In Wadi Juah and Wadi Ayan which lie north and south of Wadi Mawr respectively, similar situations as in Wadi Mawr have not been identified. Groundwater contours become parallel to the coast line as they come near the coast.

Table 3-5 presents the results from the present survey on the existing wells. (The well locations are shown in Fig. 3-2) In Fig. 3-7 the relation between well's altitude A.S.L. and the hydrostatic groundwater level is illustrated. A linear correlation is recognizable between these levels with some deviations caused by reading erros of the ground level on the maps (1/50,000 and 1/250,000 scale topographical maps). This suggests that the static groundwater level can be determined by the well altitude in coastal region.

3) Water quality

The electric conductivity of the groundwater in the Tihama coastal region is mostly higher than 1,000 $\mu\mho$/cm (corrected to 25°C values, as in the following paragraphs) and generally higher than those values in the hill region. This indicates deteriorating water quality in the coastal region.

The deterioration is due to the sea water intrusion caused by the following factors:

(1) the geographical location (i.e., lower altitudes and coastal location)
(2) salt enrichment enhanced by the scanty precipitation and significant potential evapo-transpiration, and
(3) ion exchange equibrium between groundwater and soil particles in the high saline formation.

The correlation between the intra-coast distance and the electrical conductivity of the waters of the existing wells is given in Fig. 3-8. The results do not show a simple correlation as they do in the alluvial coastal plain in Japan,

