences in cropping practices and irrigation water abstraction between the selected areas. These cropping patterns have also been introduced into the calculations of the crop water requirements in Table 29 (Subsection 4.3.3).

In Table C.1, Annex C it is 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.

The percentages relate to net cropped areas, but in addition both in the summer and winter season a certain area remains in short-term fallow. Farming systems research in Wadi Tha and Wadi Mansur has shown the extent to be 25 and 17 % of the irrigated area during respectively the summer and winter season (Ilaco, 1982c and 1983b). When the area covered by infrastructure (roads, villages and canals), for which a figure of 15 % is adopted in this report, is added too, one arrives at the gross irrigated area.

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, but this was found to be extremely low, although it must be admitted that the sample of households studied is very small.

In Table 20 the average annual abstraction per well covered by the agricultural survey and the average electrical conductivity (EC) of the well water, calculated for each of the selected areas, are indicated. The former should give an indication of the relative abundance of irrigation water, while a high EC indicates a poor quality of irrigation water. These figures were drawn up in order to study any possible correlation between these factors and the prevalent cropping patterns. Abundance of irrigation water could induce relatively high total cropping intensities, while poor-quality irrigation water could limit the area under crops sensitive to saline water such as alfalfa, onions and potatoes. The figures are, however, not consistent in this sense. The selected areas with the highest annual abstraction per well (Rada Basin and Dhi Na'im) have a lower total cropping intensity than Abbas, which has the lowest abstraction; also, in spite of having by far the highest average EC, Wadi Mansur/Amad and Wadi Mattar/Ar Rin show high percentages of respectively (summer) potatoes and alfalfa.

Table 20 - Water abstraction and areas irrigated

Selected area	Average annual[1] abstraction per well (m^3)	Max. area irrigated[2] per well (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 N.E.	21 490	1.67	1 057
4. Al Bayda W.	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/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] These represent the total annual abstractions of the wells included in the agricultural survey, exclusive of domestic use. The figures are averaged per selected area.

[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-melons.

[3] For wells included in the agricultural survey only.

3.4.2 Crop calendars

The crop calendars and growth durations for Al Bayda Province are represented in Table 21. Except for a few cases they are uniform for all selected areas. Although for almost all crops the table indicates cropping seasonas both in summer and winter, the cropping patterns indicate that sorghum is a summer crop, while barley, potato, maize and melon are basically winter crops.

Table 21 - Crop calendars and growth durations

	Cropping season		Growth duration (months)
	Winter	Summer	
Alfalfa	year-round	year-round	12
Sorghum	-	June-Dec.[1]	6
Wheat	Jan.[2]-May	July/Aug.[3]-Nov./Dec.	4-4[5]
Barley	Jan.-Apr.	July[4]-Nov.	3-3[5]
Potato	Jan.-May	June/Aug.-Oct./Dec.	4
Maize	Jan./Feb.-May	June/July-Sep./Nov.	3[5]-4
Qat	year-round	year-round	12
Onion	Jan./Feb.-May/June	June/Aug.-Oct./Dec.	3[5]-4
Melon	Jan.-June	June[5]-Nov./Dec.	5-5
Fruit	March-Variable	Oct.-Variable	12
Vegetables & others	year-round	year-round	variable

[1] The notation indicates that planting is done in June and harvesting in December.
[2] The winter season in Wadi Mansur/Amad is 1 month earlier.
[3] The summer " " " Matar/Ar Rin is from May/July until October.
[4] " " " " " Abbas runs from September to December.
[5] " " " " Juban area starts in April and ends in September.

3.4.3 Irrigation practices and water application

In the area two different ways of irrigation are practised: basin irrigation and furrow irrigation. Most crops are basin-irrigated except for potatoes, melons, and vegetables. In itself, basin irrigation can be an efficient method of water application especially for people with a relatively short experience in irrigation, such as the inhabitants of this area. There is, therefore, no reason to try and change this habit.

The application per watering depends only on the water-holding capacity of the soil. The practice in the Dhamar Agricultural Improvement Centre is that about 80 mm per irrigation is applied.

In Table 22 the observations regarding application of irrigation water in the different selected areas are indicated as an average per area, and as an overall average over winter and summer. The figures are based on observations of the well discharge, area of plots, and the time during which well discharge led into this plot. Discharge and plot area were usually measured, but information on the duration of flooding was obtained from the farmer.

As can be seen the figures within each crop and within the selected areas vary widely, although the overall figures fluctuate around the 80 mm mentioned earlier. The figures are not very consistent in the sense that applications for one crop are always higher than for others, or that applications in certain areas are all higher than in others. Exceptions are formed by the applications for Wadi Mansur/Amad and Abbas, which are consistently low, while the ones for Dhi Na'im are high. It is remarkable that the soils of Dhi Na'im are rather sandy, thus having a low water-holding capacity, which would call for a relatively low application.

The total irrigation water dosages per crop over a full season are indicated in Table 23. The variation of dosages among the selected areas for one and the same crop is even greater than for the single applications in Table 22. The difference between the two tables is that in Table 23 the total number of applications during the growing season is taken into account.

The large variation reflects in the first place the various degrees of supplemental irrigation, because in this study a crop was considered an irrigated crop if it got just one supplemental irrigation. It would have been almost impossible to exclude such crops. Other factors which influence the water dosage are:

- shallow rooting of a crop or light soil types, which require both more frequent applications;
- relative abundance of irrigation water;
- a high dosage as compensation for brackish or saline irrigation water;
- lack of experience in irrigation on the part of the farmer.

Again, the figures in Table 23 do not show a high consistency. Certain crops receive relatively small dosages in the one area, while other crops in the same area receive a high dosage. It can be concluded only that Wadi Mansur/Amad shows a consistently low dosage per crop and Wadi Dhi Na'im a consistently high one. From the latter area it is known that (ground)water is relatively abundant and that soils are somewhat sandy; both induce high water dosages.

Given the wide variation in dosages we have decided to use the averages over all 10 selected areas in the remainder of this report.

It is remarkable that tree crops like qat and fruit crops receive a relatively low dosage in spite of the fact that they are in the field all season. This may be due to their extensive root system which has access to a relatively large soil volume and is able to

Table 22 - Amount of irrigation water (mm) per application in winter and summer for the individual crops

Catchment	Winter 1982/'83											Summer 1983										
	Alfalfa	Sorghum	Wheat	Barley	Potato	Maize	Qat	Onion	Melon	Fruit	Vegetables and others	Alfalfa	Sorghum	Wheat	Barley	Potato	Maize	Qat	Onion	Melon	Fruits	Vegetables and others
1 Rada Basin	96	-	144	126	111	49	92	93	51	103	82	96	100	86	162	64	-	82	96	101	110	97
2 Sabah	88	-	83	-	82	168	85	-	-	-	149	86	159	83	-	82	49	85	44	-	-	119
3 Al Bayda N.E.	92	-	114	98	135	51	62	35	51	-	111	97	96	-	-	57	-	47	-	-	-	110
4 Al Bayda W.	77	-	75	99	115	124	84	36	-	78	147	69	100	-	-	56	-	85	114	129	56	71
5 W. Juban	110	-	-	-	-	67	77	-	-	-	167	110	64	83	-	55	36	75	59	168	46	52
6 W. Mansur/W. Amad	95	-	27	-	-	68	31	-	43	-	-	95	40	-	-	59	50	31	11	12	-	3
7 W.Matar/W. Ar Rin	148	-	-	-	-	-	42	-	-	-	-	120	110	88	-	-	-	39	-	-	-	-
8 W. Hubabah	84	-	55	41	-	76	89	-	-	67	-	84	66	-	-	-	57	89	-	-	67	-
9 W. Arsard/Saru					not available																	
10 W. Dhi Na'im	157	-	100	102	-	147	138	-	125	184	-	157	105	-	-	-	155	138	107	-	184	104
11 Abbas	53	-	-	-	29	-	40	-	53	-	30	53	-	-	26	-	-	33	36	-	68	69
12 As Sawadiyah					not available																	
Average per crop[1]	98	-	97	99	83	73	76	70	58	98	96	96	90	86	94	62	65	71	69	103	85	79
Ditto over winter plus summer[1]	97	90	93	99	71	70	73	69	72	90	86											

Note: If no figures are shown, this does not necessarily mean that no cases have been observed. It is possible that un-reliable figures have been eliminated.

[1] Weighted averages.

Table 23 - Total irrigation water dosage per crop (mm) over a full season

Catchment	Winter 1982/'83											Summer 1983										
	Alfalfa	Sorghum	Wheat	Barley	Potato	Maize	Qat	Onion	Melon	Fruit	Vegetables and others	Alfalfa	Sorghum	Wheat	Barley	Potato	Maize	Qat	Onion	Melon	Fruit	Vegetables and others
1 Rada Basin	1467	-	1150	953	442	224	455	1752[1]	1154	1076	1224	1470	853	711	1295	410	-	400	1910[1]	1618	1230	1349
2 Sabah	1465	-	444	-	739	-	256	-	-	-	1043	1413	956	660	-	734	555	256	664	-	-	476
3 Al Bayda N.E.	1337	-	785	533	602	358	490	248	506	-	-	1311	833	-	-	312	-	342	-	-	-	1206
4 Al Bayda W.	1843	-	423	506	803	869	484	214	-	299	586	1662	925	-	-	359	-	441	1715	-	291	597
5 W. Juban	1698	-	-	-	-	495	276	-	-	-	1672	1698	179[2]	665	-	324	216	343	996	2186	1554	655
6 W. Mansur/W. Amad	1388	-	161	-	-	408	182	-	640	-	-	1388	293	-	-	351	150	182	1242	-	-	337
7 W. Matar/W. Ar Rin	1897	-	-	-	-	-	255	-	-	-	-	2036	406	532	-	-	-	233	-	-	-	-
8 W. Hubabah	1732	-	464	328	-	555	199	-	-	818	-	1732	704	-	-	-	436	197	-	-	818	-
9 W. Arsard/Saru					not available																	
10 W. Dhi Na'im	2529	-	963	715	-	-	1371	-	2875	2208	-	2529	1292	-	-	-	1497	1371	1600	-	2208	1771
11 Abbas	1959	-	-	-	868	-	253	-	1782	-	700	1559	-	-	182	-	-	265	766	-	203	1399
12 As Sawadiyah					not available																	
Average per crop[3]	1659	-	713	587	726	502	404	1144	1227	205	1082	1606	756	669	739	404	684	378	1346	1902	893	1033
Ditto over winter and summer[3]	1632	756	697	601	536	582	390	1287	1350	587	1052											

N.B. If no figures are shown, this does not necessarily mean that no cases have been observed. It is possible that un-reliable figures were eliminated.

[1] "Onion" in the Rada Basin includes crops which remain in the field all year round and of which the leaves are cut at regular intervals for use as a kind of vegetables.
[2] Mostly supplemental irrigation only.
[3] Averages weighted for number of observations.

benefit better than other crops from rainfall penetrating into the soil. However, alfalfa has deep roots as well, but seems to receive a high water dosage still.

3.4.4 Water application efficiency

In general, a reduced water application efficiency can be caused by spillage of irrigation water downstream of the farm and by excessive seepage into the soil profile in case of light (sandy) soils. During our observations in the field no surface spillage from the farms was observed. Although frequent infiltration measurements had been planned for the field survey, they were not realized because of the tight work schedule. These measurements should have confirmed high infiltration rates in the relatively sandy areas such as Wadi Juban, Wadi Mansur and Dhi Na'im. In fact only Wadi Dhi Na'im fits this condition by showing both high applications and high water dosages per crop.

Although irrigation losses, especially in Wadi Dhi Na'im, could be sizeable, in this report recharge of the groundwater aquifer by seepage from irrigated plots has been neglected in the water balance. The consultants feel that this is justified, given the fact that the irrigated area in Al Bayda Province covers only a few per cent of the total surface area.

3.4.5 Water abstraction over the year

Water abstraction over the year can be studied from the monthly readings of the wells equipped with water meters. At present about 14 such wells are available, all of them in the Rada Basin. Readings started mostly in May 1982, but only a limited number of wells show an uninterrupted series of observations. From 5 wells with an uninterrupted series of readings the average monthly abstraction has been calculated over the period May 1982 to September 1983. In Table 24 the average monthly abstractions are indicated as well as the rainfall data for the same period. One would expect an increased irrigation abstraction during dry periods, but no such relation can be observed.

When studying the figures in Table 24 one should be aware that the sorghum growing season stretches from June to November. The growing of this major crop could very well be the cause of the high abstraction during August, September and October. During the remainder of the year there is not much fluctuation in well abstraction.

3.4.6 Quality of well water for irrigation

The quality of well water is determined by the pH (or alkalinity) and the electrical conductivity (EC). Both values were measured at each of the wells included in the hydrogeological survey. The pH of the water usually proved to be no problem for its use for irrigation. The EC for each individual well, as well as iso-EC lines are indicated on the maps belonging to Annex A, Volume II.

The EC values for the wells included in the agricultural survey were averaged per selected area and they are indicated in the last column of Table 20. We realize that such average figures are of limited value, but a high average EC figure will nevertheless indicate that wells with high-EC water occur relatively often.

From Table 20 it is clear that Wadi Mansur and Wadi Matar/Ar Rin are the worst areas as regards water quality, while it is also known that the groundwater of Dhi Na'im, as far as the part near the road is concerned, is of poor quality. In these areas EC values of 3800-3900 µS occur, with extreme values as high as 5000-6000 µS. From Table 25 it can be concluded that such high EC values will affect the yielding capacity of the more sensitive crops like alfalfa, qat, fruit trees, onion and potato. This effect can be compensated only to a limited extent by applying extra irrigation water.

Table 25 - Crop salt tolerance levels[1] (EC_w, in µS)

Crop	EC_w resulting in	
	100 % yield	50 % yield
Sorghum	2700	7200
Alfalfa	1300	5900
Wheat	4000	8700
Barley	5300	12000
Qat/Citrus/Almond/Apricot	1000-1200	2500-3300
Onion	800	2900
Potato	1100	3900

Source: FAO (1976).
[1] These refer to the EC levels for irrigation water, which are lower than those for soil moisture.

In general, however, it can be stated that, except for certain pockets in the selected areas, the water quality forms no limitation to irrigation development.

4 WATER POTENTIALS AND FUTURE WATER USE

4.1 Water potentials of selected areas and scope for extension of water abstraction

The present situation of groundwater abstraction in the catchment is described extensively in tables and on maps in Annex A. The results are summarized per selected area in Table 28. Column 8 in this table presents the estimated potential for water abstraction. This quantity must be considered only as a first estimate, for the following reasons:

- no rainfall data are available from any of the investigated areas except the Rada Basin. All rainfall data used have been estimated from a general rainfall map of the Arab Peninsula;
- the accuracy of collected water abstraction data is dependent on the quality of the information supplied by the farmers comparison with estimates made from the areas under irrigation gives sometimes unrealistic results;
- the absence of rainfall records makes it impossible to take the influence of long-term rainfall variations into account on water-levels and groundwater abstraction.

