社会開発協力部報告書

No. 8

YEMEN ARAB REPUBLIC
MINISTRY OF PUBLIC WORKS

THE RURAL WATER SUPPLY PROJECT
PART II

MAIN REPORT

FINAL REPORT

May 1980

JAPAN INTERNATIONAL COOPERATION AGENCY

YEMEN ARAB REPUBLIC
MINISTRY OF PUBLIC WORKS

THE RURAL WATER SUPPLY PROJECT
PART II

MAIN REPORT

FINAL REPORT

May 1980

JAPAN INTERNATIONAL COOPERATION AGENCY

PREFACE

In response to the request of the Government of Yemen Arab Republic, the Japanese Government decided to conduct a survey on the Rural Water Supply Project and entrusted the survey to the Japan International Cooperation Agency. The J.I.C.A. sent to Yemen Arab Republic a survey team headed by Mr. Kenji Shiraishi from September to December, 1979.

The team exchanged views with the officials concerned of the Government of Yemen Arab Republic and conducted a field survey (in rural area, twenty-six sites). After the team returned to Japan, further studies were made and the present report has been prepared.

I hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of Yemen Arab Republic for their close cooperation extended to the team.

May,1980

Keisuke Arita
President
Japan International Cooperation Agency

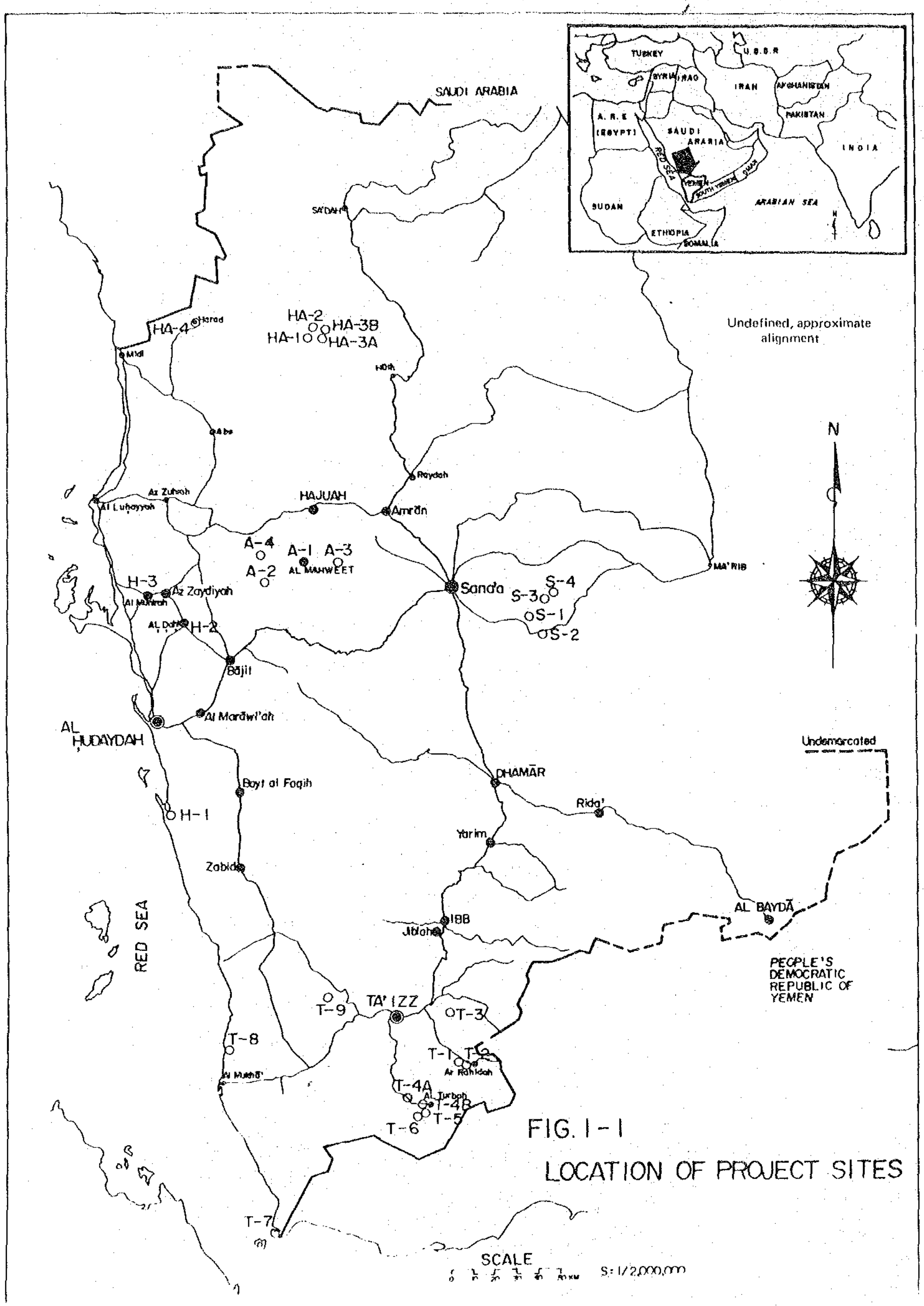


FIG. I-I

LOCATION OF PROJECT SITES

TABLE I-I LIST OF PROJECT SITES

SITE NO.	SURVEY SITE	DISTRICT	GOVERNORATE
HA - I	Al-Madan & 8 Villages	Al-Ahnoon	HAJJA (HA)
HA - 2	Elman & 4 Other Villages	Al-Ahnoon	
HA-3-A	Sihara	Sihara	
HA-3-B	Thari	Sihara	
HA - 4	Harad	Harad	
A - I	Al-Mahweet City	Al-Mahweet	AL-MAHWEET (A)
A - 2	Hufash	Al-Mahweet	
A - 3	AL-Rajam	Al-Mahweet	
A - 4	AL-Khabet	Al-Mahweet	
S - I	Bany Shaker & Bait Abo Saba'a	Al-Suhman	SANA'A (S)
S - 2	Bait Abo Hashem	AL-Suhman	
S - 3	AL-Sheab Al-Aswad	Banishadad	
S - 4	Bany Farhan & Bany Saria'a	Banishadad	
H - I	Ghulayfagah	Duraihmi	HODEIDAH (H)
H - 2	Al-Dahi	Hodeidah	
H - 3	AL-Mounirah (to supply Ebn-Abbas and Al-Harunia)	Zuhrah	
T - I	AL-Mashjab	AL-Sulou	TAIZ (T)
T - 2	AL-Manara & Al-Dukum	AL-Sulou	
T - 3	AL-Maydan, AL-Juball Sheibd Hamud	Kadier Al-Buraihi	
T-4-A	Hadad, Qahfa	AL-Turba	
T-4-B	AL-Kudha, AL-Hagl	AL-Turba	
T - 5	Shahat, AL-Kadash	AL-Turba	
T - 6	AL-Zakira	AL-Turba	
T - 7	Bab-AL-Mandab	Bad-AL-Mandab	
T - 8	Yahkhtol	Mokah	
T - 9	Makbana	Makbana	
TOTAL	26	15	5

TABLE OF CONTENTS

Page

LIST OF APPENDIX

LIST OF TABLES

LIST OF FIGURES

Page

CHAPTER I INTRODUCTION

CHAPTER I

INTRODUCTION

1. General

In response to the request from the Government of the Yemen Arab Republic (YAR) to the Japanese Government to study the feasibility to supply clean and adequate domestic water for selected rural areas in the Republic, the Rural Water Supply Project Part II was established. This is the final report of the Project.

The data collection and field survey which were performed in the three month period from September 18th to early December, 1979 were performed by the survey team of the Japan International Cooperation Agency (JICA) acting on behalf of the Government of Japan in cooperation with the Ministry of Public Works (MPW, hereinafter also referred to as "the Ministry").

The meeting was held by the MPW and the study team on the draft final report at Sana'a from 7th to 12th in April, 1980. Some comments were made on the draft final report and they are incorporated in this final report.

The survey sites under the Project consist of 26 sites distributed in fifteen districts.[1] Of these survey sites, basic design was provided for Bab Al Mandab during field survey as the construction of water supply system was so urgently required by the Ministry of Public Works. Also, since design of water supply system for Al Mahweet was already completed by the Ministry when the survey team arrived at the site, it was urgently requested by the Ministry to review the design.

Note(1) : See Fig 1-1 and Table 1-1 before the table of Contents.

All of these survey sites are problematic areas which were not included in the Rural Water Supply Project Part I under the Japanese international cooperation project due to difficulty in access and/or obtaining a stable water source.

The objective of this project is to make a feasibility study of the rural water supply for the above 26 sites leading to basic design. Usually, decisions in the field of water supply will be taken on the basis of intuition and judgement. However, this study uses cost-effectiveness analysis for the determination of feasibility.

For this purpose, optimum systems of water supply was sought for each project site.

2. Composition of the Japanese Survey Team

This survey was carried out by the Japanese Survey Team especially organized for Rural Water Supply Project Part II by the Japan International Cooperation Agency. The professional staff comprising the team are as follows:

Mr. Kenji Shiraishi	Team Leader
Mr. Akihiko Togo	Assistant Team Leader
Mr. Sakae Takada	Engineering Geologist
Dr. Mashio Yamaha	Sanitary Engineer
Dr. Motoo Saito	Hydro-geologist
Mr. Akira Sato	"
Mr. Shigeyoshi Kagawa	Hydrogeologist & Human Geographer
Mr. Ichiro Makuta	Water Supply Facility Engineer

CHAPTER II
SUMMARY CONCLUSION & RECOMMENDATION

CHAPTER II

SUMMARY AND CONCLUSION

General Background of The Project:

The Rural Water Supply Project Part II was established in response to the request from the Government of the Yemen Arab Republic to Japanese Government.

The data collection and field survey were performed by the survey team of Japan International Cooperation Agency (JICA) during the three month period from September to December, 1979.

Objective:

The major objective of the project is to make a feasibility study of supplying clean and adequate domestic water for 26 selected survey sites by the Ministry of Public Works.

These survey sites are distributed over a wide range of geographical conditions. Accordingly, cost-effective analysis was used in this study to determine feasibility whereas usually in water supply studies, decisions are made mostly on the basis of intuition and judgement.

Recent Growth in National Economy of the Republic:

More recently, especially since the quadrupling of international oil prices at the beginning of 1974, there has been an unprecedented increase in personal cash incomes based mainly on remittances by Yemenis who go to work in Saudi Arabia and the Gulf States. Largely, as a result of these cash inflows, the Republic's per capita GNP has more than doubled in real terms since 1969/70 reaching a level of about $390 in 1967/77.

Fast growing cash incomes from workers remittances opened new markets for local merchants and farmers, and provided funds for private investment in housing, transport equipment, agriculture and industry. This coincided with a vigorous expansion of public development expenditures, which were initially various ad hoc projects, to a more coordinated form through its Three Year Program and the Five Year Plan.

Although private cash incomes have risen sharply in recent years and most families can now afford substantially higher levels of consumption, the supply of social services, especially domestic water supply, has not kept pace with the growth in per capita incomes.

Rural Water Supply Schemes under the Government:

The Rural Water Supply Department (RWSD) was established in the Ministry of Public Works in March 1972 for the purpose of obtaining drinking water sources and supplies for towns and villages. However, the Local Development Associations (LDA) organized by local people are playing an important role in implementation of the projects.

At the present time there are 150 active LDAs in the Republic which design and plan programs for various projects including rural water supply. Estimates of the projects undertaken by the LDAs suggest that over 12,000 km of access road, some 1,500 water supply projects, almost 2,000 schools and 76 health centers were completed by fiscal year 1977/1978. In the Five Year Plan, a total of 2,158 projects for rural water supply was proposed to be implemented. The total investment cost for the rural water supply projects was estimated at 103 million Rials with 25% of this amount as the contribution of MPW.

Necessity of Rural Water Supply:

In spite of the great effort made by RWSD and CYDA, the majority of the people still live with a scarcity of water in rural areas. The annual precipitation in the Republic ranges from a few hundred millimeters to 1,800 mm. The wettest zone is in the western highlands which covers only a limited area.

As flood plains are distributed only at limited locations, agriculture is practiced mainly on labor-intensive stone terraces on the high-altitude steep slopes and along limited areas of the low-altitude wadis. This pattern of agriculture is based on the fact that land and water for agricultural production are available only in these limited areas. The distribution pattern of rural population is determined accordingly.

In the Republic almost 90% of the total population lives in rural areas in small clusters. The population of the majority of these clusters is less than 2,000 people; half of them being less than 1,000 people. In 1974, only 4.7% of rural population was served by a water supply. Even considering the ongoing project design capacity, only 14% of rural population will be covered by rural water supply in 1981.

In many dry areas, the available water source consists of open cisterns or shallow dug wells which are constantly subject to contamination due to the inflow of organic pollutants as well as the rapid growth of algae.

Under these circumstances, the per capita water consumption, estimated from 4 L/cap/day to 40 L/cap/day, is entirely dependent upon the availability of water.

Location of Survey Sites:

The 26 survey sites are distributed over a wide area in the country; however, the majority of the sites are located in the lowland, Tihama Plain (0-200 m ASL), and highlands (1,000 m - 2,400 m ASL) of various governorates. (See Fig. 1-1 and Table 1-1 before the table of contents.)

In sites on the Tihama Plain, rapid population growth is expected in the future because these sites will be increasingly important as transport nodes since the land transport network is now being improved.

At the moment, however, locally available water sources are highly saline and potable water sources can only be obtainable further inland to the east.

The sites on highlands villages however, are usually located on the top of mountain or on the upper steep slopes. Therefore, available water sources in the vicinity of villages are either cisterns or small springs which are not stable and always subject to contamination. In many cases potable water sources are available only in the valley floor far away from villages. The average distance from village to water source exceeds 5 km and sometimes even more than 10 km.

The most common types of water sources at the survey sites are cisterns, springs and shallow dug wells. Since the yield of these sources is limited, several different types of water sources are used wherever the water is available.

The unit water consumption rate varies from 4 L/capita/day to 40 L/capita/day depending entirely on the availability of the water. In many cases the consumption rate is far below the design criteria of 40 L/capita/day proposed by the Ministry.

Present Price of Drinking Water:

Therefore, what clean and safe water is available has a high market price at present. At 9 of the survey sites (35% of the total number of survey sites), people are paying for clean and safe domestic water transported from remote water points. The water price ranges from 8 YR/m^3 to 300 YR/m^3 including transportation cost for 20 km. The most common price was observed to be in the range of 50-60 YR/m^3 which is equivalent to almost 20,000 YR/m^3/year or 2.2 YR/cap/day assuming a daily consumption rate of 40 liters per capita.

It is obvious that the price of water is large cost for the households in the area. Even if it can be afforded by the local people, it is an unusually large household expense.

Future Demand of Rural Water Supply:

Since the conditions at the various survey sites varied some being located on the top of high mountains and the others located at extremely low altitudes in arid and saline environments, the initial task of rural water supply planning was to determine a method for providing an equitable water supply system for these sites based on a concept of cost-effectiveness. A planning period of 20 years was adopted based on the considerations of useful life for boreholes and machinery as well as durable structures like pipelines and water tanks. For estimate of the future demand of domestic water the following growth rates are adopted.

- 6% : Sites playing an important social or economic role such as transportation node, economic center or a specific site so determined by the Ministry.
- 3% : Sites which are in an embryonic stage of urbanization with relatively large population between 3,000 and 5,000 people.

2.5% : Common rural areas.

In the Republic, recently the MPW determined the design criteria of daily consumption for rural water supply to be as follows:

40 L/cap/day	:	Rural area without distribution system
70 L/cap/day	:	Semi-urban area with part of a distribution network. Population between 3,000 and 5,000 people.
80-120 L/cap/day	:	Urban area with population more than 5,000 people.

In order to estimate the future demand for cattle watering, the concept of livestock unit of consumption is used. 6 L/head/day is referred to the "livestock unit" of water consumption.

Availability of Water for Rural Water Supply:

Due to the arid conditions and the steep topography prevailing in the greater part of the Republic, general conditions for utilization of surface water is unfavorable at the present stage of rural water supply planning. Under the circumstances, a feasibility study was made on different type of water sources and the conclusion was reached that the underground water is the only available water source at many of the sites.

Nonetheless data collection and studies for the surface water development should be undertaken for the increasing future demand of water.

The estimated yield for a single borehole ranges from 200 to 1,000 m^3/day while the estimated future demand of survey sites at the end of planning period distributes between 40 and 2,500 m^3/day.

The estimated yield of a single borehole will be sufficient for the future demand at the end of the planning period at seventeen sites; however, in some other sites, multiple boreholes are required to meet the future demand to satisfy proposed design criteria by the Ministry. (See Table 2-1)

The availability of multiple groundwater sources and their location is entirely subject to the hydro-geological conditions, at the site. Under favorable conditions, a group of boreholes can be drilled within a short distance; however, where hydrogeological conditions are less favorable boreholes must be distributed over a larger distance resulting in a negative effect on the economics of water supply.

Determination of Design Capacity:

For this reason an analysis of the inventory of rural water consumption is required for the determination of the optimal design capacity of the rural water supply.

The function of domestic water at survey sites was divided into three categories:

I. Water which has direct influence on human health
II. Water for the other areas of everyday life like washing clothes
III. Watering cattle is the third category which is indispensable in the project.

The design capacity of rural water supply can be classified into three levels as follows:

Service Level A : to supply all three categories of water consumption.

Service Level B : to supply only the required water of category I and II.

Service Level C : to supply water only for category I.

For the preparation of the basic design, consideration was given to minimize the impact of water source cost to the unit price of water. Accordingly the design capacity was determined mainly based on the availability of water sources.

As a result, a design capacity was adopted for 21 of the sites to meet the future demand after 15 years from now based on the proposed design criteria (40 L/C day) by the Ministry. (See Table 2-1)

For the other sites, the design capacity was adopted to meet the water demand even after 20 years which is necessary to promote human health. (Service Level C)

Project Cost

To supply the planned design capacity shown in Table 2-1, construction of deep wells is necessary at all project sites except for Shohat, Al-Kadash (T-5) for which an underground reservoir and shallow well is planned. The total construction cost is estimated at 90.7 million Y.R. which is brokendown into the following categories as shown in detail in Table 2-2:

Cost Item	Million Y.R. (%)
Well boreholes	32.4 (35.7)
Booster pumps, pipelines, etc.	32.0 (35.3)
Distribution tanks, etc.	12.5 (13.8)
Pumps, etc.	7.5 (8.3)
Water Storage tanks	6.3 (6.9)
	90.7 (100.0)

The total construction cost including service facilities of rural water supply ranges from YR 0.6 million to YR 11.5 million depending on the specific conditions at each survey site. The average investment cost of the rural water supply under the project is estimated at 594 YR/cap.

However the total construction cost does not include consultancy cost (10% of total construction cost) and contingency (10% of total construction cost).

Benefit from the Project:

The present price of safe domestic water ranges from 0.32 YR/cap/day to 12 YR/cap/day assuming the per capita daily consumption of 40 L/cap day. On the other hand the price of water to be supplied by the proposed basic design falls between 0.03 YR/cap/day and 0.87 YR/cap/day which will obviously alleviate the present weight of domestic water cost on the household economy. In addition, the effect of the project to human health will be considerable since all of the basic designs provide safe water from an improved rural water supply system.

While the Rural Water Supply Project Part II will serve about 84,000 people at the beginning of the project, the total design capacity of the project will serve a total population of 153,000 people.

In the year 1981, 14% of rural population (720,000 people) will be served by rural water supply taking the design capacity of on-going projects into consideration.

Therefore, the contribution of this project to the total rural population served by safe domestic water is estimated at more than 10% in 1981.

In conclusion, the increased benefits of water supply to the project sites are substantial as summarized below and therefore, the project is judged to be feasible.

	Current Condition	Improved by The Project
Water Source	20% is stable and safe	100% of water which has direct influence on human health will be provided on a stable and safe basis.
Daily Consumption	4-40 L/cap/day	20-40 L/cap/day
Price of Water	0.32-12 YR/cap/day	0.03-0.87 YR/cap/day
Distance to the Safe Water	1 - 20 km	0.50 - 1.0 km

Therefore, it is concluded that the implementation of the project is recommended according to the proposal outlined in the report.

However, it is noted that accessibility to the project and construction sites are satisfactory only at some survey sites and the road improvement should be necessary for the project implementation at the sites as shown in Table 2-1.

Additional Study:

The greater part of the country is occupied by the dry area where it rains less than 600 mm/year and steep rocky topography is predominating.

In addition, usually rainfall is sporadic and occurs in torrential shower caused by the convectional disturbance of the air masses. Accordingly, river discharge occuring immediately after the rain has an extremely steep hydrograph recession curve due to the high intensity and short duration time of shower.

Accordingly, there are difficulties in assessing the volume of available water source due to above natural conditions and lack of data. Therefore, it is urgently recommended to improve the hydrometeorological observation network.

Generally, the data collection of hydrometeorology suffers from the lack of observation stations on the upper slopes of mountains. However, the Republic has an advantage in this respect since villages are located either on the top or upper slopes of mountains.

Necessary data to be collected are: daily rainfall, river and spring discharge, water levels at existing boreholes and shallow dug wells and general meteorology.

A study to assess the available water resources should be urgently undertaken on a seasonal basis. For this purpose, the concept of catchment-wise water balance should be adopted including study on behavior of groundwater.

Table 2-1 Summary of Current and Planned Water Sources

Site No.	Survey Site	Current Situation: Water Source (Distance To It)	No. of Population	No. of Livestock	Water Consumption ℓ/c/day	Proposed Basic Design: No. of Boreholes Depth of Well	Design Capacity (ℓ/c/day)	Number of Population	Number of Livestock	Service Level	Condition of Access Road
HA-1	AL-MADAN & 8 VILLAGES	Spring/Shallow Well (2 Km)	7,500	3,680	14.3	2 - 300 m	20	11,685	5,734	C	Improvement Req.
HA-2	ELMAN & 4 OTHER VILLAGES	Spring/Shallow Well (2 Km)	1,500	1,470	10.0	300 m	40	2,173	2,129	A	Improvement Req.
HA-3-A	SIHARA	Cistern (1 Km)	4,500	8,830	11.4	2 - 300 m	20	10,785	21,162	C	Good
HA-3-B	THARI	Cistern/Spring (10-15 Km)	15,000	15,000	6.0	2 - 200 m	20	23,370	23,370	C	Improvement Req.
HA-4	HARAD	Shallow Well (1-2 Km)	7,000	6,620	21.4	3 - 120 m	40	16,776	15,865	A	Good
A-1	AL-MAHWEET CITY	Spring/Cistern (2 Km)	5,400	6,320	40.0	2 - 200 m	40	7,790	9,847	C	Improvement Req.
A-2	HUFASH	Cistern/Spring (1-2 Km)	1,500	630	25.0	200 m	40	2,173	912	A	Construction Req.
A-3	AL-RAJAM	Spring/Cistern (1-2 Km)	800	630	25.0	300 m	40	1,159	912	A	Construction Req.
A-4	AL-KHABET	Spring/Surface Water (1 Km)	1,500	880	31.0	200 m	40	2,172	1,275	A	Good
S-1	BANY SHAKER & BAIT ABO SABA'A	Spring (2-5 Km)	500	860	3.8	200 m	40	724	1,246	A	Construction Req.
S-2	BAIT ABO HASHEM	Shallow Well (6 Km)	380	1,600	11.3	200 m	40	550	2,317	A	Good
S-3	AL-SHEAB & AL-ASWAD	Cistern/Spring/Shallow Well (15 Km)	2,000	8,800	23.8	100 m	40	3,116	13,710	A	Good
S-4	BANY FARHAN & BANY SERIA'A	Spring (6-10 Km)	650	1,300	16.0	100 m	40	941	1,883	A	Good
H-1	GHULAYFAGAH	Shallow Well (1 Km)	500	510	26.0	30 m	40	724	739	A	Improvement Req.
H-2	Al-DAHI	Deep Well (1 Km)	7,000	7,710	41.6	2 - 80 m	40	16,776	18,477	A	Good
H-3	AL-MOUNIRAH	Deep Well (1 Km)	1,700	640	13.3	60 m	40	4,075	1,534	A	Good
T-1	AL-MASHJAB	Shallow Well (2 Km)	800	6,670	16.7	110 m	40	1,159	9,660	A	Good
T-2	AL-MANARA & AL-DUKUM	Shallow Well/Spring (2-4 Km)	600	6,240	15.0	110 m	40	869	9,037	A	Good
T-3	AL-MAYDAN AL-JUBAIL SHEIBD HAMUD	Spring/S.Well (3-10 Km)	1,000	2,740	15.0	200 m	40	1,448	3,968	A	Improvement Req.
T-4-A	HADAD, QAHFA	Spring (2-3 Km)	1,800	2,740	30.0	180 m	40	2,607	3,968	A	Good
T-4-B	AL-KUDAH, AL-HAGL	D.Well/S.Well (2 Km)	2,500	3,430	45.0	250 m (Water source study required)	20	3,621	4,968	C	Good
T-5	SHOHAT, AL-KADASH	Shallow Well (5-10 Km)	2,000	3,740	40.0	10 m (Subsurface reservoir)	40	2,897	5,417	A	Construction Req.
T-6	AL-ZAKIRA	Cistern/Spring (3 Km)	4,000	8,220	10.0	250 m	20	6,232	12,807	C	Construction Req.
T-7	BAB-AL-MANDAB	Seawater Desalination Plant/Shallow Well (15 Km)	5,000	410	43.0	3 - 85 m (M.P.W. design)	40	11,983	983	A	Good
T-8	YAHKHTOL	Shallow Well (15 Km)	2,500	6,850	8.0	100 m	40	5,991	16,416	A	Good
T-9	MAKBANA	Shallow Well (2 Km)	7,000	2,740	33.3	300 m	40	10,906	4,269	A	Good

Table 2-2 Summary of Construction Costs

(unit = 000's Y.R.)

Site No.	Survey Site	Water Source	Pump, etc.	Water Storage Tank	Booster Pump, Pipeline, etc.	Distri-bution Tank, etc.	TOTAL Amount	TOTAL (%)
HA-1	AL-MADAN & 8 BILLAGES	3,036	600	48	3,273	1,505	8,462	(9.3)
HA-2	ELMAN & 4 OTHER VILLAGES	1,518	197	42	689	340	2,786	(3.1)
HA-3-A	SIHARA	3,014	600	48	3,679	893	8,234	(9.1)
HA-3-B	THARI	2,058	600	48	2,967	1,618	7,291	(8.0)
HA-4	HARAD	1,603	1,188	1,390	430	800	5,411	(6.0)
A-1	AL-MAHWEET CITY	1,857 (40)	600 (315)	48 (109)	1,927 (1,678)	1,618 (272)	6,050 (2,414)	(6.7)
A-2	HUFASH	1,018	197	42	3,047	340	4,644	(5.1)
A-3	AL-RAJAM	1,527	197	34	327	178	2,263	(2.5)
A-4	AL-KHABET	1,017	197	42	865	800	2,921	(3.2)
S-1	BANY SHAKER & BAIT ABO SABA'A	1,007	187	34	183	127	1,538	(1.7)
S-2	BAIT ABO HASHEM	1,015	187	42	254	127	1,625	(1.8)
S-3	Al-SHEAB & AL-ASWAD	569	126	127	95	620	1,537	(1.7)
S-4	BANY FARHAN & BANY SERIA'A	580	126	127	27	-	860	(0.9)
H-1	GHULAYFAGAH	264	126	108	108	48	654	(0.7)
H-2	AL-DAHI	819	526	972	240	360	2,917	(3.2)
H-3	AL-MOUNIRAH	356	126	168	2,766	415	3,831	(4.2)
T-1	AL-MASHJAB	514	126	197	77	-	914	(1.0)
T-2	AL-MANARA & AL-DUKUM	523	126	127	393	127	1,296	(1.4)
T-3	AL-MAYDAN AL-JUBAIL SHEIBD HAMUD	1,040	186	48	630	310	2,214	(2.4)
T-4-A	HADAD, QAHFA	965	126	109	241	340	1,781	(2.0)
T-4-B	AL-KUDAH, AL-HAGL	-					-	
T-5	SHOHAT, AL-KADASH	4,346	282	42	335	340	5,345	(5.9)
T-6	AL-ZAKIRA	-					-	
T-7	BAB-AL-MANDAB	1,797	418	1,640	7,109	534	11,498	(2.7)
T-8	YAHKHTOL	496	146	367	2,136	178	3,323	(3.7)
T-9	MAKBANA	1,467	315	415	243	893	3,333	(3.7)
	TOTAL (%)	32,406 (35.7)	7,505 (8.3)	6,265 (6.9)	32,041 (35.3)	12,511 (13.8)	90,728 (100.0)	(100.0)

* The total construction cost does not include consultancy cost and contingency.

CHAPTER III
PRESENT STATE OF RURAL WATER SUPPLY IN THE YEMEN ARAB REPUBLIC

CHAPTER III

PRESENT STATE OF RURAL WATER SUPPLY IN THE YEMEN ARAB REPUBLIC

The Rural Water Supply Department (R.W.S.D.) was established in the Ministry of Public Works (MPW) in March 1972 for the purpose of obtaining drinking water sources and supplies for towns and villages in cooperation with international organizations. During the three year program from 1972/73 to 1975/76, the administrative and the technical staff was appointed in addition to WHO experts, United Nations (U.N.) volunteers and American Peace Corps volunteers to solve the accute shortage of manpower for the water supply project. UNICEF offerred material and equipment for 15 projects.

The three year program included water supply projects for 200 wells throughout the country to reduce the distress of water scarcity and to provide drinking water for the countryside. Investment during the three year program was estimated at 36 million Rial. Contribution to this investment was made to the greatest extent by the U.N., Saudi Arabia and USAID.

Prior to establishment of the RWSD in the MPW, the government of the Yemen Arab Republic had perceived the need for rural development early in the history of the Republic and called for the creation of Local Development Associations (LDAs) in 1962. The Ministry of Social Affairs, Labour and Youth was established in 1968 to provide central government support for the LDAs. In 1973, the Confederation of Yemeni Development Associations (CYDAs) was created to formulate general policy, enhance the LDAs, design plans and programs, seek foreign and domestic support and advise the LDAs on their projects, including rural water supply projects.

Although the formation of LDAs and their operations were initially held back by the civil war, after 1970 the movement spread quickly through the country. At present there are some 150 active associations in YAR and most of them distributed in the Governorates of Sana'a, Taiz, Ibb and Haja. Each LDA is administered by a management board which is democratically elected by its association members.

Estimates of the projects undertaken by the LDAs suggest that over 12,000 km of access road, some 1,500 water supply projects, almost 2,000 schools and 76 health centers were completed by fiscal year 1977/1978. (see APPENDIX III-1) Usually these projects were carried out at much lower cost than if they had been done by contractors. These are remarkable achievements which underline the strength and dynamism of the LDA program.

The LDAs were asked to draw up three year plans for approval by CYDA and the central government in 1976. The plans, with suitable modifications, were incorporated into the National Five Year Development Plan for 1976/7 - 1980/1. In the Five Year Plan, a total of 2,158 projects for rural water supply was proposed to be implemented.

The total investment cost for the rural water supply projects was estimated at 103 million Rials with 25% of this amount as the contribution of MPW. Generally, another 25% of the investment cost of rural water supply is contributed by the local government and the balance of 50% paid by the local beneficiaries of the project.

In spite of the great effort made by RWSD and CYDA, the majority of the people still live in water scarce conditions in rural areas. Annual precipitation in the Republic ranges from a few hundred millimeters to 1,800 mm. The wettest zone is the western highlands which covers only a limited area.

The rest of area belongs to a rather dry zone. This is due to natural geographic barriers since the major component of the topographical relief in the Republic consists of jagged mountain peaks and high altitude plateau (altitudes to 3,500 m above sea level) succeeding to the rocky escarpments or extremely steep slopes incised by deep valleys. Even at the intermediate altitudes of about 1,500 m - 2,500 m ASL, where changes in elevation are less dramatic, the arid roughness of the terrain discourages all but the hardiest succulents and scrub grasses. In the increasingly desert-like conditions at the lower elevations, this sparce natural vegetation disappears. The extreme coastal region is characterized by either sand dunes or mud flats, and the soils are highly saline.

As flood plains distribute only at limited locations, agriculture is practiced mainly on the labour-intensive stone terraces on the high-altitude steep slopes and along limited areas of the low-altitude wadis. This pattern of agriculture is attributed to the fact that land and water for agricultural production are available only in these limited areas. The distribution pattern of rural population is determined accordingly.