FIG. 3-7 Relationship Between Static Water Level and Altitude

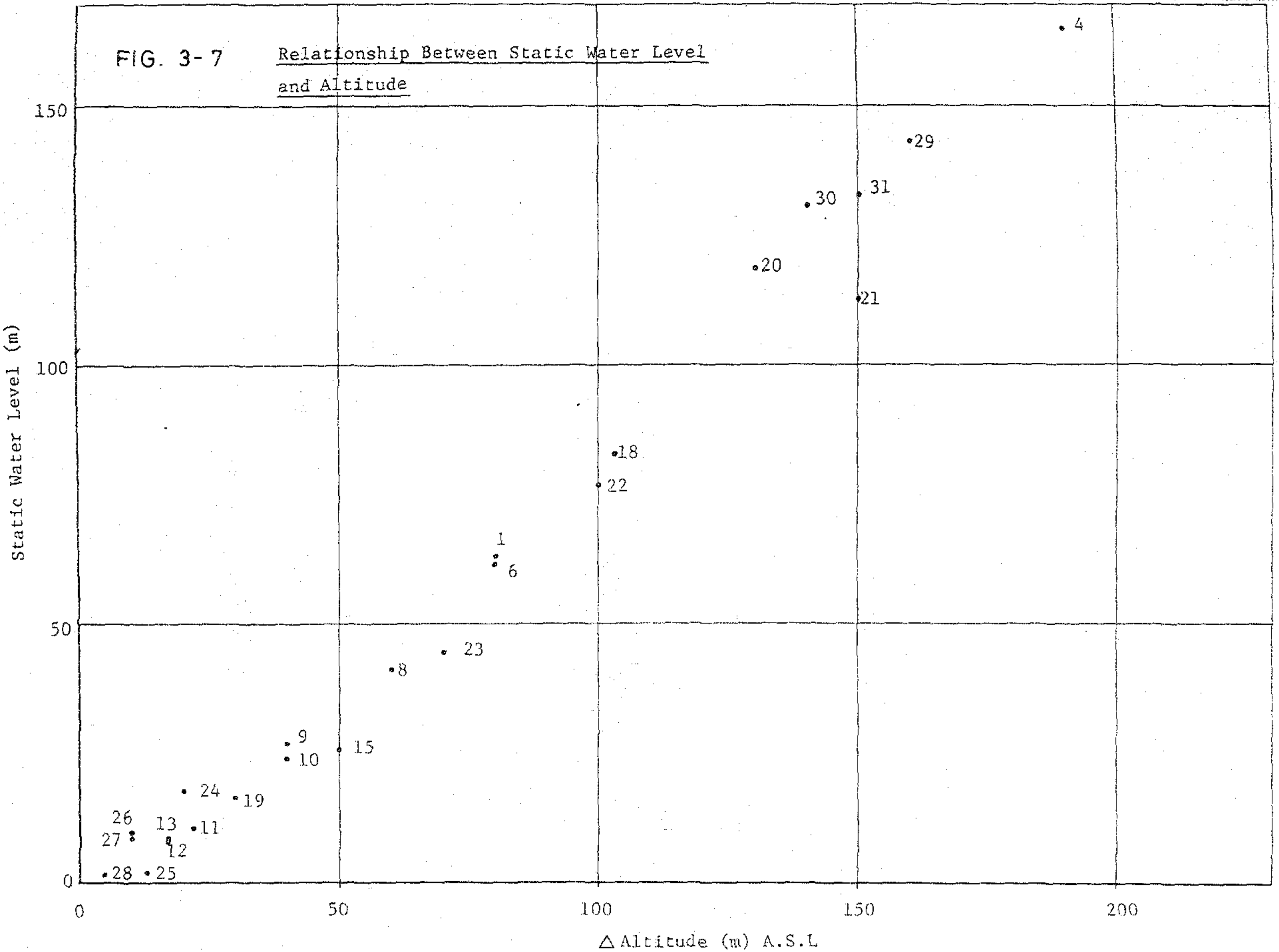