We consider the results given in the table thus as a first estimate of the water potential. Another point to take into account is that the situation within each investigated area is not homogeneous but differs from sub-area to sub-area. For any future groundwater development the extension of the monitoring network for rainfall and water-levels is indispensable.

4.1.1 Rada Basin

The potential for further groundwater development in this area is very difficult to determine because of the very complex hydrogeology of the basin. We estimate that there is scope for further development from the present abstraction of 20.6 MCM/year to the order of 30 MCM/year. This extra potential is irregularly divided over a great number of sub-areas, given in Table A.9 in Annex A. We consider this estimate only as an order of magnitude and recommend a further study with a groundwater model based on the present knowledge of the area to find a more accurate figure.

4.1.2 Al Bayda

The potential for further groundwater abstraction is estimated at 4 MCM/year. This estimate is based on an estimated rainfall of 250 mm/year. The potential for further development is irregularly spread over the area, as shown in Annex A. The estimate is based on the situation found during the present survey and is made only for the investigated sub-areas. Information from the population indicates that several years ago the water-level in the wadi north and east of Al Bayda Town was much deeper than found during the survey. Further expansion of groundwater exploitation should therefore be accompanied by monitoring of groundwater levels and rainfall.

Table 26 - Present water abstraction and estimated future water availability, per selected area

	Catchment (ha)	Alluvium (ha)	Water abstraction (1000 m^3/yr)			Present water-level depth (m)	Water availability (1000 m^3/yr)		
			Water-supply	Agriculture	Total		Total	Future water-supply	Available for irrigation
Rada	97 500	11 811	1 661	18 944	20 605	0-50	33 288	4 640	28 648
Al Bayda N.E.	14 030	1 869[3]	658[3]	2 318[3]	2 976[3]	0-15	5 450[3]	1 315[3]	4 135[3]
Al Bayda West	14 241	883[5]	178[4]	1 928[4]	2 106[4]	0-15	3 600[4]	410[4]	3 190[4]
Wadi Juban	5 280	1 395	215	1 738	1 953	3-20	3 458	527	2 931
Wadi Mansur[1]	14 771	3 725	196	1 758	1 954	2-15	3 025	407	2 618
Wadi Matar[2]	7 770	1 665	56	296	352	4-30	1 050	132	918
Wadi Dhi Na'im	5 577	1 480	208	3 337	3 545	3-10	4 550	814	3 736
Abbas	3 275	666	19	318	337	0-30	680	50	630
Total	162 444	22 701	3 191	30 637	33 828	0-50	55 101	8 295	46 806

1 Excl. Amad & As Sawadiyah.
2 Excl. Ar Rin.
3 Excl. area south of Al Bayda (BD).
4 Excl. data N.W. of Al Bayda.
5 Excl. areas in the south, outside the aerial photographs.

4.1.3 Wadi Juban

The potential for further increase of groundwater abstraction is estimated at some 250 000 m^3/year, mainly confined to the northern valleys and plains. Present water shortages in the southern part of the catchment indicate the low potential of this part of the Juban area. Water abstraction in the south should be used for domestic water-supply in the first place. Any further development requires monitoring of rainfall, water-levels and water abstraction.

4.1.4 Wadi Mansur/Wadi Amad

The potential for further increase in groundwater abstraction is restricted by water quality and the shallow depth of the aquifers. The northern parts of the main wadis, where water is brackish, have hardly any potential for increase of groundwater use for irrigation. Local pockets of fresh groundwater in the main wadis and fresh water in the side wadis should first be used as a source of drinking-water. We estimate the potential for further groundwater abstraction at 1 MCM/year, confined to the southern wadis and side wadis, as shown in Table A.13 in Annex A.

4.1.5 Wadi Matar/Wadi Ar Rin

The present groundwater abstraction in wadi Matar and wadi Ar Rin is relatively low. However, the groundwater potential is reduced by the groundwater quality, which is brackish in large areas of the plain. The potential of fresh water in Wadi Ar Rin North may be substantial but is yet unknown. It should therefore be covered by the well inventory in the second stage.

4.1.6 Wadi Dhi Na'im

Despite the relatively high groundwater abstraction in this catchment, the occurrence of shallow water-tables and the absence of complaints about water shortages indicate that there is probably still scope for a moderate increase of water abstraction of 1 MCM per year. Table A.12 in Annex A shows the division of this extra potential over the area. We consider this estimate as an order of magnitude. Any expansion in water abstraction should be accompanied by monitoring of water-levels and abstraction. Monitoring of rainfall should start as soon as possible.

4.1.7 Abbas

The present groundwater abstraction in Abbas is relatively low. Groundwater potential is reduced by limited occurrence of alluvium and weathered rock aquifers. The scope for water abstraction is restricted to tapping the faults by drilling boreholes in them. This is of special importance for the drinking-water supply of Abbas. Proper site selection by the electromagnetic method and by using aerial photos is of utmost importance for successful well drilling.

4.2 Water use for domestic consumption

4.2.1 Households

The present per capita water consumption for each of the selected areas is indicated in Table 14. It can be expected that the per capita values will increase in the future due to:

(i) an increase in the number of villages with water-supply systems.
(ii) an increase in household water using facilities.

Figure 10 has indicated the increase in water consumption which can be expected as the number of villages with water-supply systems increases. The effect of an increase in water consuming facilities is also reflected in the same curve. It could therefore be expected that a value of 100 litres/capita/day, which corresponds with 100 % of villages having water-supply systems, could be adopted as the future per capita domestic water consumption. This does not however take into account the time required to reach such a value.

Figure 12 has been produced for Al Bayda North, where the first water-supply systems were constructed around 1965. Assuming that in 1965 the average per capita water consumption was 45 l/cap./d and knowing the present consumption of 87 l/cap./d, the rate of increase in water consumption over 18 years of development (i.e. up to 1983) was calculated (see Figure 12). Using this slope as a standard, and indicating the present level of development of the other regions on the same line by their respective present per capita water consumption, the projected per capita water consumption can be estimated for each region. These are shown in Table 27. A planning period of 20 years (i.e. up to 2003) has been adopted.

Table 27 - Estimated per capita water consumption in 2003

Area	Anticipated per capita water consumption in 2003 (litres/cap./day)
1 Raḍa Basin	89
2 Sabah	90
3 Al Bayda N.E.	98
4 Al Bayda W.	92
5 Wadi Juban	88
6 Wadi Mansur	90
7 Wadi Matar/Wadi Ar Rin	90
8 Wadi Hubabah/Wadi Ar Riashiyah	88
9 Wadi Arsard/Saru	96
10 Wadi Dhi Na'im	90

VARIATION OF PER CAPITA WATER CONSUMPTION WITH TIME (BASED ON ALBAYDA NORTH)

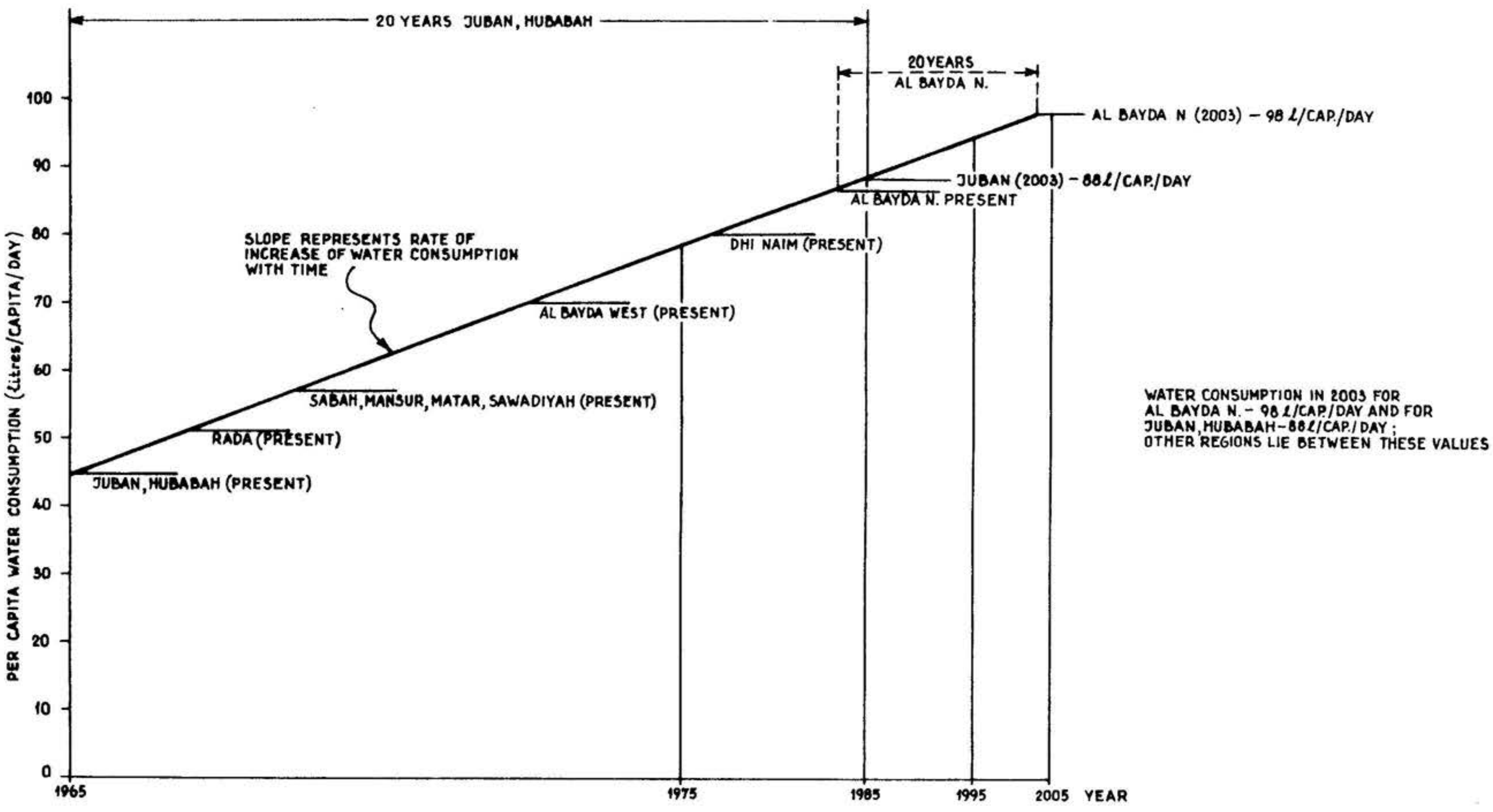


FIG. 12

This exercise assumes, however, that the rate of increase will be the same as has occurred in Al Bayda North during the first 18 years. Since the rate of increase in water-supply systems and water consuming facilities is likely to be greater during the next 20 years, the above values are probably an underestimate.

It can be seen that the values shown in Table 28 appear to be approaching 100 litres/capita/day, which therefore seems a reasonable estimate of the future water consumption in the year 2003, assuming that by this date all regions have reached more or less the same level of development of water-supplies.

A value of 100 litres/capita/day will therefore be adopted in all regions as the domestic water consumption in 2003.

4.2.2 Other users

By the year 2003 it is assessed that all schools will be equipped with flush toilets; a water consumption of 15 litres/student/day has been adopted. It has further been assumed that the entire population in the 5-14 age group will be at school.

It is also anticipated that mosques will be equipped with taps and showers for washing. The future mosque water consumption has therefore been increased to 5 litres/person/day.

4.2.3 Water use for livestock consumption

It is considered neither desirable nor likely that any significant increase in livestock population will occur in the future, because of the present state of the rangelands and because the present livestock population appears sufficient, even allowing for the projected increase in inhabitants in the province. Future livestock water consumption has therefore been taken as equal to the present consumption (assuming, of course, that the per animal consumption remains constant, see Subsection 3.3.3).

4.2.4 Total water consumption for non-agricultural purposes

Table 28 indicates the estimated water consumption in the year 2003 for non-agricultural purposes, based on the following assumptions:

(i) The projected population in 2003 is calculated by applying a 2.4 % per annum growth rate to the estimated present population per region.
(ii) The per capita domestic water consumption in 2003 is estimated at 100 litres/capita/day for all regions.
(iii) The total population in the 5-14 age group is assumed to go to school, i.e. 26.9 % of the population according to the 1975 CYDA census.
(iv) No increase in either livestock population or per animal consumption will occur.
(v) School and mosque water consumption values of 15 litres/pupil/day and 5 litres/person/day respectively.

Table 28 - Projected total water consumption for non-agricultural purposes (year 2003)

Area	Projected population	Projected school-going population	Projected water consumption (m^3/day)				Total
			Domestic	Livestock	Schools	Mosques	
1 Rada Basin	100 600	27 000	10 060	1 324	405	503	12 292
2 Sabah/Ar R.	39 200	10 500	3 920	1 175	158	196	5 449
3 Al Bayda N.E.	54 600	14 700	5 460	716	221	273	6 670
4 Al Bayda W.	37 400	10 000	3 740	361	150	187	4 438
5 W. Juban	20 400	5 500	2 040	653	83	102	2 878
6 W. Mansur/W. Amad	20 400	5 500	2 040	578	83	102	2 803
7 W. Matar/W. Ar Rin	10 300	2 800	1 030	135	42	52	1 259
8 W. Hubabah	13 700	3 700	1 370	408	56	69	1 903
9 W. Arsard/Saru	13 700	3 700	1 370	588	56	69	2 083
10 W. Dhi Na'im	11 900	3 200	1 190	337	48	60	1 635

4.3 Irrigation potential

4.3.1 Land resources

Cultivable land is a pre-requisite for irrigation development. For each selected area an estimate has been made in the absence of a systematic soil survey. To this end the selected areas which were surveyed were divided into about 150 sub-areas. It was necessary to work on a sub-area basis, since available water and suitable land should not be too far apart. Cultivable land without water resources is of no use.

In order to assess the area of available land, first for each sub-area the gross area of alluvium was measured on the basis of aerial photographs. These alluvia are indicated as white areas on the general layout maps nos. C.1-C.8 which are discussed in Annex C. As "alluvium" are considered the flatter parts of wadis enclosed by the bare and rocky hills, which form the major part of catchments. Then, on the basis of our field impressions an estimate was made of the cultivable part. In this cultivable or irrigable area we have also included those parts of the selected areas which are presently either saline or waterlogged, but which according to our opinion could be reclaimed. This area was subsequently reduced with the area required for accommodation of the infrastructure. Given the fact that the irrigation systems are rather simple and the road system extensive, the relatively low percentage of 15 % of the gross irrigated area was adopted for this infrastructure.

Of course, part of the cultivable land is already under irrigation at present, and this has to be subtracted from the potential irrigation area in order to arrive at the incremental irrigation area given in Table 31 at the end of Subsection 4.3.5. The gross irrigated land is represented on the layout maps mentioned earlier, but it has to be reduced first with the same 15 % for infrastructure. In addition, the short-term fallow area has to be deducted. The percentage of land involved varies over the selected areas as well as over the seasons. As mentioned in Section 3.4 farming systems research has yielded figures like 25 % and 17 % for the summer season in Wadi Tha and Wadi Mansur respectively. However, during the field survey in Al Bayda W. a percentage of only 9 % was observed during the summer season. Since no other data are available, a uniform percentage of 15 % fallow land was adopted for all the selected areas as the average over the seasons.