In the Republic almost 90 % of the total population lives in rural areas in small clusters. The population of the majority of these clusters is less than 2,000 people; half of them have less than 1,000 people. (Appendix III-2)

In 1974, only 4.7 % of rural population was served by a water supply. Even taking account of on-going project design capacity, only 14 % of rural population will be covered by rural water supply in 1981. (Appendix III-3)

Under the circumstances, per capita water consumption, estimated from 4 L/cap/day to 40 L/cap/day, entirely depends on the availability of the water.

CHAPTER IV

NECESSITY OF SAFE AND ADEQUATE WATER SUPPLY

CHAPTER IV

NECESSITY OF RURAL WATER SUPPLY

Since the end of the civil war in mid-1970, economic activity in the Republic has expanded vigorously. GDP at constant market prices is estimated to have grown at an annual average rate of 8-9 percent between 1969/70 and 1975/76.

More recently, especially since the quadrupling of international oil prices at the beginning of 1974, there has been an unprecedented increase in personal cash incomes based mainly on remittances by Yemenis who go to work in Saudi Arabia and the Gulf States. It is estimated that worker remittances rose from some 40 million U.S. dollars in 1969/70 to over $800 million in 1976/77. Largely as a result of these cash inflows, the Republic's per capita GNP has more than doubled in real terms since 1969/70 reaching a level of about $390 in 1976/77.

Fast growing cash incomes from worker remittances opened new markets for local merchants and farmers, and provided funds for private investment in housing, transport equipment, agriculture and industry. This coincided with a vigorous expansion of public development expenditures. The government increased its development spending which were initially various ad hoc projects, to a more coordinated form through its Three Year Program and the Five Year Plan, from 57 million Yemen Rial (YR) ($13 million) in 1972/73 to YR 340 million ($75 million) in 1975/76. While these expenditures had a direct impact on the gross domestic product, they also supported private development initiatives.

Under the circumstances, however, the need for the basic living requirements of the population is greatest in the rural areas since most rural inhabitants still live under sub-standard conditions, frequently isolated from the rest of the country. Villages and houses are often located on barren land far away from sources of drinking water and in many cases with no schools, no health facilities and no electricity. Although private cash incomes have risen sharply in recent years and most families can now afford substantially higher levels of consumption, the supply of social services, especially domestic water supply, has not kept pace with the growth in per capita incomes. (Section 5-3)

As shown in Appendix III-3, only 4.7 % of the rural population had easy access to village water supplies in 1974, and taking the design capacity of on-going project into consideration, only 14 % of rural population will be served by rural water supply in 1981. The survey sites in this project are in greatest need on water particularly since they were not considered to have sufficient potential or economic accessibility to be included in Part I of the Rural Water Supply which is undertaken by the Ministry sponsored by Overseas Economic Cooperation Funds of Japan.

In many cases present water supply is not considered safe for health. In many dry areas, the available water source consists of only open cisterns or shallow dug wells which are constantly subject to contamination due to the inflow of organic pollutants as well as the rapid growth of algae. (See Section 5-3-4) Clean water for domestic purposes has a very high price: YR 50-60 for 1 m^3 of drinking water. This obviously has a large impact on household expenses. (Table 5-3)

A number of impact studies have revealed that a gap exists between the potential and realized benefits of water supplies in developing countries. (Feachen et al, 1977 and Saunders and Warford, 1976). The conclusion of most impact studies is that the provision of water, however necessary, is not in itself sufficient to produce significant economic benefits to justify its feasibility. However, the provision of a safe water supply creates opportunities in agriculture, animal husbandry, health, child welfare and home economics. Often these opportunities can be exploited at low cost, sometimes only the cost of conveying information.

The provision of a water supply means that the quality of water is improved, the reliability is greater, the quantity of water available will be increased and its distance from the consumers will be reduced.
The reduced walking distance to the water source saves time and energy and releases labour which may be used for productive purposes leading to an economic benefit. Even if the economic value of the saved labour is negligible, there is a social benefit from time saved and drudgery eliminated because more time can be spent with the family or on domestic activities, education and leisure. The improved quality of the water will also lead to improved health conditions.

In conclusion, the necessity and benefits of water supply to the project sites is substantial.

CHAPTER V PROJECT SITES

CHAPTER V

PROJECT SITES

5-1 Introduction

The survey sites were selected by the Ministry according to the priority of rural water supply schemes in the Republic. The 24 selected sites are distributed in 14 Districts. (Appendix V-1)

However, the final determination of the sites was made at the discussion on the Feasibility Study for Rural Water Supply Project Part II held from 20th to 24th of September, 1979 at Sana'a as shown by the minutes in Table 5-1.

At the discussion it was found that the site originally listed as Al-Dahi in "Zuhrah District" was located in Hodeidah District. In addition, through the field survey it was found that two sites consisted of completely separated village units in Hajja and Taiz Governorates. The major areas of Sihara and Thari in Hajja situated on the summit of the mountain are separated by a steep and wide valley. Also, Site Number 4 in the Taiz Governorate consists of two areas widely separated from each other.

Accordingly, these sites were identified more precisely as follows:

Hajja No. 3 Sihara & Thari:	Hajja No. 3-A Sihara and Hajja No. 3-B Thari
Taiz No. 4 Hadad & Qahfa and Al Kudha & Al Hagl:	Taiz No. 4-A Hadad & Qahfa and Taiz No. 4-B Al Kudha & Al Hagl

Table 5-1

REVISED SURVEY SITE LIST

GOVERNORATE	DISTRICT	NUMBER	SURVEY SITE
HAJJA (HA)	Al-Ahnoom	1	Al-Madan & 8 Villages
	Al-Ahnoom	2	Elman & 4 Other Villages
	Sihara	3-A	Sihara
		3-B	Thari
	Harad	4	Harad
AL-MAHWEET (A)	Al-Mahweet	1	Al-Mahweet City
		2	Hufash
		3	Al-Rajam
		4	Al-Khabet
SANA'A (S)	Suhman	1	Bany Shaker & Bait Abo Saba'a
		2	Bait Abo Hashem
	Banishadad	3	Al-Sheab Al-Aswad
		4	Bany Farhan & Bany Saria'a
HODEIDAH (H)	Duraihmi	1	Ghulayfagah
	Hodeidah	2	Al-Dahi
	(Zuhrah)	3	Al-Mounirah
TAIZZ (T)	Al-Sulou	1	Al-Mashjab
	Al-Sulou	2	Al-Manara & Al-Dukum
	Kadier Al-Buraihi	3	Al-Maydan, Al-Jubail Sheiba Hamud
	Al-Turba	4-A	Hadad, Qahfa
		4-B	Al-Kudha, Al-Hagl
	Al-Turba	5	Shohat, Al-Kadash
		6	Al-Zakira
	Bab-Al-Mandab	7	Bab-Al-Mandab
	Mokah	8	Yahkhtol
	Makbana	9	Makbana
TOTAL = 5	15		26

Consequently, the field survey was carried out at 26 sites distributed in 15 Districts as shown in Table 5-1.

However, since implementation of water supply scheme was so urgently required for Al Mahweet City (A-1) and Bab Al Mandab (T-7), basic design was made for Bab Al Mandab and the survey team was requested to review the already completed design for Al Mahweet City.

Therefore, in this report, the results of hydro-geological study and alternative basic designs for Al Mahweet City is included for the two sites are provided.

From viewpoint of physiography, the Republic is divided into four major slopes facing to the north, east, south and west. Each major slope consists of lowlands, midlands and highlands. The survey sites distribute over a wide area in the country; however, the majority of the sites are located in the lowland, Tihama Plain (0-200 m ASL), and highlands (1,000 m - 2,400 m ASL) of various governorates. (Fig. 5-1)

In sites on the Tihama Plain, rapid population growth is expected in future because these sites will be increasingly important as transport nodes since the land transport network is now being improved.

At the moment, however, locally available water sources are highly saline and potable water sources can only be obtainable further inland to the east.

On the other hand, at the sites on highlands villages are usually located on the top of mountain or on the upper steep slopes. Therefore, available water sources in the vicinity of villages are either cisterns or small springs which are not stable and always subject to contamination. In many cases potable water sources are available only in the valley floor far away from villages. The average distance from village to water source exceeds 5 km in many sites and sometimes even 10 km.

Due to the scarcity of water, drinking water has high price. In many cases, one cubic meter of drinking water costs at 50 to 60 Rials. An extremely high price was observed at Dare in Hajja Province. In this case, one cubic meter of drinking water is sold at 300 Rials which includes truck transportation for about twenty kilometers of steep mountain road. (Table 5-3)

It is obvious that this price of water is a large cost for the households in the area. Even if it can be afforded by the local people, it is an unusually large household expense.

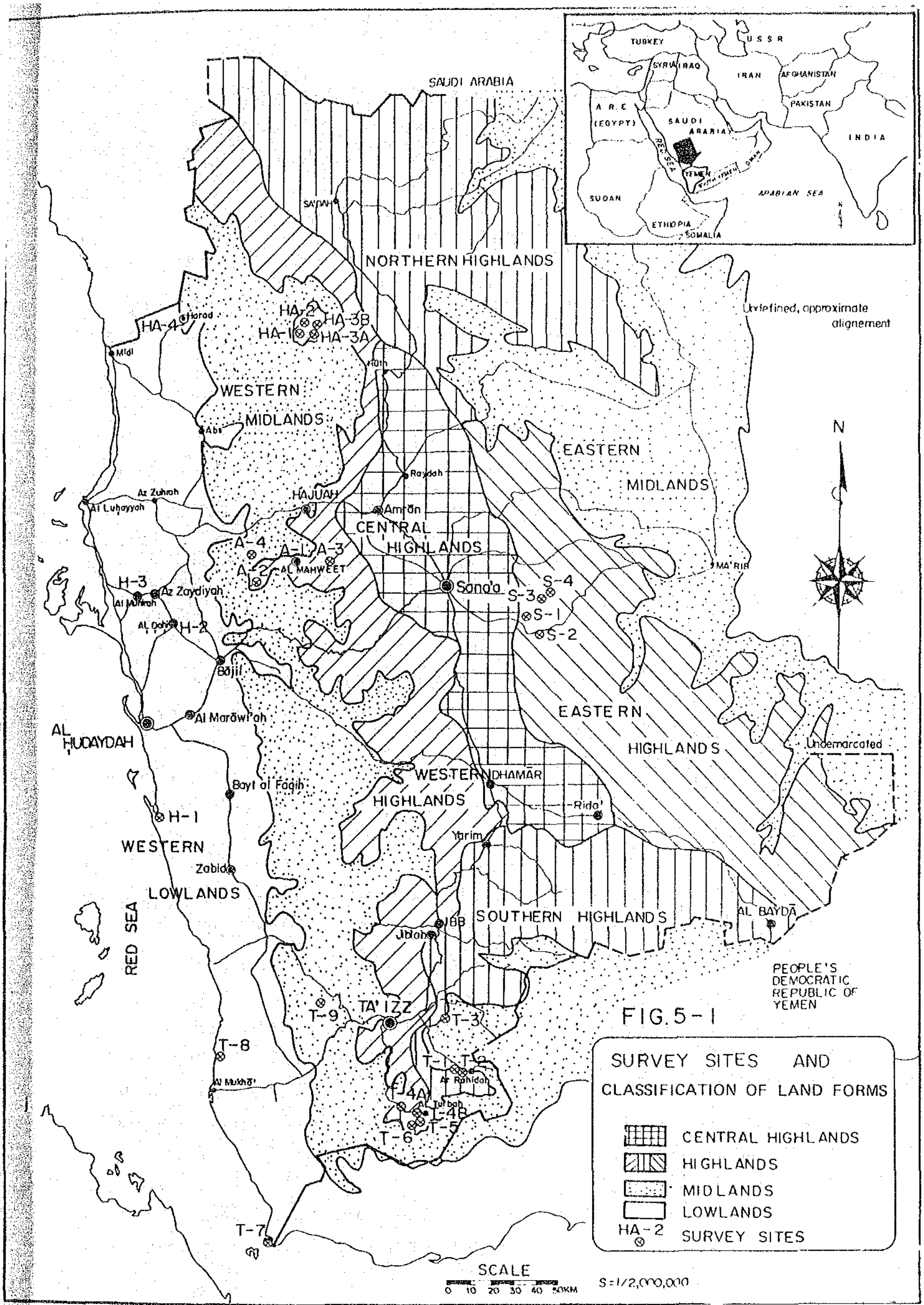

SAUDI ARABIA
TURKEY
U S S R
SYRIA
IRAQ
IRAN
AFGHANISTAN
PAKISTAN
A. R. E (EGYPT)
SAUDI ARABIA
INDIA
RED SEA
YEMEN
OMAN
ARABIAN SEA
SUDAN
ETHIOPIA
SOMALIA
NORTHERN HIGHLANDS
Undefined, approximate alignement
HA-2
HA-3B
HA-1
HA-3A
HA-4
Harad
Midi
WESTERN MIDLANDS
Abs
EASTERN MIDLANDS
Raydah
Az Zuhrah
HAJJAH
Al Luhayyah
Amran
CENTRAL HIGHLANDS
A-4
A-1
A-3
A-2
AL MAHWEET
MA'RIB
H-3
Az Zaydiyah
Al Munirah
Sana'a
S-4
S-3
S-1
S-2
H-2
Bajil
Al Marawi'ah
EASTERN HIGHLANDS
AL HUDAYDAH
Undemarcated
Bayt al Faqih
WESTERN HIGHLANDS
DHAMAR
Rida'
H-1
Yarim
WESTERN LOWLANDS
Zabid
RED SEA
SOUTHERN HIGHLANDS
AL BAYDA
IBB
Jiblah
PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN
T-9
TA'IZZ
T-3
T-8
T-1
T-2
Al Mukha'
Ar Rahidah
T-4A
Al Turbah
T-4B
T-6
T-5
T-7
N
SURVEY SITES AND CLASSIFICATION OF LAND FORMS
CENTRAL HIGHLANDS
HIGHLANDS
MIDLANDS
LOWLANDS
HA-2 SURVEY SITES
SCALE
0 10 20 30 40 50KM
S=1/2,000,000

FIG.5-1

5-2 General Description of Survey Sites

The survey sites of the project were distributed in the following physiographic units:

1. Western Highlands
2. Western Midlands
3. Western Lowlands
4. Eastern Highlands
5. Southern Highlands

5-2-1 Western Highlands

This is a land unit facing to Red Sea at an altitude between 1,500 m and 2,500 m A.S.L. The area has seven sites: four in Hajja Governorate and three in Al-Mahweet Governorate.

a. Hajja Area

The major component of morphology is the independent steep rocky mountains reaching 1,500 m - 2,500 m ASL about 130 km to the north-north west from Sana'a. Geology in this area consist of Yemen Volcanics alternating basaltic lava, andesite, dyorite and tuff with more than 1,000 m thickness.

Al-Madan (HA-1), Elman (HA-2), Sihara (HA-3A) and Thari (HA-3B) are located on the top of these mountains. Due to the steep rocky nature of the topography, accessibility is very poor. However, these areas have a long history in the Republic and size of population is rather large, ranging from 1,500 to 15,000 people. Except for poor vegetation at the peripheral area of small springs at Al Madan and a narrow strip along wadis, barren ground surface occupies the vast area.

On the bottom of wadis sorghum is cultivated and on the steep slopes, well maintained stone terraces are observed.

Major crops on the stone terraces are coffee and qat. Among these sites cisterns are the predominating water source for domestic purposes.

At Al-Madan, springs play the major role in water supply and the supply system is well maintained.

The rest of the three sites entirely depend on cisterns for domestic water sources; however, at Elman and Thari, the cisterns dry up during dry season and people have to pay for water brought from water sources further away.

b. Al-Mahweet Area

This area is also consist of steep rocky mountains. The major geological component is Tawilah sandstone underlain by upper Jurassic limestone. Due to the steep rocky nature of the topography, accessibility to the sites, Al-Mahweet (A-1), Hufash (A-2), Al-Rajam (A-3) and Al-Khabt is difficult.

Al-Mahweet (A-1) is located on the steep slope of mountain top at an altitude of 2,200 m A.S.L. At present, potable water sources are small springs; however, the yield only meets the demand for drinking water for the people. Since this site is the center of the economy and local government, provision of safe and sufficient water supply is urgently required for the present population of 5,000 plus future demand.

Hufash (A-2) is located on the top of mountain at an altitude of 2,400 m A.S.L. Accessibility is so poor that only four wheel drive vehicle can reach the village. The water source is a small spring and its storage basin; however, the demand for only drinking water for 1,500 people is hardly met by the present capacity of the water source.

Al-Rajam (A-3) is a small village situated on the bottom of flat basin-like terrain at an altitude of 2,200 m A.S.L.

Flatland and slops are well utilized for cultivation of sorghum. This site plays the role of cattle market.

At present a tiny spring and cisterns are the major sources for domestic water.

5-2-2 Western Midlands

Midlands have relatively moderately flat topography at altitudes between 500 m - 1,500 m A.S.L. and are regarded as a transition land unit between the highlands and lowlands. Al-Khabet (A-4) in Al Mohweet Governorate and Makbana (T-9) in Taiz Governorate are located in this land unit.

Al-Khabet (A-4) is located on the Tawilah sandstone plateau about 90 km to west-north west from Sana'a.

The water source is only a small spring on the floor of a wadi a few kilometer away from the village.

However, the yield of the spring farely meets the demand of domestic (1,500 people) and cattle (800 head) water.
Due to hot climate, landuse is observed to be very poor and barren ground surface is prevalent in the area.

On the other hand, Makbana (T-9) is located on Yemen volcanics at an altitude of 1,300 m A.S.L. 30 km to west-north west from Taiz.
There are several shallow dug wells on the wadi floor providing water for 7,000 people and some 2,000 head of cattle.

Further downstream from the village, wells constructed on the same wadi floor are used for irrigation.

Due to the moderately flat topography of both sites, there is no difficulty of access.

5-2-3 Western Lowlands

This land unit is considered to be the Tihama Coastal Plain at altitudes between 0 m and 200 m A.S.L. along the alluvial coast plain of the Red Sea.
Harad (HA-4) in Hajja Governorate, Ghulayfagah (H-1), Al-Dahi (H-2), Al-Mounirah in Hodeida Governorate and Yahkhtol (T-8) in Taiz Governorate are located within this coastal plain.

Harad (HA-1) is located near the national border with Saudi Arabia about 170 km to north-west from Sana'a.
This site is a transit station for Yemenis going to work in Saudi Arabia and for the transportation of imported materials.

At present there are two Harads: one is a old traditional village and the other is rather new public center in the vicinity. The population is 3,000 people for old Harad and 4,000 people in new Harad. Also a total of about 6,600 head of cattle are kept in the two Harads. Present water sources for both Harads consist of some shallow dug wells. Water quality is satisfactory. However, considering the importance of the location in the transportation network, an accute shortage of domestic water can be expected in future. Improvement of the water supply system will be also required to satisfy a standard level of the urban water supply system.

Ghulayfagah (H-1) is to the south of Hodeidah about 45 km: the population is only 500 people distributed along with date palms along the coast.
Domestic water is taken from shallow dug wells and the quality of water is satisfactory.

Al-Dahi (H-2) is located to the north-north east 50 km from Hodeidah along national highway which is under construction. At present, the population is 7,000 people. The area has abundant cultivated lands and animal husbandary is also prevalent since there are 6,000 head of cattle.

The present water source for domestic purposes is a single borehole (65 m deep) and a partly private service connection was observed. Upon completion of the national highway which was scheduled for the end of 1979, a rapid increase in domestic water demand can be expected.

Al-Mounirah (H-3) is a prospective water source for Ebn Abbas and Al-Harunia which are located on coast where groundwater, the present water source, is contaminated by extremely high salinity.

Makbana (T-8) is located along the coast of the Red Sea about 75 km from Taiz Town in the west-southwest. The population is 2,500 people and the total number of livestock is estimated at 5,000 head.
Due to the location of the village close to the sea, water obtained from a shallow dug well contains high salinity reaching an electrical conductivity of 4,700 μ /cm.

For this reason, drinking water is carried by vehicle from inland places almost 20 km from the village.

5-2-4 Eastern Highlands

This land unit is moderately undulating terrain lying at altitudes between 2,100 m and 2,200 m A.S.L. adjacent to the Sana'a Basin.

The geological feature in the area is the Upper Cretacious Tawilah sandstone which unevenly covers Amran limestone.

This area includes four sites in the Sona'a Governorate, Bany Shaker/Bait Abo Saba'a (S-1), Bait Abo Hashem (S-2), Al-Sheab/Al Aswad (S-3) and Bany Farhan/Bany Saria'a (S-4).

Bany Shaker/Bait Abo Saba'a (S-1) is located 40 km from Sana'a to the east-southeast. About 500 people used to obtain water from a small dug well which is dried up at present.
The present water source is a small spring, 5 km away from the village. The water is carried by hand or on donkeys. There is no access to the village by vehicle at present.

Bait Abo Hashem (S-2) lies on the quaternary lava plateau intruded through limestone. The distance to Sana'a is 45 km to the northwest. The population is only 380 people with 1,300 head of cattle.

At present no domestic water source is available in the vicinity of the village. Domestic water is obtained by car from shallow wells at Wadi Maswar 6 km from the village.

Al-Sheab/Al Aswad (S-3) is located 40 km from Sana'a to the west. The population is 2,000 people and during rainy season large numbers of cattle (7,000 head) gather at the village.

There is no source for domestic water within the village. The present water source for this village is a small spring 6 km away from the village and water is carried by hand and on donkeys.

During the field survey, however, people in the village were ready to make a test drilling and the site chosen by the survey team produced a successful result.

Bany Farhan and Bany Sharia'a are located further 5 km to the west from the site S-3. The population of the village is 650 people with 1,000 head of cattle. The source of domestic water entirely depends on a small spring 6 km from the village.

5-2-5 Southern Highlands

This is a part of the catchment area where water flows into the Gulf of Aden. Seven sites of the Taiz Governorate are included in this land unit. Of these sites Al-Mashjab (T-1), Al-Manara & Al-Dukum (T-2), Al-Maydan/Al-Jubail/Sheiba Hamud (T-3), Hadad/Qahfa (T-4B) have easy access to the wadi in the midlands where sufficient and safe water is available.

Al-Mashjab (T-1) and Al-Manara/Al-Dukum (T-2) are about 35 km from Taiz to the southeast having populations of 800 and 600 people respectively. Both sites have relatively large numbers of cattle (2,000 - 2,500 head each).

People depend on shallow wells for their domestic water source and cisterns are used for cattle water. However, seasonal fluctuation of the amount of available water is a distressing problem for the villages.

Al-Maydan/Al-Jubail/Sheiba Hamud (T-3) is lying at altitudes between 1,400 and 1,500 m A.S.L, 35 km from Taiz Town to the east. There three villages are within a few kilometers of each other. The total population is 1,000 people with 2,000 head of cattle.

The present water sources for domestic purposes are small springs and shallow wells on the floor of the Wadi Al Mahken, 3 km away from the villages.

Hadad/Qahfa (T-4A) is located along the national highway, Tuluba Road, 35 km from Taiz Town to the south.

The total population is 1,800 people with 1,500 head of cattle.

Al-Kudha/Al-Hagl (T-4B), Shohat/Al-Kadash (T-5) and Al-Zakira (T-6) are located 45 km from Taiz Town to the South. The populations are 2,500, 2,000 and 4,000 people respectively with the same number of cattle as size of population at each village. However, these sites are located on a plateau of Tawilah sandstone surrounded by high cliffs which isolates these sites from the midlands below.

Geologically, Yemen Volcanics cover Tawilah Sandstone unevenly. Shallow dug wells are constructed mainly along this fault line. However, the available amount of water fluctuates widely on a seasonal basis.

Generallly speaking, the plateau-like morphology made of hard rocks develops into cliffs along the structurally weaker zones which tends to produce poor conditions for ground water recharge and storage.
Therefore special measures will be necessary for provision of water for these three sites. A kind of water master plan covering a wide area including such problematic sites is urgently required.

The geologic column in relation to the survey sites is summarized in Fig. 5-2. Also, the size of population and number of cattle at all the sites are summarized in Table 5-2.

Fig. 5-2

Geologic Column in the Yemen Arab Republic

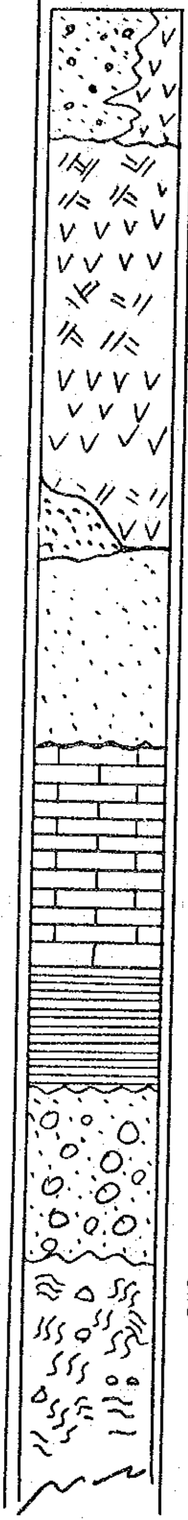
Geological Age	Log	Formation & Lithology	Thickness	Area
Quaternary		Alluvial deposits	20 - 300^{m}	Tihama Coastal Plain
		Basalt Lava	100 - 500^{m}	Central Highlands
Tertiary Upper Cretaceous		Yemen Volcanics Basalt Andesite Trachyte Dyorite Tuff	2000^{m} +	Central Highlands Western Highlands Southern and South-eastern Highlands
Upper Cretaceous		Tawilah Group & Medj-Zir Series	300^{m}	Sana'a Region
		Sandstone, Conglomerate	350^{m}	Western Highlands
Upper Jurassic		Amran Series Limestone Shale, Marl	600^{m} +	Central, Northern and Eastern Highlands
Lower Jurassic		Kohlan Series Shale, Sandstone	300^{m}	Northern Highlands
Ordovician		Wajid Sandstone	250^{m}	Sa'adah and Ma'reb Area
Pre-Cambrian		Basement Complex Granite, Gabbro Gneiss, schists	Unknown	Northern, Southern and Eastern Yemen.

TABLE 5-2

Population of People and Livestock

	Survey Sites	Population	Livestock Units	Livestock head	Cattle	Sheep	Camel	Donkey
HA-1	Al-Ma'dan & 8 Villages	7,500	3,680	2,511	170	1,738	28	575
HA-2	Elman & 4 Other Villages	1,500	1,470	1,000	70	690	10	230
HA-3-A	Sihara	4,500	8,830	7,250	410	6,630	70	140
HA-3-B	Thari	15,000	15,000	10,190	700	7,020	120	2,350
HA-4	Harad	7,000	6,620	4,500	310	3,100	50	1,040
A-1	Al-Mahweet City	5,000	6,320	5,875	75	5,600	10	190
A-2	Hufash	1,500	630	580	10	550	0	20
A-3	Al-Rajam	800	630	521	20	468	8	25
A-4	Al-Khabet	1,500	880	819	10	782	2	25
S-1	Bany Shaker & Bait Abo Saba'a	500	860	690	35	610	10	35
S-2	Bait Abo Hashem	380	1,600	1,280	65	1,130	20	65
S-3	Al-Sheab Al-Aswad	2,000	8,800	6,995	375	6,160	110	350
S-4	Bany Farhan & Bany Saria'a	650	1,300	1,040	55	920	15	50
H-1	Ghulayfagah	500	510	390	30	340	5	15
H-2	Al-Dahi	7,000	7,710	6,005	420	5,280	70	235
H-3	Al-Mounirah (to supply Ebn-Abbas and Al-Harunia)	1,700	640	491	35	428	8	20
T-1	Al-Mashjab	800	6,670	1,958	1,400	54	4	500
T-2	Al-Manara & Al-Dukum	600	6,240	2,510	1,000	800	10	700
T-3	Al-Maydan, Al-Jubail Sheibd Hamud	1,000	2,740	1,850	160	1,320	20	350
T-4-A	Hadad, Qahfa	1,800	2,740	1,460	315	840	15	290
T-4-B	Al-Kudha, Al-Hagl	2,500	3,425	2,502	204	2,041	27	230
T-5	Shohat, Al-Kadash	2,000	3,740	2,710	230	2,200	30	250
T-6	Al-Zakira	4,000	8,220	6,005	490	4,900	65	550
T-7	Bāb-Al-Mandab	5,000	410	302	24	248	3	27
T-8	Yahkhtol	2,500	6,850	5,004	407	4,080	54	463
T-9	Makbana	7,000	2,740	2,003	163	1,634	21	185

5-3 Present State of Water Supply

5-3-1 Introduction

In order to draw a clear picture of the present state of water supply at the survey sites, general information and data were collected from the various governmental and United Nation agencies at Sana'a. Further information and data were obtained from interviews with senior members of cooperative societies and investigations conducted by the study team during the field survey.

Through these activities, the following major aspects of the present state of rural water supply were clarified:

* Present state of water sources and water supply facilities
* Present state of water consumption
* Price of drinking water in rural area
* Water quality of existing water sources

The results of the above data collection and their analysis are briefly described in the following sections of this chapter.

5-3-2 Existing Sources and Facilities of Rural Water Supply

The most common types of water sources at the survey sites are cisterns, springs and shallow dug wells. Since the yield of these sources is limited, several different types of water sources are used wherever the water is available.

Typical water source facilities are storage basins at spring outlets and hand pumps at dug wells.

Only a few cases of water supply facilities such as storage tanks, trunk mains and distribution mains were observed.

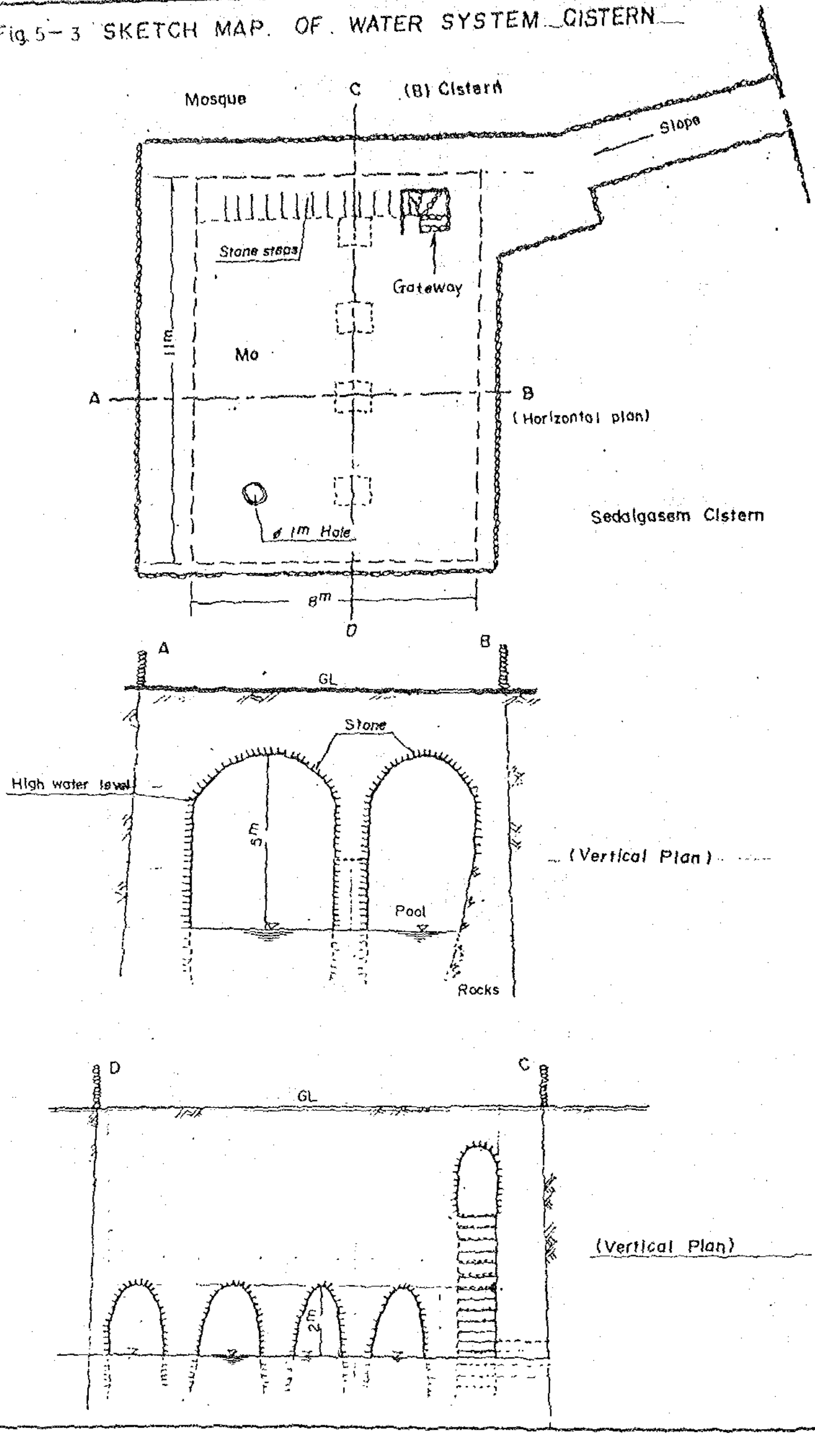
In some cases especially at Bany Shaker, Bait Abo Sabaa, and Al-Sheab Al-Aswad, water from dug wells and cisterns is available for only limited months in a year because of severe climatic conditions.