4.3.2 Future cropping patterns

For various reasons, future cropping patterns for Al Bayda Province are difficult to predict. For one thing, this study does not concern a settlement in a virgin area, but an area which is already occupied and largely owned by private farmers, who are free to plant whatever they deem useful in view of either their personal needs or the market situation.

A second reason is that there is no national or regional agricultural sector plan available, so that the consultants have no guidelines as to what crops the government would like to promote or discourage.

Only the following considerations may serve as guidelines:

- The import of all fruits into Yemen will be limited in future, so that these will have to be grown locally, but there are probably better areas to do this (Taizz).
- The Yemeni farmer is subsistence-oriented: he wants in the first place to secure his personal supplies of staple cereals such as sorghum and wheat and also livestock products.
- Profitable crops such as qat and vegetables have limited market possibilities.
- If the market for qat would become saturated, fruit trees will take its place. They have a similar management and water requirements. Within the group of vegetables and others, some species may be replaced by other vegetables or by crops such as onions, potatoes and water-melons, which are in the same category in terms of management and water requirements.

Given the above considerations, it has been taken that the cropping patterns will basically not change in the near future. Thus the cropping patterns per selected area indicated in Table C.1, Annex C will remain valid.

This approach is also based on the consideration that there must be specific factors which determine the cropping pattern for a certain area. As such could be considered:

- the proximity of an urban area as consumption centre;
- the relative abundency of irrigation water;
- the quality of soils and irrigation water.

4.3.3 Adopted crop water uses

Potential evaporation over the seasons has been studied on the basis of Class-A pan evaporation. Since no data on the empirical values of the individual crop factors are available (except for alfalfa, see Annex C, Section C.3.4), potential evapotranspiration for the different crops could not be determined. Since irrigation technology however is not at a very high level in the area, it is not much use to calculate the crop water requirements to a high degree of precision. Under such conditions it is the irrigation efficiency that weighs much more heavily.

In Table 23 the overall irrigation dosages per crop and per season were calculated. Given the considerable variation over the selected areas an overall average was calculated for Al Bayda Province. In Table 29 these water dosages have been multiplied with the present cropping patterns for the different selected areas (see Table C.1, Annex C). The irrigation water requirements per hectare adjusted for the prevailing cropping patterns are indicated in the bottom line

Table 29 - Irrigation water requirements and crop intensity

	Irrigation requirements per crop (mm)	Rada basin		Sabah/Ar Riashiyah		Al Bayda N.E.		Al Bayda W		Wadi Juban	
		CI[1] (%)	IR[2] (mm)	CI (%)	IR (mm)	CI (%)	IR (mm)	CI (%)	IR (mm)	CI (%)	IR (mm)
Alfalfa[3]	3264	12.1	395	12.2	398	11.4	372	5.4	176	6.5	212
Sorghum	756	35.0	265	9.2	70	74.7	565	59.9	453	32.8	248
Wheat	697	9.6	67	87.4	609	21.8	152	9.6	67	3.6	25
Barley	601	1.2	7	-	-	24.0	144	15.7	94	-	-
Potato	536	1.1	6	53.6	287	6.1	32	6.2	33	5.1	27
Maize	582	0.2	1	6.1	36	0.5	3	-	-	12.0	70
Qat[3]	780	40.9	319	3.2	25	8.2	64	14.1	110	50.6	395
Onions	1287	1.2	15	1.3	17	0.4	5	4.6	59	0.1	1
Melons	1350	5.1	69	-	-	1.2	16	3.0	41	-	-
Fruits[3]	1174	0.8	9	-	-	-	-	4.1	48	-	-
Veg. + others	1052	5.4	57	9.4	99	3.1	33	12.0	126	0.6	6
Total		166.3	1210	197.7	1541	170.8	1386	158.2	1207	168.5	984

	Wadi Mansur/ Wadi Amad		Wadi Matar/ Wadi Ar Rin		Wadi Hubabah/ Wadi Ar Riashiyah		Wadi Dhi Na'im		Abbas		Overall average	
	CI (%)	IR (mm)	CI (%)	IR (mm)	CI (%)	IR (mm)	CI (%)	IR (mm)	CI (%)	IR (mm)	CI (%)	IR (mm)
Alfalfa[3]	13.9	454	41.3	1348	4.4	144	13.1	427	3.2	104	9.9	323
Sorghum	61.3	463	39.4	298	63.3	479	74.9	566	-	-	44.2	334
Wheat	20.6	144	31.2	217	6.5	45	22.4	156	-	-	16.3	114
Barley	1.0	6	-	-	5.6	34	19.1	115	0.9	5	8.3	50
Potato	5.1	27	-	-	-	-	-	-	8.4	45	5.1	27
Maize	9.3	54	-	-	16.5	96	5.6	32	-	-	3.3	19
Qat[3]	4.8	37	5.8	45	29.7	232	3.6	28	43.9	342	27.6	215
Onions	1.0	13	-	-	-	-	2.5	32	6.6	85	1.7	22
Melons	20.9	282	-	-	-	-	0.3	4	32.1	433	9.5	128
Fruits[3]	-	-	-	-	0.5	6	3.6	42	2.7	32	2.5	29
Veg. + others	2.1	22	-	-	-	-	0.8	8	21.7	228	5.3	56
Total	158.7	1502	164.8	1908	161.1	1036	166.2	1410	169.2	1274	173.6	1317

Notes: [1] CI is crop intensity in %.
[2] IR is water requirements in mm.
[3] For alfalfa, qat and fruit (perennial crops) the crop intensity percentage is the average of summer and winter.

of this table. Multiplied by the net irrigable land the total irrigation requirements are obtained as given in Table 31 (Subsection 4.3.5).

4.3.4 Ways to save on irrigation water

Waste of irrigation water occurs in two ways:

- surface losses on the downstream side of the farm;
- seepage losses by application of more irrigation water than the root zone of the soil profile can hold.

During the field survey no cases of surface losses of irrigation water were observed.

Seepage losses are invisible and can only be determined on the basis of the soil-water characteristics. Unfortunately these are not available at present, but should be determined in a soil survey during the follow-up stage. Once such characteristics are available, a closely fitting irrigation regime can be drawn up by proper adaptation of application depth and interval to both the soil type and crop features.

For illustration of the approach in determining an irrigation regime, the following can be said on the basis of the assumptions indicated:

According to the depth of their (main) rooting mass, crops can be divided into 3 categories:

- Rooting depth up to 1.20 m - fruit trees, qat and alfalfa.
- " " " " 0.60 m - wheat, barley, maize and sorghum.
- " " " " 0.30 m - potatoes, onions, water-melons and vegetables.

Assuming that loam can be taken to be the representative soil type for the selected areas, the percentage of water available to the crop is about 17 % (by volume). In general, a crop cannot extract all of it and therefore we assume that 75 % can be depleted at the maximum; at the same time this is the amount that should be replenished at each application. The irrigation interval is determined by the evapotranspiration rate, which we assume to be 6 mm per day as an average over the year (see also Annex C, Section 3.4). Relevant dosages and irrigation intervals for the above conditions are indicated in the summary below.

Rooting depth	Water dosage (mm per time)	Irrigation interval (days)
deep (trees, alfalfa)	150	25
intermediate (cereals)	75	13
shallow (vegetables)	38	6

The above calculations aim at the optimum regime to provide the crops with the optimum soil moisture conditions. As additional information on soils becomes available the above figures may be improved upon, but nevertheless they give an impression of the order of magnitude and can serve as a guideline for extension activities in this field. It will assist in elimination of the larger part of seepage losses, at least in the case of basin irrigation. Then it is a clear-cut operation, as the highest possible discharge should be led into the basin until the water has reached the indicated depth.

Another way of achieving a more efficient use of irrigation water is under-irrigation, or in other words extensive use of irrigation water. This means that a less than optimal irrigation dosage is applied, which may result indeed in a reduced yield per ha, but on the other hand a high efficiency of water use and a higher total production for the same water abstraction will be attained. Obviously this is a most important aspect in a country where water is such a critical factor.

The effects of such an approach can be illustrated by trials carried out during spring and summer 1981 by the Dhamar Agricultural Improvement Project. Wheat and barley were sown in border strips and received either a single irrigation application at the time of seeding, or several irrigation applications with intervals of 10, 12, 15, 20 or 25 days, in addition to rainfall. Each time about 80 mm of water was applied. Results of the experiments were consistent in the sense that irrigation every 12/15 days resulted in the highest yield per hectare, but a single irrigation at seeding showed the highest production of grain per mm of irrigation water applied. It is interesting to note that the farmers around Dhamar have adopted a correct irrigation practice, since they irrigate about every 12 to 14 days. In Table 30 the results of two trials for wheat of the Sonalika variety are represented.

Table 30 - Grain yield and irrigation intensity

Trial	Growth duration (days)	Intensive irrigation[1]		Extensive irrigation[2]		
		Yield (per ha)	Kg grain per mm of water	Yield		Kg grain per mm of water
				(per ha)	(total)	
Spring 1981[3]	116	3 146	3.79	2 445	17 115	6.97
Summer 1981[4]	111	1 523	1.87	767	6 903	4.34

Source: Dhamar Agricultural Improvement Centre (1983).

[1] In the intensive irrigation the spring crop received 7 irrigations of 80 mm, the summer crop 9 applications of 80 mm.

[2] In the extensive case the same total amount of water as used on 1 ha in the intensive trials was spread in 1 application over a proportionally larger area, i.e. 7 ha for the spring crop and 9 ha for the summer crop.

[3] The spring crop was sown on 10 February and harvested on 6 June.

[4] The summer crop was planted on 13 July and harvested on 1 November.

From the table it is clear that under-irrigation on a proportionally larger area results in a 4 to 5 times higher total grain production with the same quantity of water. Of course, this is a purely technical comparison of water and grain yield only; other factors such as cultivation costs (labour, agricultural inputs) are not taken into account. These cost are high, as shown in Annex D and this may be the main reason for the farmers not to introduce under-irrigation. Nevertheless, water may become so scarce at a certain moment that under-irrigation becomes a viable alternative. Moreover, the solution need not be one of the extreme cases represented in the table but can also be an intermediate step of under-irrigation, which might prove to be the most interesting one from the economic point of view.

4.3.5 Irrigation potential

The main objective of the present study is to assess for each of the selected areas the incremental irrigation area on the basis of the groundwater and land resources available. By comparing the water available for irrigation (obtained from Annex A) with the total irrigation requirements, of which the calculation has been discussed in Section 4.3.3, the proportion of the net irrigable land which can be provided with irrigation can be calculated. This then has to be reduced with the net irrigated area at present. Thus one arrives at the figures indicated in the last column of Table 31. The whole exercise has been done on the basis of sub-areas (see the tables on irrigation potential per selected area in Annex C) and have been totalled afterwards in order to compose Table 31.

For the southern part of both Al Bayda N.E. and Al Bayda W. no aerial photographs are available and therefore it was impossible to get a correct impression of the total area of alluvium, and consequently, the area of net irrigable land. We consider it quite probable that in these areas an additional irrigation potential is present, but its extent cannot be assessed with the means at our disposal. The results of this study in terms of incremental irrigation potential are certainly positive. A total potential of about 1500 ha of irrigated land, which is about 60 % of the area already under irrigation at present, is considerable. The potentials are in the first place in Rada Basin, but also in Al Bayda area, Juban and Dhi Na'im.

It is clear that when under-irrigation, as discussed in the previous subsection, is practiced, the incremental area under irrigation can grow substantially, as far as irrigable land is available.

4.4 Economics of irrigated crop production

4.4.1 General

This section provides a summary of the analysis of the economics of groundwater use for irrigation by shallow wells and deep tubewells (boreholes), as detailed in Annex D. It gives the estimated returns to irrigation per crop and cropping pattern prevailing in the various

Table 31 - Irrigation potential

Area	Alluvium (ha)	Presently irrigated area		Net irrigable land (ha)	Irrigation requirements (1000 m^3)	Available for irrigation (1000 m^3)	Incremental irrigation potential (ha)
		Gross (ha)	Net (ha)				
1. Rada Basin	11 813	1 995	1 443	6 207	75 119	> 28 648	993
2. Sabah			not available				
3. Al Bayda N.E.	1 869[1]	245	177	827	11 462	(> 4 135)[2]	> 127
4. Al Bayda W.	883[1]	149	107	361	4 358	(3 190)[2]	> 57
5. Wadi Juban	1 395	280	202	818	8 049	2 932	115
6. Wadi Mansur[3]	3 725	460	333	1 415	21 252	2 618	10
7. Wadi Matar/ Wadi Ar Rin[4]	1 665	34	24	351	6 697	918	29
8. Wadi Hubabah			not available				
9. Wadi Arsard/Saru			not available				
10. Wadi Dhi Na'im	1 480	241	175	772	10 887	3 736	113
11. Abbas	666	30	22	373	4 752	630	28
12. As Sawadiyah			not available				
Total	23 496	3 434	2 483	11 124	142 576	> 46 807	> 1 472

[1] As far as situated within the aerial photographs available.
[2] More water is available, but since the irrigable land is unknown in the sub-areas concerned, these amounts have been disregarded.
[3] Excluding Wadi Amad and sub-area MG which is considered to belong to As Sawadiyah.
[4] Figures relate to Wadi Matar only, since data for Wadi Ar Rin are not available.

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.

The RIRDP has recently made a start with farming system research and a production economics survey as well as the collection of market prices. However, the present information on farm management is still very limited and a number of assumptions had to made with regard to crop yields, produce prices, labour requirements and other farm inputs. These assumptions are outlined in Annex D.

4.4.2 Cost of and returns to irrigated agriculture

The net returns, that is gross proceeds (yield times price) minus the cost of farm inputs and hired labour, of individual crops is given in Table 32. It can be seen that high values per ha and m^3 irrigation water are obtained, particularly for qat. If qat cannot be cultivated, potatoes, vegetables and fruit would be attractive alternative commercial crops. Detailed crop budgets are given in Annex D.

Table 32 - 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[3]	34 520	13 500	2.56

Notes: [1] See Annex D.
[2] Derived from agronomic survey (see Section 3.4).
[3] Vegetables and fruits represented by water-melon.

As described in Section 3.4 and elaborated in Annex C, there is a variety of cropping patterns in the province. These are based partly on the production of alfalfa and food crops and partly on the production of qat and other commercial (cash) crops such as water-melon. Table 33 presents the net returns for the average cropping patterns found in the selected areas. Rada Basin, Wadi Juban, Wadi Hubabah/ Wadi Ar Riashyah and Abbas have a high proportion of qat or other high-value crops in their cropping patterns and this is notable in the high returns obtained per ha and m^3 irrigation water.