The typical type of dug well is two meters in diameter with the depth ranging from 15 m to 20 m depending on the depth of impermeable strata. Therefore, the usual thickness of water holding strata covers only a limited area and this results in limited yield.

It was also observed that spring water is utilized without any type of storage basin at many sites. At the sites where a storage basin is provided, a large amount of water is lost because of overflow due to insufficient capacity of the storage basin or leakage because of poor lining.

A cistern is a kind of storage basin distributed throughout the Republic collecting surface run-off during rainfall. (See Fig.5-3) Especially in Hajja Governorate, many cisterns play an important role in providing domestic water. Usually they have masonry structures and are located within the village. This may be attributed to the fact that the location of the cistern is determined by its accessibility since the water source of a cistern is the surface flow which is available only where topographical conditions are favourable. However, it also means that the water is subject to contamination from human activities within the cistern collection area. For this reason, cisterns are not recommended as the water source of drinking water except in some limited cases where no other water source is available. In such special cases, consideration must be given to protection from water contamination.

Fig. 5-3 SKETCH MAP. OF. WATER SYSTEM CISTERN



In general, many water sources, dug well, storage basin and cisterns, are open to the air which results in contamination of water quality. This can be improved by provision of a simple structure to cover the water source.

Location and type of all existing water sources and facilities of rural water supply at survey sites were studied and the amount of available water from the existing source was estimated at each survey site. (Table 5-3)

Based on the above study, the type of water source and water supply system were classified as shown in Table 5-4.

5-3-3. Present State of Water Consumption

In order to estimate present state of water consumption, it is necessary to sample reliable numbers of inhabitants and livestocks at each project site. However, the statistical yearbook of the Republic indicates only the size of population at the Nahyah level while the necessary data for the project is the data at village level. Therefore, numbers of households, size of population and number of livestock were obtained at each site through interview with senior members of cooperatives. (Table 5-3)

Daily water consumption at survey sites varies from 10 m^3/day to 130 m^3/day and the water requirements of livestocks exceeds that of domestic water requirements in many cases. (Table 5-3)

The unit water consumption rate varies from 4 L/capita/day to 40 L/capita/day entirely depending on availability of the water. In many cases the consumption rate is far below the design criteria of 40 L/capita/day proposed by the Ministry.

Therefore, provision of safe and adequate water sources for rural water supply appears to be most crucial task. In addition consideration has to be given to the construction of cattle troughs as a part of rural water supply schemes.

Total water consumption classified by types of sources is summarized in Fig. 5-4.

Table 5-3 Present State of Water Consumption at Survey Sites

Site		Population	Unit Consumption (L/cap/day)	Number of Livestock	Unit Consumption (L/cap/day)	Total Consumption: Domestic Water (m^3/day)	Total Consumption: Livestock Water (m^3/day)	Total Consumption: Total (m^3/day)	Price of Water (Rial/m^3)
HA-1	Al Madan	7,500	14	3,680	6	105	22.1	127.1	–
HA-2	Elman	1,500	10	1,470	6	15	8.8	23.8	–
HA-3A	Shihara	4,500	12	8,830	6	54	53	107	–
HA-3B	Thari	15,000	6	15,000	6	90	90	180	300
HA-4	Harad	7,000	22	6,620	6	154	39.7	139.7	25
A-1	Al Mahweet City	10,000	40	6,320	6	500	37.9	537.9	–
A-2	Hufash	1,500	25	630	6	37.5	3.8	41.3	500
A-3	Al Rajam	500	20	630	6	10	3.8	13.8	–
A-4	Al Khabet	1,500	31	880	6	46.5	5.3	51.8	–
S-1	Bany Shaker & Bait Abo Sabaa	500	4	860	6	2	5.2	7.2	–
S-2	Bait Abo Hashem	380	11	1,600	6	4.2	9.6	13.8	50
S-3	Al Sheab & Al-Aswad	2,000	24	8,800	6	48	52.8	100.8	60
S-4	Bany Farhan & Bany Saria'a	650	16	1,300	6	10.4	7.8	18.2	–
H-1	Ghulayfagah	500	26.6	510	6	13.3	3.1	16.4	-
H-2	Al Dahi	7,000	41.6	7,710	6	291.2	46.3	337.5	–
H-3	Al Mounirah	5,000	13.3	640	6	66.5	3.8	70.3	Some
T-1	Al Mashjab	1,500	16.7	6,670	6	25.1	40	65.1	–
T-2	Al Manara & Al Dukum	800	15	6,240	6	12	37.4	49.4	–
T-3	Al Maydan, Al Jubail & Sheibd Hamud	1,000	15	2,740	6	15	16.4	70.4	–
T-4A	Hadad & Qahfa	1,800	30	2,740	6	54	16.4	70.4	–
T-4B	Al Kudha & Al Hagl	2,500	45	3,425	6	1,125	205.5	1,330.5	110
T-5	Shohat & Al Kadash	10,000	40	3,740	6	400	22.4	422.4	–
T-6	Al Zakira	4,000	10	8,220	6	40	49.3	89.3	–
T-7	Bab Al Mandab	2,800	43	410	6	120.4	2.5	122.9	–
T-8	Yahkhtol	4,500	8	6,850	6	36	41.1	77.1	75
T-9	Makbana	7,000	33.3	2,740	6	233.1	16.4	249.5	250

TABLE 5-4

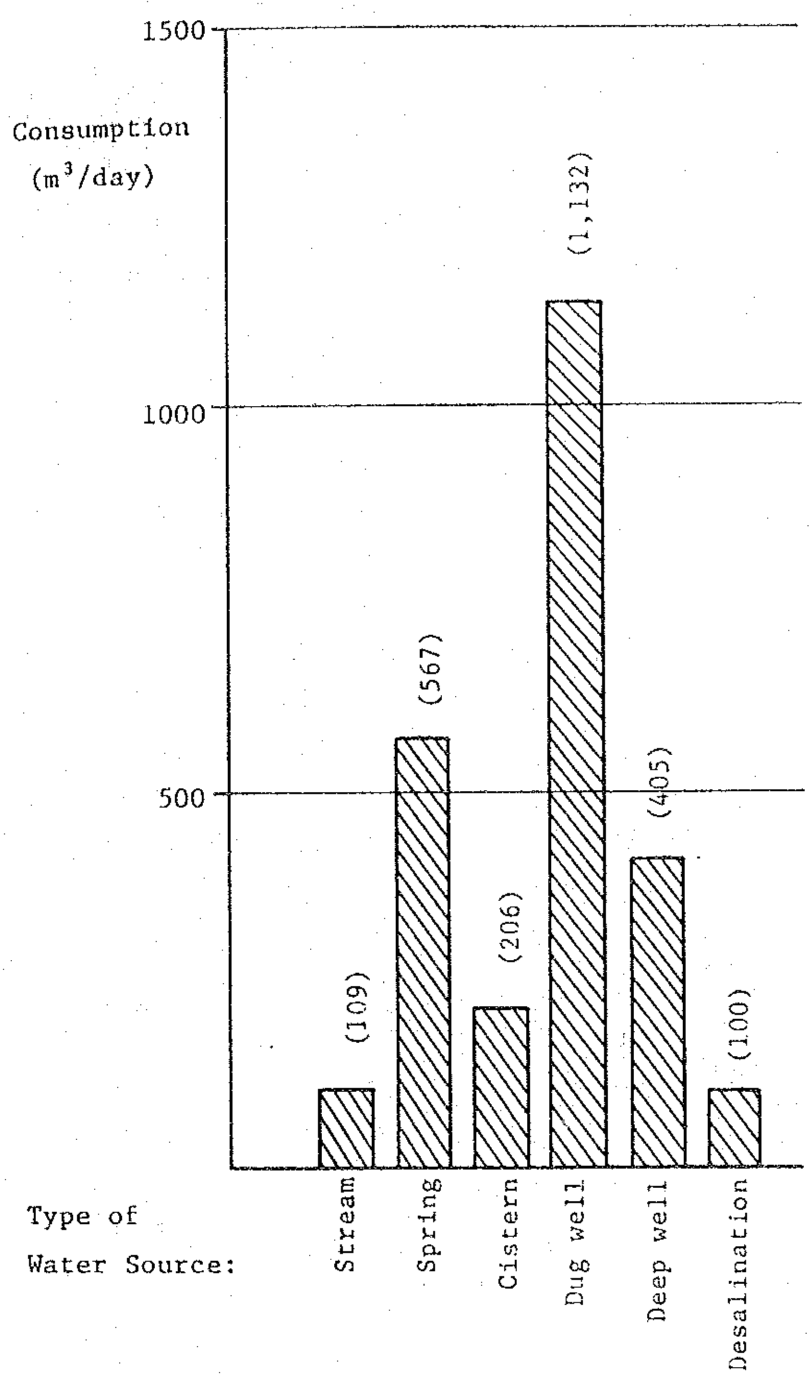
TABLE 5-4 Classified Water Supply System

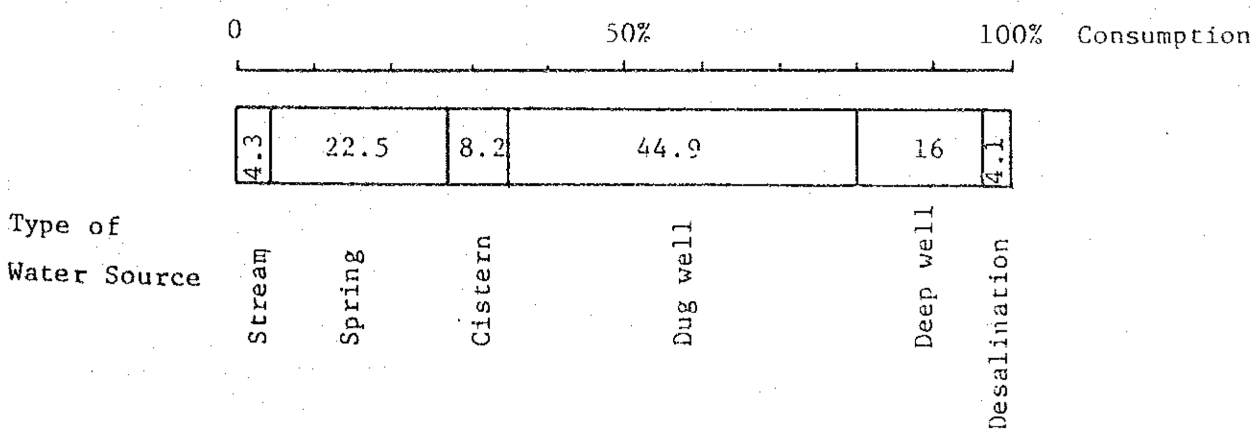
◎ major type
○ supplementary type

Site No.	SURVEY SITE	Water Source				Intake Facility				Method of Intake			Distribution Method			
		Ground Water	Surface Water	Desalination	None	Bore Hole	Dug Well	Storage Basin	Cistern	Pumping	Hand Lifting	Hand Ladle	Piping System	Vehicle	Donkey, etc.	Hand Carried
HA-1	Al-Madan & 8 Villages	◎					○	◎		○	○	○			○	○
2	Elman & 4 Other Villages	◎	○					○	○		○	○				○
3A	Sihara		◎						◎			◎				◎
3B	Thari	○	◎				○	○	◎	○		◎		◎		◎
4	Harad	◎					◎			◎			○		○	○
A-1	Al-Mahweet City	◎	○					◎	○			◎			○	◎
2	Hufash	○	◎						◎			◎				◎
3	Al-Rajam	○	◎						◎			◎			○	◎
4	Al-Khabet	○	○						○			◎			○	○
S-1	Bany Shaker & Bait Abo Saba'a	○	◎				○		◎	○		◎		○	○	○
2	Bait Abo Hashem	◎					◎			◎				◎	○	○
S-3	Al-Sheab Al-Aswad	○	○				○		◎	○		◎		◎	○	○
4	Bany Farhan & Bany Saria'a	○	○				○		◎	○		○		◎	○	○
H-1	Ghulayfagah	◎					◎				◎		○		○	◎
2	Al-Dahi	◎				◎				◎			○	○	○	○
3	Al-Mounirah (to supply Ebn-Abbas and Al-Harunia)	◎				◎				◎				◎	○	
T-1	Al-Mashjab	◎	○				◎		○		◎	○			○	○
2	Al-Manara & Al-Dukum	◎	○				◎		○		◎	○			○	○
3	Al-Maydan, Al-Jubail Sheibd Hamud	○	○				○		○		○	○		○	○	○
4A	Hadad, Qahfa	◎					◎	○			○	○		○	○	○
4B	Al-Kudha, Al-Hagl	◎				○	○			○	○			○	○	○
5	Shohat, Al-Kadash	◎					◎			○	○			○	○	○
6	Al-Zakira	◎	○					○	○			◎		○	○	○
7	Bab-Al-Mandab	○		◎			○				○			○	○	○
8	Yahkhtol	◎					◎			◎	○			◎	○	
9	Makbana	◎					◎				◎			○	○	◎

Fig. 5-4

TOTAL WATER CONSUMPTION BY TYPE OF WATER SOURCE, YAR





5-3-4 Water Quality

At present, the data of water quality of the rural water supply is hardly obtainable in the Republic. However, discussion is made on the water quality at survey sites in this section based on the analysis obtained from the field survey and laboratory test.

Since the survey sites are distributed in dry areas high salinity is the prevalent problem of quality for domestic water.

In the inland area of Hajja and Taiz Governorate the electric conductivity of water obtained from spring, shallow wells is relatively high falling into the range of 1,000 and 2,000 μ℧/cm. Also the total hardness was observed to be higher than a few hundred mg/ℓ and the extremely high value was observed more than 600 mg/ℓ at Makbana.

On the other hand in the lowland area in Tihama Coastal Plain, the quality of water distributed in a wide range. The electric conductivity was observed to be ranging from 1,300 to 5,000 μ℧/cm. The total hardness is also distributing between 100 and 1,000 mg/ℓ.
However, there found some exception of highly concentrated salinity at some shallow wells in wadis. Probably the high salinity may be caused by high evaporation due to strong solar radiation and the lower salinity of the shallow wells in the wadi can be attributed to the fact that seasonal flood spate washes out the precipitated salts in the water course along wadis.

The salinity of the water obtained from cisterns in highlands indicate relatively small value. Since the water source of cistern is surface run-off.

However, it should be noted that most of the water in cisterns are highly contaminated by bacteria although identification of coliforms was not tested.
Further details are discussed in Appendix 2.

5-4 Available Water Source

5-4-1 Introduction

Through the study it was observed that the majority of the surveyed rural water supply sites depend on groundwater, either shallow dug wells or small springs, for their water source. This can be attributed to the fact that severe climatic conditions prevail over the survey sites.

In order to identify the feasible water sources and to estimate the magnitude of the available water sources for the rural water supply schemes, various kinds studies and field investigations were undertaken.
Based on these studies, the available sources for the rural water supply under the project were classified into categories which are discussed in the following parts of this section.

5-4-2 Ground Water

1. Deep Ground Water

This is a type of ground water which does not have immediate influence of surface hydrology in the area. This type of water source provides steady yield for rural water supply scheme where hydrogeological conditions are favourable.

The yield, however, has to be determined based on a long term water balance analysis to prevent over extraction of ground water which may result in distruction of ground water sources.

The ground water developed based on prudent hydro-geological considerations will provide potable water for domestic purposes without any significant treatment devices. This is an advantage over domestic water taken from the surface water which requires various kinds of treatment in many cases.

Most of the survey sites under the project, distribute over a wide range of dry areas which receives annual precipitation less than 600 mm/year. In addition, since the available hydrometeorological data is very limited in these areas, it is difficult to estimate the volume of surface water available.

Accordingly priority was given to the ground water as the domestic water supply source under the project in order to provide potable and stable water for urgent requirements.
Based on the hydrogeological study and analysis, the ground water proposed for the sources of the rural water supply at survey sites is listed as shown in Table 7-4. (See The Technical Report Hydrogeology)

2. Shallow Ground Water

This is a type of ground water which has immediate influence of surface hydrology in the area. Most of the shallow dug wells in Wadis depends on this type of water for their water source. However, due to the severe climatic condition, the amount of yield from this water source fluctuates to a great extent according to the surface hydrological conditions.
Generally speaking, a large yield can not be expected. However, where some measures are applicable for artificial recharge and effective water collection system, this type of water source can play an important role for the future rural water supply.

For this purpose, the study on the run-off structure of these prospecting wadis and determination of the physical properties of aquifers should be undertaken. Under the project, the subsurface reservoir, a type of shallow ground water development, was proposed at Shohat/Al-Kadash (T-5), since no alternative water source is available at present. (See Section 7-3)

3. Springs

From hydrogeological point of view, spring water sources observed in the area are classified into three types:

a. Water along fissure or fracture of dykes. This type of spring are found at Al-Madan, El-man, Sihara, Dare, and Zakirah.
b. Water in the boundary zone between rock stratum. The spring observed at Al-Madan falls in this category.
c. Water in the boundary zone between rock strata and alluvial or colluvial deposits. This type of spring are found at Elman, Dare Sihara, Shohat, and Kadash.

Since most of the spring water sources are supplied by fissure water, the yield is limited and fluctuates seasonally.

However, since spring water is usually potable, it has been playing an important role in the provision of domestic water especially for people in the highland areas. The importance of spring water for domestic water supply may even increase in future. Especially at the sites where hydrogeological conditions are unfavourable to meet the necessary future demand of domestic water in the vicinity of the service area, spring water should be efficiently utilized combined with ground water and other available sources for the provision of potable water for the increasing future demand of the rural population.

At present, the common type of intake facility provided for springs is a simple storage basin at the outlet; however, the storage capacity of this storage basin is insufficient in many cases.

Therefore, an improvement of this type of water source will be made to a certain extent by the provision of storage devices for the effluent of the water from the existing storage basins.

In addition, techniques for the improvement of spring water was proposed for the following survey sites: (See Chapter IV, Technical Report)

HA-1	Al-Madan
HA-2	Elman
HA-3A	Sihara
S-1	Bany Shaker/Bait Ab Sabaa
T-6	Al-Zakirah

For this purpose, detailed observation of spring yield and study of the recharge mechanism should be urgently undertaken.

5-4-3 Surface Water

Due to severe climatic conditions, surface water is unreliable in the area except in the mountainous regions in the southern part of the Republic.

Usually, rainfall is sporadic and occurs in torrential shower caused by the convectional disturbance of the air masses. Accordingly, river discharge occuring immediately after the rain has an extremely steep hydrograph recession curve due to the high intensity and the short duration time of showers. Therefore, a system to trap the flood waters effectively for utilization of the surface water is urgently required.

For this purpose, either a type of reservoir or flood trap were proposed for the following survey sites (See Chapter IV, Technical Report):

Proposed reservoir

S-1	Bany Shaker/Bait Abo Sabaa
S-3	Al-Sheab/Al-Aswad
T-4A	Hadad/Qahfa

Proposed flood trap

HA-1	Al-Madan and 8 Villages
T-5	Shohat/Al-Kadash
T-7	Bab-Al-Mandab

Data collection to determine the design capacity is necessary for the implementation of these techniques.

As discussed in the section 5-3-2, a cistern is a kind of storage basin distributed throughout the Republic collecting surface runoff from rains. Especially in the dry highlands, this type of water source has been playing an important role in providing domestic water. The highly developed traditional masonry works are well adopted to the structure of cisterns. The importance of the cistern in provision of water for the highland areas will probably not diminish even in future since in such areas stable water is obtainable only on the floor of Wadi beds far below the villages.

The basic data of hydrometeorology for design of cisterns is not available at present. Under the circumstances, the preliminary design considerations were made based on the limited data available.

At Wadi Mawr, it is estimated that the average specific yield of surface runoff ranges between 30 to 50 mm/year based on the seven years rainfall records from 1970 to 1976 as shown in Table 5-5 which is modified from the Report of Development of Wadi Mawr, 1979 by Tipton and Kalmbach, Inc.

Table 5-5

Rainfall and Runoff

Wadi Mawr and Wadi Zabid Catchment Areas

Return Period (Years)	Probability (%)	Wadi Mawr		Wadi Zabid	
		Rainfall mm/year	Specific Yield mm/year	Rainfall mm/year	Specific Yield mm/year
1.11	90	370	18	502	31
2	50	524	30	665	46
2.33(Mean)	43	551	32	694	48
10	10	765	49	922	70

Size of Catchment Area: Wadi Mawr 7,912 km^2
Wadi Zabid 4,338 km^2

The catchment area occupied by Wadi Mawr in Hodeida Governorate and the area above the discharge gauging station consisting of 7,912 km^2 is primarily a rugged mountain region rising to elevations over 3,000 m at the river's headwaters. The catchment is composed of weathered and fractured rock with relatively steep slopes. The soils are fine grained. Only about 17 % of the area is terraced or cultivated and natural vegetation covering the area is sparse.

The catchment area of Wadi Zabid is located to the south of Wadi Mawr. The greater part of this catchment area occupies the Tihama Coastal Plain and the headwaters flow out from the high mountainous area in the western part of Ibb where the highest annual rainfall is recorded in the Republic. Nonetheless, the specific yield in a dry year at 90 % excedence probability is estimated at 18 to 30 mm/year. This specific yield can provide 10,000 to 18,000 m^3/km^2/year assuming 40 % losses due to evaporation and leakage. This amount of water can serve a population of 740 to 1,200 assuming per capita daily consumption is 40 L/cap/day.

However, at the survey sites located in the dry highlands areas under the project, the specific yield should be much smaller compared with that of the above catchment areas. At present, there is no basis to estimate the specific yield at these sites where the necessity for utilization of cisterns is critical. Therefore, the study of the runoff structure should be urgently made at these dry highlands.

Another important aspect for the utilization of cisterns is the consideration of water quality control.

The water in a cistern is subject to pollution primarily due to the inflow of the organic pollutants and mud from the catchment area. This may cause secondary pollution due to the reproduction of the aquatic microorganisms. The continuous reproduction the aquatic microorganisms tends to produce a eutrophic environment which may cause tertiary pollution due to organic sediments at the bottom of cisterns.

Therefore, the conservation of the catchment area of cisterns is necessary. For this purpose, the cisterns should be located outside of the village and herds of cattle should not be allowed to access the catchment area.
In addition an improved design should be adopted to cover the cistern or to store water underground.

A modern water treatment plant usually consists of chemical flocculation/coagulation, setting/filtration and sterilization by chlorine. However, this type of purification system requires a large annual cost for the relatively small design capacity expected of the limited capacity of cisterns. Therefore, it is recommended to apply some modified slow sand filter which is comparatively easy to operate including washing of the sand filter.

Although study should be undertaken to determine the detailed design condition of the slow sand filter for cisterns, the provisional design conditions proposed are as shown in Table 5-6 based on a filtration rate of 5 m^3/m^2/day.

Table 5-6

Proposed Design Condition of Slow Sand Filter

Design Capacity (m^3/day)	2	10	50	100
Surface Area of Sand Filter (m^2)	0.4	2	10	20

5-5 Hydro-geography

The physiography of the Republic is divided into three major relieves; lowlands, midlands and highlands. The survey sites distribute over a wide area in the country: however, the majority of the sites are located in the lowland, Tihama Plain and highlands of various governorates. Only two sites (Al-khabet A-4, Makubana T-9) are located in the midlands.

In the highlands, the major component of morphology is the independent steep rocky mountains reaching 1,500 m - 2,500 m A.S.L. or the plateau-like morphology with surrounding steep cliffs, incised by deep valleys. The climatic condition in the highlands is relatively cool: The average monthly air temperature ranges between 16°C and 26°C and annual precipitation is only 400 - 500 mm/year.

Predominating geology in the highlands is Yemen Volcanics and Tawilah Sandstone. The highlands succeeds to the midlands where changes in elevation are less dramatic however, the arid roughness of the terrain discourages all but the hardiest succulents and scrub grasses.
In the increasingly desert-like conditions at the lower elevations, this sparse natural vegetation disappears.
The extreme coastal region in the lowlands is characterized by either sand dunes or mud flats, and the soils are highly saline. The climate in the lowlands is characterized by high air temperature ranging from 22°C to 35°C of monthly average and low rainfall (50-300 mm/year). Although the water is available only to a limited extent the highlands

area is much more favourable than the lowlands in terms of availability of water.

As flood plains distribute only at limited locations, agriculture is practiced mainly on labour-intensive stone terraces on the high-altitude steep slopes and along limited areas along wadis.

The distribution pattern of rural population is determined accordingly. Major crops of these farmlands are sorghum for staple food, coffee and qat for cash crops. Especially qat has great impact to the household income in the highland areas.

Although the yield fluctuates seasonally, many springs are observed in the highland area. This can be attributed to the fact that the major geological components of the area are Yemen Volcanics and Twilah Sandstone and the higher rainfall than the lowlands. The schematic maps of landuse pattern in the highland area are shown in Figs. 5-5 to 5-10.

In the lowland areas, greater portion is occupied by flat low altitude lands covered by sands. Climatic condition in this area is very dry and hot. Annual precipitation ranges from 50 - 300 mm/year while mean monthly temperature ranges 22 to 35°C. Due to the severe climatic condition natural vegetation is hardly observed except extremely sparse grasses and shurabs along major wadis. Water is available at these wadis seasonally. In some places shallow dug wells and spate are well utilized for irrigation. In the rest of the area, water is hardly available or contaminated by high salinity. The schematic maps of land use pattern in the lowland areas are shown in Figs. 5-11 to 5-13.

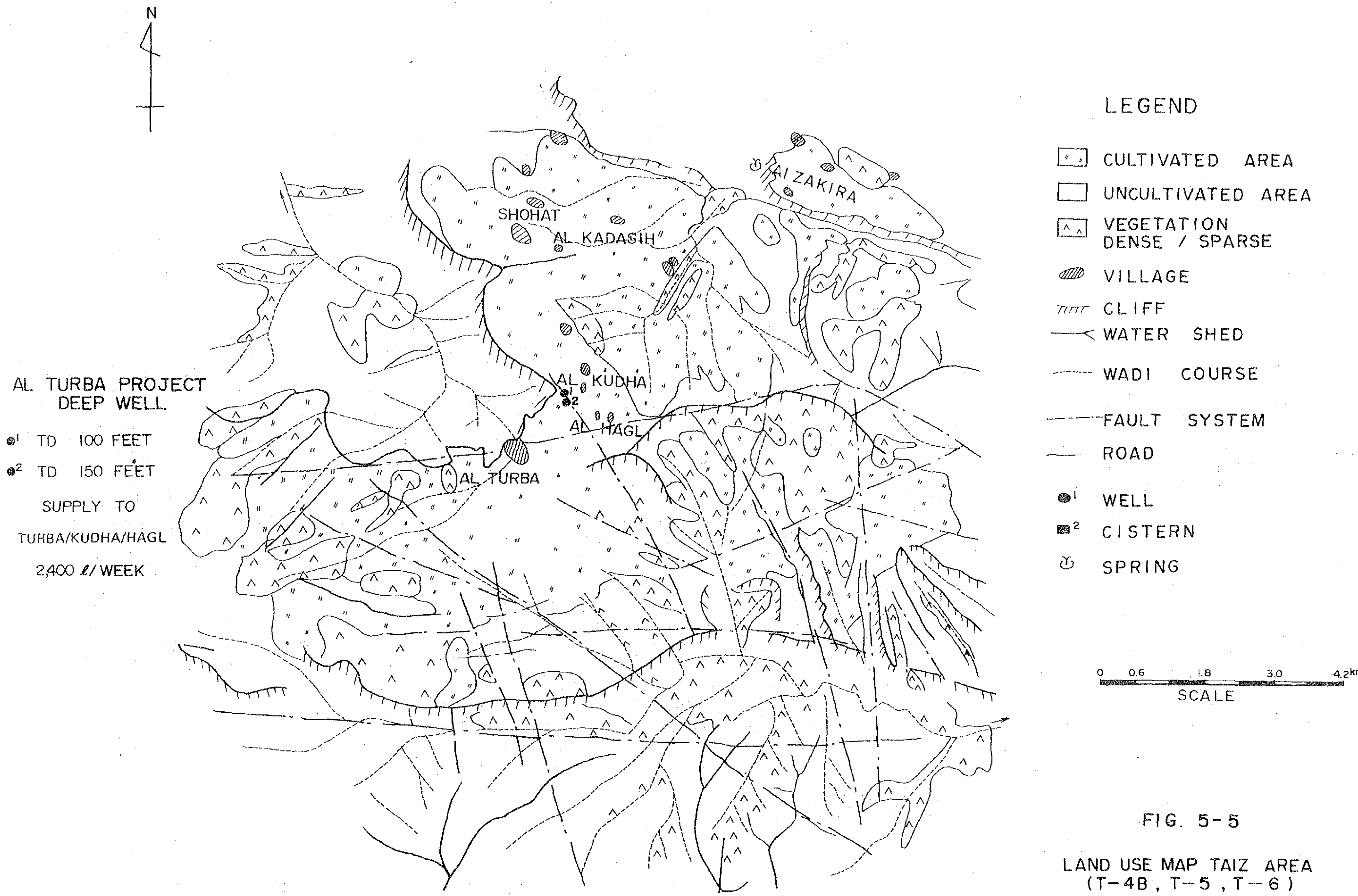


FIG. 5-5

LAND USE MAP TAIZ AREA
(T-4B, T-5, T-6)

EXISTING WATER SOURCE

GEOLOGY;

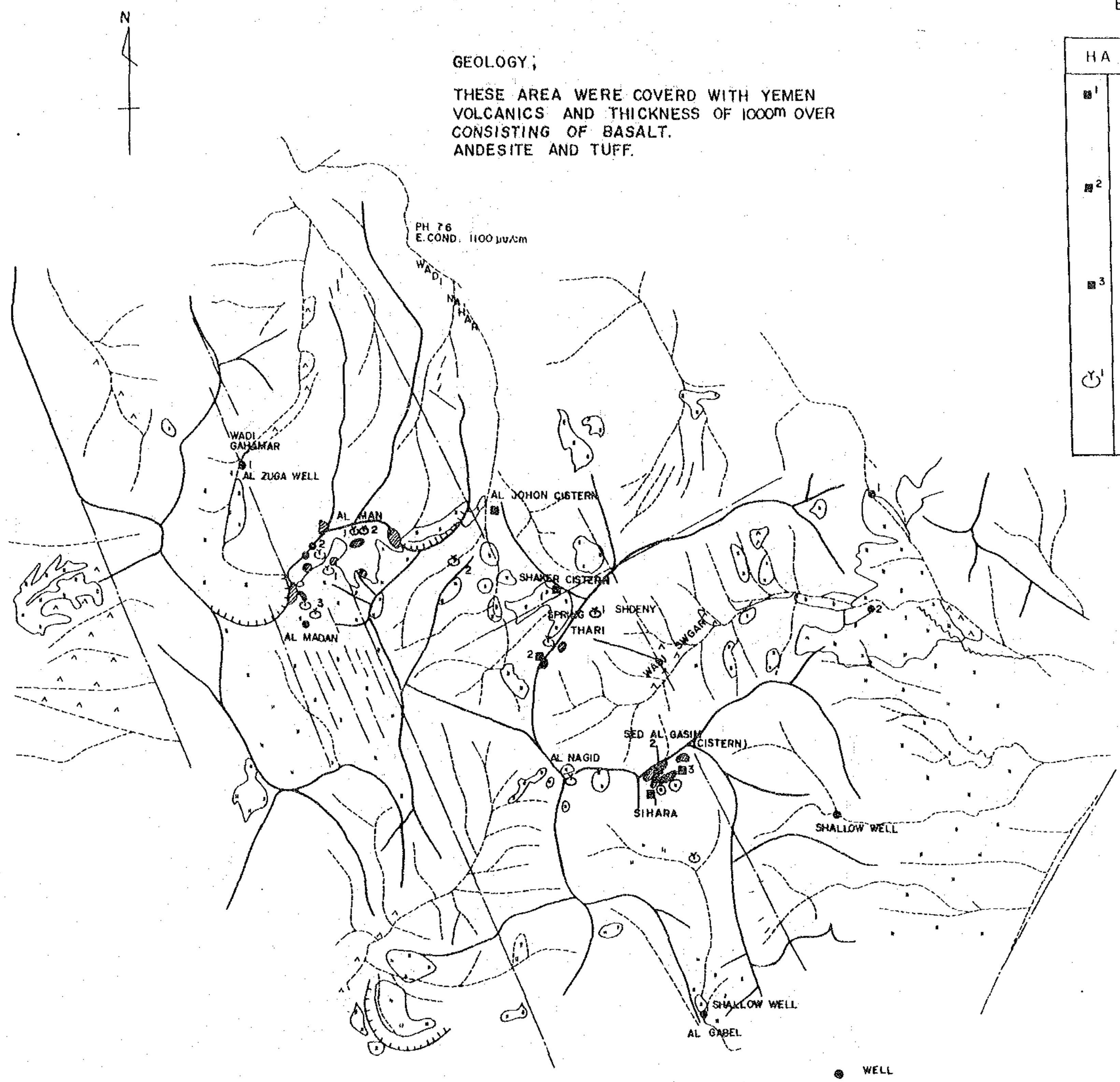
THESE AREA WERE COVERD WITH YEMEN VOLCANICS AND THICKNESS OF 1000m OVER CONSISTING OF BASALT. ANDESITE AND TUFF.