Table 33 - 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 (average)	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
Average	70 339	13 170	5.3

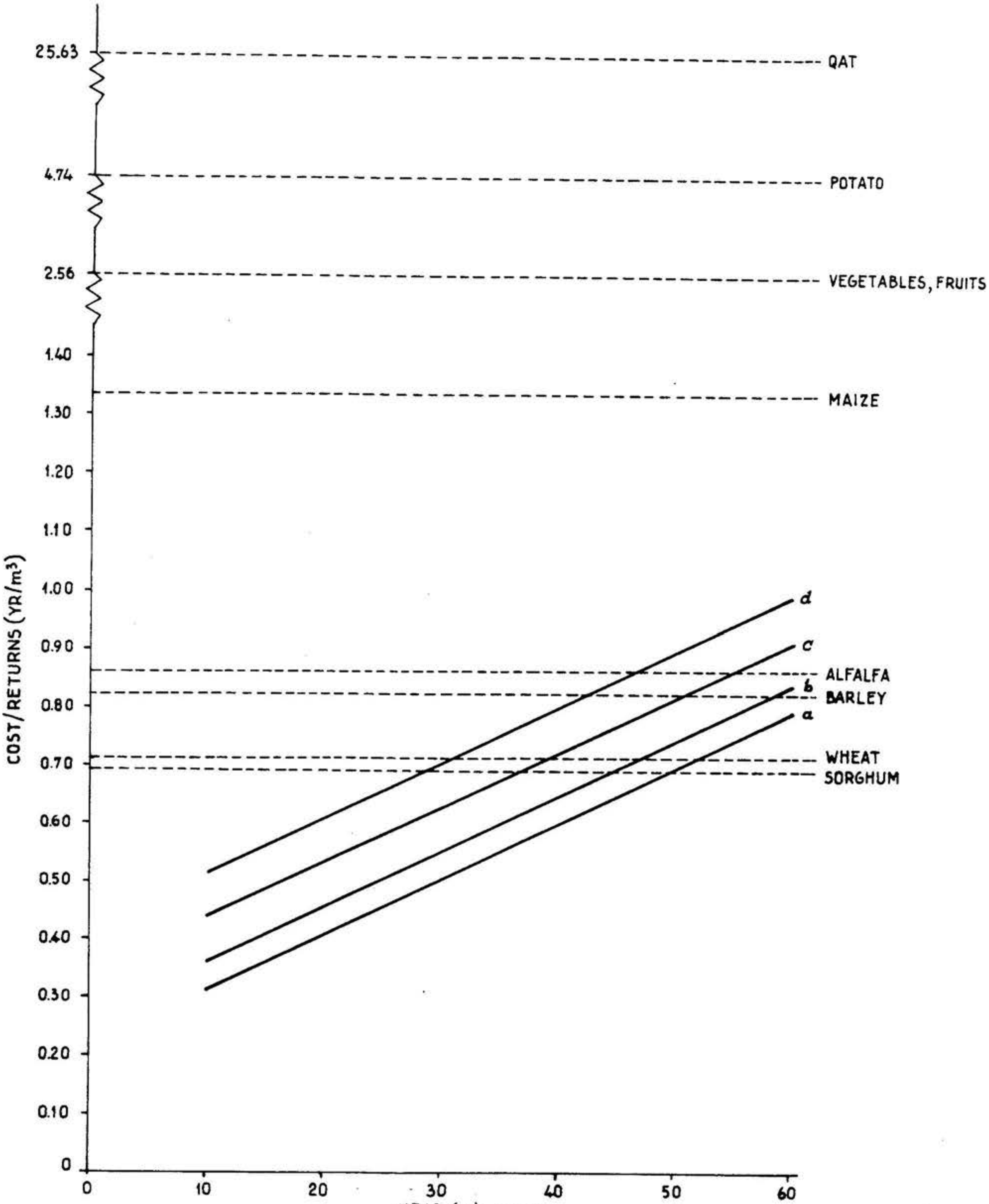
Notes: [1] See Annex D.
[2] Derived from agronomic survey (see Section 3.4).

The costs of providing one m^3 of water by borehole or shallow are shown in Tables 34 and 35 for various well depths and water-table depths (heads). The costs consist of investment in well construction, pump house, pump, engine and ancillary equipment converted to an annuity (i.e. equal annual amounts over the economic life of the investment), as well as of the recurrent costs of maintenance and fuel. The total costs are divided by an average annual abstraction to obtain the cost per m^3 water. Except for qat, the cost of the distribution system is not included, as this generally consists of simple hand-made earthen field channels and bunds which need restoration every year as part of the farm labour input.

Comparison of costs and returns can be done on the basis of the tables or by means of simple graphs, as is illustrated in Figure 13 for boreholes and sorghum. It is shown that production of sorghum, which has an average net return of YR 0.69 per m^3 water, becomes economically unattractive when pumping heads 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.

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 200m
d - WELL DEPTH AT 250m

FIG. 13

Table 34 - Cost of irrigation water pumped from boreholes (YR/m^3)*

Well depth (m)	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 13).

Table 35 - Cost of irrigation water pumped from shallow wells (YR/m^3)

Well depth (m)	Head (m)	Annual abstraction (m^3)*			
		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 13).

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-table 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. The same excercise can be done for other crops or cropping patterns.

The comparison of net returns and costs per m^3 indicates that pumping from boreholes at all well depths and water depths considered in this study is economically viable for the production of commercial crops such as qat, potato and other crops including vegetables and fruits and for all average cropping patterns found in the selected areas. However, as indicated in Figure 16, food crop production becomes marginal with boreholes of greater depths of well and water-table.

Shallow wells are less viable, especially at low annual discharges and when the water is used for the production of food crops or for cropping patterns which have a small proportion of commercial crops. For example, in Wadi Matar/Wadi Ar Rin, which has an average annual water abstraction of about 12 000 m^3 and an average head of 16 m, the unit costs per m^3 water pumped from shallow wells is approximately between YR 1.7 and YR 2.5, as against an average return of YR 1.4 per m^3 water. Although this conclusion in many cases does not apply to existing wells, - many are old and are written off in economic terms -, it is of importance for future investment decisions. In recent years, groundwater has been exploited mainly through boreholes. The results of the analyses indicate that boreholes are indeed more economic than shallow wells.

Sections 4.1 and 4.3 have shown that more groundwater and land are available. It is economically justified to develop these resources, bearing in mind the underlying assumptions on crop output and input data. Of course, the speed at which and the extent to which they will be actually developed depend also on other factors such as the availability of capital and manpower.

5 WATER-SUPPLY AND SANITATION SYSTEMS

5.1 Health situation in Al Bayda Province

The prevalence of water-related diseases are discussed in detail in Annex B. Most of the typical diseases are present, and it is clear from the rate of incidence of helminthic diseases that the lack of satisfactory excreta disposal facilities is a major cause of illness. Lack of personal hygiene and fly infestation also contribute to the spread of disease (see Annex B).

Health hazards identified in the rural villages were:

(i) Lack of garbage disposal facilities.
(ii) Polluted drinking-water.
(iii) Existing excreta disposal systems.
(iv) Mosque hammans.
(v) Lack of personal hygiene.
(vi) Free running cattle and dogs.
(vii) Emptying of 'baladiyah' vaults.
(viii) Cattle inside the house.
(ix) Pools of stagnant sewage and excreta.

5.2 Existing water-supply systems

5.2.1 General

A total of 162 villages including the larger ones were visited during the survey. The status of the water-supply facilities in each of these villages is indicated on Maps. The water-supply situation of 43 % of the population in the selected areas and 25 % of the provincial population was investigated. The selected areas constitute 58 % of the provincial population. The coverage on a provincial level is shown in Table 5 of Subsection 2.3.2.

In the villages investigated, piped water-supply systems were present as specified in Table 36.

For specific remarks about each selected area, reference is made to Annex B.

General comments applicable to the individual regions are as follows:

(i) Rada Basin: in general the only water-supply schemes are those constructed by RIRDP. For reliable water-supplies it is necessary to tap the deeper water resources, consequently increasing the cost of water. The water-supply of Rada Town has been the subject of a separate study (DHV, 1983).

Table 36 - Piped water-supply systems in villages in selected areas

Selected area	No. of villages surveyed	% with piped w.s. system	% with no supply
1 Rada Basin	30	50	50
2 Sabah/Ar Riashiyah	18	6	94
3 Al Bayda N.E.	20	95	5
4 Al Bayda West	9	78	22
5 Wadi Juban	12	8	92
6 Wadi Mansur/Wadi Amad	27	7	93
7 Wadi Matar/Wadi Ar Rin	6	17	83
8 Wadi Hubabah/Wadi Ar Riashiyah	11	18	82
9 Wadi Dhi Na'im	11	64	36
10 Villages along Rada-Al Bayda road incl. part of As Sawadiyah	18	6	94

(ii) Sabah/Ar Riyashiyah: Surface water resources are available in this region and are often used in order to avoid the construction of deep wells. The steep topography and the often poor quality of surface water, however, make the task of obtaining water arduous and time-consuming for the women, and the water they fetch is unsafe for human consumption. The RIRDP has commenced the construction of several schemes in Sabah, but elsewhere there are no piped village water-supplies.

(iii) Al Bayda N.E.: Most of the larger and medium-size villages in this region have been provided with a piped water-supply, often through the Rural Water Department and/or the Local Development Association. The shallower depth of groundwater in this region has resulted in the possibility of constructing schemes at a relatively low cost. Al Bayda Town has a water-supply system which is generally adequate, requiring only some modification; however, this is not considered to be within the scope of this report. Some water shortages do occur during the dry season.

(iv) Al Bayda West/Az Zahir: The situation is in general similar to that in Al Bayda N.E., although the region is less adequately provided with water-supply systems. Water shortages are frequently experienced in the larger villages.

(v) Wadi Juban: With the exception of Juban Town there are no water-supply systems in the Juban Basin. Competition between agricultural and domestic water requirements occurs, resulting in severe water shortages. Juban Town has a piped supply, which is however inadequate for the entire settlement.

(vi) Wadi Mansur/Wadi Amad: The situation with regard to water-supply schemes is similar here to that in the Rada Basin, although as a projected RIRDP development area it has received some additional attention from the project. Groundwater in this area, however, tends to be highly saline.

(vii) Wadi Matar/Wadi Ar Rin: This is also an RIRDP development area and a number of water schemes have been constructed by the project. Salinity in Wadi Matar is also a problem and careful site selection is important to provide water-supplies with adequate quality.

(viii) Wadi Hubabah: This area has similar characteristics to Sabah, and water-supply systems are often based upon a spring source. As in Sabah, people wihout piped water spend many hours per day walking to and from the source. The spring sources are generally of good quality, but shortages often occur in the dry season.

(ix) Wadi Dhi Na'im: This is the most densely populated and accessible area of Dhi Na'im nahiyat and contain a number of larger villages. Many of these villages have recently been provided with a water-supply system based on shallow wells, which suffer, however, from shortages during the dry season.

(x) As Sawadiyah:Sawadiyah nahiyat contains numerous small, scattered villages which were not covered by the survey. The area considered in this report is adjacent to the main Rada-Al Bayda road and Wadi Mansur and has most of the characteristics of the latter; in particular salinity problems.

To understand the reasons behind the adoption of particular water-supply systems and to determine the most appropriate future development, it is necessary to examine the social factors involved in domestic water use. The most important basic fact is that it is the women who are most involved with water use in the household; they fetch the water (if necessary); they do the cooking and the laundry, water the livestock, and set the standards for cleanliness in the house and for the hygienic use of water. This is discussed in detail in Ilaco Technical Note No. 10 (Ilaco, 1983a).

Health aspects are a primary reason for the provision of a piped water-supply, in particular the presence of illnesses due to water-related diseases as mentioned in Section 5.1. Supplying sufficient water of adequate quality would help to reduce these diseases now so prevalent throughout the province. In order to realize these improvements, however, hygienic water usage habits must be adopted by the women. Ilaco (1983a) discusses certain unhygienic aspects of water use in the Yemeni home, with the conclusion that, in general, the women would be receptive to a health education programme with regard to water use, with the objective of improving public health. Almost all respondents to the household questionnaires (see Section 1.3) indicated a desire to see a health education programme in the province.

Provision of a piped water-supply system can, in addition to improving health conditions, save the women many hours of time and effort in fetching water, thus leaving them time for other productive or social activities. As indicated in Annex B, the average time spent by women on fetching water, where there is no piped water supply system, is up to 6.4 hours per day.

5.2.2 Engineering aspects

The vast majority of the population aspire to a water-supply system piped to a tap in the house. This has meant that in Al Bayda Province, a water-supply system generally includes:

- a borehole, shallow well, spring or cistern;
- a pumping plant consisting of diesel engine and pump. Due to the elevated location of most Yemeni villages, gravity supply is rare;
- a storage tank to balance the fluctuation of peak and low flows, and also to provide security against breakdowns in the pumping plant;
- a pipe network for distributing water to private connections or public standpipe.

The types of source used in each of the selected regions are given in Annex B. There is a growing tendency to prefer boreholes, which are presently found only in Rada Basin, to shallow wells now that drilling rigs are available, and often the cost of a borehole can be less than that of a shallow well. Spring sources are found in Sabah, Wadi Ar Riashiyah and Wadi Tha and some cisterns north of Rada Basin and in Juban. Water quality of cistern sources is often poor, but the properly developed springs, especially in Sabah and Wadi Ar Riashiyah, yield good-quality water although water shortages do occur.

A vertical turbine pump with a diesel engine is used for all groundwater sources. The major problems appear to be a lack of standardization in pump and engine brands (although spare parts are available for most sets), and inadequate consideration of the duties of the pump and engine when the set is purchased. This often results in engines of greater capacity than is really necessary.

Either reinforced-concrete, elevated reservoirs or blockwork reservoirs at ground level are used for all systems. Distribution systems generally comprise galvanized iron pipes laid above the ground and with diameters varying from 100 mm to 12 mm. Often excessive lengths of small-diameter pipe cause limitations in the system capacity. House owners commonly make their own connections, with the result that the network resembles a labyrinth. Leakage often occurs due to damaging of the above-ground pipelines by trucks etc. or due to faulty valves and fittings.

5.2.3 Water quality

The major water quality problems uncovered by the water quality testing programme carried out during the survey were both chemical and bacteriological.

Chemical

- high fluoride in parts of Rada Basin and Sabah;
- excessive salinity in Wadi Mansur, Matar and As Sawadiyah;
- some isolated wells in Rada and Al Bayda with high nitrate content;
- very high hardness of all water sources throughout the province.

Bacteriological

- severe pollution by (faecal) coliforms in all uncovered shallow wells throughout the province.

5.2.4 Operation and maintenance

Operation and maintenance is normally carried out by operator(s) employed by the village. While the survey did not reveal many admitted operation and maintenance problems, it is clear that many of the operators have little mechanical knowledge, and a breakdown may often mean replacement of the entire pump resulting in a lack of water for many days. Similarly pipe leaks are often repaired in a provisional manner, and for the smaller villages spare pipes are rarely available. In the few cases where a trained water operator is available, however, the improvement in the condition of mechanical equipment can be quite obvious. Availability of fuel and spare parts is rarely a problem.

5.2.5 Organization and management

At present there are a number of authorities involved in the provision of water-supply facilities in Al Bayda Province. These are:

- Ministry of Agriculture, through RIRDP;
- Ministry of Public Works - Rural Water Department (RWD);
- Local Development Associations (LDAs) covering every nahiyah;
- National Sewerage and Water Supply Association (NSWA) - involved only in Rada and Al Bayda towns.