HA-1 AL MADAN	
⊙1	HAND DUG WELL ø 2.7m SWL 10.80m T.D. 12.20m PH 7.3 E.COND 970 μυ/cm
♉1	SPRING/WELL WITH PUMPING FACILITIES ø 2.0m S.W.L. 9.80m T.D. 10.10m PH 8.1 E.COND 590 μυ/cm
♉2	SPRING / WELL S.W.L. 10.0m T.D. 10.37m PH. 8.1 E.COND 645 μυ/cm 1 ~ 1.5 l/min
♉3	MANY SPRINGS PH 7.9 E.COND 700 μυ/cm

HA-2 AL MAN	
♉1	SPRING PH. 7.0 E.COND 735 μυ/cm
♉2	SPRING PH. 6.9 E.COND 760 μυ/cm

HA-3A SIHARA	
▣1	CISTERN PH 7.6 E.COND. 250 μυ/cm
▣2	CISTERN PH. 7.5 E.COND 505 μυ/cm
▣3	CISTERN PH. 7.1 E.COND. 400 μυ/cm
♉1	SPRING PH. 7.3 E.COND. 1230 μυ/cm

HA-3B THARI	
▣1	CISTERN PH 8.1 E.COND. 980 μυ/cm
▣2	CISTERN PH 8.9 E.COND. 1600 μυ/cm
♉1	SPRING PH. 8.1 E.COND 1000 μυ/cm
♉2	SPRING PH. 7.6 E.COND. 1107 μυ/cm
⊙1	HAND DUG WELL PH. 7.5 E.COND 1200 μυ/cm
⊙2	HAND DUG WELL ø 2.3m S.W.L. 19.80m T.D. 22.20m PH. 7.5 E.COND. 810 μυ/cm



LEGEND

- CULTIVATED AREA
- UNCULTIVATED AREA
- VEGETATION
- VILLAGE
- WELL
- SPRING
- CISTERN
- WATER SHED
- WADI COURSE
- FAULT SYSTEM

E.COND. = ELECTRIC CONDUCTIVITY

SCALE

0 0.6 1.2 1.8 2.4 3.0 4.2km

FIG. 5 - 6

HYDROGEOGRAHIC AND LAND USE MAP HAJJA AREA (HA-1, HA-2, HA-3A, HA-3B)

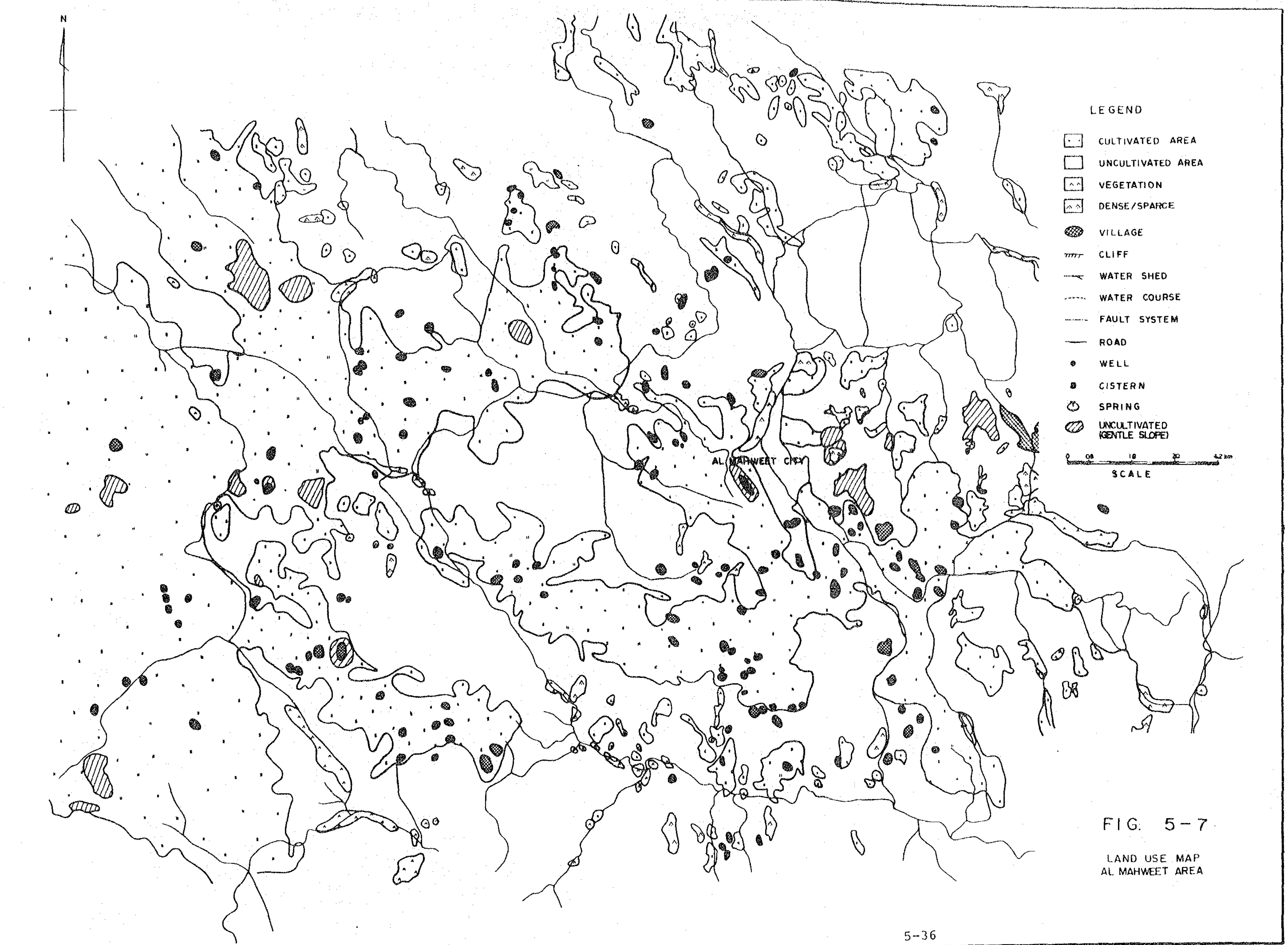


FIG. 5-7

LAND USE MAP
AL MAHWEET AREA

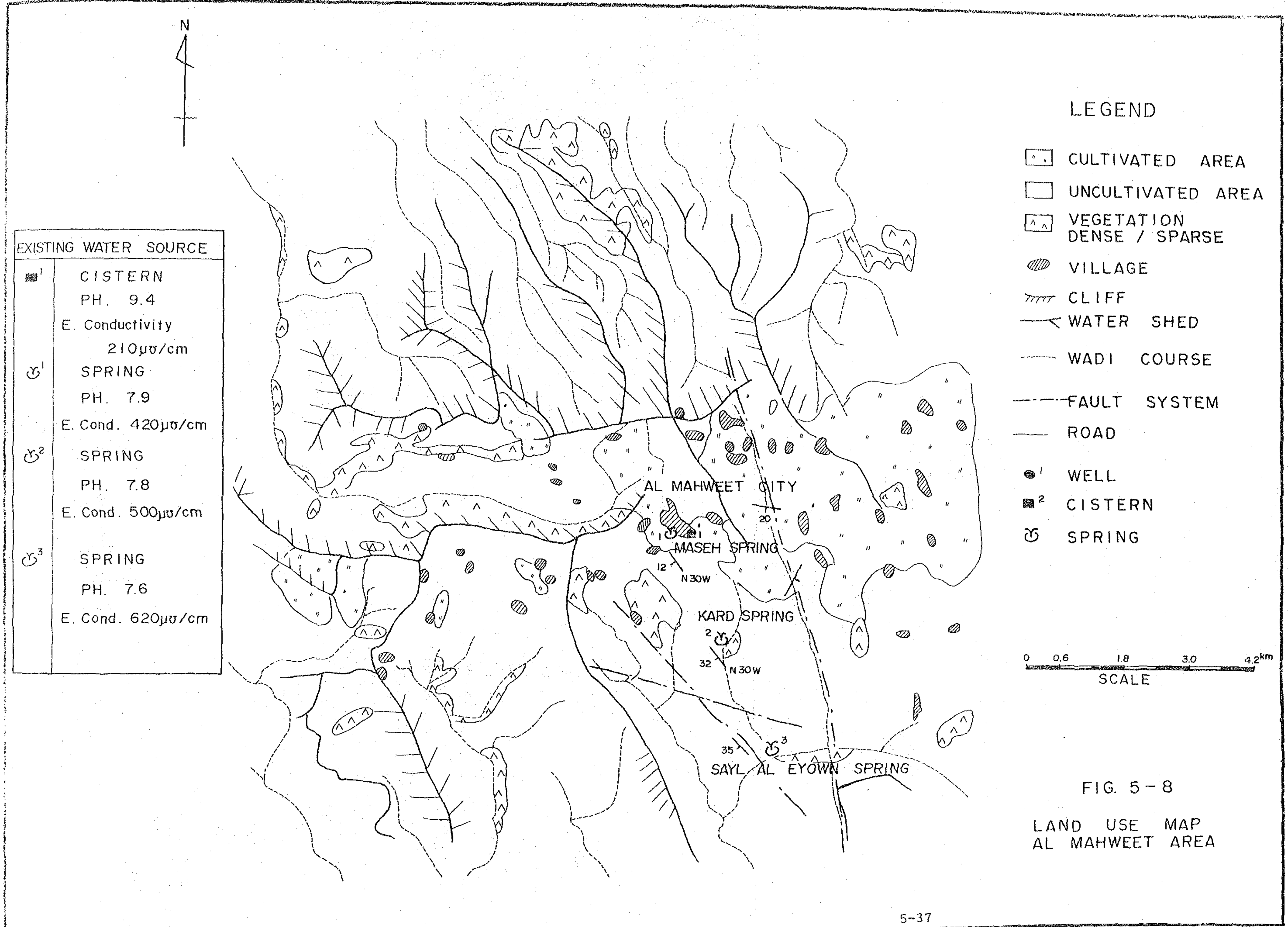


FIG. 5-8

LAND USE MAP
AL MAHWEET AREA

BAIT ABO HASHEM HAS NO WATER SOURCE IN THE VILLAGE.

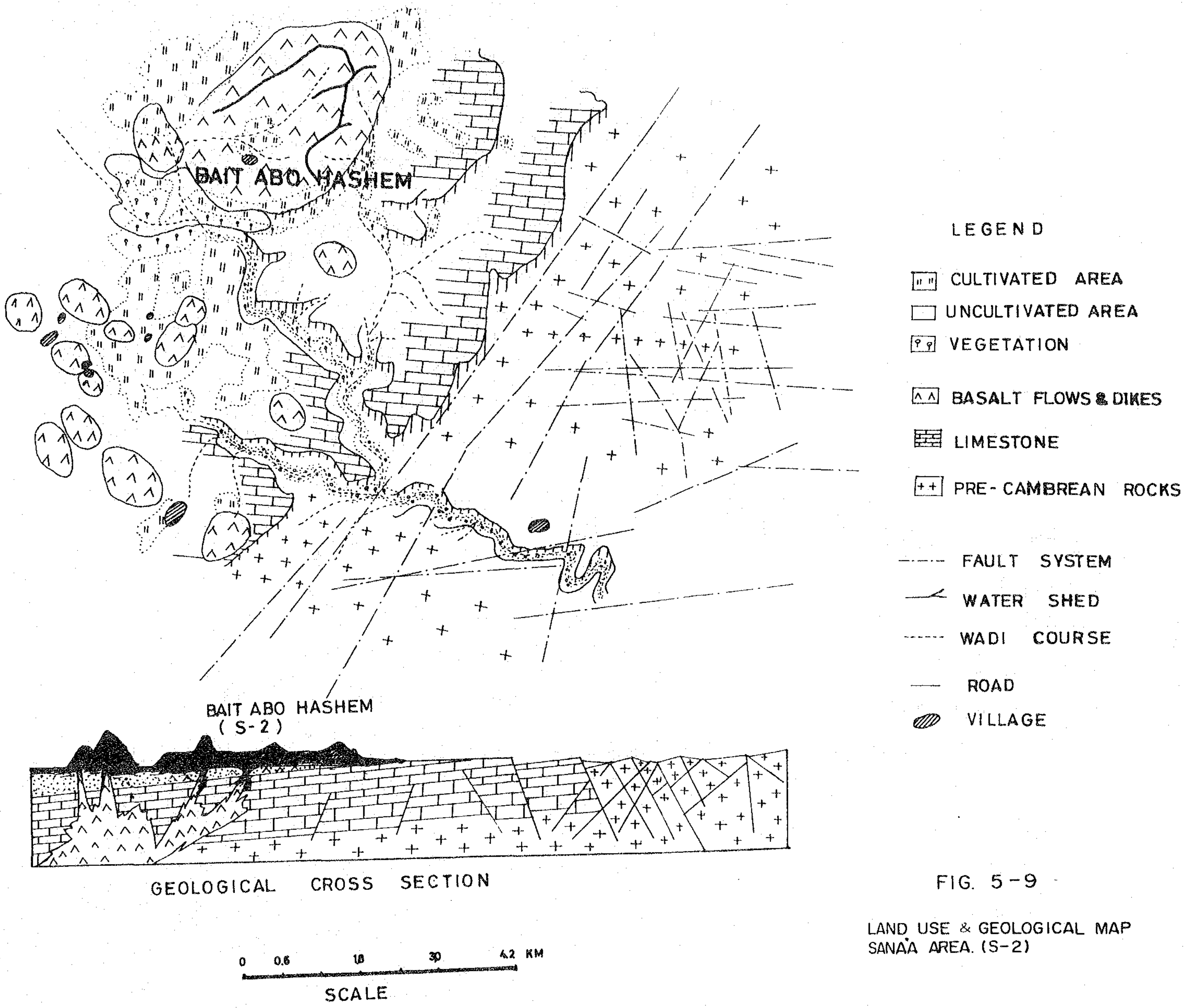
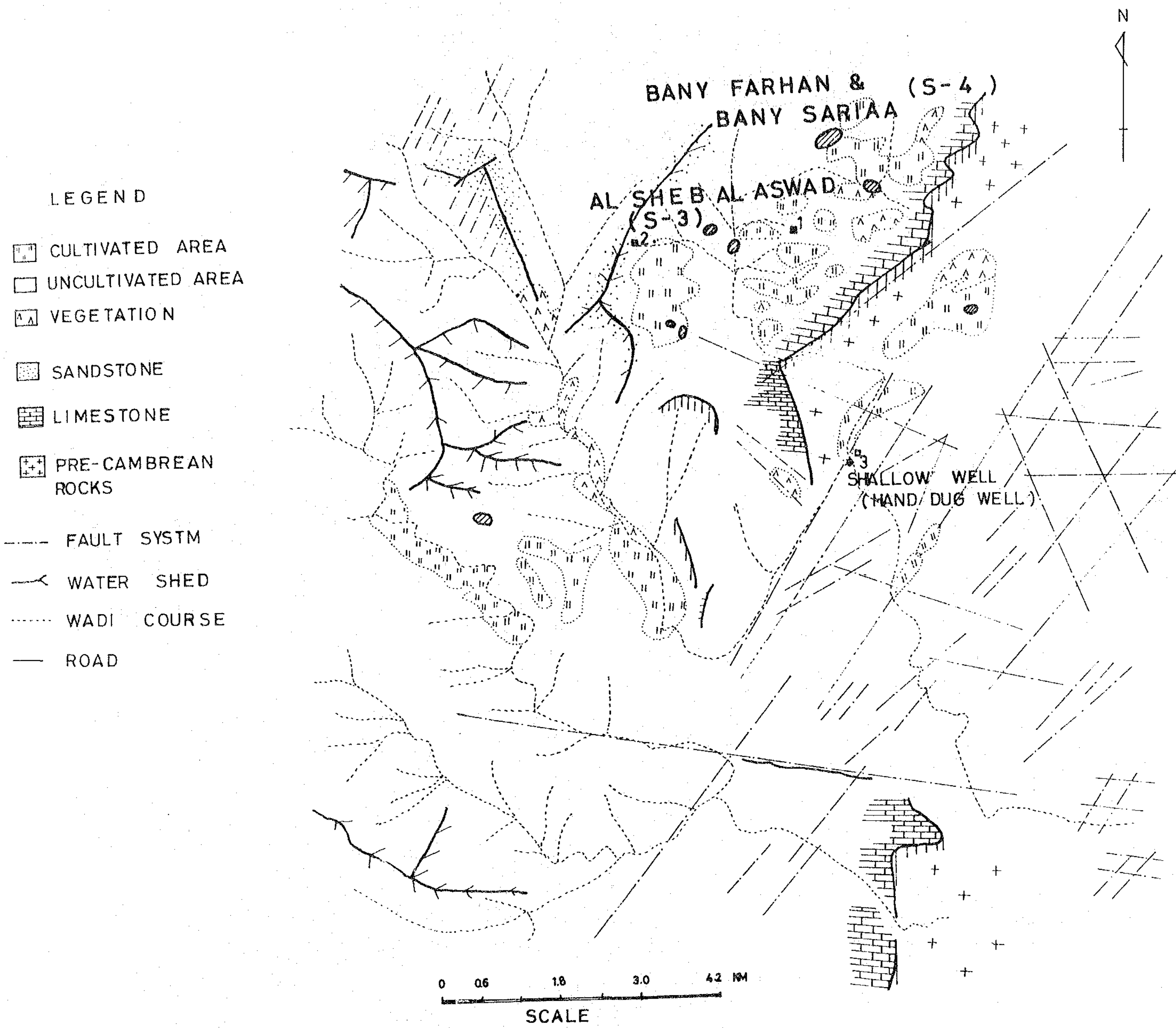


FIG. 5-9

LAND USE & GEOLOGICAL MAP
SANA'A AREA. (S-2)



EXISTING WATER SOURCE	
S-3	
1	CISTERN (DRY)
2	CISTERN PH 7.3 E. Cond. 155 μv/cm
3	WELL of OTHER VILLAGE (BUYING) PH 7.3 E. Cond. 734 μv/cm
S-4	
	NO WATER SOURCE IN THE VILLAGE
ዑ	SMALL SPRING

FIG. 5-10

LAND USE MAP SANA'A AREA (S-3, S-4)

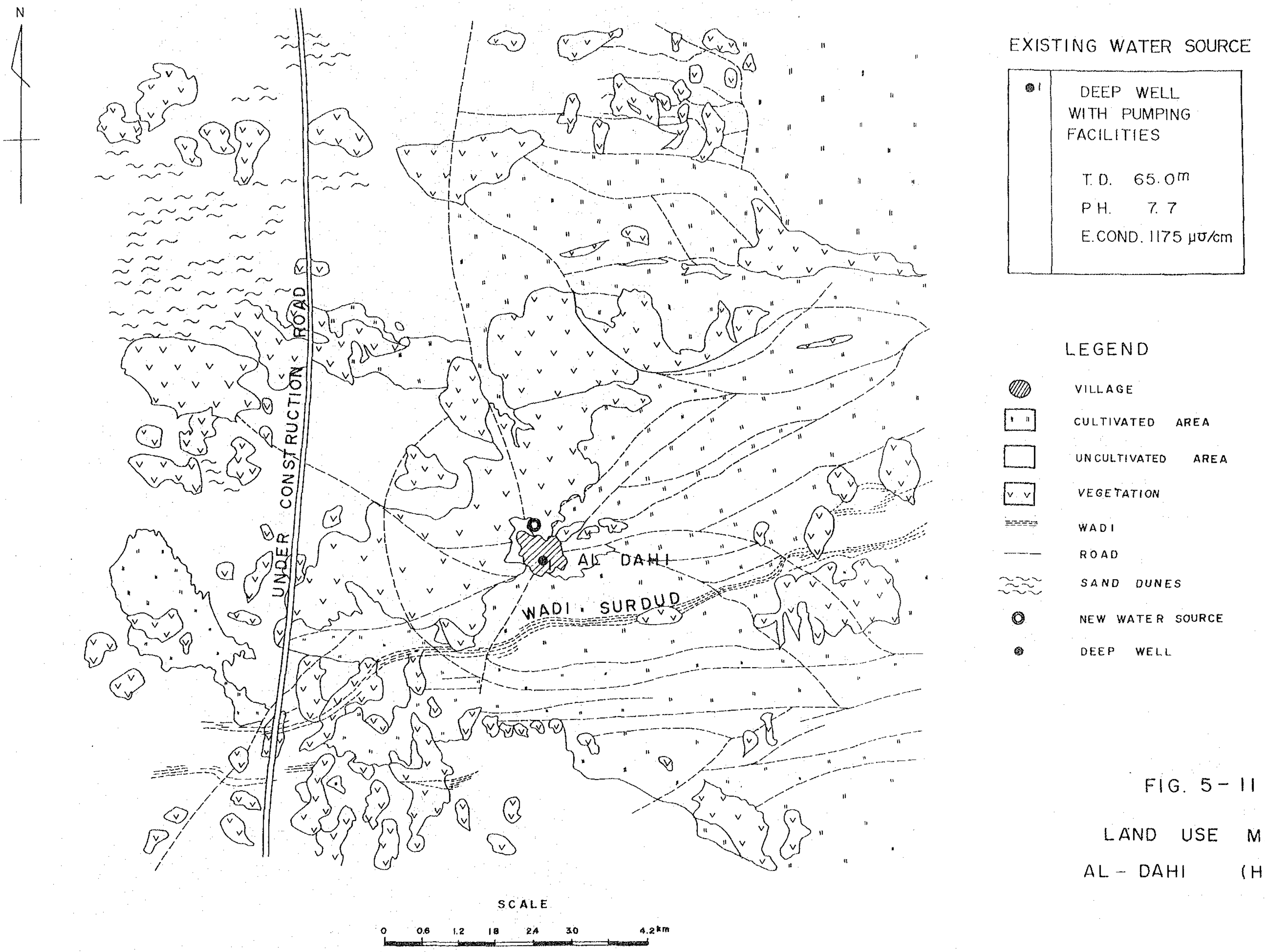


FIG. 5-11

LAND USE MAP

AL - DAHI (H-2)

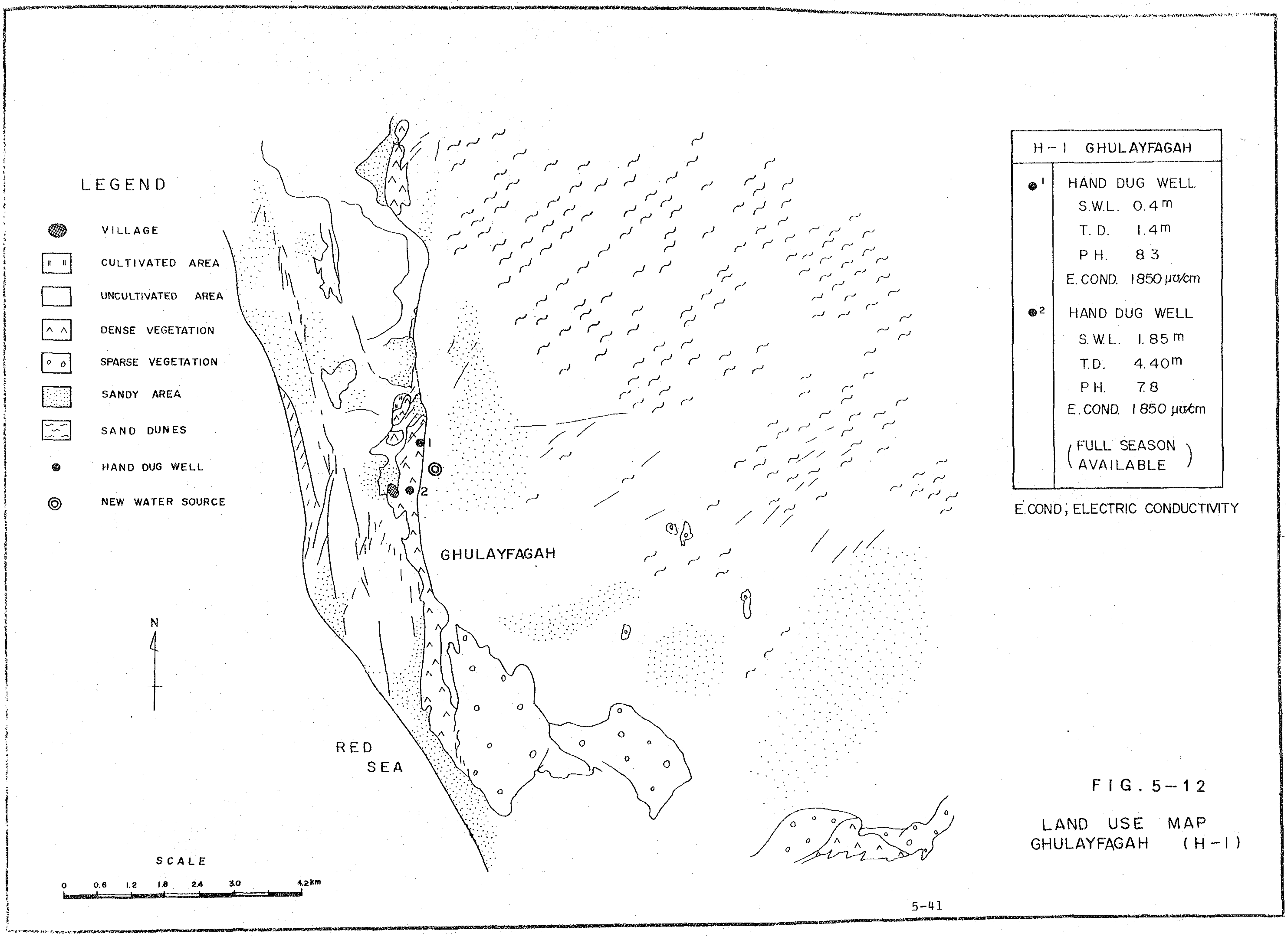


FIG. 5-12

LAND USE MAP
GHULAYFAGAH (H-1)

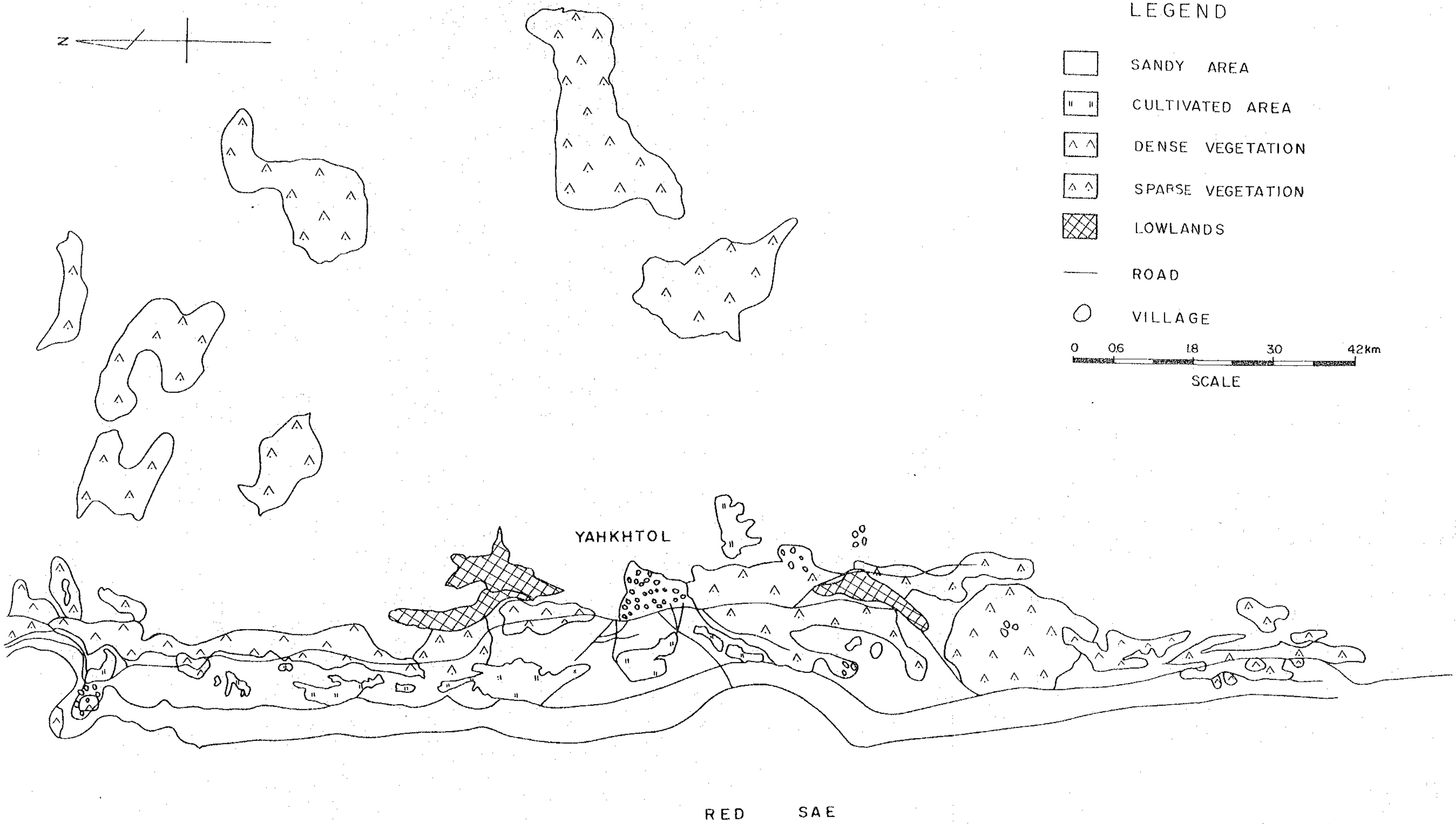


FIG. 5-13

LAND USE MAP TIHAMA PLAIN
YAHKHTOL (T-8)

CHAPTER VI
COST COMPONENTS OF RURAL WATER SUPPLY

CHAPTER VI

COST COMPONENTS OF RURAL WATER SUPPLY

6-1 Introduction

In order to determine the optimal system for the provision of equitable water supply to the various types of survey sites, unit cost analysis of investment cost and annual capital cost was made for the project.

This analysis also indicates the percentage of each unit cost of water supply system in the total cost. In addition, the price of water was compared for the survey sites on the basis of total annual cost including annual capital cost and operation maintenance cost. For this purpose, the cost of substantial items like material, labour and transportation were obtained, mainly from Unit Rates for Estimating The Cost of Projects and The Builders Price Book Volume 1 published by MPW; the cost for other necessary items was estimated.

6-2 Life of Machinery and Facilities

The useful life of machinery and facilities for water supply estimated as follows for this project.

LIFE OF MACHINERY & FACILITIES

Wells	10 years
Submercible Pumps	10 years
Pumps	10 years
Diesel Engines & Generators	10 years
Water Tanks	20 years
Pipes	20 years
Service Taps & Cattle Trough	20 years
Pump House and other permanent structures	20 years

6-3 Unit Cost of Rural Water Supply

6-3-1 Introduction

Water supply system is divided into several substantial units as shown below (See Chapter VIII): The cost of each unit is determined in the sections which follow.

- Water source including construction cost of pumps and engines
- Distribution Tank
- Main Pipeline
- Pumping Facility including booster pumps
- Service Tank and Public Taps including cattle troughs

6-3-2 Cost of Water Source

The major type of water source for the project is deep ground water. According to the result of hydro-geological analysis, the optimum depths of the borehole were classifed into three groups:

100 m deep or less
200 m deep
300 m deep.

The yield of each type depends on the nature of aquifer which varies from place to place ranging from a few hundred m^3/day to 1,000 m^3/day. (Technical Report: Hydrogeology Chapter V)

The average drilling cost is estimated as shown below:

Drilling Cost ø 10"	2,600 YR/m
Casing & Screen ø 8"	600 YR/m
Logging	6,700 YR/Borehole
Well Development & Pumping Test	43,800 YR/Borehole
Transportation, Mobilization & Demobilization	59,000 YR/site
Contingency	20% of Total Cost

The overall average drilling cost is estimated at 4,400 YR/m.

The cost of the pump and engine was determined by the total head required and the capacity of the determined pumping rate as follows:

$$1 \text{ HP} = 0.7461 \text{ KW - hr} = 273.89 \text{ m}^3\text{-m}$$

assuming 70% of pumping efficiency

$$1 \text{ HP} = 273.89 \times 0.7 = 191.723 \text{ m}^3\text{-m.}$$

Therefore required horsepower is determined by:

$$1 \text{ HP} = \frac{Q \times H}{191.72.}$$

Where Q is the capacity of pumping rate and H is the necessary total head. H and Q are determined by the hydro-geological conditions of the aquifer and the amount of water demand.

Thus the estimated necessary horsepower and capacity of water to be pumped determines the capacity of engine and pump; their cost is fixed in accordance with a performance-cost diagram.

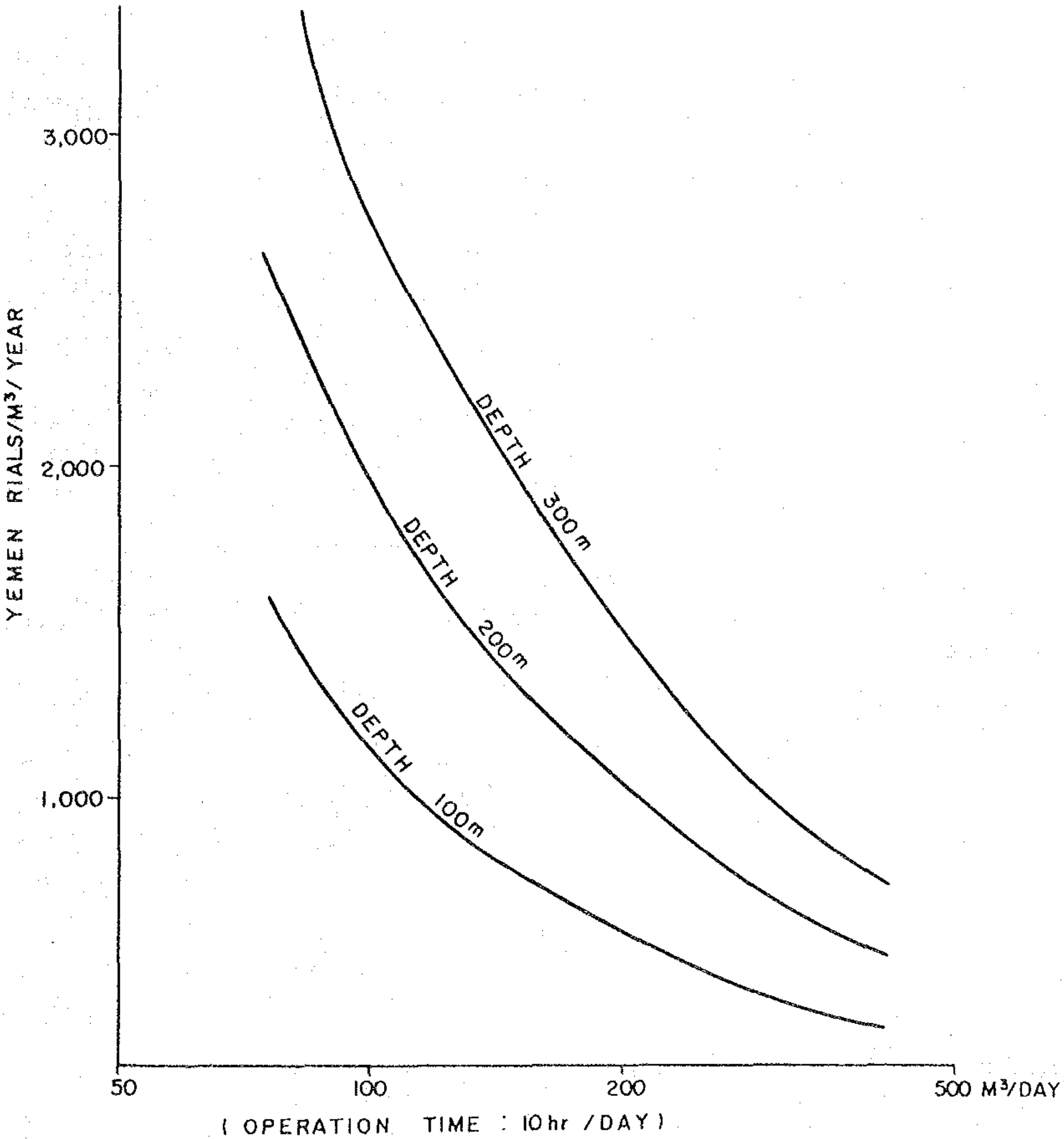
Investment cost of water source consists of drilling cost and machinery cost. The necessary unit investment cost (YR/m^3) was estimated for each group of aquifer (see Table 6.1.) and plotted against yield of borehole as shown in Fig. 6-1.

Table 6-1 Investment Cost and Total Annual Cost of Water Source

10 hr operation time
Yemen Rials

	m3/day	Drilling Cost	Machine with Pump House	Investment Cost	Investment Cost per m^3	Annual Capital Cost per m^3	Mainte-nance & Operation Cost per m^3	Total Annual Cost per m^3
Water Source Depth 100 m	80	440,000	178,000	618,000	7,726	1,152	386	1,538
	125	440,000	178,000	618,000	4,944	736	248	986
	170	440,000	178,000	618,000	3,636	542	182	724
	200	440,000	190,000	630,000	3,150	470	158	628
	250	440,000	190,000	630,000	2,520	376	126	502
	290	440,000	190,000	630,000	2,172	324	108	432
	330	440,000	202,000	642,000	1,946	290	98	388
	375	440,000	202,000	642,000	1,712	256	86	342
	415	440,000	202,000	642,000	1,546	230	78	308
Water Source Depth 200 m	80	880,000	199,500	1,079,500	13,493	2,010	674	2,684
	125	880,000	199,500	1,079,500	8,636	1,288	432	1,720
	170	880,000	199,500	1,079,500	6,350	946	318	1,264
	200	880,000	199,500	1,079,500	5,398	804	268	1,072
	250	880,000	199,500	1,079,500	4,318	644	216	860
	290	880,000	210,000	1,090,000	3,758	560	188	748
	330	880,000	210,000	1,090,000	3,304	492	166	658
	375	880,000	210,000	1,090,000	2,906	434	146	580
	415	880,000	210,000	1,090,000	2,626	392	132	524
Water Source Depth 300 m	80	1,320,000	210,000	1,530,000	19,126	2,850	956	3,806
	125	1,320,000	210,000	1,530,000	12,240	1,824	612	2,436
	170	1,320,000	210,000	1,530,000	9,000	1,340	450	1,790
	200	1,320,000	210,000	1,530,000	7,650	1,140	382	1,522
	250	1,320,000	210,000	1,530,000	6,120	912	306	1,218
	290	1,320,000	210,000	1,530,000	5,276	786	264	1,050
	300	1,320,000	210,000	1,530,000	4,636	690	232	922
	375	1,320,000	210,000	1,530,000	4,080	608	204	812
	415	1,320,000	210,000	1,530,000	3,686	550	184	734

Fig. 6-1 INVESTMENT COST OF WATER SOURCE



6-3-3 Cost of Storage Tank

Prefabricated tanks are recommended for the majority of project sites in the mountainous areas because of workability and transportation factors. For the sites on the coastal plain, concrete tanks are preferable. (See Section VIII-2.) There are 7 types of water tanks according to functions, but in this cost analysis only the main distribution tanks of prefabricated steel and concrete were included. Consideration for the other types of water tanks are included in each relevant facility. The necessary unit investment cost (YR/m^3) was estimated for various sizes of tanks (see Table 6-2 and Fig. 6-2).

Table 6-2-(1)

Investment Cost and Total Annual Cost of Main Tank

Prefabricated Steel Tank

Yemen Rials

Size (M^3)	Investment Cost	Investment Cost per M^3	Annual Capital Cost per M^3	Maintenance & Operation Cost per M^3	Total Annual Cost per M^3
5	35,400	5,080	517	2.6	519.6
10	36,000	3,600	367	1.8	368.8
50	120,800	2,416	246	1.2	247.2
100	200,400	2,004	204	1.0	205.0
200	347,200	1,736	177	0.9	177.9
300	433,000	1,444	147	0.7	147.7
400	565,000	1,412	144	0.7	144.7
500	689,200	1,378	140	0.7	140.7
1,000	1,266,840	1,266	129	0.6	129.6

Continued

Table 6-2-(2)

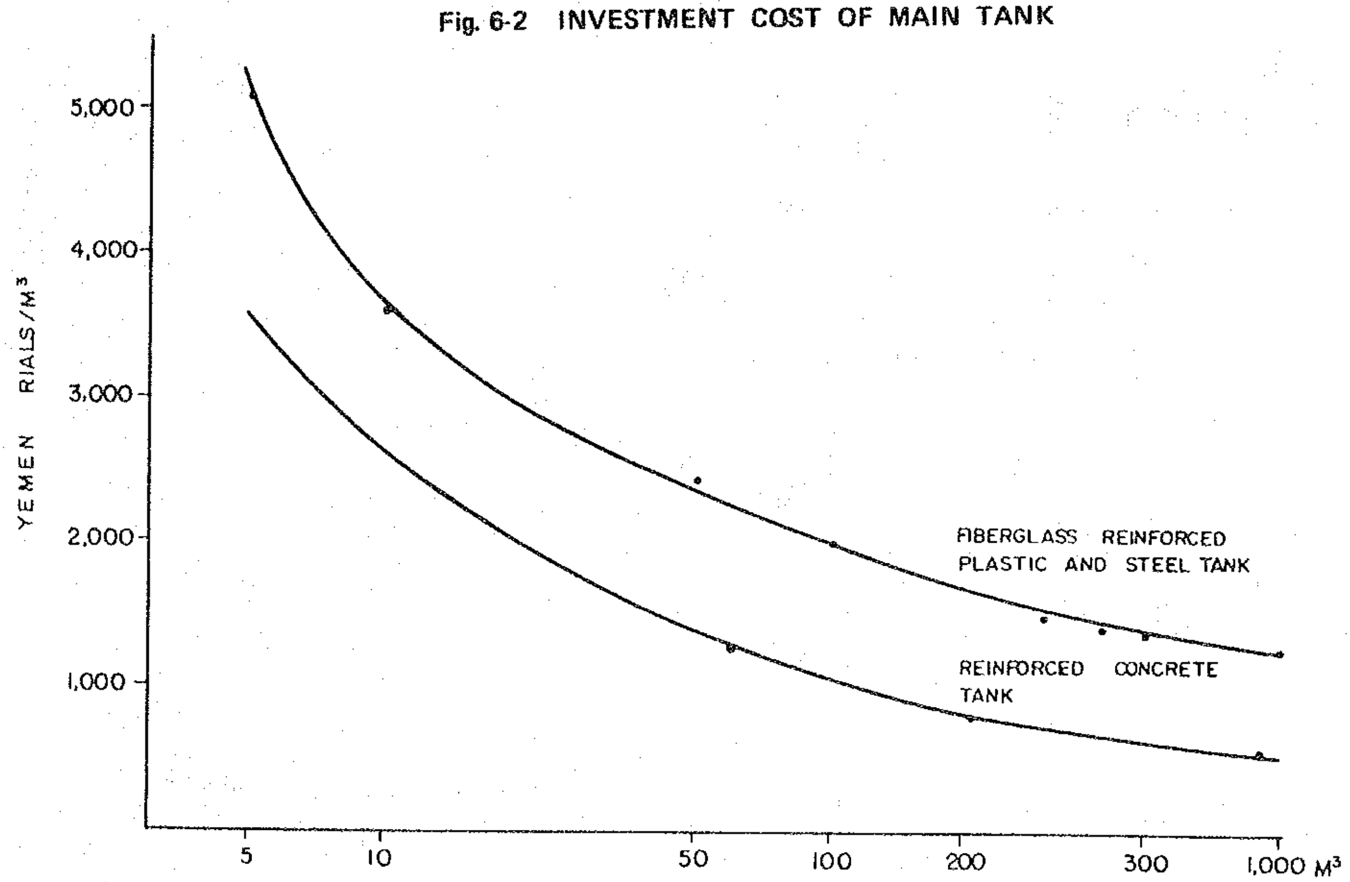
Investment Cost and Total Annual Cost of Main Tank

Reinforced Concrete Tank

Yemen Rials

Size (M^3)	Investment Cost	Investment Cost per M^3	Annual Capital Cost Per M^3	Maintenance & Operation Cost Per M^3	Total Annual Cost Per M^3
5	17,500	3,500	356	1.8	357.8
10	26,000	2,600	264	1.3	265.3
50	68,000	1,360	138	0.7	138.7
100	106,000	1,060	107	0.5	107.5
200	168,000	840	85	0.4	85.4
300	219,000	730	74	0.4	74.4
400	264,000	660	67	0.3	67.3
500	310,000	620	63	0.3	63.3
1,000	550,000	550	56	0.3	56.3

Fig. 6-2 INVESTMENT COST OF MAIN TANK



6-3-4 Cost of Main Pipeline

The cost of the main pipeline depends on the energy cost and the size and material of pipes. The size of pipe is determined by the required amount of water flow and necessary amount of hydraulic head.

The most economical way to deliver water through a pipeline is to rise the hydraulic head equivalent to the required friction loss of the pipe.

In order to determine the optimum size of pipe, friction loss and its energy cost were obtained for various volumes of water flow.

Fuel and engine oil consumption per horsepower in the Republic were estimated as shown below:

Diesel	0.1 L/HP/hr
Engine oil	0.01 L/HP/hr

where the unit price is:

Diesel	2.2 YR/L
Oil	5.2 YR/L.

Therefore, the energy cost is as follows:

Diesel	2.2 x 0.1 =	0.22 YR/HP/hr
Oil	5.2 x 0.01=	0.052 YR/HP/hr
Total cost		0.272 YR/HP/hr

1 British HP = 76.08 kg-m

1 HP-hr = 76.08 x 3,600 = 273.89 m^3-m.

Assuming 70% of pump efficiency, the energy cost is estimated as follows:

$$1 \text{ HP-hr} = 191.723 \text{ m}^3\text{-m}$$

$$\frac{0.273}{191.723} = 0.001434 \text{ YR/m}^3\text{-m.}$$

In Table 6-3, the friction loss and investment cost for various different size of pipes are shown.

Under the project, steel pipes are recommended for the pipelines in the mountainous areas and asbestos cement pipes in the coastal areas (see Section 8-4-4).

The annual cost of each size of pipe was estimated assuming 20 years life and 8% of annual interest rate. Thus adding the energy cost and capital cost, the total annual cost of pipe was obtained to determine the optimal size of pipe. (Fig. 6-3)

The relationship between investment cost (YR/m^3) and design capacity of pipe (m^3/day) is shown in Table 6-4 and plotted in Fig. 6-4.

Table 6-3 Cost Estimate of Steel Pipes

Yemen Rials

∅ (in)	Q (m^3/day)	Friction (L)	Total (m^3/year)	Energy x cost YR/year	Mainte-nance	Capital cost YR/year	Total
1" GSP-W	12	4.78	4,380	30.20	41.3	840	911.5
	24	17.3	8,760	218.2	"	"	1,099.5
	36	36.6	13,140	692.5	"	"	1,573.8
	48	68.2	17,520	1,720.7	"	"	2,602.0
	60	94.2	21,900	2,971.1	"	"	3,852.0
	84	176	30,660	7,770.4	"	"	8,651.7
	96	225	35,040	11,353.5	"	"	12,234.8
	120	340	43,800	21,444.48	"	"	22,325.8
2" GSP-W	12	0.164	4,380	1.03	100	2,032	2,134
	24	0.590	8,760	7.44	"	"	2,140.4
	36	1.25	13,140	23.7	"	"	2,156.7
	48	2.13	17,520	53.74	"	"	2,186.7
	60	3.22	21,900	101.6	"	"	2,234.6
	84	6.01	30,660	265.3	"	"	2,398.3
	96	7.69	35,040	388.0	"	"	2,520
	120	11.6	43,800	731.6	"	"	2,863.6
	144	16.3	52,560	1,233.8	"	"	3,365
	168	21.7	61,320	1,916.1	"	"	4,048
	360	88.9	131,400	16,751.0	"	"	18,632

Table 6-3-(3)

COST ESTIMATE OF STEEL PIPES (Cont'd)

o (in)	Q (m^3/day)	Friction (L)	Total (m^3/year)	Energy x cost YR/year	Mainte-nance	Capital cost YR/year	Total
3" GSP-W	48	0.296	17,520	7.47	138	2,810.5	2,956
	60	0.447	21,900	14.1	"	"	2,962.6
	84	0.837	30,660	36.95	"	"	2,985.5
	120	1.61	43,800	101.6	"	"	3,050.1
	144	2.26	52,500	171.1	"	"	3,119.6
	168	3.01	59,130	256.3	"	"	3,204.8
	192	3.85	70,080	388.5	"	"	3,337
	240	5.82	87,600	734.2	"	"	3,682.7
	360	12.3	131,400	2,327.4	"	"	5,275.9
	480	21.0	175,200	5,298.0	"	"	8,246.5
	960	75.9	345,600	37,772.7	"	"	40,721.2
4" GSP-W	60	0.110	21,900	3.54	207	4,215.7	4,426.2
	96	0.263	35,040	13.3	"	"	4,436
	120	0.397	43,800	25.0	"	"	4,447.7
	144	0.557	52,560	42.2	"	"	4,464.9
	168	0.741	59,130	63.1	"	"	4,485.8
	216	1.18	78,840	133.96	"	"	4,556.7
	240	1.43	87,600	180.4	"	"	4,603.1
	360	3.04	131,400	575.2	"	"	4,997.9
	480	3.18	175,200	802.3	"	"	5,225
	600	7.83	219,000	2,469.3	"	"	6,892
	840	14.6	206,600	6,446.0	"	"	10,868.7
6" GSP-W	120	0.0552	43,800	3.5	417	8,498	8,918.5
	168	0.1029	61,320	9.1	"	"	8,914.1
	216	0.164	78,840	18.2	"	"	8,933.2
	240	0.199	87,600	25.1	"	"	8,940.1
	480	0.719	175,200	181.4	"	"	9,096.4
	360	0.422	131,400	79.85	"	"	8,994.9
	600	1.09	219,000	343.7	"	"	9,258.7
	720	1.52	262,800	575.2	"	"	9,490.2
	840	2.03	300,600	896.3	"	"	9,811.3
	1,200	3.92	438,000	2,472.4	"	"	11,387.2
	1,680	7.31	613,200	6,454.8	"	"	15,369.8
	1,920	11.7	700,800	11,807.1	"	"	20,722.1
	2,400	14.2	897,900	18,807.1	"	"	27,275
8" GSP-W	480	0.177	175,200	44.7	693.2	14,119.3	14,857.2
	600	0.268	219,000	84.5	"	"	14,897
	720	0.375	262,800	141.1	"	"	14,954.4
	840	0.499	306,600	220.3	"	"	15,032.8
	960	0.639	350,400	322.4	"	"	15,134.9
	1,200	0.966	438,000	609.3	"	"	15,421.8
	1,680	1.80	613,200	1,589.4	"	"	16,401.9
	1,920	2.87	700,800	2,896.3	"	"	17,708.9
	2,400	3.49	897,900	4,512.5	"	"	19,325.0
	3,120	5.67	1,138,800	9,298.1	"	"	24,110.6

Fig. 6-3 ANNUAL CAPITAL COST OF PIPELINES

Life Time: 20 years. Interest Rate 8/"year

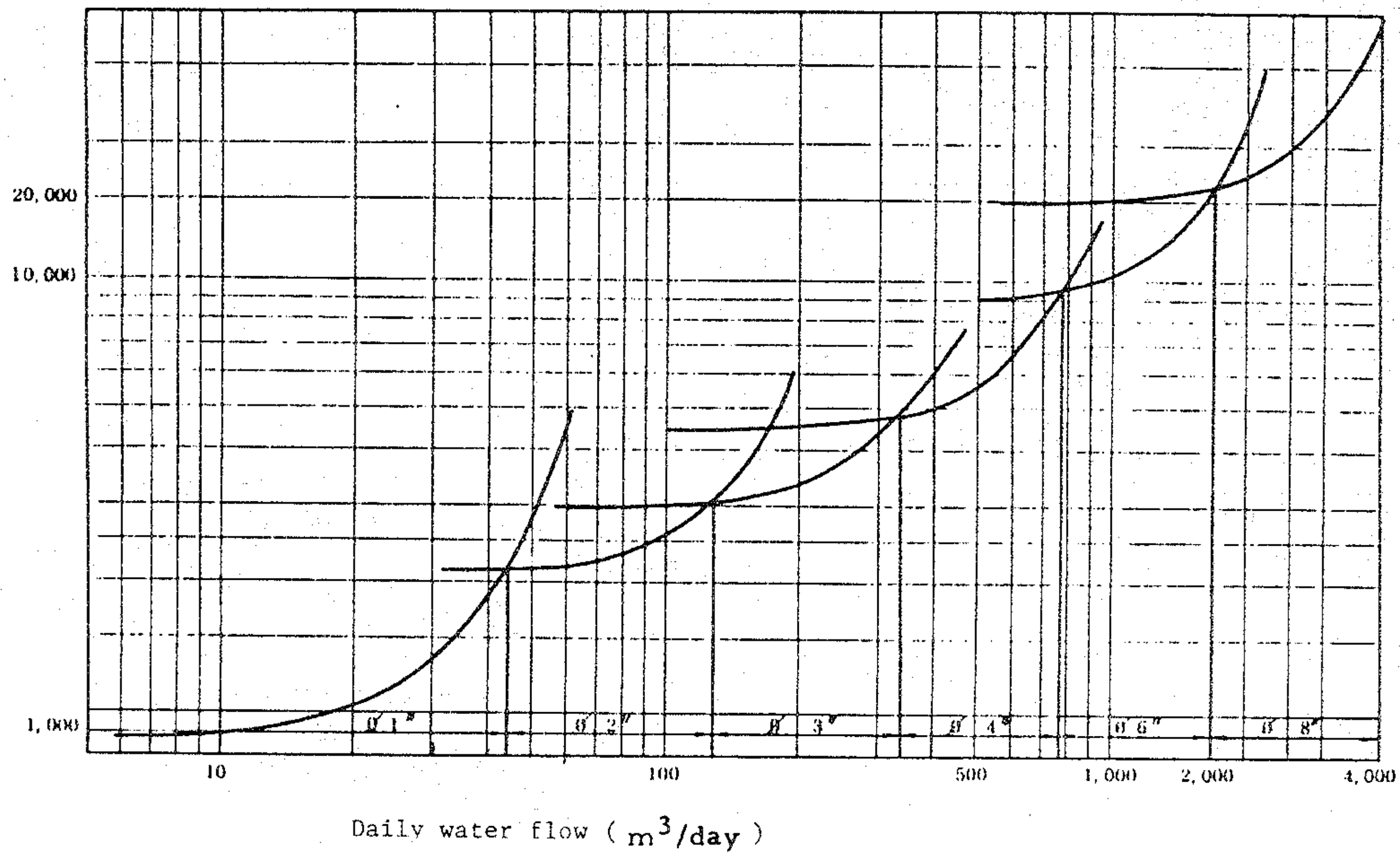


Table 6-4

Annual Cost of Pipelines

Type	∅ (M3/day)	(M)	Invest-ment Cost (Y.R.)	Annual Capital Cost (Y.R.)	Mainte-nance & Operation Cost (Y.R.)	Total Annual Cost (Y.R.)
Galvanized Steel Pipe	2" GSP (45-120)	100	4,200	428	21	449
		1,000	42,000	4,278	210	4,488
		5,000	210,000	21,388	1,050	22,438
		10,000	420,000	42,778	2,100	44,878
	3" GSP (120-340)	100	10,000	1,018	50	1,068
		1,000	100,000	10,186	500	10,686
		5,000	500,000	50,926	2,500	53,426
		10,000	1,000,000	101,850	5,000	106,850
	4" GSP (340-780)	100	13,200	1,344	66	1,410
		1,000	132,000	13,444	660	14,104
		5,000	660,000	67,222	3,300	70,522
		10,000	1,320,000	134,442	6,600	141,042
Asbestos Cement Pipe	3" ACP (120-340)	100	6,000	610	30	640
		1,000	60,000	6,110	300	6,410
		5,000	300,000	30,550	1,500	32,050
		10,000	600,000	61,110	3,000	64,110
	4" ACP (340-780)	100	9,000	920	40	960
		1,000	90,000	9,170	450	9,620
		5,000	450,000	45,830	2,250	48,080
		10,000	900,000	91,660	4,500	96,160
	5" ACP (780-1620)	100	12,000	1,220	60	1,280
		1,000	120,000	12,220	600	12,820
		5,000	600,000	61,110	3,000	64,110
		10,000	1,200,000	122,220	6,000	128,220

Fig. 6-4-(1) INVESTMENT COST OF PIPELINE (Steel Pipe)

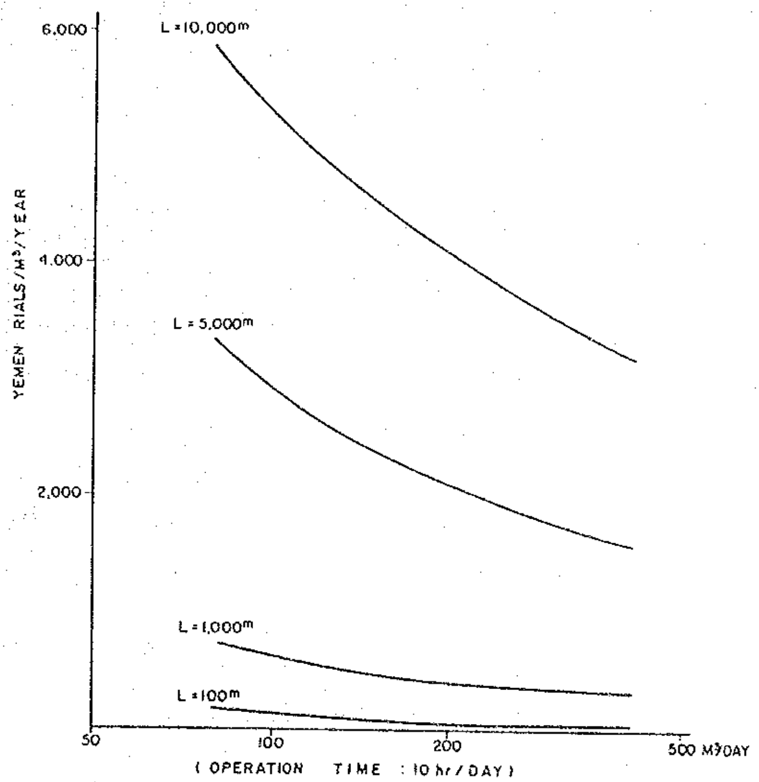
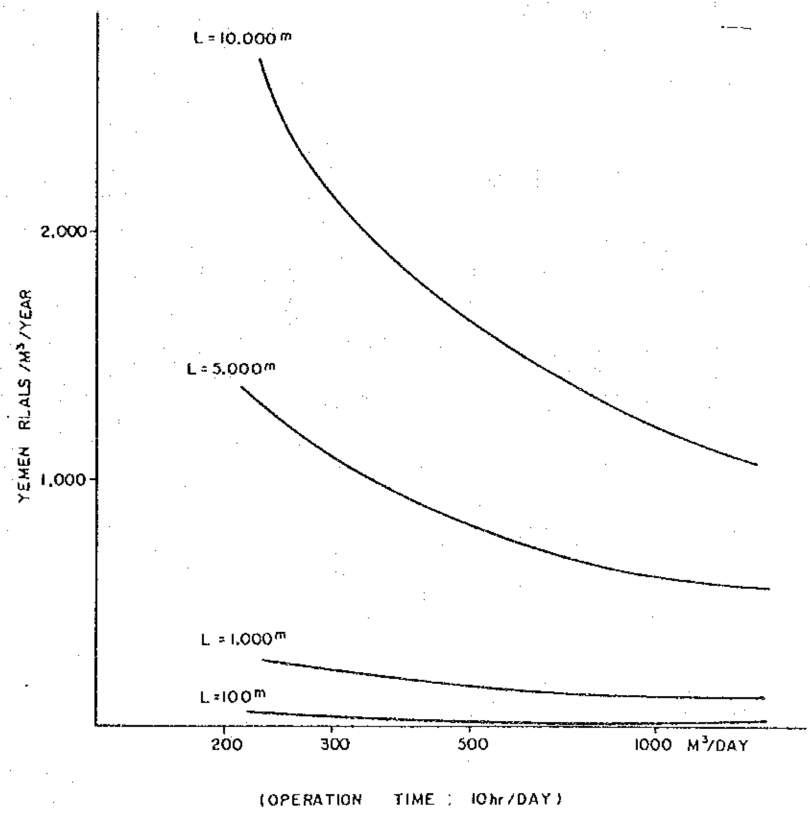


Fig. 6-4-(2) INVESTMENT COST OF PIPELINE (Asbestos Cement Pipe)



6-3-5 Cost of Pumping Facility

According to the design criteria proposed by the MPW, the service taps should be located less than 250m from the beneficiaries houses. In this project, many survey sites are located on the top of mountains.

In such cases, the relative height between water source and the service-area well exceeds 1,000m. Although the determination to which extent booster pumps are installed is subject to policy decision, booster pumping stations are substantial elements of the rural water supply in the project. Consideration was given to locate the public taps within 500 m to 1,000 m access from each house in this analysis.

Since the range of the required head of the booster pumps falls between 50m and 1,200m, the cost estimate was made based on the price of necessary machinery and facilities for 50m, 100m and 250m head. Although booster pumps are available which can lift water even upto 3,000m by a single unit, this is not applicable for the rural water supply because of its maintenance costs and cost of pipes and joints. (See Section 8-4-5.)

Therefore, for the sites which require a pumping head of more than 250m, multiple pumping systems of 50m, 100m and 250m head are proposed.

In Table 6-5 and Fig. 6-5, the investment cost of booster pumping facilities (YR/m^3) for various pumping heads and design capacities, including pumping house and tank with capacity for 30 minutes of daily design capacity, are shown.