The first three are involved in the initiation and implementation of rural water-supplies, although after completion of the scheme the village operator(s) generally comprise the extent of the organization for operation and maintenance.

Implementation of domestic water-supply systems was started in the province in the early seventies by the RWD and the LDA, and some years later the RIRDP commenced with schemes in Rada District. Some villages had of course constructed their own systems independently. There has been little co-ordination between the implementation authorities, however, which has resulted in different contribution percentages between villages, lack of standardization in designs and mechanical equipment, and duplication of plans for the same village.

Since 1982 regular meetings have been held between the LDA and the RIRDP, which has resulted in a more co-ordinated approach to planning. It is intended to include the Rural Water Department in this process, but to date progress in this regard has been slow.

5.2.6 Identification of problem areas in village water-supply

Specific problem areas in village water-supplies can be defined as:

(i) no water distribution system in village;
(ii) water shortage;
(iii) poor water quality;
(iv) operation and maintenance problems.

Table 37 indicates the prevalence of each of the above categories according to the survey results.

Table 37 - Main problems in village supply

Selected region	No water-supply system % villages	Water shortage % villages	Chemical analysis results	Bact. analysis (% unsatis-factory)	O & M problems % villages
1 Rada Basin	50	20	Fluorides	90	26
2 Sabah/Ar Riashiyah	94	44	Fluorides	33	0
3 Al Bayda N.E.	5	25	Good	50	10
4 Al Bayda West	22	33	-	-	28
5 Wadi Juban	92	42	Good	100	100
6 Wadi Mansur/Wadi Amad	93	45	Salinity	80	100
7 Wadi Matar/Wadi Ar Rin	83	33	-	100	0
8 Wadi Hubabah/Wadi Ar Riashiyah	82	18	-	-	50
9 Wadi Dhi Na'im	36	45	-	-	38
10 Villages along Rada-Al Bayda road incl. part of As Sawadiyah	94	33	-	60	100

5.3 Existing sanitation systems

5.3.1 General

There is little variation between the selected areas regarding the type of sanitation systems used in the household. The 'balladiyah' system as described in Annex B is by far the most common. Flush toilets are sometimes encountered in villages where sufficient water-supplies, are available, in Al Bayda Town where a sewerage system has been provided, and in some schools. The survey indicated that over 90 % of the people considered their present household sanitation system to be unhealthy.

Mosques often have a facility for liquid excreta but rarely for solid excreta. No mosque investigated during the survey was found to have the 'baladiyah' system as is commonly found in houses. The washing basin in the mosques was in all cases found to be heavily polluted.

A number of schools have been constructed quite recently throughout the province, and many of the latrines in these schools have been fitted with flush toilets. Often, however, there is insufficient water for them to operate satisfactorily or if water is available, the toilets are neither used correctly nor maintained.

Very few of the surveyed villages had either a sanitation or a garbage disposal system. These were only found to some extent in the following villages, details of which are given in Annex B.

- Al Bayda Town: sewerage system to stabilization pond and garbage disposal system.
- Madhawagayn: sewerage system for liquid excreta and wastewater to stabilization pond and soakaways.
- Ad Dahaki: sewerage system to soakaways, some garbage disposal.
- Al Khilaw and Khulan: individual drainage system for liquid excreta and wastewater.

Other villages in the province have no integrated system although some households may provide for individual disposal of their wastes.

Some aspects which are basic to an understanding of the existing sanitation practices in Yemen are the following :

(i) Defecation and urination practices: Men are more flexible than women in choosing their place of defecation. The male may use the latrine in the house (if available), the mosque, or simply the field. Women, however, do not have the same access to public places, and even if there is no latrine in the house, she must usually still defecate at home, often on the roof. Liquid and solid excreta are not generally mixed, although the existing baladiyah toilets are constructed in such a way that liquid excreta from women often enter the vault. Men can urinate into the channel which drains away from the hole.

(ii) Defecation and washing/bathing facilities are usually separated, although often a small tap is present in the latrine for anal cleaning.

(iii) The baladiyah system commonly in practice requires emptying of digested sludge about once a year. According to traditional practice this can only be done by lower-class people, who are often not available in a village. Nevertheless, overflowing baladiyah vaults were not found in the province.

(iv) Public toilets, in principle a low-cost method of providing village sanitation facilities, are not suitable for the Yemeni situation, primarily because by tradition they are not accessible to women.

(v) The survey indicated that nearly 100 % of the people desired improved sanitation facilities. Most were dissatisfied with the existing baladiyah system, considering it unhealthy, but it is not clear what level of system they would accept. Even people in Al Bayda with flush toilets and a sewerage system expressed dissatisfaction. The enumerators considered that in general people would probably be satisfied with an improved baladiyah system, together with proper facilities for disposal of wastewater, liquid excreta and garbage. There will of course always be a certain proportion of the population who desire nothing less than a flush toilet.

5.3.2 Operation and maintenance

Al Bayda Town has an operation and maintenance organization for sanitation facilities, the responsible authority being the Ministry of Municipalities. No mechanical equipment is involved, and the major problems experienced seem to be connected with inadequate design of the disposal facilities and a lack of funds for extension of the system.

In other villages with some type of sanitation system, no formal operation and maintenance organization exists. The systems have generally been initiated by residents motivated to improve the sanitary facilities and, where possible, these people look after the systems. The clearing of baladiyah vaults is also a potential maintenance problem, as has been discussed above.

5.3.3 Organization and management

The authority responsible for rural sanitation is the Ministry of Municipalities, Department of Environmental Health. Within this organization there are departments dealing with both village sanitation and mosque sanitary facilities. Sanitarians are employed in Al Bayda and Rada towns; these persons are theoretically responsible for rural sanitation, but to date they have not really been involved in sanitation activities in the rural villages. Local Development Associations in the province have not yet demonstrated much activity in village sanitation, possibly because to date it has not been perceived by the community as a pressing need.

5.3.4 Constraints to sanitation development

Many of the specific problems relating to sanitation within the province have been discussed above and in Annex B, and there is undoubtedly a need for improvement of the sanitation facilities in rural villages. While the survey indicated that the vast majority of the population would like to see improvements in sanitation in their village, this was in response to a direct question and it is uncertain whether it is a perceived need. Unless the population understands the necessity for sanitary improvements, it is unlikely that they will allocate time or money to these activities.

Where a sanitation system does exist, such as in Madhawagayn or Ad Dahaki, it is usually a result of the efforts of a group of interested and motivated residents. However, technical advice is rarely available and this results in some uncertainty as to the most suitable system to adopt. Failure can then occur and the initial enthusiasm is lost. Facilities by which village representatives can obtain advice regarding the type of system to be adopted should be available at a provincial level together with the means of obtaining a suitable latrine or system design.

5.4 Improved water-supply systems

Clearly there is a need for water-supply systems, as evidenced by the diseases prevalent in the province and time spent by women fetching water. The situation is most critical in Sabah, where the topography is steep and the fetching time consequently long. In these areas, but also elsewhere, an overwhelming preference is expressed for a piped supply to an individual connection. Although Yemen is a somewhat individualistic society, results from the household questionnaires indicate that the people are willing to co-operate in the construction of 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 the method of implementation of this programme. The approach is different from 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, 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 into the RIRDP water programme.

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

- Social constraints on types of systems to be adopted
  Traditional or religious considerations do not prevent the people from wanting a 'complete' water-supply system, as is indicated by the overwhelming majority of respondents to the survey who favoured this approach. Moreover, simple, low-cost technology such as handpumps is unlikely to be acceptable and should not be considered unless specifically requested by the people.
- Hygienic water use in the household
  Water use in the household is discussed in detail by Ilaco (1983a). Clearly there are a number of measures which can be taken to advance the hygienic use of water and these should be incorporated into an extensive health education programme.
  Wastage of water is not excessive at present, and policies such as discouraging individual connections or provision of constant-volume taps for public supplies need not be considered unless the situation changes.

- Community participation
  While the RIRDP projects do provide for community participation at the initiation stage, this is not always the case during the design and operation stage. It is considered that a 'complaint desk' should be established at RIRDP to which consumers can turn if they have any problems with their water-supply systems.

With the present funds and staffing, it is only possible for RIRDP to construct about 10 schemes per year. In order to provide a greater coverage with the same funds and manpower it is suggested that a programme of simple measures to improve water quality be carried out concurrently with the water-supply programme, which would at least assist the smaller villages with their basic needs. This is further worked out in Chapter 6. These measures would largely consist of improving water quality at the source. This would involve:

- lining, covering and provision of drainage facilities for shallow wells;
- source protection of a spring;
- simple treatment of a spring or cistern;
- chlorination of polluted supplies;
- development of a new source, if necessary.

Details of proposed methods of achieving these improvements are outlined in Annex B.

The survey results indicated that the 60 litres/capita/day (including livestock) for a household connection presently adopted by RIRDP in the design of schemes is less than the actual water consumption and considerably less than that predicted for the future. Consideration should therefore be given to an increase in the design water consumption at an individual connection.

With regard to pumping facilities it is not considered appropriate to attempt to utilize any energy source other than diesel power. Attention should be paid to providing advice on power requirements for the engines, as the installed power was often found to be far in excess of that required.

A number of modifications could be made to the design of distribution systems (see Annex B). However, these do not generally take precedence over the provision of a clean supply and need not be implemented until after the basic need programme discussed above.

An improved organization structure for rural water-supplies in Al Bayda Province is needed which will provide for scheme implementation according to an approved priority ranking and which will assist village operators in their operation and maintenance problems. A suggested organization structure is discussed in Annex B and illustrated in Figure 14.

In essence it is proposed that the Al Bayda Province Co-ordinating Council be responsible for the co-ordination of the initiation of

Suggested Organization Chart for Rural Water-supplies in Al Bayda Province.

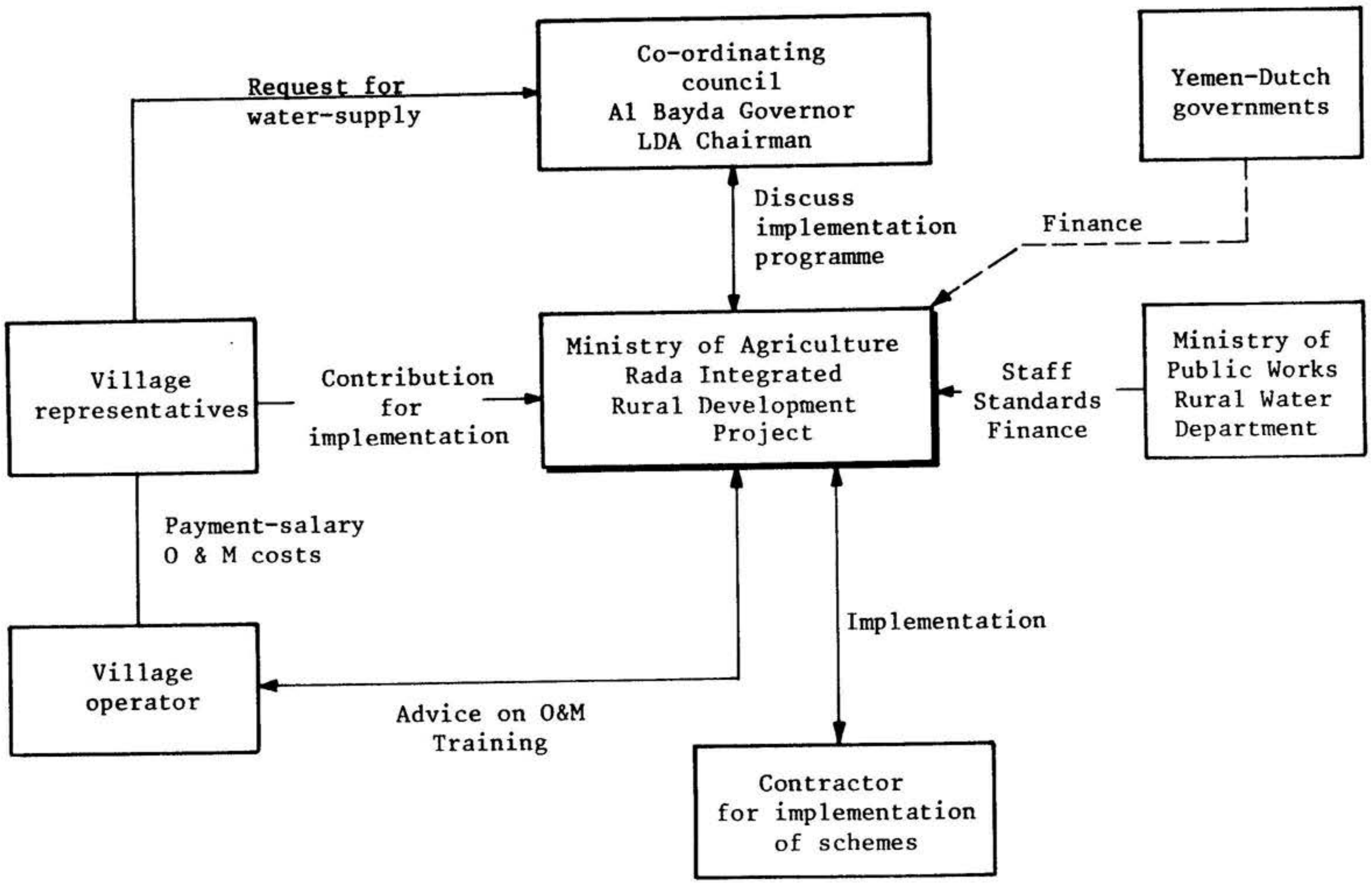


FIG. 14

water-supply schemes according to an agreed priority ranking. One organization should then be the sole authority in the Province responsible for the construction of water-supply schemes as well as the supervision of operation and maintenance. It is suggested that the RIRDP, reinforced with suitable manpower from the Ministry of Public Works, be that organization so that the experience in standardization, design, construction, operation and maintenance of both can be utilized. Moreover, it is considered vital that regular training courses for village operators should be available.

5.5 Improved sanitation systems

5.5.1 General

One of the primary objectives of providing of a water-supply system is to improve community health. The control of excreted infection requires improvement in one or all of the following areas, namely water-supply, sanitation, and personal hygiene depending on the category of infection. Annex B indicates that the health situation can be expected to improve only if clean potable water is provided concurrently with sanitation and if an effective and sustained programme of hygiene education is organized.

As shown in Section 5.3, very few rural villages have any sort of wastewater or garbage disposal facilities, and excreta disposal consists largely of individual baladiyah systems. Consequently there are very few precedents in Al Bayda or indeed in Yemen for a sanitation programme. In order therefore to develop systems which may be acceptable to the public, it is necessary to strengthen the research into the social and economic aspects which may affect the choice of system.

The important social aspects which influence the choice of sanitation technology to be adopted are:

- existing defecation practices;
- differences between tribes or sexes;
- important taboos related to custom and religion;
- latrine emptying and sludge re-use practices;
- opinions regarding public toilets;
- attitudes to possible systems.