Table 6-5-(1)

Cost of Booster Pump Station

10 hrs. Operation time
Yemen Rials

Total Head	M^3/day	Investment Cost per M^3	Annual Capital Cost per M^3	Maintenace & Operation Cost per M^3	Total Annual Cost per M^3
50M	80	1,958	292	98	390
	125	1,252	186	62	248
	170	922	138	46	184
	200	844	126	42	168
	250	676	100	34	134
	290	582	86	30	116
	330	522	78	26	104
	375	460	68	22	90
	415	416	62	20	82
100M	80	2,178	324	108	434
	125	1,394	208	70	278
	170	1,024	152	52	204
	200	906	134	46	180
	250	724	108	36	144
	290	624	94	32	126
	330	610	92	30	122
	375	538	80	26	106
	415	486	72	24	96
250M	80	3,050	454	152	606
	125	1,952	290	98	388
	170	1,436	214	72	286
	200	1,422	212	70	282
	250	1,138	170	56	236
	290	980	146	50	196
	330	1,116	166	56	222
	375	982	146	50	196
	415	888	132	44	176

-Continued-

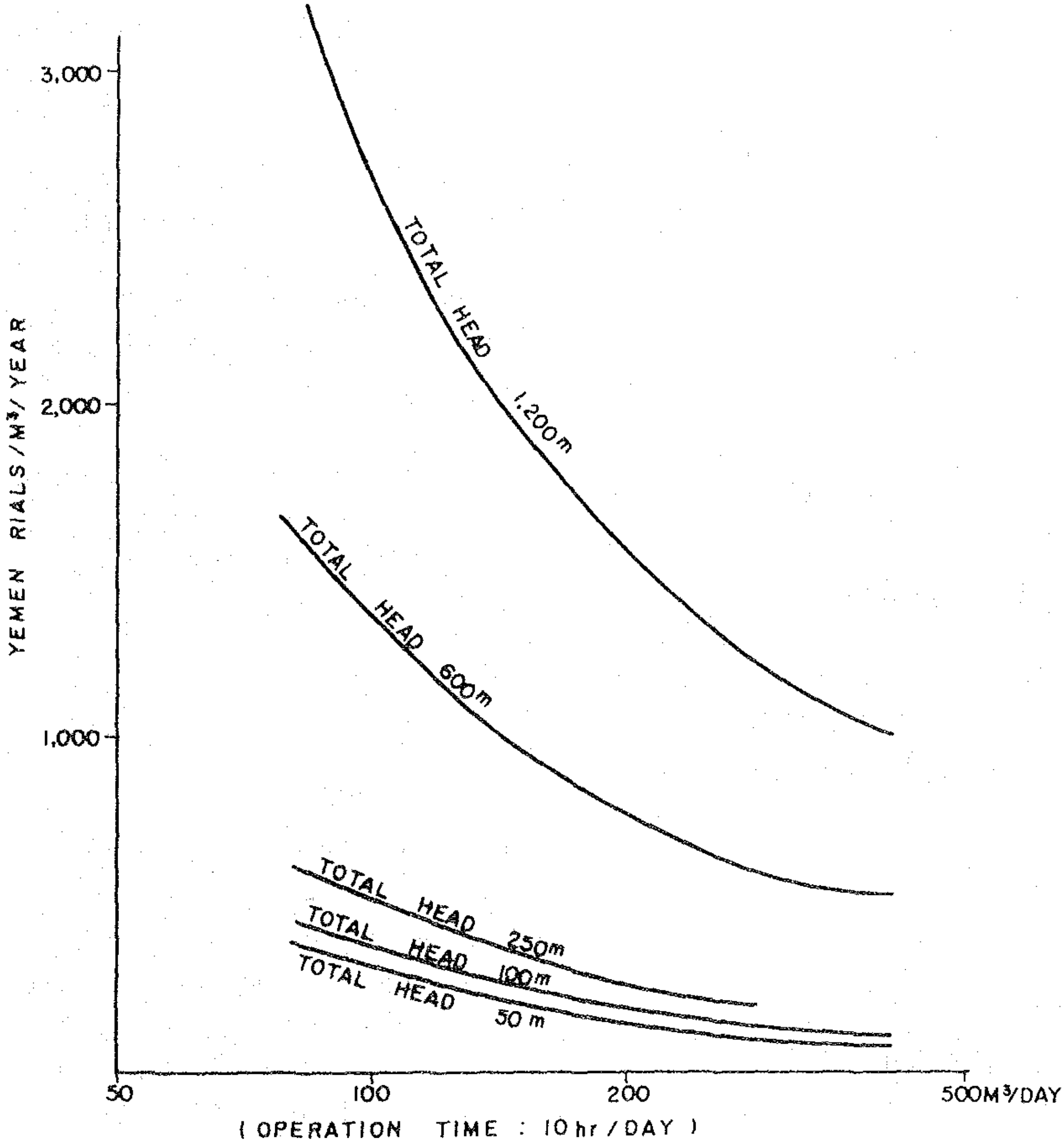
Table 6-5-(2)

Cost of Booster Pump Station

10 hrs. Operation time
Yemen Rials

Total Head	M^3/day	Investment Cost per M^3	Annual Capital Cost per M^3	Maintenance & Operation Cost per M^3	Total Annual Cost per M^3
600M	80	9,150	1,364	458	1,822
	125	5,856	872	292	1,164
	170	4,306	642	216	858
	200	4,266	636	214	854
	250	3,412	508	170	678
	290	2,942	438	148	586
	330	3,350	500	168	668
	375	2,948	440	148	588
	415	2,664	398	134	532
1200M	80	18,300	2,728	912	3,640
	125	11,712	1,746	586	2,332
	170	8,612	1,234	430	1,714
	200	8,532	1,272	426	1,698
	250	6,826	1,018	342	1,342
	290	5,884	876	294	1,170
	330	6,702	998	336	1,334
	375	5,898	878	294	1,172
	415	5,330	794	266	1,060

Fig. 6-5 INVESTMENT COST OF BOOSTER PUMP STATION



6-3-6 Cost of Service Taps and Cattle Troughs

Since the design capacity and the size and number of taps are determined by the capacity of the service tank, the cost of service taps and cattle troughs was estimated at 30 % of the construction cost of the service tank.

6-4 Investment Cost of Rural Water Supply

The investment cost of the rural water supply was analysed based on the unit cost for several different design conditions in each unit of the water supply system. The investment cost for tanks is relatively small compared with the other units. The unit cost of water source varies from 150 to 6,400 YR/m^3 according to the design capacity ranging from 400 to 100 m^3/day.
In many cases where the rural water supply system is composed of varying design elements, the cost of the water source occupies almost half of the total investment cost of the water supply system.

In addition, the investment cost of pipelines is considerable where the total extension of the pipeline required is more than 10 km.

Another cost impact on the total water supply system appears to be introduced by the cost of the booster pump stations. The investment cost of the booster pump station easily exceeds the cost of water source when a design head is required for more than 1,000 m. An equitable allocation of the cost among the units of water supply system is necessary to provide the maximum effect for the rural water supply investment.

6-5 Annual Cost

In order to estimate annual cost of water, annual capital cost of each water supply unit is calculated based on the estimated investment cost in the previous section.

For this purpose assumption is made:

Life Time

machineries & boreholes	10 years
pipes & tanks	20 years

Discount rates for 8% of interest rate

0.14903	10 years
0.11683	15 years
0.10185	20 years.

Annual cost of each unit of rural water supply system is shown in Figs. 6-6 to 6-9 including the maintenance and operation cost.

Operation and maintenance cost is estimated as below:

Machinery	5% of investment cost
Pipe and tanks	0.5% of investment cost
Other structures	0.5% of investment cost.

The annual cost of rural water supply consists of the total of annual capital cost of each unit of system plus operation and maintenance cost as shown in Figs. 6-10 to 6-12.

Fig. 6-6 ANNUAL COST OF WATER SOURCE

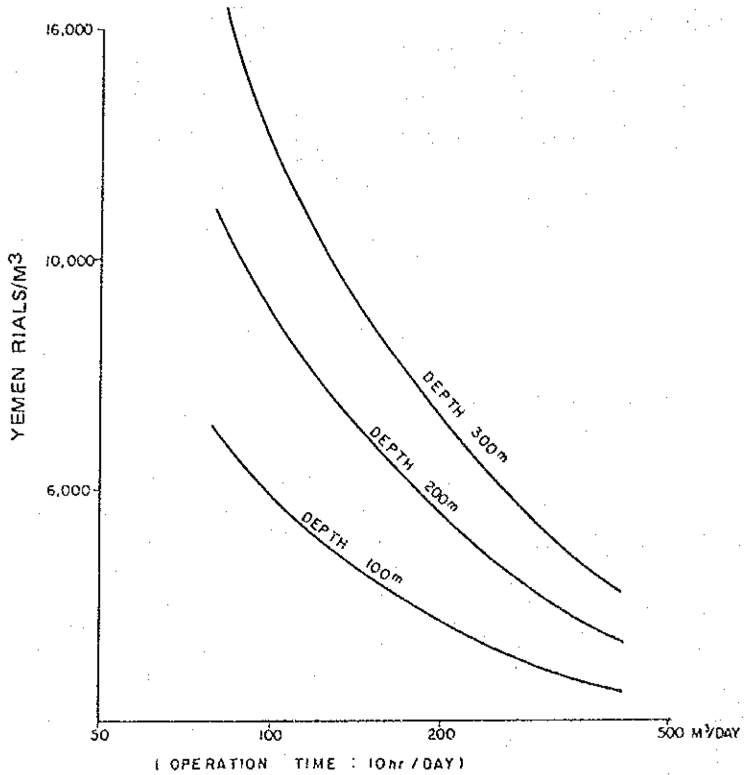


Fig. 6-7 ANNUAL COST OF MAIN TANK

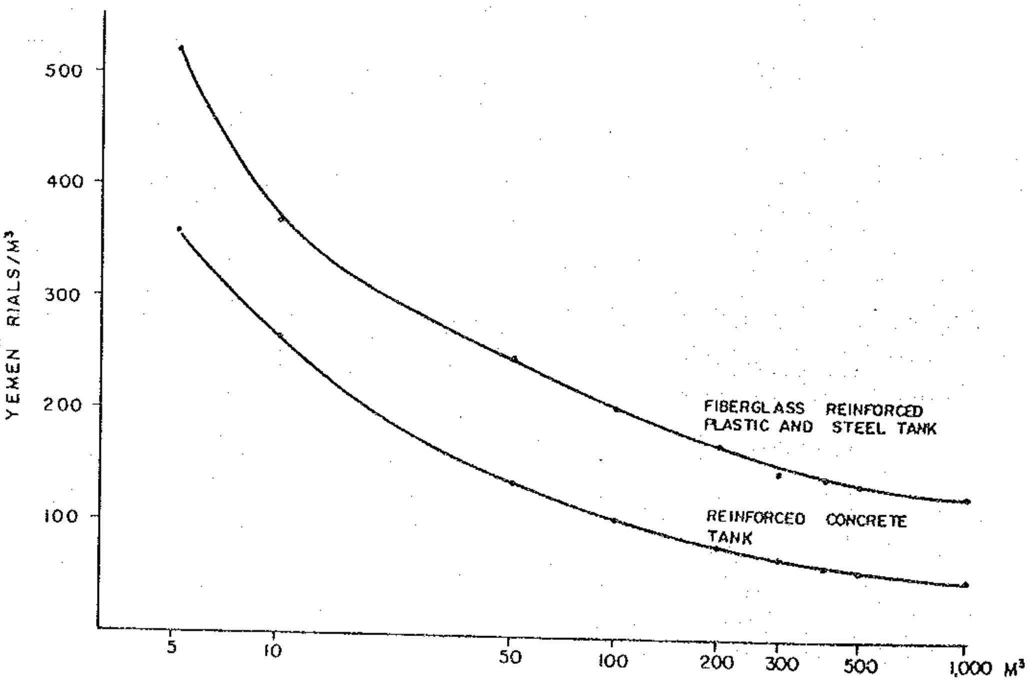


Fig. 6-8-(1) ANNUAL COST OF PIPELINE (Steel Pipe)

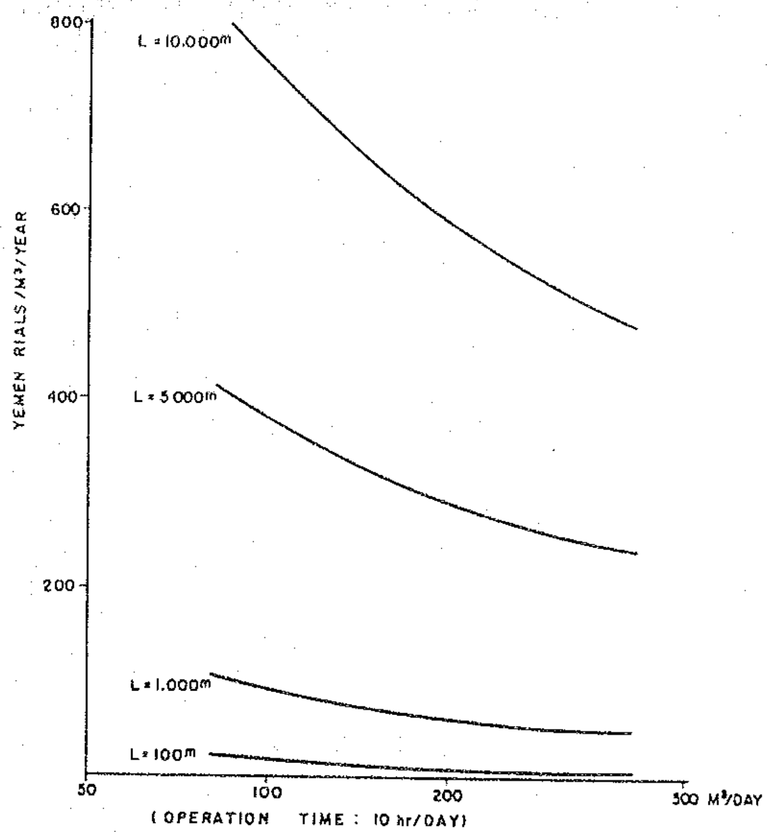


Fig. 6-8-(2) ANNUAL COST OF PIPELINE (Asbestos Cement Pipe)

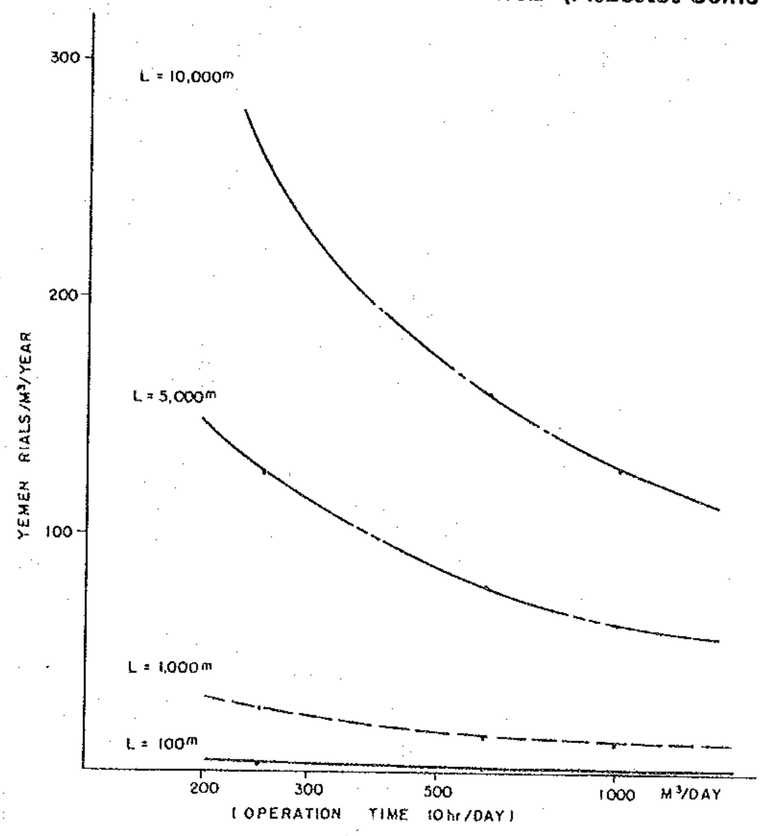


Fig. 6-9 ANNUAL COST OF BOOSTER PUMP STATION

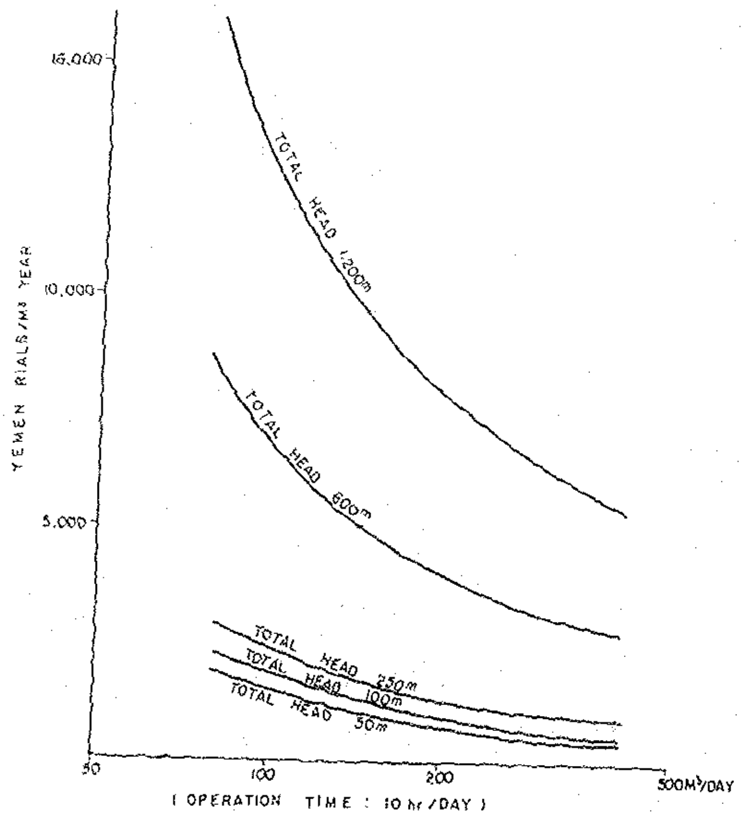


Fig. 6-10 TOTAL ANNUAL COST, WATER SOURCE BOREHOLE 100M DEEP

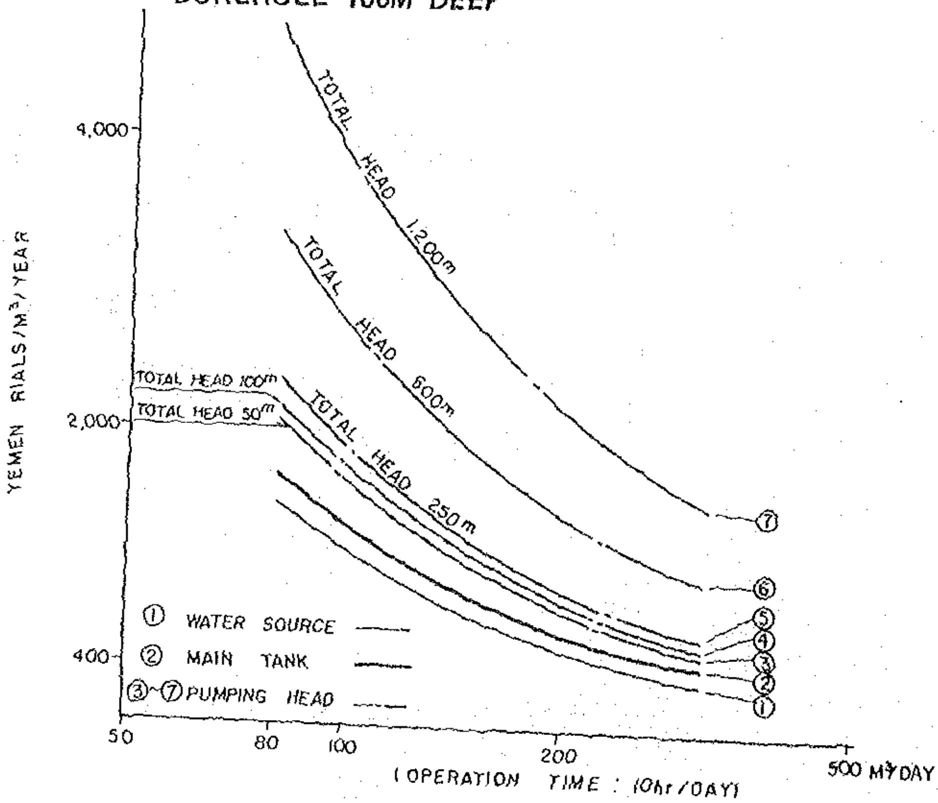


Fig. 6-11 TOTAL ANNUAL COST, WATER SOURCE BOREHOLE 200M DEEP

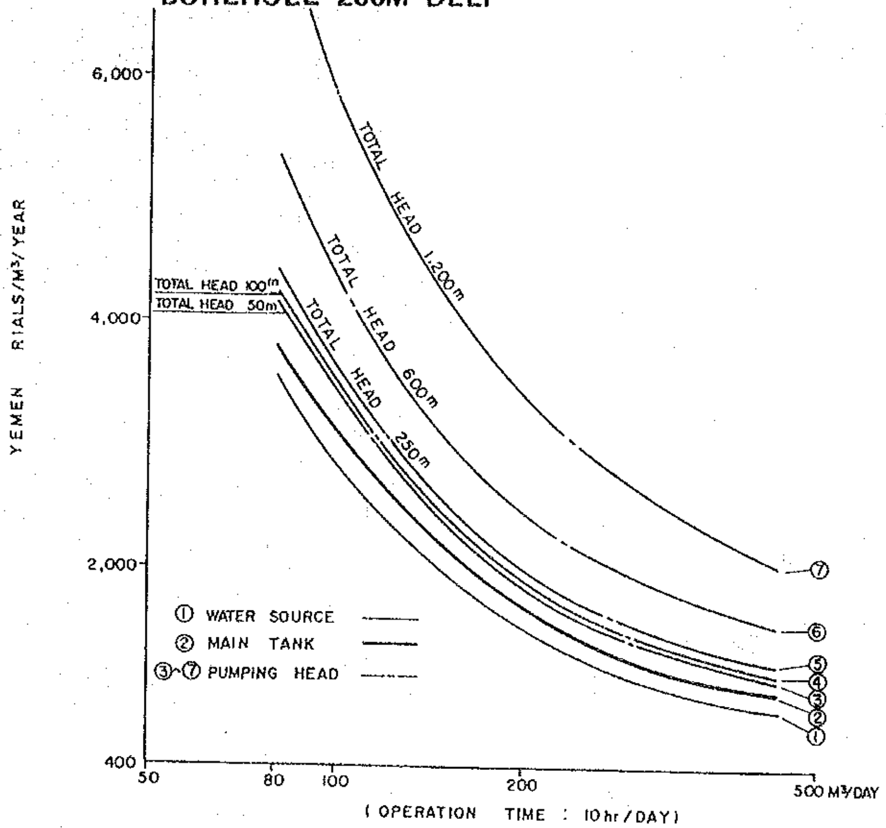
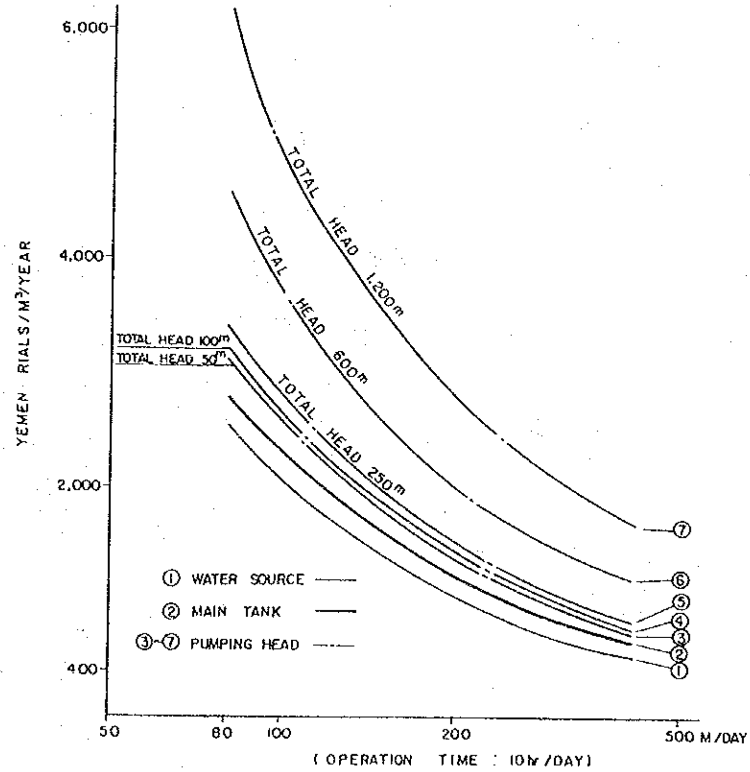


Fig. 6-12 ANNUAL TOTAL COST, WATER SOURCE BOREHOLE 300M DEEP



CHAPTER VII
PLANNING OF RURAL WATER SUPPLY

CHAPTER VII

PLANNING OF RURAL WATER SUPPLY

7-1 Introduction

As shown in Chapter V, all of the survey sites under the project have problem areas for the rural water supply schemes. In addition, the conditions of these survey sites vary: some are located on the top of high mountains and the others are located at extremely low altitudes in arid and saline environments. The initial task of rural water supply planning is to determine a method to provide an equitable water supply system for these sites based on the cost-effectiveness concept.

Since the early 1970s, the economy of the Republic achieved a dramatic expansion; however, there is no basis for determining whether the same situation will continue in the long run. Consequently, too long a projection into the future is not relevant for this project.

From the technical point of view, the main facilities involved in this project will consist of boreholes and machinery. The life of these facilities is considered to be 10 years. The other facilities with simple and durable structures, like pipelines and water tanks, will last for 20 years. To cover both durations, a planning period of 20 years was adopted. (Section VI-1)

7-2 Rural Water Supply Demand

7-2-1 Introduction

The major components to determine future demand of rural water supply are unit water consumption rate and size of population, including both number of people and head cattle, as determined by their expected growth rates.

7-2-2 Growth Rate of Population

In the past, the annual growth rate of Yemen's population was estimated at 2.5%-3% (Central Planning Organization 1975). Recently Allman and Hill (1977) calculated a growth rate of only 1.8% per year, while the Swiss Technical Assistance team estimated at 2.4% for 1980.

However, under this project the socio-economic conditions of survey sites differs from place to place.

Accordingly, three different levels of the future growth rates were used:

6%: Sites playing an important social or economic role such as transportation node, economic center or a specific site so determined by the Ministry. The following sites fall into this category:

Sihara(HA-3A)	Harad (HA-4)
Al-Dahi(H-2)	Al-Mounirah(H-3)
Yahkhtol(T-8)	

3%: Sites which are in an embryonic stage of urbanization with relatively large populations between 3,000 and 5,000 people. The following sites fall into this category:

Al-Madan & 8 Villages (HA-1)	Thari (HA-3B)
	Al-Mahweet City(A-1)
Al-Sheab, Al-Aswad (S-3)	Al-Zakira(T-6)
	Makbana (T-9)

2.5%: The common rural areas.
The following sites fall into this category

Elman & 4 Other Villages (HA-2)
Al-Rajam (A-3)
Bany Shaker & Bait Abo Saba'a (S-1)
Bany Farhan & Bany Saria'a (S-4)
Al-Manara & Al-Dukum (T-2)
Al-Maydan, Al-Jubail Sheibd Hamud (T-3)
Hadad, Qahfa (T-4A)
Al-Kudha, Al-Hagl (T-4B)
Shohat, Al-Kadash (T-5)
Hufash (A-2)
Al-Khabet (A-4)
Bait Abo Hashem (S-2)
Ghulayfagah (H-1)
Al-Mashjab (T-1)

7-2-3 Daily Consumption

The total daily per capita water consumption was determined by a number of factors: such as the availability of water, its quality, the cost of the water, the income and size of the family cultural habits, standard of living, ways and means of distribution, and climate, etc. Statistics on daily per capita water consumption also exist in a large number of studies.
The World Health Organization (WHO) has published data on the average daily consumption per capita for rural areas for several areas of the world (1973) as shown in Table 7-1.

Table 7-1

RANGE OF AVERAGE DAILY CONSUMPTION IN RURAL AREAS

(Unit = L/cap/day)

Africa	13-35	Latin America & Caribian Area	70-190
South East Asia	30-70		
Western Pacific	30-75	World Average for Developing Countries	35-90
Eastern Mediterranean	40-85		

Feachem et al. (1977) summarized the average daily per capita domestic water consumption for various types of supplies in rural areas of developing countries as shown in Table 7-2.

Table 7-2

AVERAGE DAILY CONSUMPTION AND RANGE OF DAILY CONSUMPTION: L/cap/day

Type of Supply	Average Daily consumption	Range of daily consumption
Unpiped supplies	15	5 - 25
Piped supply with standpipes	30	10 - 50
Piped connection:		
- Single tap	50	10 - 100
- Multiple tap	150	50 - 300

In the Republic, recently the MPW determined the design criteria of daily consumption for rural water supply as follows:

40 L/cap/day .... Rural area without distribution system

70 L/cap/day .... Semi-urban area with part of a distribution network. Population between 3,000 and 5,000 people.

80 - 120 L/cap/day ... Urban area with population more than 5,000 people.

By comparison, the daily per capita consumption of water for rural areas in the Republic is relatively small compared with the average for developing countries except for Africa. However, considering the arid conditions prevailing in the greater part of the Republic and the common type of public taps for rural water supply systems, the magnitude of 40 L/cap/day can be regarded as reasonable.

Of the total number of survey sites, nineteen sites (73%) fall in the rural area.

Several survey sites (Al-Madan & 8 Villages) are in a mixed transitional stage between rural and semi-urban conditions. In these places, the center of the site forms a kind of semi-urban structure and the surrounding area is inhabited by farmers grouped in small clusters. For this reason, the criteria of a semi-urban area is used for the central part of the site and the criteria of a rural area is applied to the surrounding areas. The following sites fall into semi-urban areas:

HA-1	Al Madan & 8 Villages
HA-3A	Sihara
HA-4	Harad
T-4B	Al Kudha & Al Hagl
T-6	Al Zakira
T-9	Makbana

The sites regarded as urban area, in terms of water consumption design criteria is a part of Al Mahweet City (A-1) and Bab-Al-Mandab (T-7).

Another important aspect of the project is cattle watering. Various kinds of cattle were observed in the sites. The total number of cattle is more than 100 thousand heads. In order to estimate the future demand for cattle watering, the concept of livestock unit of consumption is used. 6 L/head/day is referred to the "livestock unit" of water consumption.

The daily consumption of different types of livestock is estimated as shown below:

Type of animal	Livestock unit of consumption	L/day
1 sheep or goat	1	6
1 donkey	2	12
1 cattle or camel	4	24

7-2-4 Future Demand Based on the Design Criteria

Based on the above discussed rate of population growth and daily consumption of water, the total daily water demand was estimated for 20 years in each survey site. The results are shown in Table 7-3.

Table 7-3

Future Demand for Rural Water Supply
Based on the Design Criteria of the MPW

(Unit = m^3/day)

Site	Area*	Pop.*	1979	5 years	10 years	15 years	20 years
HA-1 Al Madan	SU: 47%	H	405.0	469.5	544.3	631.0	731.5
& 8 Villages		L	22.1	25.6	29.7	34.4	39.9
	R: 53%	T	427.1	495.1	574.0	665.4	771.4
HA-2 Elman &	R	H	60.0	67.9	76.8	86.9	98.3
4 Other		L	8.8	10.0	11.3	12.8	14.5
Villages		T	68.8	77.9	88.1	99.7	112.8
HA-3A Sihara	SU	H	315.0	421.5	564.1	755.0	1,010.2
		L	53.0	70.9	94.9	127.0	169.9
		T	368.0	492.4	659.0	882.0	1,180.1
HA-3B Thari	R	H	600.0	695.6	806.4	934.8	1,083.7
		L	90.0	104.3	121.0	140.2	162.6
		T	690.0	799.9	927.4	1,075.0	1,246.3
HA-4 Harad	U: 57%	H	720.0	1,124.1	1,289.4	1,725.5	2,309.1
		L	39.7	53.2	71.1	95.2	127.3
	SU: 43%	T	759.7	1,177.3	1,360.5	1,820.7	2,436.4
A-1 Al Mahweet City	SU	H	500.0	579.4	672.0	779.0	903.1
		L	37.9	44.0	51.0	59.1	60.5
		T	537.9	623.4	723.0	838.1	971.6
A-2 Hufash	R	H	60.0	67.9	76.8	86.9	98.3
		L	3.8	4.3	4.8	5.5	6.2
		T	63.8	72.2	81.6	92.4	104.5
A-3 Al Rajam	R	H	32.0	36.2	41.0	46.4	52.4
		L	3.8	4.3	4.8	5.5	6.2
		T	35.8	40.5	45.8	51.9	58.6
A-4 Al Khabet	R	H	60.0	67.9	76.8	86.9	98.3
		L	5.3	6.0	6.8	7.7	8.7
		T	65.3	73.9	83.6	94.6	107.0
S-1 Bany	R	H	20.0	22.6	25.6	29.0	32.8
Shaker & Bait		L	5.2	5.8	6.6	7.5	8.5
Abo Saba'a		T	25.2	28.4	32.2	36.5	41.3

(Continued)

Table 7-3 (Cont'd)

(Unit = m^3/day)

Site	Area*	Pop.*	1979	5 years	10 years	15 years	20 years
S-2 Bait Abo Hashem	R	H	15.2	17.2	19.4	22.0	24.9
		L	9.6	10.9	12.3	13.9	15.7
		T	24.8	28.1	31.7	35.9	40.6
S-3 Al Sheab & Al Aswad	R	H	80.0	92.8	107.5	124.6	144.5
		L	52.8	61.2	71.0	82.3	95.4
		T	132.8	154.0	178.5	206.9	239.9
S-4 Bany Farhan & Bany Saria's	R	H	26.0	29.4	33.3	37.6	42.6
		L	7.8	8.8	10.0	11.3	12.8
		T	33.8	38.2	43.3	48.9	55.4
H-1 Ghulay-fagah	R	H	20.0	22.6	25.6	29.0	32.8
		L	3.0	3.5	3.9	4.4	5.0
		T	23.0	26.1	29.5	33.4	37.8
H-2 Al Dahi	U	H	840.0	1,124.2	1,504.3	2,013.1	2,694.0
		L	46.3	61.9	82.8	110.9	148.4
		T	886.3	1,186.1	1,587.1	2,124.0	2,842.4
H-3 Al Mounirah	R	H	68.0	91.0	121.8	163.0	218.1
		L	3.9	5.1	6.9	9.2	12.3
		T	71.9	96.1	128.7	172.2	230.4
T-1 Al Mashjab	R	H	32.0	36.2	41.0	46.4	52.4
		L	40.0	45.3	51.2	58.0	65.6
		T	72.0	81.5	92.2	104.4	118.0
T-2 Al Manara & Al Dukum	R	H	24.0	27.2	30.7	34.8	39.3
		L	37.4	42.4	47.9	54.2	60.7
		T	61.4	69.6	78.6	89.0	100.0
T-3 Al Madan & Al Jubail	R	H	40.0	45.3	51.2	57.9	65.6
		L	16.4	18.6	21.0	23.8	26.9
		T	56.4	63.9	72.2	81.7	92.5
T-4A Hadad & Gahfa	R	H	72.0	81.5	92.1	104.3	118.0
		L	16.4	18.6	21.0	23.9	26.9
		T	88.4	100.1	113.1	128.2	144.9
T-4B Al Kudha & Al Hagl	SU	H	100.0	113.2	128.0	144.8	163.9
		L	20.6	23.3	26.3	29.8	33.7
		T	120.6	136.5	154.3	174.6	197.6
T-5 Shohat & Al Kadash	R	H	80.0	90.5	102.4	115.9	131.1
		L	22.4	25.4	28.7	32.5	36.8
		T	102.4	115.9	131.1	148.4	167.9

(Continued)

Table 7-3 (Cont'd)

(Unit = m^3/day)

Site	Area*	Pop.*	1979	5 years	10 years	15 years	20 years
T-6 Al Zakira	SU	H	280.0	324.6	376.3	436.2	505.7
		L	49.3	57.2	66.3	76.8	89.1
		T	329.3	381.8	442.6	513.0	594.8
T-8 Yahkhtol	R	H	100.0	133.8	179.1	239.6	320.7
		L	41.1	55.0	73.6	98.5	131.8
		T	141.1	188.8	252.7	338.1	452.5
T-9 Makbana	SU: 43%	H	370.0	429.0	497.2	576.5	668.3
		L	16.4	19.0	22.1	25.6	29.6
	R: 57%	T	386.4	448.0	519.3	602.1	697.9

*Note:

AREA	R = Rural Area (2.5% annual growth rate)	
	SU= Semi-urban Area (3% annual growth rate)	
	U = Urban Area (6% annual growth rate)	
Pop.	H = Human Comsumption	
	L = Livestock Consumption	
	T = Total Consumption	

7-3 Provision of Water Source

Due to the arid conditions and the steep topography prevailing in the greater part of the Republic, general condition for utilization of surface water is unfavourable at the present stage of rural water supply planning. (see sections V-3-3 and V-5)

Under the circumstances, feasibility study was made on different type of water sources and the conclusion was reached that the underground water is the only available water source at many sites.