Each of these aspects is discussed in Annex B and in Section 5.3, and the systems recommended in the present section are based upon these considerations. It should be stressed that a health education programme is essential in order to make people aware that their health is affected by a polluted environment and a low standard of sanitation.

Selection of a sanitation system on purely economic or technical grounds would therefore not succeed. It is perhaps most useful to consider the possible technologies in terms of their average annual cost (Annex B), as well as in social and environmental terms. The options that emerge should be tested in pilot schemes, as discussed in Chapter 6.

5.5.2 Proposed sanitation facilities

A discussion of the options for household latrines in terms of the social, economic and technical criteria is included in Annex B. It is concluded that the most appropriate household system for rural Yemeni villages is a compost toilet for the disposal of solid excreta together with individual soakaways or stabilization ponds for the disposal of liquid excreta. The reasons for adopting this type of system are as follows:

- it is appropriate to the prevailing traditional practices;
- no water is used;
- there is no need for expensive sewerage systems and there are no effluent problems;
- operation and maintenance is easy and little institutional infrastructure is required;
- local materials and labour can be utilized;
- 90-95 % of pathogens are destroyed after one year of aging;
- the system produces fertilizer, which has an economic value;
- it is not unusual in Yemen to use human excreta as fertilizer;
- the poorest families will benefit from the project.

The proposed compost toilet (see Figure 15) is a modification of the existing 'baladiyah' toilet. For details see Annex B.

Particular attention should be given to the improvement of sanitary conditions in the mosques, where at present the ritual washing before prayer is done in heavily polluted basins. Provision of taps or showers and toilets is necessary if this severe health hazard is to be eradicated.

Provision of other public sanitation facilities is not considered appropriate, primarily because the men find it distasteful to see women using such public facilities.

The proposed compost toilets and soakaways will, where possible, be individual household facilities, and only in the case where either large soakaways, septic tanks or stabilization ponds connecting groups of houses are utilized is a village system envisaged. Such a system will be necessary under the following conditions.

(i) where soil conditions do not permit construction of an individual soakaway;
(ii) where soil conditions do not permit construction of either individual or group soakaways and a stabilization pond is required;
(iii) where flush toilets are utilized and septic tanks combined with either soakaways or stabilization ponds are required;
(iv) where so much wastewater is produced that a sewerage system connected to a stabilization ponds is required.

5.5.3 Effluent re-use and resource recovery

The benefits of provision of a sanitation system are not always immediately obvious to a population or government. Acceptance of

ADJUSTED MULTRUM COMPOSTING TOILET

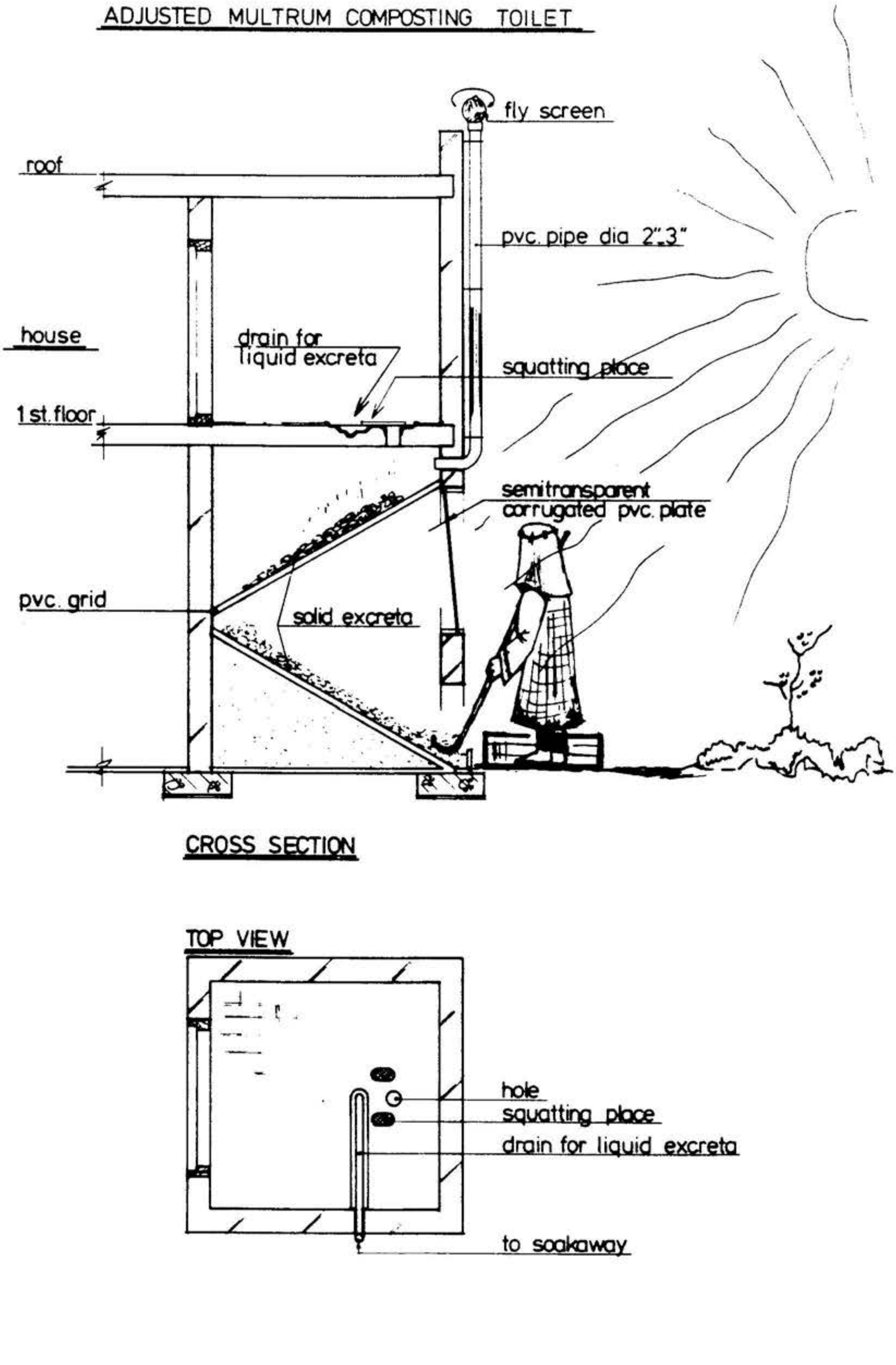
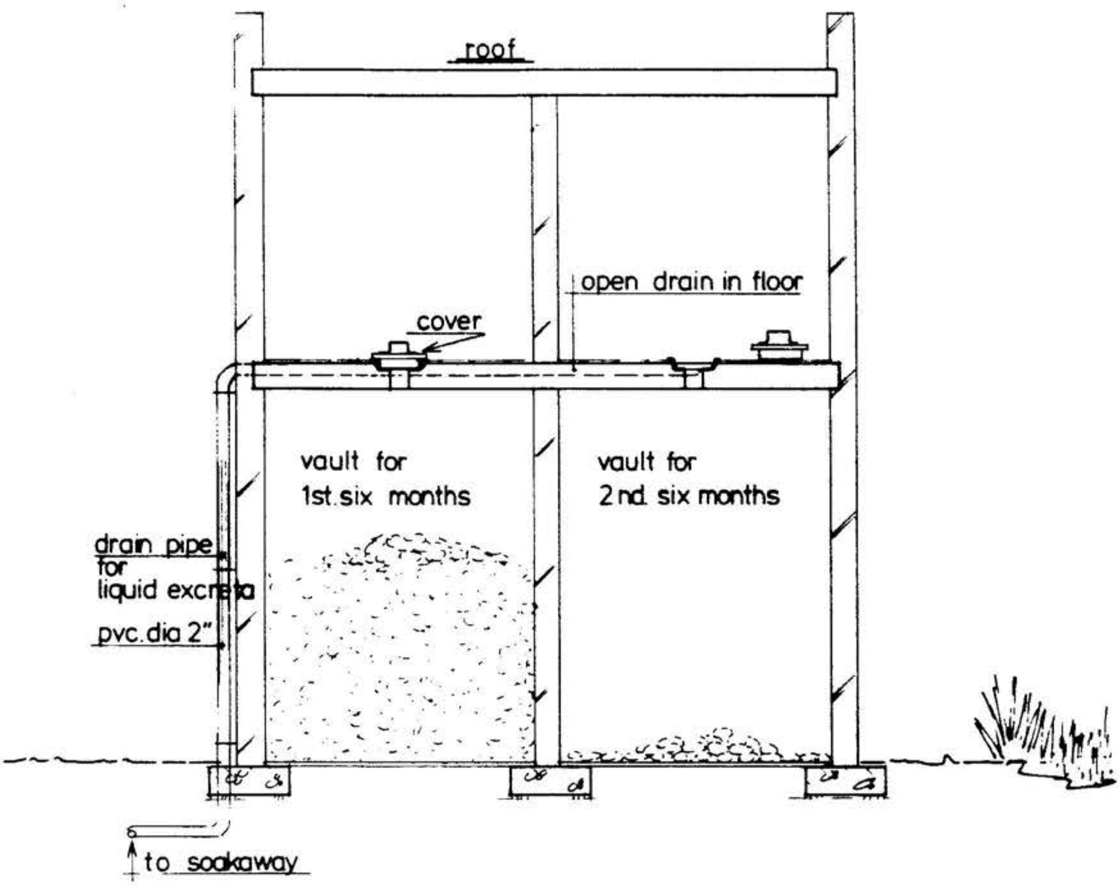


FIG. 15[a]

ADJUSTED MULTRUM COMPOSTING TOILET
2 VAULT



CROSS SECTION

FIG. 15 b

a sanitation programme can be enhanced by demonstrating that the programme will have not only physical benefits (e.g. improved health conditions) but also economic benefits (e.g. reuse of effluent).

The digested excreta from the compost toilet will provide useful crop fertilizer, provided that basic rules are adhered to in the composting of waste. In particular, a minimum of 12 months composting before use is required. There are several possibilities for reuse of liquid effluent, such as:

- parts of the wastewater (shower, laundry) can be diverted from houses 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 stabilization ponds can be used for direct application to certain crops.

A potential hazard of irrigation with effluent from stabilization ponds or evapotranspiration beds is that without tertiary treatment some pathogens may survive, although with a retention time of at least 30 days 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 carried out.

Other resource recovery methods such as biogas production and aquaculture are not considered appropriate for Al Bayda Province at this point in time, as discussed in Annex B.

5.5.4 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. It is a potential problem in Al Bayda Province, where shallow aquifers are utilized for water-supply, and especially if soakaways, stabilization ponds or agricultural re-use are envisaged, care must be taken with the location of these treatment facilities. Fecal pollution and high nitrate concentration are the most serious results of uncontrolled disposal of excreta and wastewater. Annex B discusses the implications of these types of pollution, which may be controlled by adopting the following measures:

- ensure emptying of latrines when contents have stabilized;
- reduce hydraulic load as much as possible;
- impose minimum distance between groundwater supply borehole and soakaways of at least 15 m, but preferably much more;
- where necessary extend the lining of boreholes to a significant depth below groundwater level, thus ensuring longer groundwater flow paths;
- impose regulations on the location of stabilization ponds with respect to hydrogeological conditions and groundwater supply installation;
- consider lining of pond base to reduce seepage;
- impose regulations on the irrigation schedule to reduce nitrates in the soil.

5.5.5 Garbage disposal

The problems of garbage disposal in Yemeni towns and villages have been documented by Ilaco (1983a) and DHV (1983). The latter report, which was concerned with Rada and surroundings, recommended a number of short-term improvements including a health education programme on the hygienic aspects of waste handling and the risks to public health. Health education is probably the key to the garbage disposal problem, as without a proper understanding of the implications on 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 take any measures.

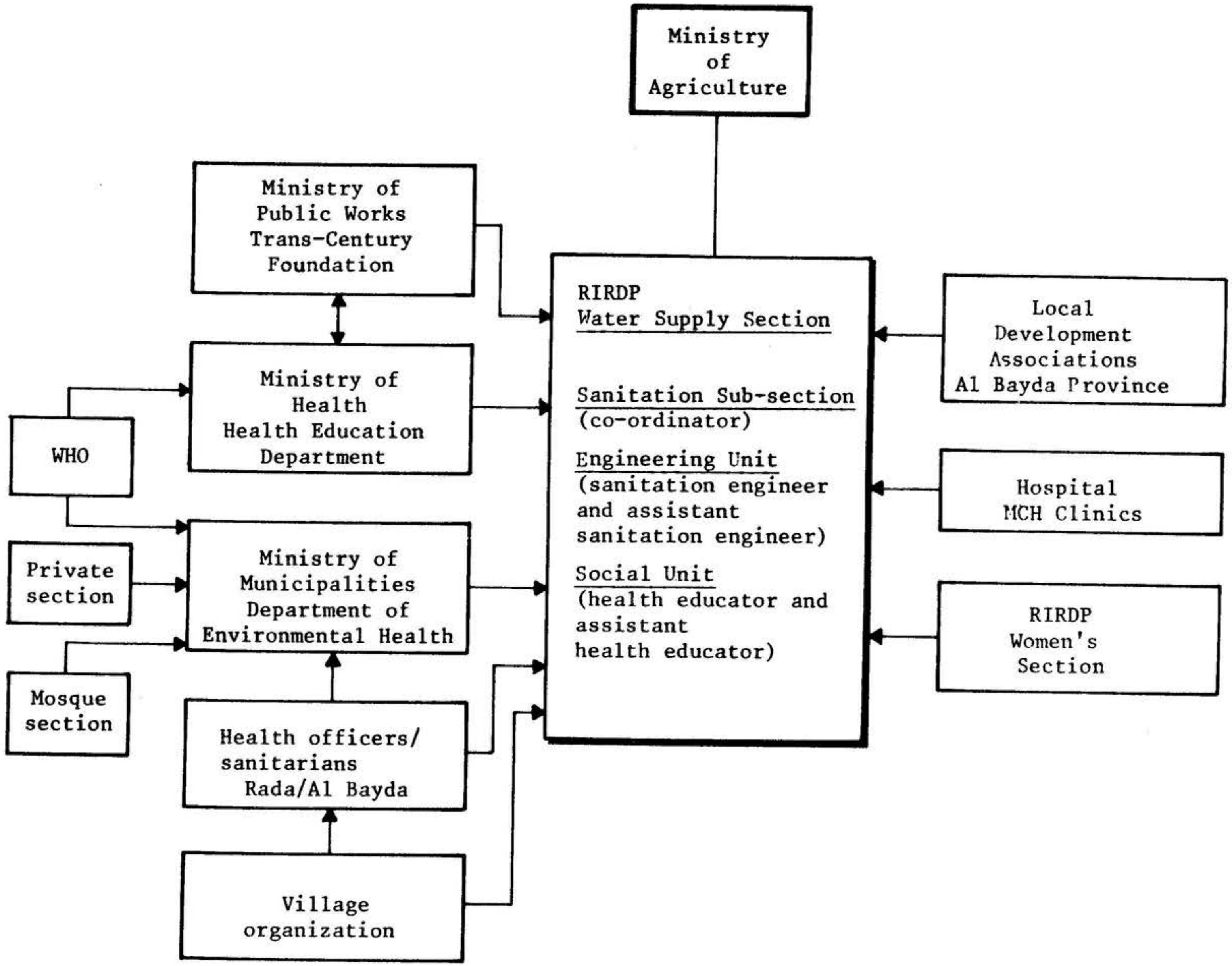
It is not considered appropriate at this stage to consider garbage collection services organized by either the LDA or the municipalities as there is no existing infrastructural base for such a programme. Instead, the health education programme should be commenced and then hopefully initiatives will develop in the villages for collection and disposal services. Advice and possibly funds for such services should be available from the RIRDP.