According to the conclusion derived by hydro-geological analysis on the survey sites based mainly on the analysis of existing boreholes and their aquifer, the possibility to obtain groundwater under the project is summarized as shown in Table 7.4. (See further details in Chapter V, Technical Report)

In the table 7.4, the yield of groundwater was classified into three categories.

Category A : Expected volume of yield obtainable was determined based on the data and information of existing boreholes and hydro-geological analysis.

Category B : The hydrogeological conditions are the same as category A however, the data of existing boreholes are insufficient.

Category C : Expected volume of yield obtainable with difficulty is determined based on the data and information of hydro-geological analysis, but the number of existing boreholes is only limited.
General conditions of hydrogeology is far less favourable than the above two categories.

Table 7-4 Type of Water Source and Yield

Number	Survey Site	Classification of Yield	Diameter (mm)	Depth (m)	Pumping Head (m)	Yield (m^3/day)	Remarks
HA-1	Al-Madan & 8 Villages	B	200	300	200	300	Based on analysis of existing Boreholes (200-400 m3/day)
HA-2	Elman & 4 Other Villages	B	200	300	200	300	
HA-3-A	Sihara	B	200	300	200	300	
HA-3-B	Thari	B	200	200	150	300	
HA-4	Harad	A	200	120	100	1,000	
A-1	Al-Mahweet City	B	200	200	150	300	
A-2	Hufash	B	200	200	150	300	
A-3	Al-Rajam	B	200	300	200	200	
A-4	Al-Khabet	B	200	200	150	200	
S-1	Bany Shaker & Bait Abo Saba'a	B	200	200	150	200	
S-2	Bait Abo Hashem	B	200	200	150	200	Estimated based on Yield of existing Borehole
S-3	Al-Sheab Al-Aswad	B	200	100	100	300	"
S-4	Bany Farhan & Bany Saria'a		200	100	100	300	"
H-1	Ghulayfagah	A	200	30	150	100	
H-2	Al-Dahi	A	200	80	50	1,000	
H-3	Al-Mounirah (to supply Ebn-Abbas and Al-Harunia)	A	200	60	50	1,000	
T-1	Al-Mashjab	A	200	110	100	400	Average Yield of existing Borehole
T-2	Al-Manara & Al-Dukum	A	200	110	100	400	
T-3	Al-Maydan, Al-Jubail Sheiba Hamud	B	200	200	150	700	Average Yield of aquifers in Yemen Volcanics
T-4-A	Hadad, Dahfa	A	200	180	150	500	
T-4-B	Al-Kudha, Al-Hagl	C	200	250	200	100	
T-5	Shohat, Al-Kadash	C		10		200	Sub-surface Reservoir
T-6	Al-Zakira	C	200	250	200	100	
T-7	Bab-Al-Mandab	A	200	(85)	50	500	Yield of existing Borehole
T-8	Yahkhtol	A	200	100	50	1,000	
T-9	Makbana	A	200	300	200	700	Average Yield of aquifers in Yemen Volcanics

About 38% of the sites fall in "Category A" and 50% of the sites in "Category B". The balance of 12% of the sites are considered to be problematic even in terms of availability of groundwater.

The sites classified in Category C (Al Kudha/Al Hagl (T-4B), Shohat/Al Kadash(T-5) and Al Zakira(T-6)) are located at the southern fringe of the Taizz Governorate where annual precipitation is less than 400 mm per year.
In addition, these sites are located on the Tawila Sandstone Plateau which is unevenly covered by Yemen volcanics.

Generally speaking, the plateau-like morphology made of hard rocks which develops into cliffs along the structurally weaker zones tends to produce poor conditions for groundwater recharge and storage.

In fact, the area where these sites are located is characterized by cliffs over several hundred meters high which makes a natural barrier to wadis where water is available to some extent. The reason for the scantiness of water is the same in all these three sites. Therefore, a coordinated solution is required to combine resources on a regional level instead of allocating a smaller amount of resources for each individual village.

As shown in Table 7-4, the estimated yield of a single borehole ranges from 200 to 1,000 m^3/day while the estimated future demand of survey sites at the end of planning period distributes between 40 and 2,500 m^3/day. The demand will exceed 1,000 m^3/day in the year 1999 at all five sites.
The estimated yield of a single borehole will be sufficient for the future demand at the end of the planning period at fifteen sites; however, multiple boreholes are required to meet the future demand to satisfy proposed design criteria by the Ministry.

At some sites Al-Madan & 8 Villages(HA-1), Sihara(HA-3A), Thari(HA-3B), Al-Mahweet City(A-1) and Al-Dahi(H-2), the estimated yield of a single borehole cannot meet the demand to satisfy the design criteria even assuming the present maximum 19 hours of pump and machine operation. Determination of water source design capacity is subject to cost analysis based on the cost-effectiveness concept since the cost of water source occupies almost 50% of the total cost of rural water supply in the project.

7-4 Provision of Optimal Water Supply System

7-4-1 Introduction

In order to determine a method to provide an equitable water supply system for these sites based on the cost-effectiveness concept, further analysis was made.
As observed in the previous section, some sites require a multiple source of groundwater and the cost of water source occupies almost half of the total cost of rural water supply in project. (Section VI-4 and 5)

The availability of multiple groundwater sources and their location is entirely subject to the hydro-geological conditions, at the site. Under the favourable conditions, a group of boreholes can be drilled within a short distance; however, where hydro-geological conditions are less favourable boreholes must distribute over a wider distance which results in a negative effect on economics of water supply.

For this reason an analysis of the inventory of rural water consumption is required for the determination of the optimal design capacity of the rural water supply.

7-4-2 Inventory of Rural Water Supply Consumption

The present water consumption rate at the survey sites is estimated to range between 5 and 40 L/cap/day. (see section V-3-3)

Due to difficult conditions to obtain water, the consideration of water usage is limited to the substantial areas of everyday life such as drinking, cooking and washing. Through the field survey and interview with people at sites, water consumption for specific purposes was estimated and compared with the same type of consumption of an average medium size town. (Table 7-5)

Table 7-5

Water Consumption by Purpose

Purpose	Survey Sites Q at 25 L/cap/day		Av. Medium Size Town Q ≦ 300 L/cap/day	
1. Drinking & Cooking	12 %	(3 ℓ)	19 %	(57 ℓ)
2. Cleaning Hands & Face	8 %	(2 ℓ)	9 %	(27 ℓ)
3. Bathing	-	-	17 %	(51 ℓ)
4. Washing Clothes	60 %	(15 ℓ)	30 %	(90 ℓ)
5. Toilet	-	-	16 %	(48 ℓ)
6. Other purposes	20 %	(5 ℓ)	5 %	(15 ℓ)

Based on the above classification of water consumption, the function of domestic water at survey sites was divided into three categories:

I. Water which has direct influence on human health (1-3)

II. Water for the other areas of everyday life like washing clothes (4-6)

III. Watering cattle is the third category which is indispensable in the project.

In this respect, the first order quality standard is required for the water of category I to protect human health, whereas the water quality for category II and III need not be necessarily to the same standard as the quality required for category I water.

Assuming that as living standards improve, the water consumption pattern of survey sites will become similar to an average medium size town, the increase in water consumption for drinking, cooking, washing and bathing purposes can be expected. In the average medium size town, the water consumption under the category I occupies about 45 % of the total consumption.
Therefore it is recommended that at least 50 % of daily demand satisfy the safe standard of water quality for human health.

Accordingly, based on the purpose of water use the type of water is classified into three categories:

Category I	:	50 % Human uses related to human health.
Category II	:	50 % Human uses for other purposes.
Category III	:	Cattle watering.

Therefore, the design capacity of rural water supply can be classified into three service levels as follows:

Service Level A	:	to supply all three categories of water consumption.
Service Level B	:	to supply only the required water of category I and II.
Service Level C	:	to supply water only for category I.

7-4-3 Comparison of the Price of Water

In order to compare the unit price of water in the project sites and also to make comparison of water price with that of other developing countries, the annual cost of rural water supply at each site was estimated assuming that the capacity of water source is available according to the hydro-geological condition summarized in Table 7-4 to satisfy the demand of Level A at the end of design period (15 years) as discussed in the previous section.

In this case, multiple water sources were assumed where single hole cannot afford the required demand. At Al-Madan & 8 Villages(HA-1), for instance, 5 boreholes are required to meet the required demand assuming 10-hour operation. Also, 9 boreholes are provided for Thari (HA-3B).

As shown in Fig. 7-1, the annual cost of water supply (YR/m^3/year) varies from 500 YR/m^3 to almost 7,900/YR/m^3. Although even the most expensive price is cheaper than buying water at the annual price of 18,250 YR/m^3 (equivalent to 50-60 YR/m^3/day), it is still a very high price compared with the cost of water in other countries.
(The average construction cost is estimated at $60/cap in the Guidelines for Rural Center Planning, 1979 published by Economic and Social Commission for Asia and the Pacific)
Almost half number of the sites are able to obtain safe water at the price better than or equivalent to the price of 10-12 YR/m^3 which is considered to be much more favourable price in the Republic compared with the selling price of water at 50-60 YR/m^3. Nontheless consideration is required to the extremely unbalanced unit price of water distributed in the sites. The annual cost in Fig. 7-1 was compared with the curves of unit cost of water supply obtained with the assumption that the water source and construction fund are available to supply required volume of water determined by the design criteria of the Ministry. (Fig. 7-2 to 7-4)

In the figures, curves indicate the unit price of water (YR/m^3/year) of standardized average condition of all survey sites. The unit price of water is estimated at 1,800 YR/m^3 year with capacity of 200 m^3/day from 100 m deep borehole including pumping up to 500 m under the standardized conditions over the all sites. (Fig. 7-2)

On the other hand, these points plotted in the same figures indicate the unit price of each sites representing each specific condition. The relative height between the service area of H-3 and its water source is relatively small (30 m) however, the unit price of water is relatively high compared with the unit price curve. This can be attributed to the fact that this water supply scheme requires 23 km of pipeline. (Fig.7-2) The unit price of water at Bany Shaker & Bait Abo Saba'a(S-1), Bait Abo Hashem(S-2), Al-Maydan, Al-Jubail Sheiba Hamud(T-3) and Hufash (A-2) (Fig 7-3) is also high since the capacity of borehole yield much exceeds the required demand.

In other words, in these sites only a part of investment for water source is actually benefitted.

At Thari(HA-3B), Al-Mahweet City(A-1) and Al-Madan & 8 villages(HA-1), many numbers of boreholes are required to meet the water demand determined by the design criteria proposed by the Ministry, which resulted in the higher unit price of water at these sites compared with the standardized unit price. The impact of the cost for the pumping facility to the unit price of the water is observed only at five sites (Elman & 4 Other Villages). Therefore, the reduction of the pumping cost is not an effective method to reduce the unit price of the water in the project.

Accordingly, consideration has to be given to the cost for water source. To a certain extent the solution is obtainable by increasing the operation hours of pump and machinery together with the consideration of the service level. (Section 7-4-2)

Fig. 7-1 ANNUAL COST OF WATER SUPPLY PER SURVEY SITE
(Including Amortization Interest Maintenance and Operation Cost)

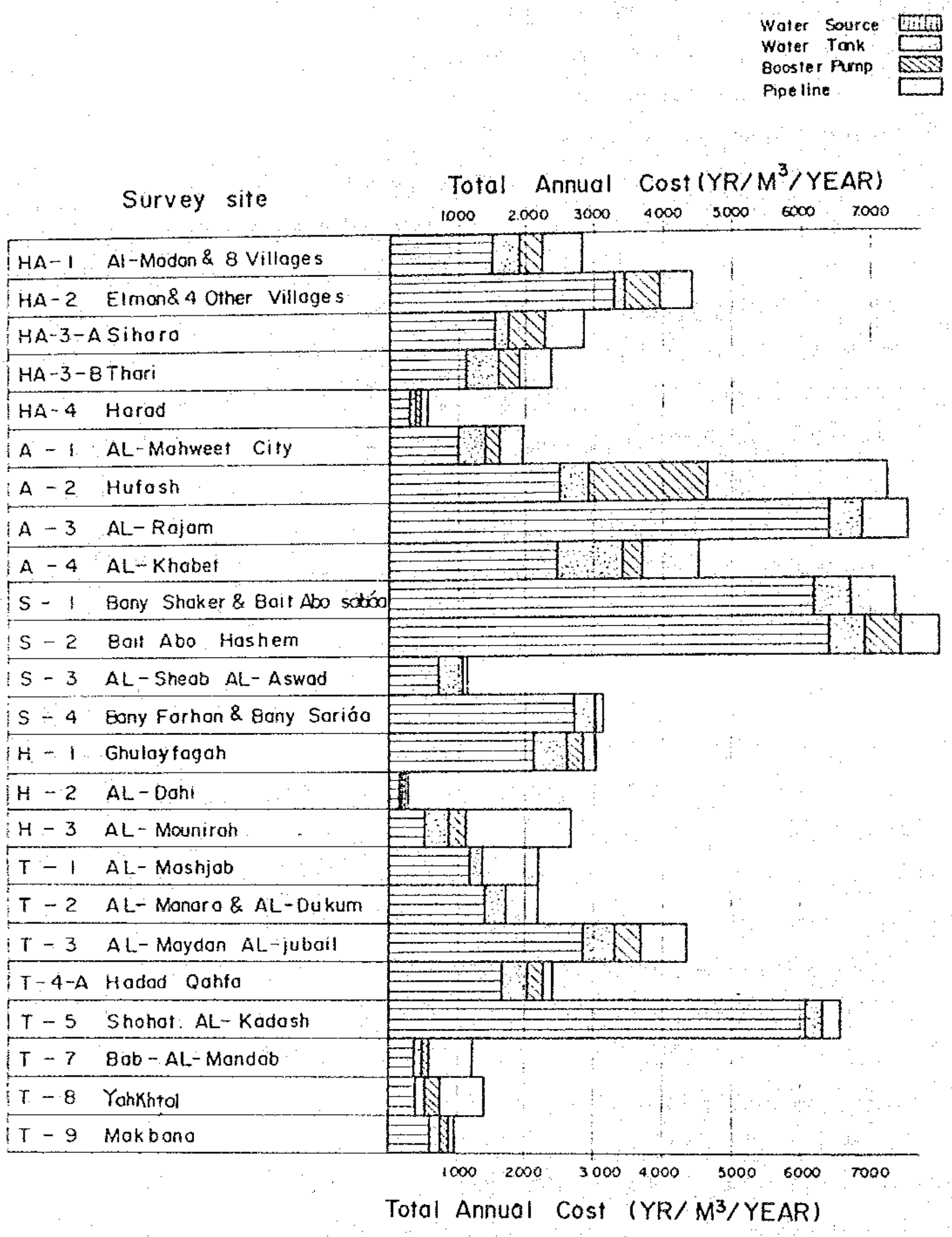


Fig. 7-2 COMPARISON OF ANNUAL COST AND UNIT COST WATER SOURCE BOREHOLE DEPTH 100M

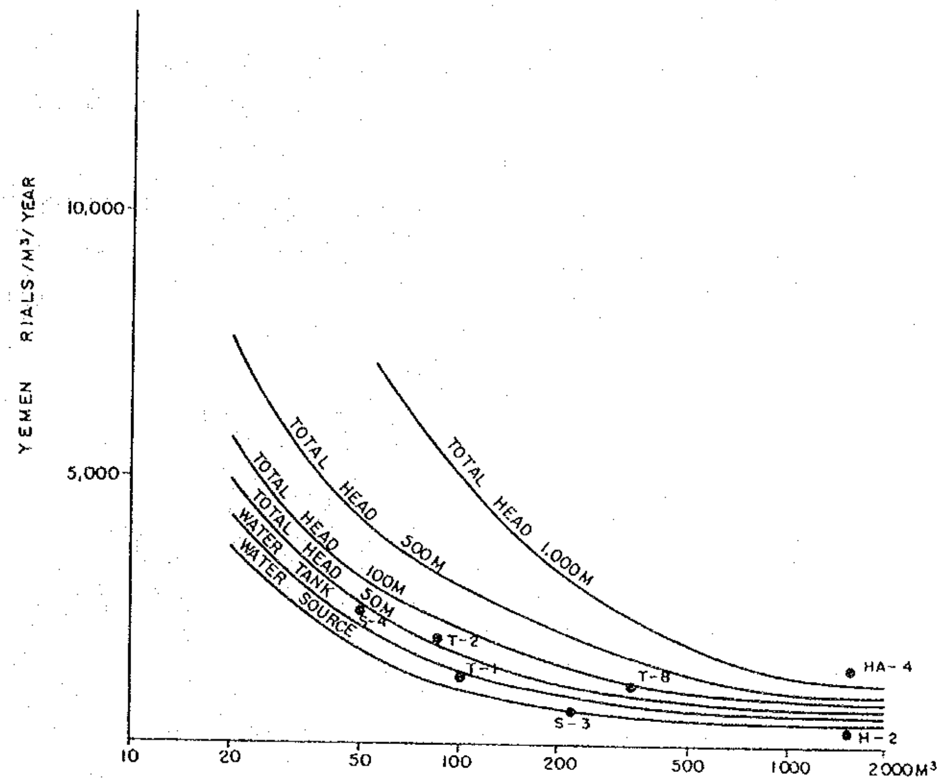


Fig. 7-3 COMPARISON OF ANNUAL COST AND UNIT COST WATER SOURCE BOREHOLE DEPTH 200M

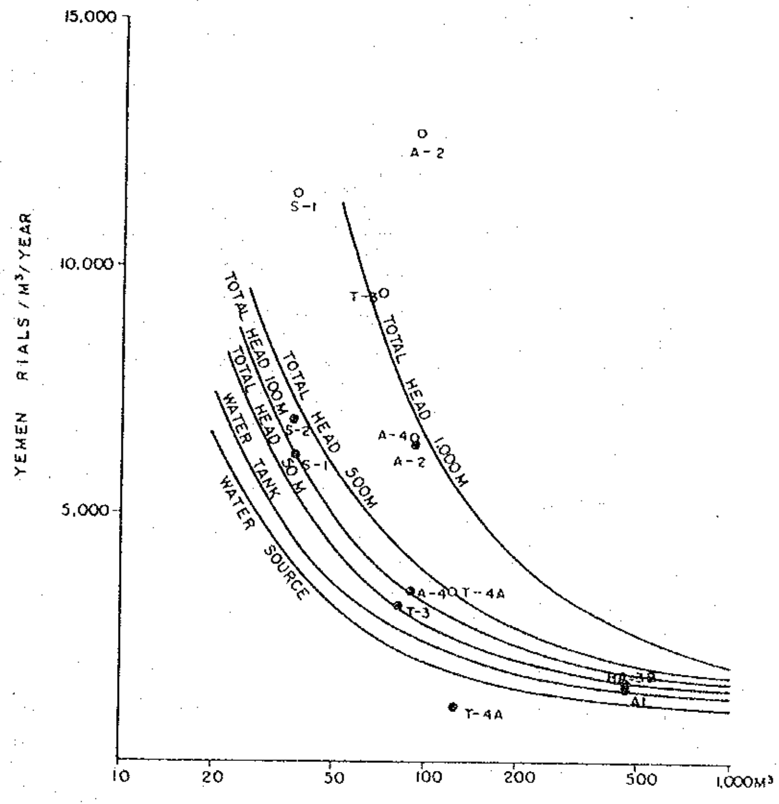
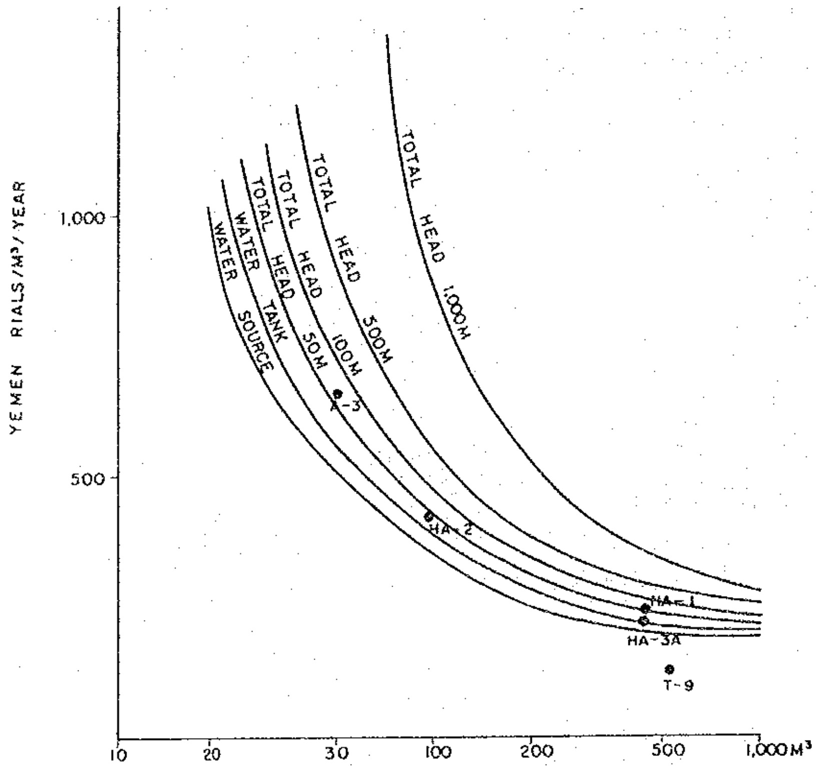


Fig. 7-4 COMPARISON OF ANNUAL COST AND UNIT COST WATER SOURCE BOREHOLE DEPTH 300M



7-4-4 Determination of Design Capacity

Although the life of machinery can be fixed at 10 years and other facilities with simple and durable structure, like-pipelines and water tanks, will last for 20 years, there is no basis for determining present growth trend of economy in the Republic. Considering these conditions, the design period is recommended to be 15 years in order to make necessary review of the rural water supply planning in 10 to 15 years from now.

As discussed in the previous section, the impact of the cost to develop water sources to the unit price of water is so great in the project that consideration has to be given to minimize the cost to develop water sources.
For this reason, the operation hours of pump and machinery are designed as long as possible except for those sites which have more sufficient supplies of water in terms of their water demand. (Bany Shaker & Bait Abo Saba'a)

Increasing the operation time of pump and machinery should reduce the unit price of water, however, the time for fuel supply and maintenance must be considered. The design pause time of pump and machinery is required to be 5 hours per day (19 hours for operation).

In the Republic, the mean operation time is currently 5 to 8 hours per day for shallow dug wells. The short operation hours are because of the small volume of water; however for deep wells designed in this Project, longer operation times are proposed since there is larger water supply capacity.

By increasing the operation time of pump and machinery from 10 to 19 hours, the required number of boreholes can be decreased at 7 sites and still satisfy the demand of service level A after 15 years estimated by the design criteria proposed by the Ministry. The revised number of boreholes at these sites is listed below.

Required Number of Boreholes

		10 hrs Operation	19 hrs Operation
Al-*Madan* & 8 Villages	(HA-1)	5	3
Sihara	(HA-3A)	7	4
Thari	(HA-3B)	9	4
Harad	(HA-4)	4	2
Al-Mahweet City	(A-1)	7	4
Al-Sheab, Al-Aswad	(S-3)	2	1
Al-Dahi	(H-2)	5	3
Makbana	(T-9)	2	1

Based on 19 hours operation of pump and engine, the approximate safe yield was compared with the future demand of rural water supply in each survey site at different service levels. (see Fig. 7-5)

As shown in the *figure*, at almost 50% of the sites the yield of a single hole is sufficient to meet the demand at service level A even after 20 years. These sites are as follows:

Elman & 4 Other Villages	(HA-2)
Hufash	(A-2)
Al-Rajam	(A-3)
Al-Khabet	(A-4)
Bany Shaker & Bait Abo Saba'a	(S-1)
Bait Abo Hashem	(S-2)
Al-Sheab, Al-Aswad	(S-3)
Bany Farhan & Bany Saria'a	(S-4)
Ghulayfagah	(H-1)
Al-Mounirah	(H-3)
Al-Mashjab	(T-1)
Al-Manara & Al-Dukum	(T-2)
Al-Maydan, Al-Jubail Sheiba Hamud	(T-3)
Hada, Qahfa	(T-4A)
Yahkhtol	(T-8)
Makbana	(T-9)

In all cases above, the sufficiency of water is determined by their relatively small demands rather than by an abundance of water source.

For these sites, the design capacity was determined to be the same capacity as the demand of the service level A after 15 years from now in order to attain the maximum use of investment for the water source.

On the other hand, the yield of a single borehole is not sufficient to meet the demand of the service Level A after 15 years in the following sites:

T-9	Makbana
HA-1	Al-Madan & 8 Villages
HA-3B	Thari
A-1	Al Mahweet City
H-2	Al Dahi
T-4B	Al Kudha, Al Hagl
T-5	Shohat, Al Kadash
T-6	Al Zakira

The hydro-geological conditions at the last three sites, Al-Kudha, Al-Hagl(T-4B), Shohat, Al-Kadash(T-5) and Al-Zakira(T-6) were classified as category C according to the result of the hydro-geological study and it is recommended to seek a coordinated solution to combine resources on a regional level instead of allocating a smaller amount of resources for each individual village. (Section 7-3)

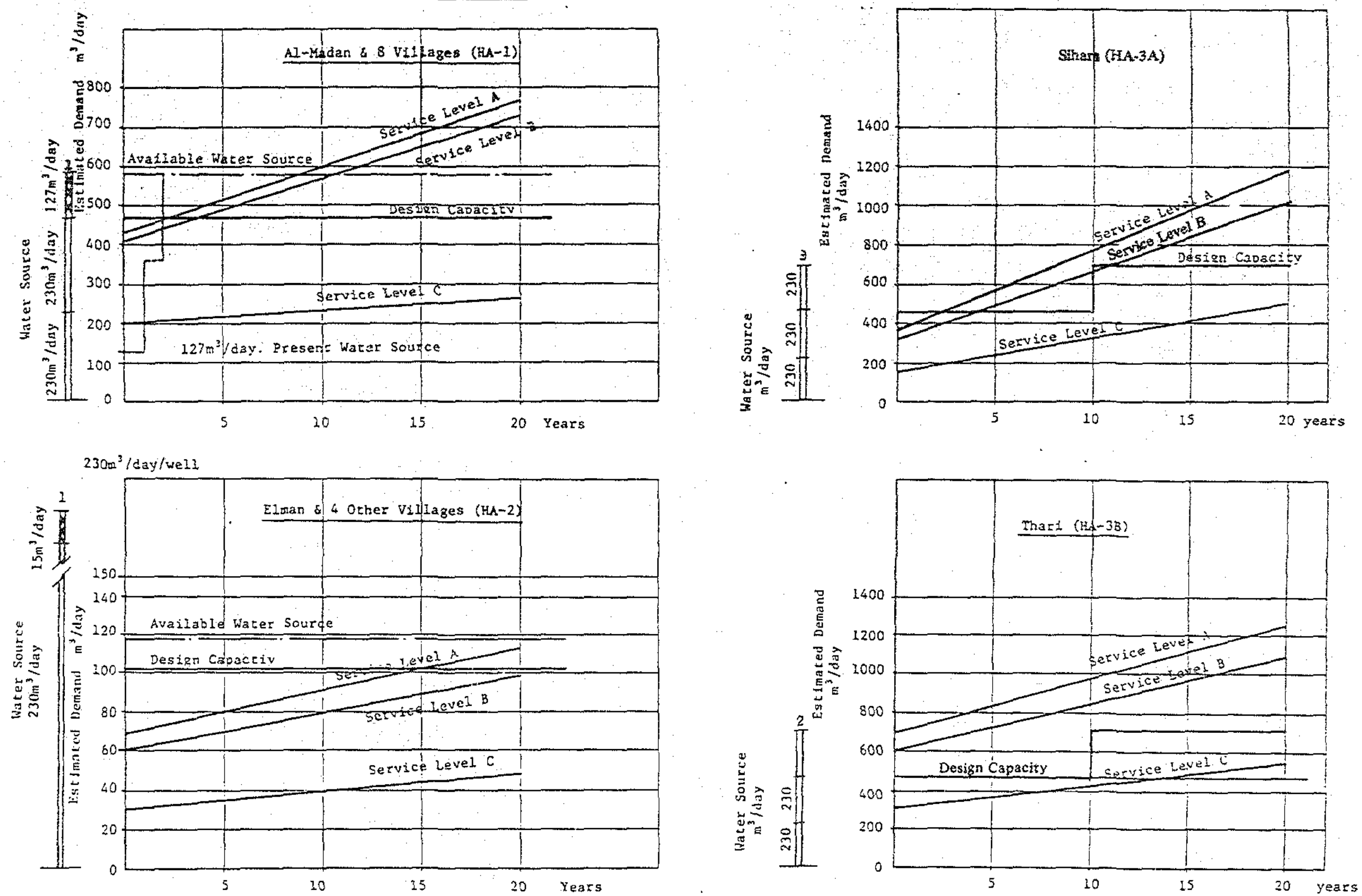
In order to solve this problem, sub-surface reservoir is proposed at the site T-5 however, data collection and analysis on water sources in this area are urgently required to solve the acute shortage of domestic water prevalent on this plateau.

For the other 5 sites listed above, it is proposed that the design capacity to cover the service level C demand at the end of planning period and be incorporated with the presently available safe water sources.

The gap between the design capacity of improved water supply and the total demand will be met by other water sources. For this purpose, springs, shallow dug wells and cisterns should be utilized efficiently. Although most of the area is located in dry areas, some 200 to 300 mm/year of specific yield of surface water is available which can be collected in cisterns and be used for cattle watering and washing clothes. The traditionally developed cistern technique should be improved to minimize its water loss and contamination. Such recommendations are shown in the Section 5-4 and in the Technical Report.