Each village would require a collection vehicle (e.g. donkey cart) together possibly with receptacles for depositing garbage. These should only be provided once it is clear that a desire for such a service exists. At present there is no such evidence and further steps must await the results of the health education programme.

5.5.6 Organization and management

It is proposed that the organizational structure of sanitation activities in the province should be similar to that outlined for water-supply in Section 5.4 with the Co-ordinating Council of LDAs and RIRDP responsible for planning and implementation/operation respectively. In the case of sanitation, however, it is the Ministry of Municipalities that should provide technical assistance through their Department of Environmental Health as well as through their sanitarians based in Rada and Al Bayda. For health education activities co-operation should be maintained with the Ministry of Health and Ministry of Public Works, who are operating such programmes in other parts of Yemen. A suggested organization chart is illustrated in Fig. 16.

Proposed Organization Chart for RIRDP Sanitation Section.



→ Co-operation

FIG. 16

6 FUTURE DEVELOPMENT OF WATER RESOURCES

6.1 Introduction

The results of the study indicate that there is scope for future development of water resources. The results, which are summarized in Section 6.2 form a firm basis for future development activities to be undertaken by RIRDP.

These activities are twofold. The first category inlcudes concrete steps that should be taken on the short term within the framework of the 1984/85 Operational Plan of the RIRDP. Activities which fall in this category are implementation of the second stage of the study which covers the selected areas not yet investigated, site selection for boreholes, and pilot schemes for the development of sanitation systems.

The second category includes activities which are long-term in nature or even continuous. As mentioned several times in the report, the present data base allows for preliminary estimates of land and water resources and their economic potential. In order to add information on these aspects and to increase the reliability and accuracy of the preliminary data, additional studies should be carried out which would be spread over several years or in some cases be continuous. Activities under this category are monitoring of rainfall, water-levels, water quality and well abstraction; groundwater modelling; soil surveys; applied research on irrigation practices; and farm management studies. The provision of water-supply systems and the proposed programme for the improvement of the quality of water for domestic consumption are both short-term and long-term activities.

The activities mentioned above are discussed in more detail in Section 6.3. They should be carried out within the framework of RIRDP and in accordance with defined development objectives and strategies as elaborated in the operational plans. In essence, this means that the activities would contribute to achieving the project's objectives, which are an increase of productivity in the agricultural and livestock sectors and improvement of infrastructure, and fit into its approach of involving the rural population and meeting its basic needs as well as training of and transferring responsibility to the Yemeni staff.

6.2 Development scope

6.2.1 Water resources

Table 38 summarizes the development potential for further groundwater abstraction in the investigated areas.

Table 38 - Estimated development potential for groundwater in the investigated areas

Area (ha)		Present water abstraction ($m^3 \times 1000$)	Total water potential ($m^3 \times 1000$)	Extra potential for development ($m^3 \times 1000$)
Rada Basin	97 500	20 605	33 288	12 683
Al Bayda North-East	14 030	2 976	5 450	2 474
Al Bayda West	14 241	2 106	3 600	1 494
Wadi Juban	5 280	1 953	3 458	1 505
Wadi Mansur	14 771	1 954	3 025	1 071
Wadi Matar	7 770	352	1 050	698
Wadi Dhi Na'im	55 717	3 545	4 550	1 005
Abbas	3 275	337	680	343
Total	162 444	33 828	55 101	21 273

This estimate has been based on the situation of water abstraction and water-levels found between May and October 1983. The lack of rainfall data, long-term water-level observations, and well abstraction data over longer periods in Al Bayda Province except the Rada Basin makes the presented estimates preliminary. Any development activity of groundwater should, therefore, be accompanied by a monitoring programme of rainfall, water-levels, well abstractions, and surveys to define the actual potential more accurately. Despite this lack of data we consider that there is still scope for development of water resources. From the data it is clear that the Rada Basin has the largest scope for further development with an estimated extra potential of 12.7 MCM; 3 MCM of this water should be reserved for domestic water-supply, 9.7 MCM is available for an increase of irrigation. This potential depends very much on local and hydrogeological conditions, present abstraction, and water use, and is therefore strictly confined to the areas and sub-areas given in Annex A. The above table contains similar estimates for all other areas covered by the hydrogeological survey. The total potential for further groundwater development in the 8 investigated areas is in the order of 21 MCM/year of which 5.3 MCM is required for domestic water-supply in the coming 20 years.

Traditionally, water management in Al Bayda Province has only been applied for the division of spring water for irrigation over different farmers in small areas of the province, like Wadi Tha, and not for well abstraction. Any further development of groundwater has its effects on water-levels, well depths, pump depths, pump costs and water quality. The scarcity of water resources and the occurrence of adverse effects on existing wells and water quality makes some form of water management necessary in order:

- to regulate the number of wells, well distance and well abstraction, and water use sub-area wise;

- to prevent overpumping and deterioration of water quality;
- to reserve and protect areas for abstraction of groundwater for domestic water-supply especially for the larger towns like Rada, Mallah, Al Bayda, and Juban;
- to make optimum use of the scarce water resources.

Some stop on further well drilling in sub-areas with overpumping or in areas set aside for drinking-water supply will be necessary in the future, starting with sub-areas in the Rada catchment.

Legislation on a national level to enforce such measures, and explanation of the measures to the people concerned will be indispensible. Legislation should include obliged reporting of the drilling of new wells connected to a system for obtaining a drilling license. Licenses for drilling a new well for irrigation should depend sub-area wise on:

- the present abstraction of groundwater in that area;
- the potential for further development minus the future need for drinking-water to be abstracted from the sub-area;
- protection of groundwater against inflow of saline water;
- minimum distance to neighbouring wells.

For the purpose of water management prior to and simultaneous with programmes for water development, monitoring of rainfall, water-levels, water abstraction, and water quality are indispensible.

6.2.2 Water-supply and sanitation

Drinking-water is a primary human need; it should be available in sufficient quantities and it should be of good quality. Table 39 summarizes the water-supply situation in the areas investigated. The areas are ranked according to their need for water-supply: Sabah/Ar Riashiyah has the highest need, Al Bayda N-E the lowest. There is ample scope for improvement. However, considering the implementation capacity of the RIRDP, which is about 10 complete water-supply systems per year, it will be clear that it will take years before all villages in the areas have been provided with a system. Besides, other areas not yet surveyed also need water-supply systems. In order to develop a realistic construction programme it will therefore be necessary to use certain criteria for the selection of villages which will be served first. We propose the following criteria:

(a) villages with a severe water shortage;
(b) large villages so as to provide benefits for a maximum number of people;
(c) villages which are willing to contribute to the funds for construction, especially when complete systems are installed;
(d) villages that are part of the integrated package of services provided by the RIRDP, i.e. activities of the water section, agricultural section, women's participation section and road section. Particularly integration with the road programme is necessary to allow accessibility for construction, maintenance and operation.

Table 39 - Ranking of the areas investigated according to water-supply requirements

Ranking	Area	% of villages without water-supply system	% of villages with water shortage
1	Wadi Mansur/Wadi Amad	93	45
2	Sabah/Ar Riashiyah	94	44
3	Wadi Juban	92	42
4	Villages along the Rada/Al Bayda road incl. As Sawadiyah	94	33
5	Wadi Matar/Wadi Ar Rin	83	33
6	Wadi Dhi Na'im	36	45
7	Wadi Hubabah/Wadi Ar Riashiyah	82	18
8	Rada Basin	50	20
9	Al Bayda West	22	33
10	Al Bayda North-East	5	25

Thus, villages which meet the above conditions and, moreover, are located in the areas of the highest need as indicated in Table 39 should be given priority.

In addition to construction activities, action is also required for improving the water quality. As elaborated in Section 6.3, this should be done by simple measures in a multitude of villages spread throughout the province.

Since there is at present no organized sanitation programme within the province it is not possible to provide a future programme based on past experience. The most appropriate action will be to initiate 'pilot projects' based on the conclusions reached from the survey and to monitor the progress of these pilot projects so that modifications based upon the reaction of the people can be made in future sanitation projects. At the same time the inhabitants should be instructed in the proper use of the new sanitation facilities and the projects should be used as demonstration models for other people in the province. This should be combined with a health education programme for which provisions have been made in the proposed organization (see Fig. 16).

The objective of the pilot projects will also be to convince the inhabitants of the benefit of a sanitation programme so that they will be prepared to make contributions for the construction of a sanitation system in their village and for the operation and maintenance of the system.

6.2.3 Irrigated agriculture

Table 40 summarizes the irrigation potential of the areas surveyed by both the agronomic survey and the hydrological survey. The remainder of the selected areas have either been covered by the agronomic survey only or have not been visited at all.

Table 40 - Irrigation potential in the areas investigated (ha)

Area	Net irrigable land	Net irrigated at present	Incremental irrigation potential
High potential:			
Rada Basin	6207	1443	993
Al Bayda North-East	827	177	> 127*
Al Bayda West	361	107	> 57*
Wadi Juban	818	202	115
Wadi Dhi Na'im	772	175	113
Limited or low potential:			
Wadi Mansur	1415	333	10
Wadi Matar/Wadi Ar Rin	351	24	29
Abbas	373	22	28

* Incremental irrigation potential might well be more than the figures indicated, since the water in certain locations is almost unlimited, while no full inventory of land resources was possible because of incomplete coverage by aerial photographs.

The Rada Basin, the Al Bayda areas, and Wadi Dhi Na'im have the great advantage that they are situated at the end of a good quality tarmac road, which links them with the rest of the country. This simplifies import of agricultural inputs and export of products.

Wadi Juban is more or less isolated at the end of a 55 km-long road, through an otherwise not very populated area. It will benefit enormously from the new tarmac road which is under construction. Unlike Wadi Matar/Wadi Ar Rin and Abbas, Wadi Mansur has a considerable area under irrigation at present. This makes it relatively important in Al Bayda Province.

The economic analysis indicates that on the basis of present crops and cropping patterns, further development of irrigated agriculture is economically justified. Present cropping patterns, which are different in each area investigated, are the result of certain specific conditions and we believe that these will not change in the near future. However, on the longer run, the anticipated return of emigrants may necessitate changes in the cropping pattern.

The consultants understand that the Ministry of Agriculture attaches great importance to the formulation of programmes on crops and cropping patterns as well as to the development of modern irrigation techniques to maximize agricultural production and the use of irrigation water. Extension work in Al Bayda has just begun and in setting area priorities it will benefit from the results of the present and future resource studies. However, in order to be effective, extension must be backed up by proper (applied) research and trials and by a farm management survey. Also, soil surveys are required in order to prepare land suitability maps for crops and to obtain information on soil-water data for better advice on water application.

One aspect needs special attention. The market for qat is limited. However, both on technical and economic grounds, its cultivation could be replaced by fruit trees (or vegetables). This alternative is becoming more opportune now that the government has restricted the import of fruits. It is, therefore, advisable that a study of the possibilities for expansion of fruit tree cultivation in Al Bayda Province be undertaken.

6.3 Proposed activities

6.3.1 Study into water resources in Al Bayda Province, Stage 2

As indicated in Table 1 and mentioned throughout the report, not all selected areas could be surveyed during the present study. The areas that still need to be investigated are listed in Table 41; two new areas have been added: an area north-west of Al Bayda Town which has been termed Al Bayda North-West and an area south-west of Wadi Mansur on the southern side of the Rada-Al Bayda road; this area is called Sha-Aban. It should be noted that, except for Sabah/Ar Riashiyah and Wadi Arsard/Wadi Saru, these areas are small. In four areas (Al Bayda West, Wadi Amad, Wadi Ar Rin and Wadi Dhi Na'im) a small part of the wells have yet to be surveyed. However, the coverage of the wells in these areas to date has been sufficient to allow for the conclusions reached in this study.

The second stage of the study, of which the hydrogeological survey (well inventory) already started in January 1984, should be concluded at the end of 1984. The same approach, methodology, and questionnaires as used in the first stage of the study will be applied in the second stage.

Table 41 - Areas to be covered in Stage 2 of the study

Areas	Hydro-geological study	Water-supply and sanitation study	Agricultural study
1. Sabah/Ar Riashiyah	x	-	x*
2. Wadi Arsard/Wadi Saru	x	x	x
3. Al Bayda North-West	x	x	x
4. Sha-Aban	x	x	x
5. Wadi Hubabah/Wadi Ar Riashiyah	x	-	-
6. As Sawadiyah	x	-	x

* Completion of Stage 1.

6.3.2 Water resources

Any programme for continued hydrogeological study should aim at:

- providing sufficient good quality drinking-water;
- making optimum use of groundwater for irrigation;
- protecting groundwater resources against overpumping and water quality deterioration.

To this end the following activities are required in addition to the completion of the well inventory as indicated in Section 6.3.1:
- monitoring of rainfall, water-levels, well abstraction, well drilling, and water quality;
- groundwater modelling in certain areas.

(a) Monitoring

(i) Rainfall

A lack of rainfall data, the great variability of the precipitation, and the importance of water in the project area make a more detailed study of its spatial distribution necessary. It will, therefore, be necessary to extend the rainfall monitoring network to other areas outside the Rada catchment which is, at present, the only area in the province where rainfall is recorded.

Priority catchments for the monitoring of rainfall data are the mountainous regions south of Al Khabar, Wadi Juban and Sabah/ Ar Riashiyah. Due to the irregular nature of the precipitation with respect to both space and time it is advisable to install more than one automatic recorder in the wadis mentioned.

In the wadi system of Juban at least two rain-gauges should be installed, while two more should be installed on the high mountainous plain surrounding the wadi system - on the weather side and lee side of the wadi - in order to be able to middle out differences of exposure to rainfall due to the prevailing direction of the wind.

In Sabah/Ar Riashiyah the situation is more complex, and for practical reasons measurements will have to be done in the wadi itself only. One rain-gauge of the existing monitoring network is already stationed in the Sabah region (in Al Hajar), so two more will be sufficient to allow for the collection of reliable data for the whole region.

In the Wadi Mansur region two rain-gauges are in operation: one in Bayt Al Jabri and one at the extension centre of the project in Wadi Mansur. Installation of more rain-gauges does not seem necessary at present.

Another important catchment in Al Bayda Province is Wadi Dhi Na'im. In contrast to Wadi Juban or Sabah/Ar Riashiyah, the topography is not rugged but undulating, local relief being low. Two automatic rainfall recorders should suffice to obtain interpretable results in a period of a few years.

The same goes for Al Bayda: the local relief differences are only moderate and are not likely to induce localized rainstorms. The total wadi system, however, is much bigger and it is therefore advisable to install at least four rain-gauges: one in Al Bayda Town, one in the wadi system west of Al Bayda Town (Wadi Az Zahir), one in the wadi north of Al Bayda (Wadi Hazzah), and one in the wadi system east of Al Bayda Town (near Madhwagayn).

Located north-east of As Sawmah is a very large wadi system, Wadi Arsard/Wadi Saru. The monitoring network in this region is of importance because of its location in the province. Information obtained locally suggests that this is an important area for the production of onions, potatoes, and tomatoes. This wadi system is far from Al Bayda Town and it proved to be impossible to visit it within the time available. The wadi will be covered in the proposed follow-up survey in 1984. Given the absence of data it is considered that at least two rain-gauges should be installed.

Summarizing we propose the installation of rain-gauges in the following areas:

Rada	1 meter
Juban	4 meters
Sabah/Ar Riashiyah	2 meters
Al Bayda	4 meters
Dhi-Na'im	2 meters
Wadi Saru	2 meters
	15 meters

Monthly servicing of this number of meters and processing of their data using conventional recorders is very time-consuming and costly. We therefore recommend the installation of electronic rainfall recorders which require cleaning every three months and changing of memory blocks plus processing of the rainfall data on an annual basis. Reading and processing is done by computer.

(ii) Water-levels

The recording of water-levels is required:

- to determine the reaction of the groundwater reservoir on rainfall and water abstraction;
- to determine the recharge of the aquifers;
- to determine and to warn timely against overpumping.

At present water-levels are observed monthly in 13 wells of the Rada Basin only. We consider that water-levels should also be recorded simultaneously with rainfall in the other areas to be investigated in Al Bayda Province. Here also 15 to 20 recorders will be required. For the same reasons as mentioned above use should be made of electronic recorders spread more or less as the rainfall recorders over the different areas. At the same time six recorders (one in each area) must be installed as barometer to allow correction for air pressure differences.

(iii) Well abstraction

At present the water abstraction from 14 irrigation wells is metered on a monthly basis in the Rada Basin only. The present survey showed large differences in water abstraction per hectare irrigated land which are difficult to explain. Large differences also occur in well abstraction data obtained by the hydrogeological survey and the agronomic survey of the same wells.

Electronic recorders recording water-levels on an hourly basis could be used if placed in a shallow well equiped with pump for determining simultaneously:

- the rest water-level;
- the dynamic water-level;
- the pumping hours.

We propose, therefore, to place half the number of electronic water-level recorders in shallow wells pumped for irrigation or drinking-water supply.

Water-level recorders for monitoring water-levels and water abstraction should in any case be placed in areas selected for substantial increases in water abstraction for drinking-water supply and irrigation.

(iv) Well drilling

Monitoring the drilling of new wells is needed in order:

- to keep the well inventory updated especially in the Rada area;

- to determine if an area becomes overcrowded with wells and overpumped;
- to follow the increase in groundwater abstraction in the light of the groundwater potential and,
- to serve as basic data for groundwater model studies.

(v) Water quality

Groundwater in the investigated catchments is generally fresh. Brackish groundwater occurs in parts of wadis with shallow water tables in the Al Bayda region and in the north-east corner of the Rada Basin. Furthermore, water with a higher fluor content than allowed for drinking occurs in some parts of the catchments, for example the Rada catchment. The water quality should therefore be investigated during the hydrogeological survey by taking the electrical conductivity of each well, and a chemical analysis should be made of water from every tenth well. The heavy pumping, especially in the Rada catchment, make a reversal of groundwater flow possible in the north-east corner of the Rada Basin. Water-levels as well as water quality should be regularly recorded to determine if the slope of the water-table and consequently the flow direction reverses and brackish groundwater moves south into the plain. Brackish groundwater also occurs in other wadis with otherwise fresh groundwater. Any increased development of groundwater in such wadis may cause the migration of this water and increase the size of the areas with bad quality water. Water-level control as well as water quality control should, therefore, be included in each development plan for the increase of water abstraction.

(b) Groundwater modelling

Table 38 and the tables about groundwater potential in Annex A show that the extra potential for water abstraction differs greatly area-wise within all investigated catchments. The same variability is found in the whole geohydrological situation. For example, water-levels vary from less than 5 m to more than 60 m below the surface in the Rada catchment, and water quality differs from brackish to fresh. The same applies for the water potential. Very deep water-levels exist and little scope for further development of groundwater is available in the areas between Rada and Mussalah (sub-area RR) while in other sub-areas there is still some scope for development.

Another matter concerning the planning of water development is the hazard of deterioration of water quality in the groundwater north of Rada. At present the brackish groundwater in the north-east corner of the Rada Basin is kept in its place by the south to north groundwater flow. If, due to excessive pumping, the groundwater table in the south is lowered to such an extent that the groundwater slope and groundwater flow reverses, the backward flow of brackish groundwater could cause the water quality around Rada to deteriorate considerably. This would seriously endanger the water-supply for domestic use and agriculture. The hydrogeology is so heterogeneous and the abstraction pattern is so complicated that it is very difficult to give more than a first estimate of the groundwater potential, and to do more than warn against the danger of saline water intrusion.

Therefore, we propose, also in view of the importance of the Rada Basin in the province, that this groundwater catchment be the first area for groundwater modelling.

Use of this model will enable us to:

- make a more accurate assessment of the groundwater potential for different parts of the catchment;
- assess the reaction of the water-levels on different abstraction regimes in order to obtain the optimum well field for safe abstraction of groundwater without depleting the aquifers; and
- formulate methods to protect the Rada Basin against brackish water flowing backwards from the north-east corner of the catchment to Rada.

The development of groundwater models of other areas in the Al Bayda Province is not yet possible due to the lack of basic data about rainfall and water-level fluctuations.

6.3.3 Water-supply

A programme for the development and improvement of water-supply systems should have the following components:

- site selection of boreholes;
- provision of water-supply systems;
- improvement of the quality of water.

(a) Site selection

Site selection is required to trace the faults and to find areas of deep weathering, deep alluvium, and good water quality.

Aerial photographs, and the geo-electrical method and electro-magnetic method are required to locate the aquifers accurately enough to ensure successful drilling.

Proper site selection

- increases the chances for successful drilling several times;
- increases the average yield per well considerably;
- decreases the average depth and cost of well drilling;
- traces areas of fresh groundwater;
- minimizes, but does not exclude, failures;
- decreases the cost of water per cubic metre.

The following methods and measures are required for successful site selection:

- aerial photographical interpretation in order to trace faults and other geological features favourable for groundwater;
- electro-magnetic measurements
  - . for tracing faults covered by alluvium in the field accurate enough for successful drilling;

  . for quick surveying of the relative thickness of the weathered rock zone, the alluvium, and the water quality;

- geo-electrical measurements to determine:

  . the depth of the different formations such as:
    - the thickness of the weathered rock zone,
    - the thickness of alluvium,
  . groundwater quality.

All three methods in combination with the present and future results of the well inventory are required for site selection in the Al Bayda Province.

The tables in Appendix B.IV list the towns and villages with present and future water shortages due to insufficient supply. Although the list contains all villages with a population greater than 500, it should be supplemented with the villages surveyed during the second phase of the study. It can be concluded that nearly all the towns and villages require one or more boreholes to meet their needs.

The list and its supplement should be regarded as a starting point for a plan of action for site selection for the coming years to be worked out and implemented by RIRDP, or other agencies, in accordance with the funds and manpower available.

(b) Provision of water-supply systems

This activity implies the continuation of the present RIRDP policy of providing water-supply systems. With the existing funds and staffing approximately 10 villages per year can be covered. However, in most cases the construction includes the provision of a water distribution system. It is recommended that in areas and villages with severe a water shortage the assistance be limited to the provision of a borehole with pump and engine and a small buffer reservoir near the source or village, if this is acceptable to the village concerned. In this manner, more villages could be covered.

The greater part of the new construction is required in Wadi Mansur/Wadi Amad, Sabah/Ar Riashiyah and Wadi Juban, and emphasis should be initially placed on these regions, which also concurs with the present RIRDP development plans and with the provisional road development plans. Villages within these areas should be selected as much as possible in accordance with the criteria set out in Section 6.3.2. As mentioned before, a preliminary list of villages has been prepared in Annex B, Appendix B.IV.

(c) Improvement of the quality of water

This includes a programme for reducing the bacteriological pollution of drinking-water from shallow wells. Simple measures should be used such as covering and lining of wells, source protection, suitable drainage facilities at the wells and, if necessary, simple chlorination.

This activity can be expected to provide a wide coverage of the selected areas where a bacteriological problem is apparent and should include villages of all sizes where the provision of a water-supply system is not envisaged for the near future.

Emphasis should initially be placed in Rada, Al Bayda, Sabah/Ar Riashiyah and Juban, where the water quality problems are the most serious. The programme could take the form of provision of materials by the RIRDP and labour by the inhabitants; standard designs can be provided by the RIRDP. Also health education should be given in conjunction with the RIRDP sanitation unit.

6.3.4 Sanitation

For the improvement of sanitation, the following pilot projects are recommended:

(a) The construction of modified baladiyah toilets, together with suitable disposal facilities for liquid excreta and wastewater, in groups of houses in up to 3 villages spread over the province.
(b) The construction of washing and excreta disposal facilities near a mosque.
(c) The construction of treatment facilities for sewage and wastewater for a large village, together with agricultural re-use of effluent.

Each of these pilot projects must be carried out in conjunction with an intensive health education programme in order to ensure proper use of the facilities so that the benefit of the new systems can be demonstrated to as many of the inhabitants as possible. Moreover, as has been discussed previously, lack of personal hygiene is the primary cause of a range of water-borne diseases, and without health education the benefits of both the water-supply and sanitation programmes will be greatly diminished.

Based on the results of the survey the following villages have been identified for each of the three types of pilot projects;

- Modified baladiyah system	:	Al Khilaw (Rada)
		Adh Dhahaki (Al Bayda N.E.)
		As Sawma'ah (Al Bayda N.E.)
- Improvement of mosque hammams	:	Draybah (Rada)
		Nowah (Juban)
- Sewage and wastewater disposal		Madhwagayn (Al Bayda)
and re-use of effluent	:	Awwayu (Al Bayda)
		Adh Dhahaki (Al Bayda)

The number of pilot projects that can be undertaken depends on the funds available, but at least one of each type should be implemented in 1984/85.

6.3.5 Irrigated agriculture

The activities proposed for the agricultural sector can be grouped under two headings:

- soil survey,
- optimum use of irrigation water.

(a) Soil survey

As indicated several times in this report the absence of a systematic soil survey has been an obstacle in arriving at precise figures of cultivable land potential in the province. It is proposed to carry out a semi-detailed soil survey at least in the areas with high irrigation potential such as Rada Basin, Sabah, Al Bayda North-East (including Wadi Arsard and Wadi Saru) and Wadi Juban.

The survey should lead to a soil suitability map on a scale 1:20 000, indicating the suitability of the soil for the various categories of crops (cereals, vegetables, and fruit trees).

The survey should not only focus on the soil fertility but also on such constraints as salinity and physical features (e.g. soil-moisture characteristics (Pf-values) and infiltration rates).

(b) Optimum use of irrigation water

Better use of irrigation water can be achieved by the selection of suitable crops, varieties and crop mixes, by increasing productivity through the use of modern inputs and improved farm management, and by better irrigation practices. In addition to the agricultural research presently carried out by RIRDP in co-operation with the Central Agricultural Research Station at Taizz and the studies conducted by the Agro-economic section of the RIRDP, we suggest investigations in the following fields.

(i) Crop-water use

The current irrigation methods practised in Al Bayda Province, e.g. basin irrigation for cereals, alfalfa, qat and fruit trees, and furrow irrigation for water-melons and vegetables, are adequate and efficient. Therefore, it is not necessary to change the irrigation application methods.

Border irrigation on 5-m wide strips as propagated by the Dhamar Agricultural Improvement Centre might be too sophisticated under the prevailing conditions in Al Bayda Province. When not correctly handled it results in poor irrigation of at least part of the crop (local shortages and excesses). Furthermore, considerable land development is required since the strips not only have to be completely level across, but length-wise they must be carefully graded under a slight gradient for the water to run evenly and gradually down-slope.

Water management can be improved upon, and application depths and irrigation intervals must be better-adapted to soil type and crop characteristics. This can only be done on the basis of certain soil-physical data and irrigation research results.

The soil-physical data will have to be collected during a follow-up soil survey. They include soil texture and the water-holding capacity of the soil.

Specific irrigation research is at present not being conducted at the RIRDP farm at Al Khabar. Problem-oriented research under Al Bayda conditions should include trials on the following subjects:

- assessment of the optimum irrigation interval and application depth of water for the various crops. The optimum water management is formed by that (long) irrigation interval that combines with the highest possible water application without creating seepage losses, thus saving expensive labour on crop irrigation;
- the benefits of pre-irrigation before sowing of crops;
- the benefits of under-irrigation, or, in other words spreading the available water over a larger cropped areas.

These trials are similar to the ones conducted at the Dhamar Agricultural Improvement Centre during 1981. The results of intensive and extensive irrigation should be evaluated economically afterwards, taking into account all crop cultivation costs.

(ii) Farm management investigations

Continuous farm management research for at least one year, thus covering both the summer and winter seasons, is necessary to obtain a better insight into present farm management practices, its constraints and its possibilities for improvement, and into the scope for more economic crops and cropping patterns. It should also provide accurate and reliable information on costs and returns of crop production under different irrigation conditions in the province. The results of the investigations will form a basis for advice on crops and cropping patterns both for existing areas under irrigation and the potential irrigable areas.

It is suggested that the units to be covered by the farm management survey be the areas irrigated from wells which are presently being monitored. The information to be collected would include the following:

- areas under crops in the summer and winter seasons;
- quantity and costs of farm inputs, e.g. mechanization services, labour input (family and hired), fertilizers and agro-chemicals;
- yields and produce prices; home consumption and production for market;
- irrigation practices, irrigation intervals, application rates, hours of pumping, pump discharge and total water abstraction.

The above list is not intended to be exhaustive but to give a general idea of the aspects which should be covered by the survey.

Weekly visits (perhaps daily visits in the peak periods) are required to obtain reliable data on the above aspects. The survey should be carried out by the RIRDP Agro-economic section, which may need more staff for this purpose, and the RIRDP Agricultural and Extension section.

(iii) Crop studies

Farm management investigations should culminate in integrated studies of crops that have relatively high returns to water. Such studies should comprise technical, economic and marketing aspects. Development of fruit production may serve as an example. In many areas in Al Bayda Province, there is a history of fruit cultivation and recently the area under trees has been expanded in Al Bayda N.E., despite the strong competition of qat. In general, there seems to be an increasing interest on the part of farmers to grow fruits. However, there is hardly any information on the technical, economic and marketing aspects of fruit cultivation in Al Bayda, nor on the long-term prospects of fruit production.

Therefore, after the soil and farm management surveys, a study could be undertaken which should include the following aspects:

- the technical feasibility of growing fruit crops in Al Bayda Province;
- the economic feasibility of growing fruit crops and their marketing situation as compared to other crops;
- identification of actions/projects for enhancing fruit production.

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