Fig. 7-5

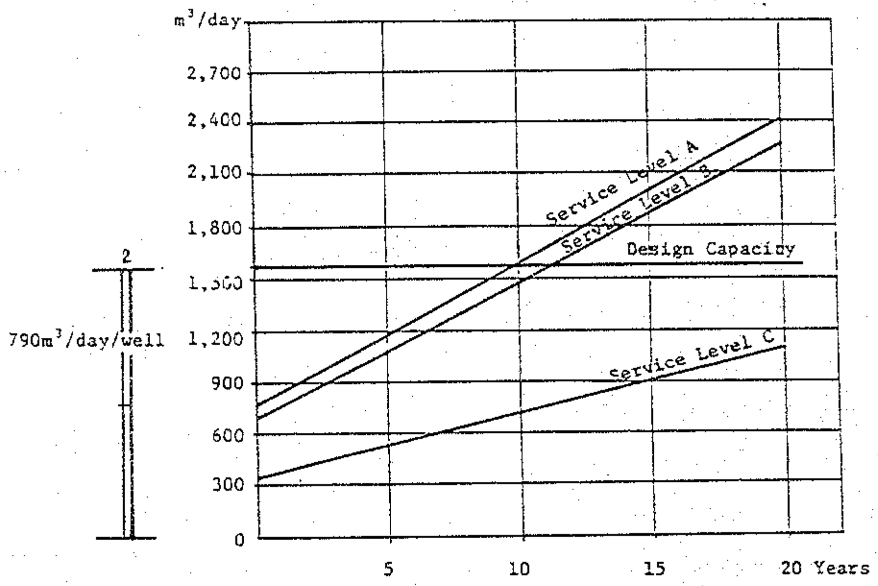
Future Demand & Design Capacity of Rural Water Supply



Continued

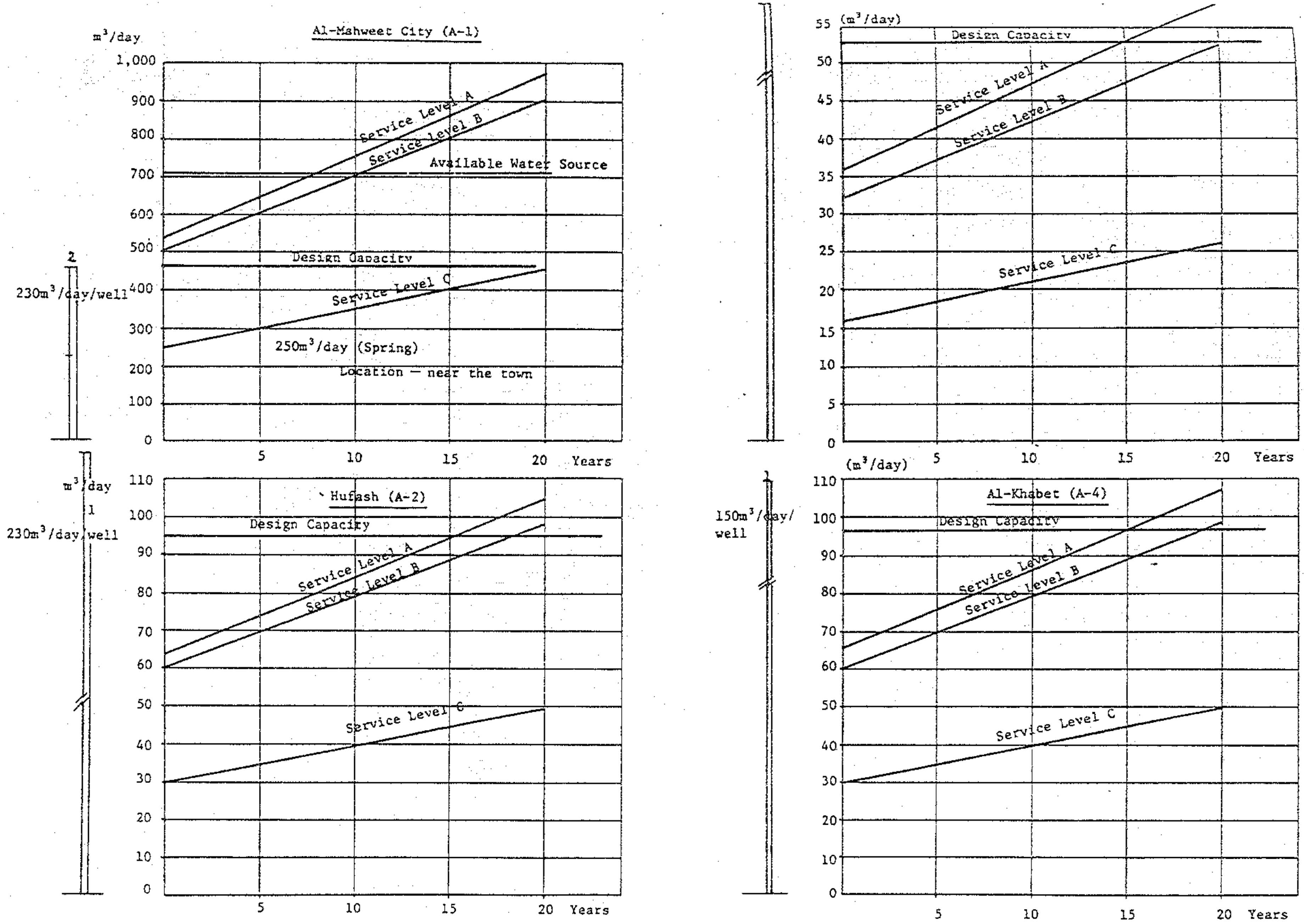
Fig. 7-5 (Cont'd)

Harad (HA-4)



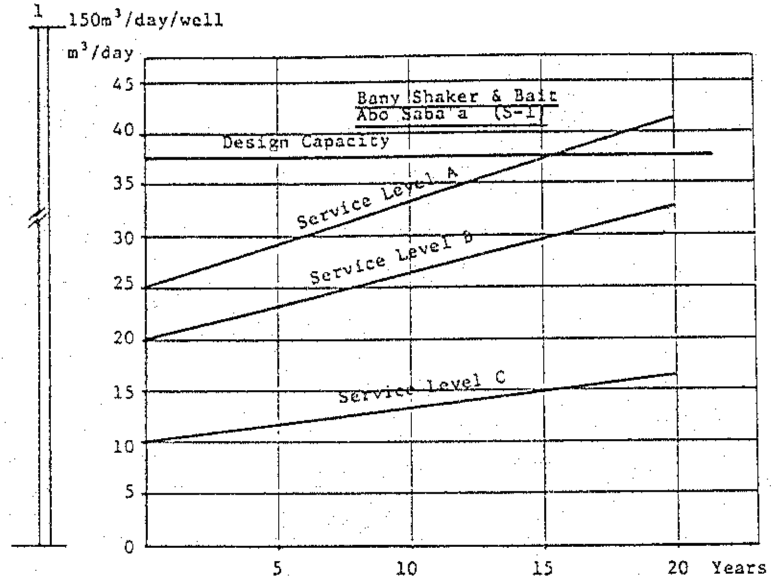
Continued

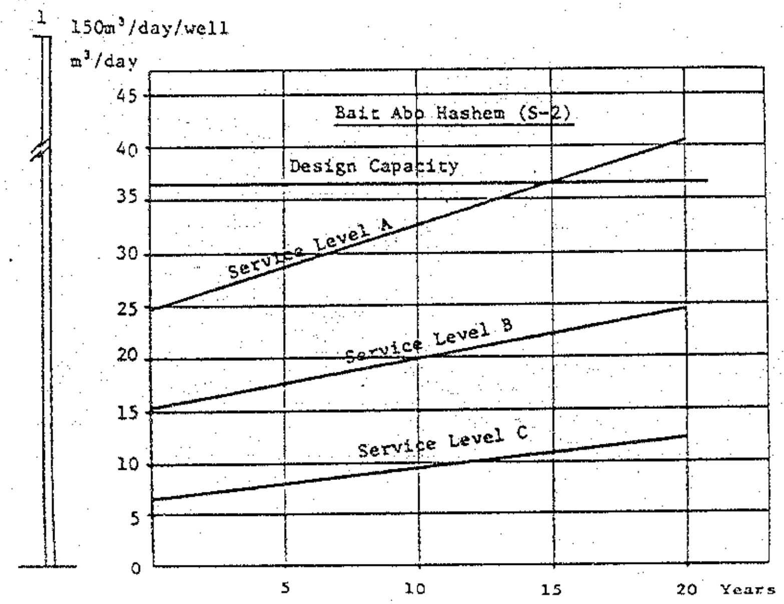
Fig. 7-5 (Cont'd)

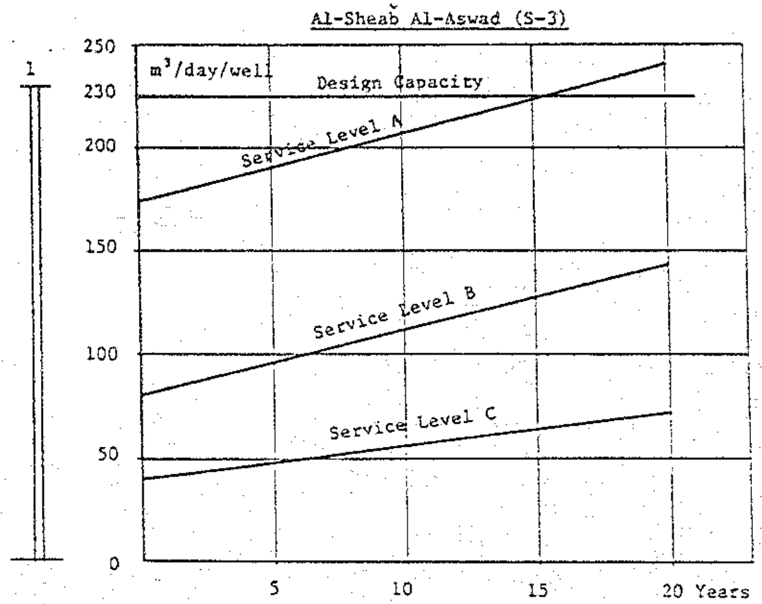


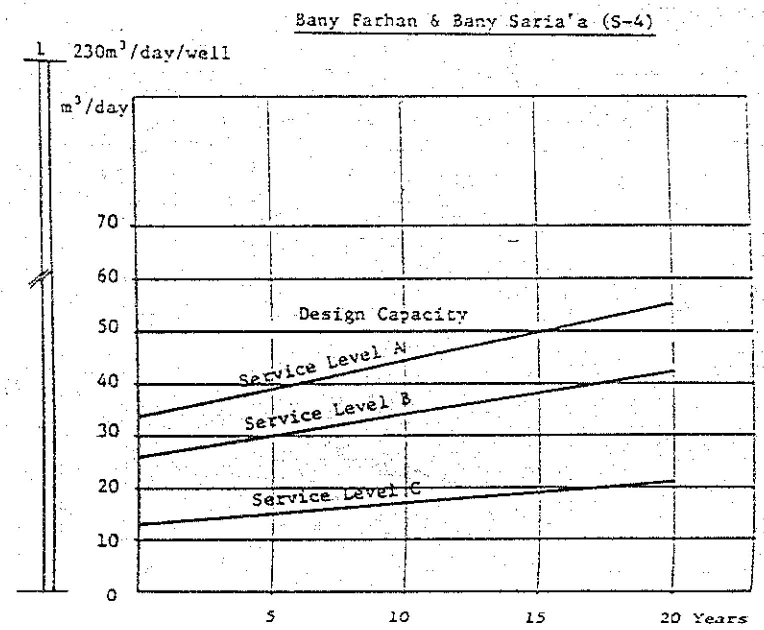
Continued

Fig. 7-5 (Cont'd)



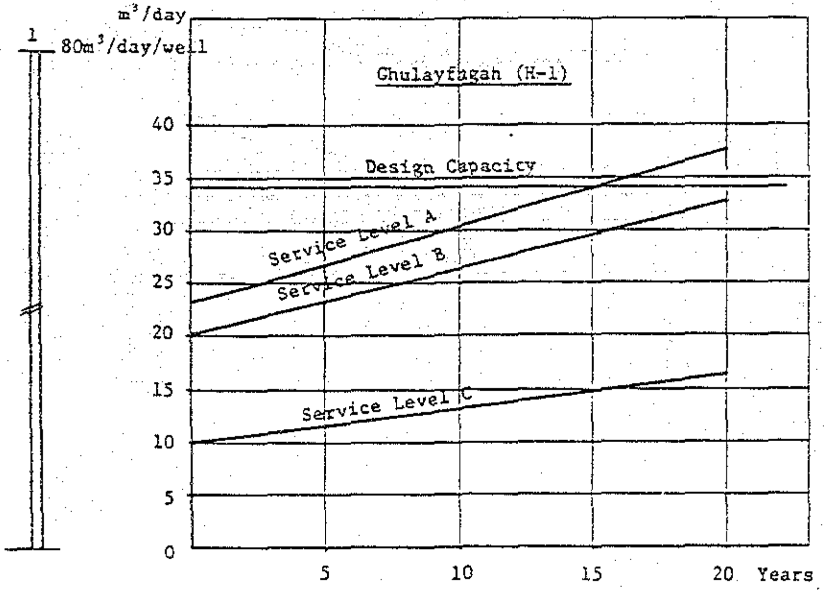


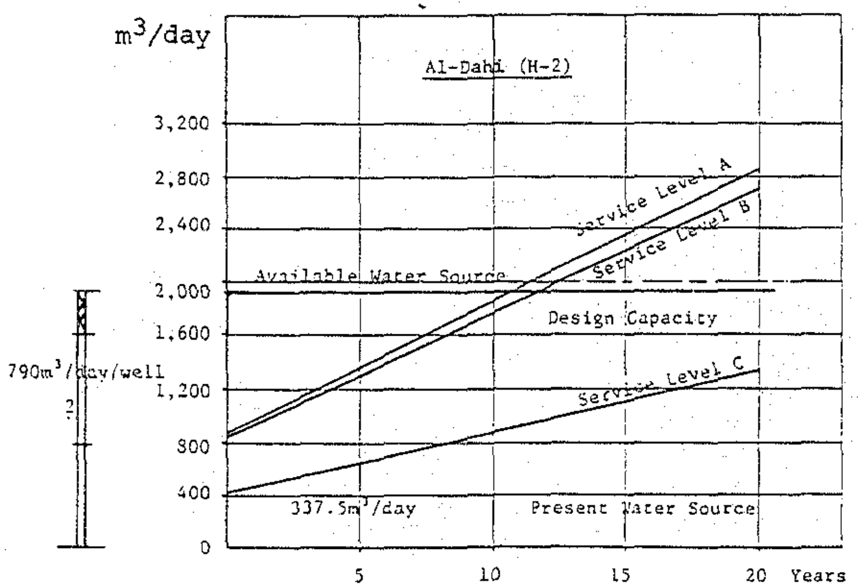


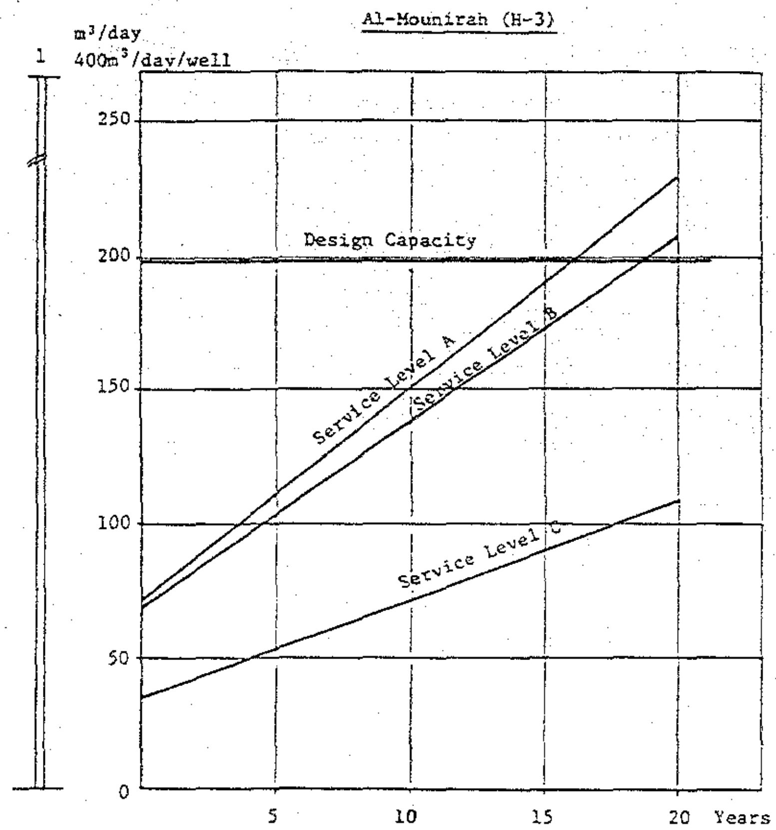


Continued

Fig. 7-5 (Cont'd)

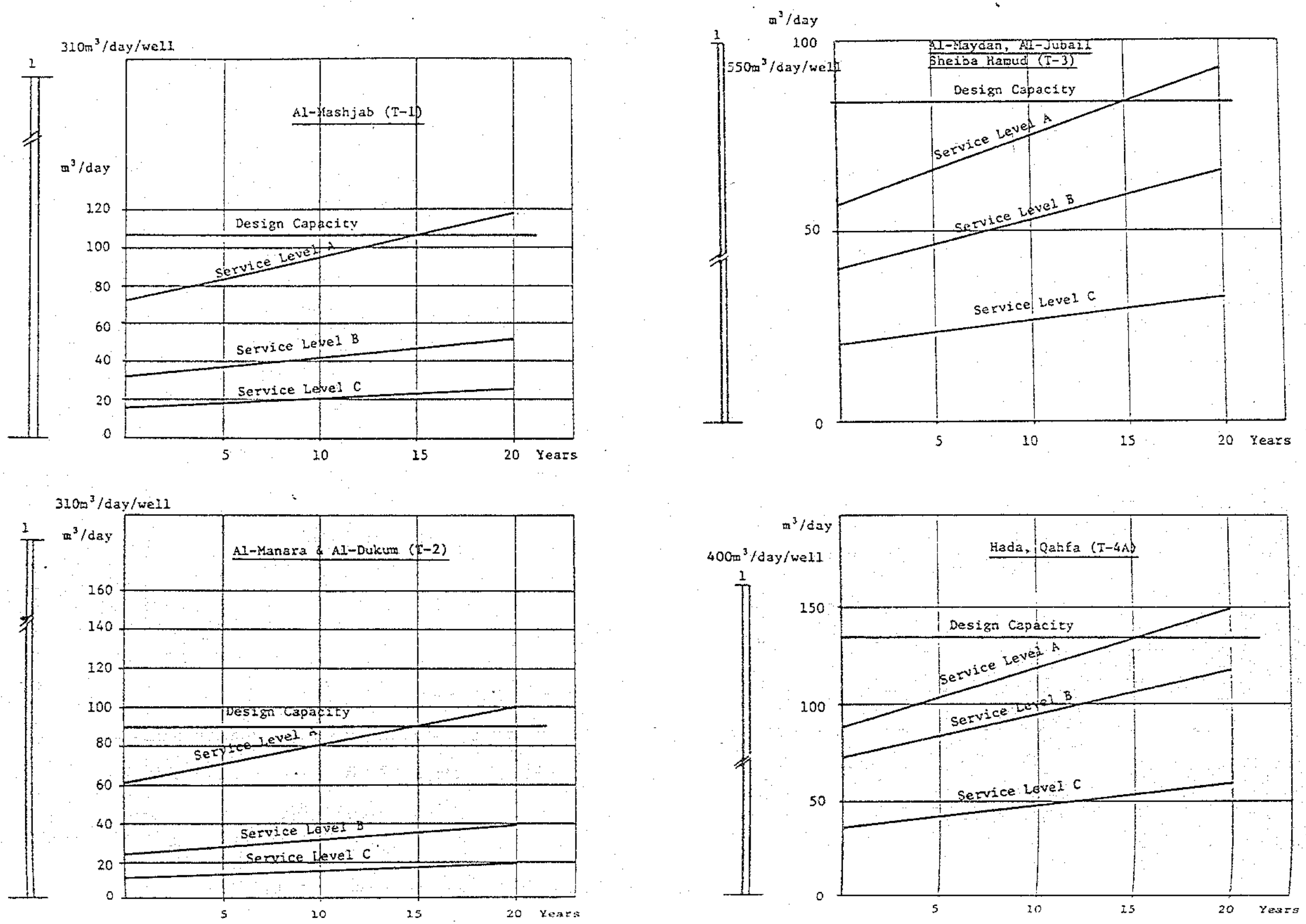




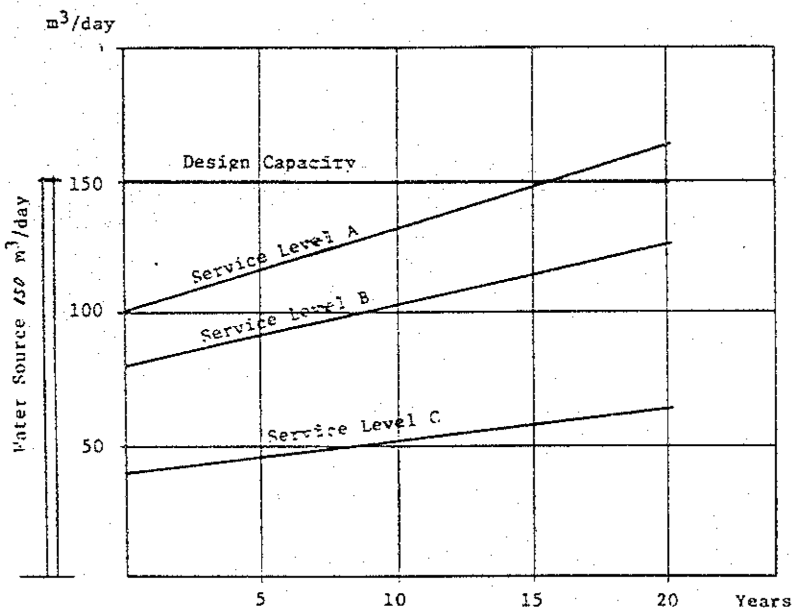


Continued

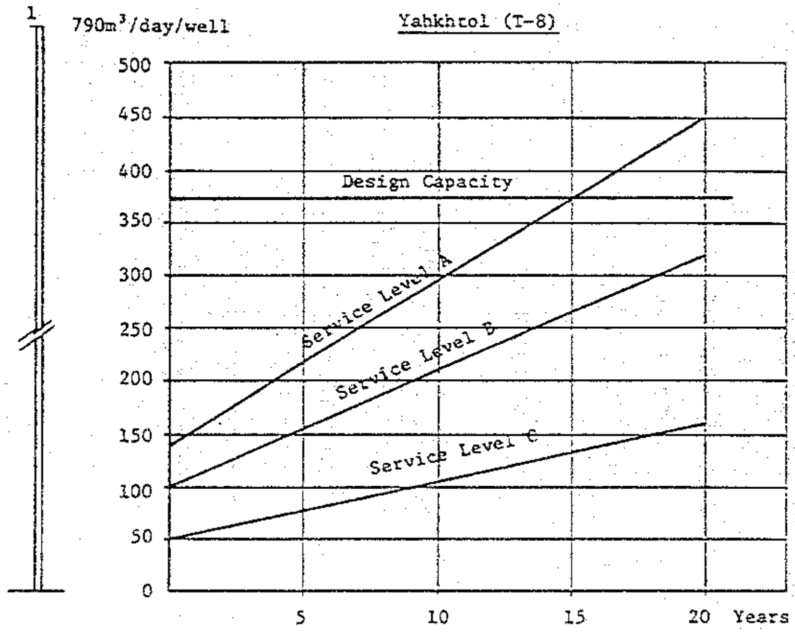
Fig. 7-5 (Cont'd)

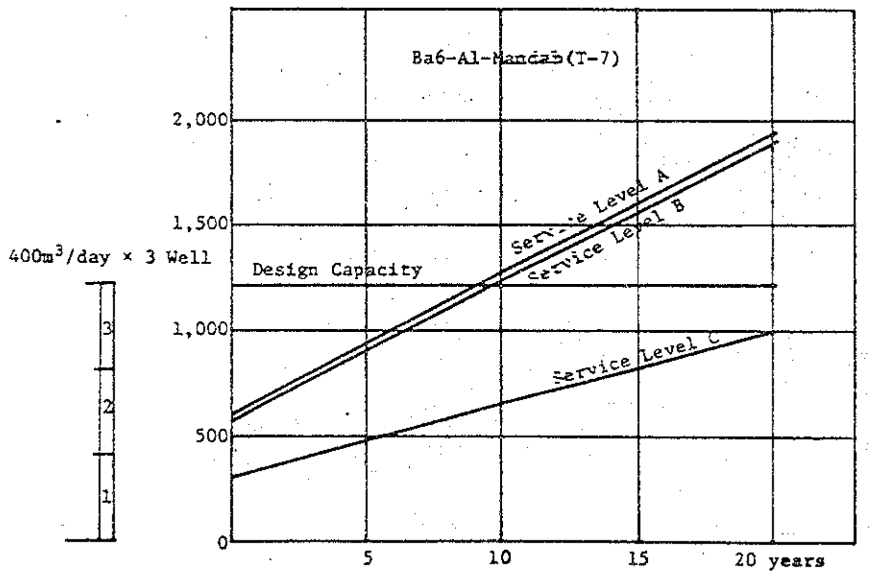

Al-Mashjab (T-1)
310m³/day/well
m³/day
Design Capacity
Service Level A
Service Level B
Service Level C
Years
Al-Maydan, Al-Jubail
Sheiba Hamud (T-3)
550m³/day/well
Al-Manara & Al-Dukum (T-2)
Hada, Qahfa (T-4A)
400m³/day/well

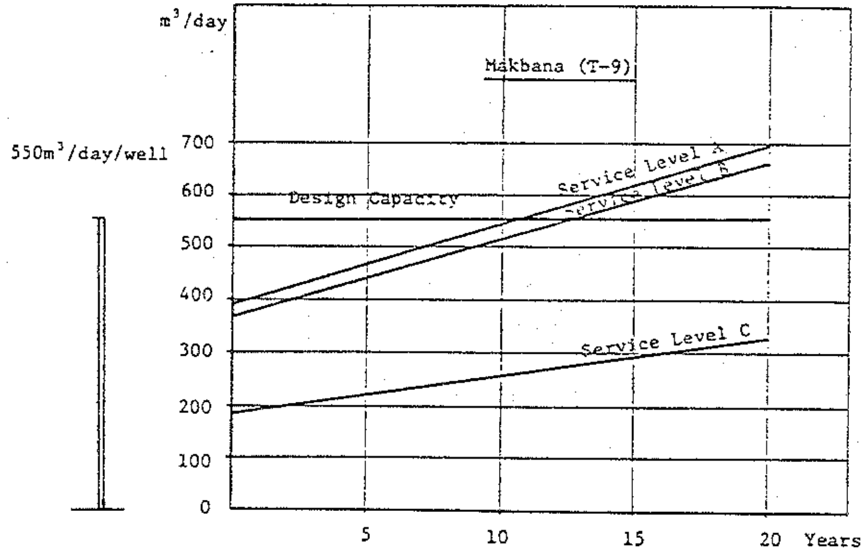
Shohat Al-Kadash (T-5)
(UnderGround dam)



Yahkhtol (T-8)





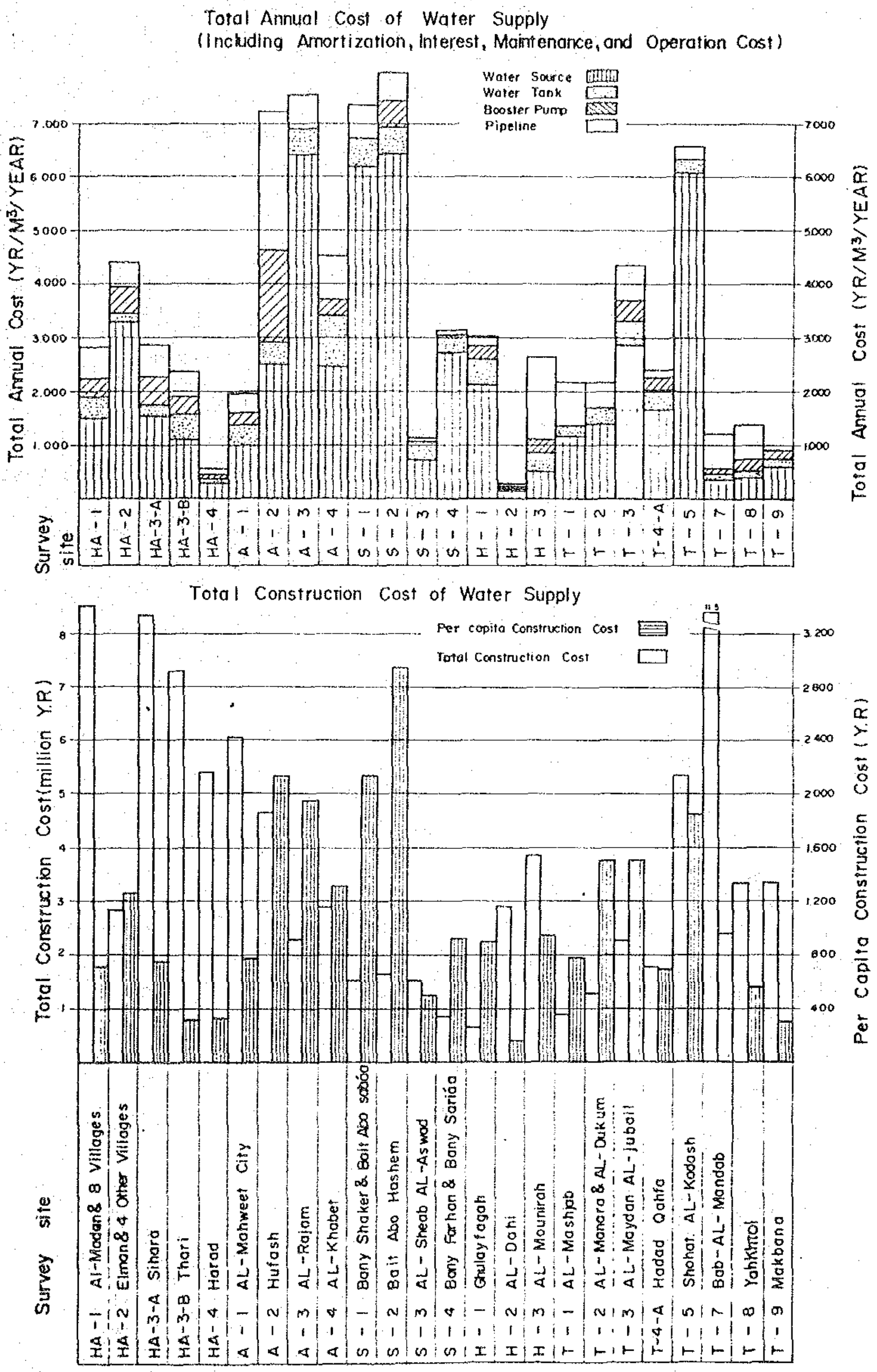


7-4-5 Construction Cost and The Price of Water

According to the design capacity determined based on the cost-effective analysis, total annual costs and construction costs were estimated at survey sites and summarized as shown in Fig. 7-6.

Total annual cost varies in a wide range from 500 to 7,900 YR/m^3/year and it is estimated less than 3,500 YR/m^3/year at 16 sites (70% of the total survey sites). The extremely high annual cost more than 6,000 YR/m^3/year is required at Hufash (A-2), Al Rajam (A-3), Bany Shaker/Bait Abo Sabaa(S-1) and Bait Ab Hashem (S-2). This is attributed to the fact that the future demand is much less than estimated safe yield of borehole while the construction cost of borehole is determined by the depth of drilling. However, since the design capacity is relatively small, the total construction cost is also estimated to be small. Therefore, the construction cost of these sites does not produce significant impact to the entire construction cost of the project.

Fig. 7-6 Annual Cost and Total Construction Cost Per Survey Site



7-5 Operation and Maintenance

Although in the design of water supply facilities, the durable life of machinery is fixed at 10 years and other facilities with simple and durable structures, e.g. pipelines and water tanks, are fixed at 20 years. It is said that the durable years will continue in the good manner of operation with the appropriate maintenance.

If poor techniques for operation or lack of maintenance are applied to the water supply system, in spite of the good quality of machinery, the durable life will be much shorter than the designed life, and this fact will have a disasterous effect on the Project. Accordingly, to leave the operation and maintenance to the local communities involves a large risk because of their lack of knowledge about facilities.

For the execution of the Project according to the design, it is recommended to establish a new organization/team for operation and maintenance under direct control by the Ministry of Public Works.

The new team should have staff and members who have good knowledge about facilities and mechanism of water supply systems and are technically trained. The new team will cope with accidents or troubles in the proper manner.

All the facilities which are widely separated throughout the coundtry will be under the jurisdiction of the new organization/ team, and so, the new team should have enough staff and materials for their activities.

A study of the organization, staff and structure for the new team should be undertaken.