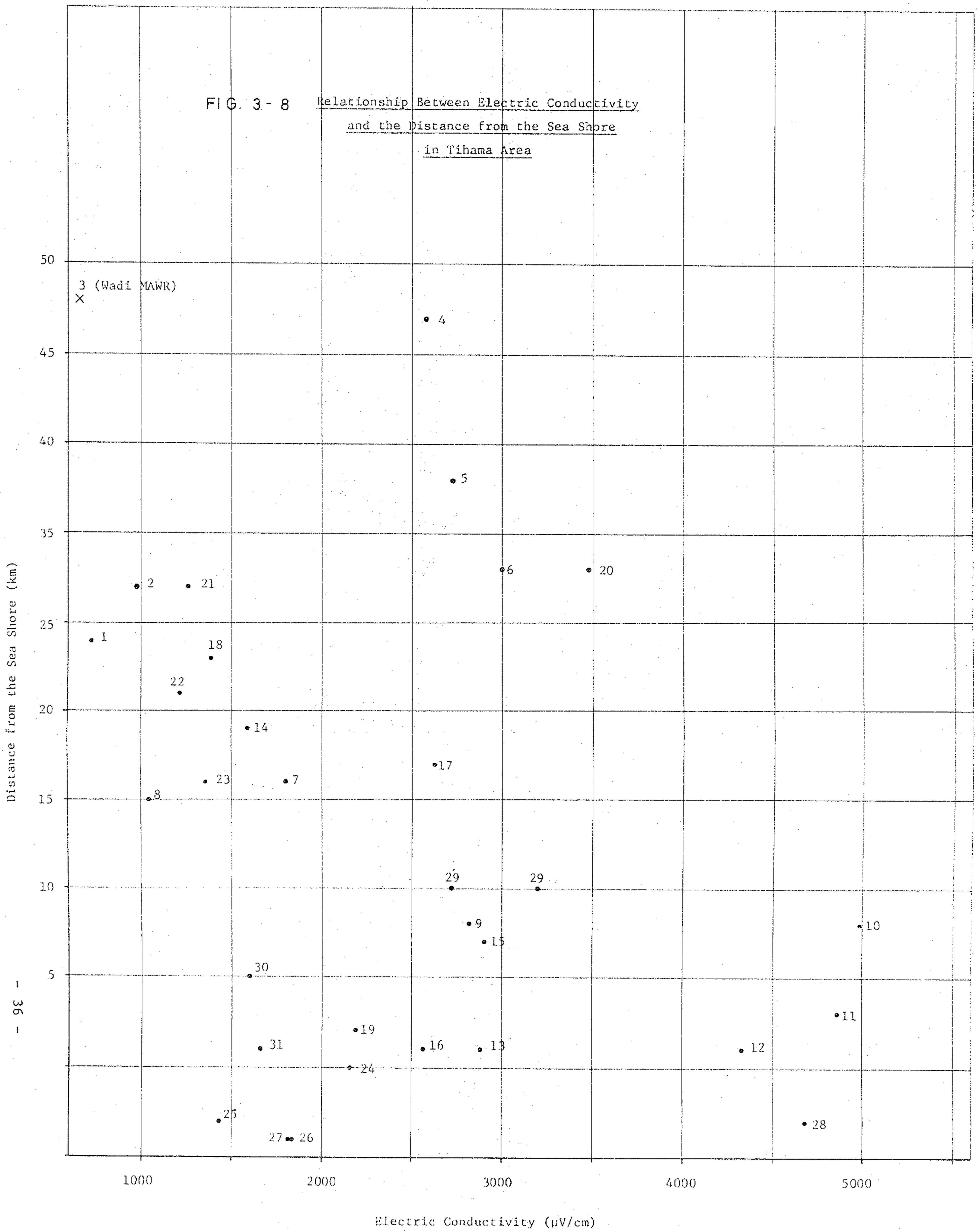
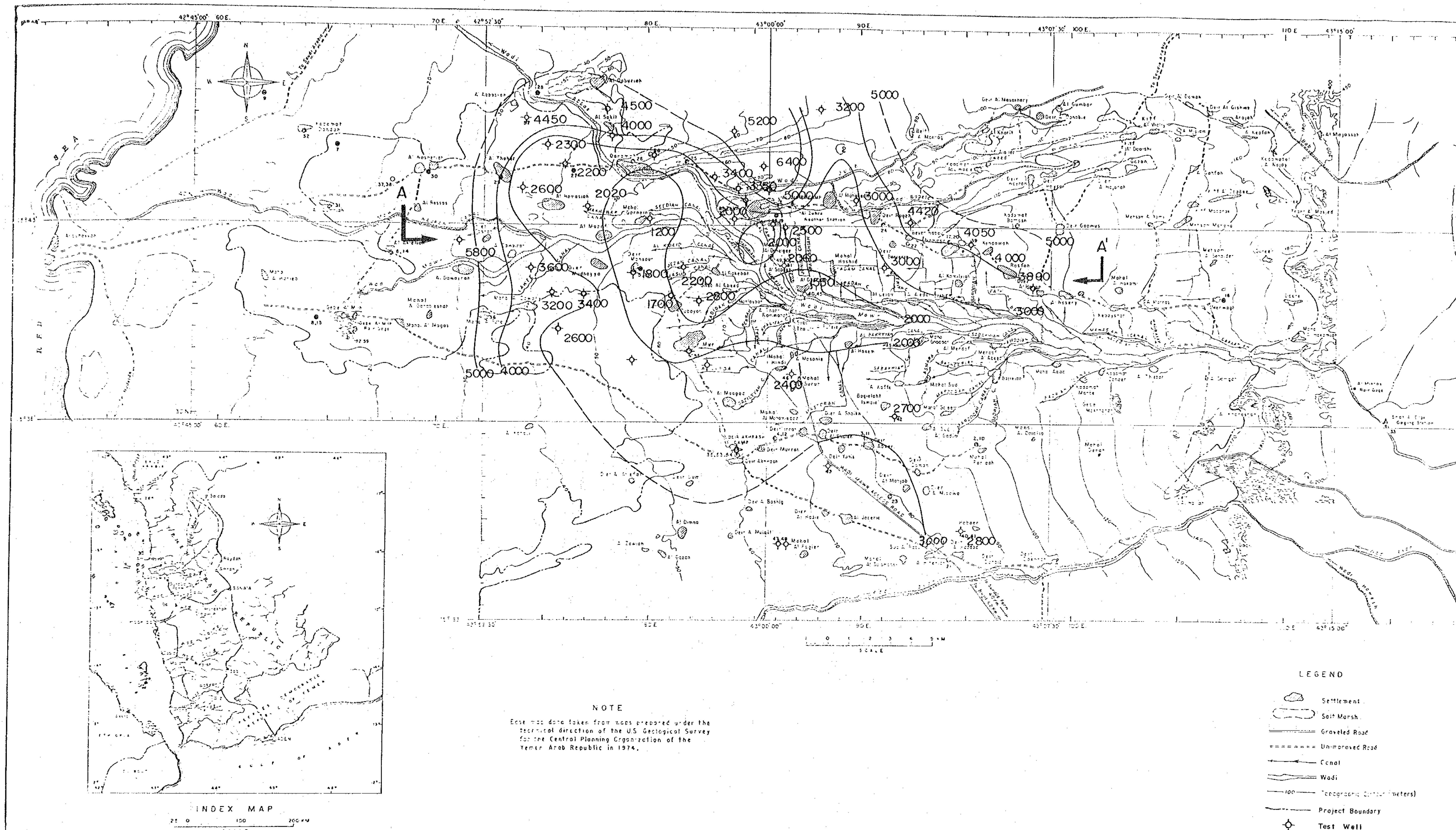


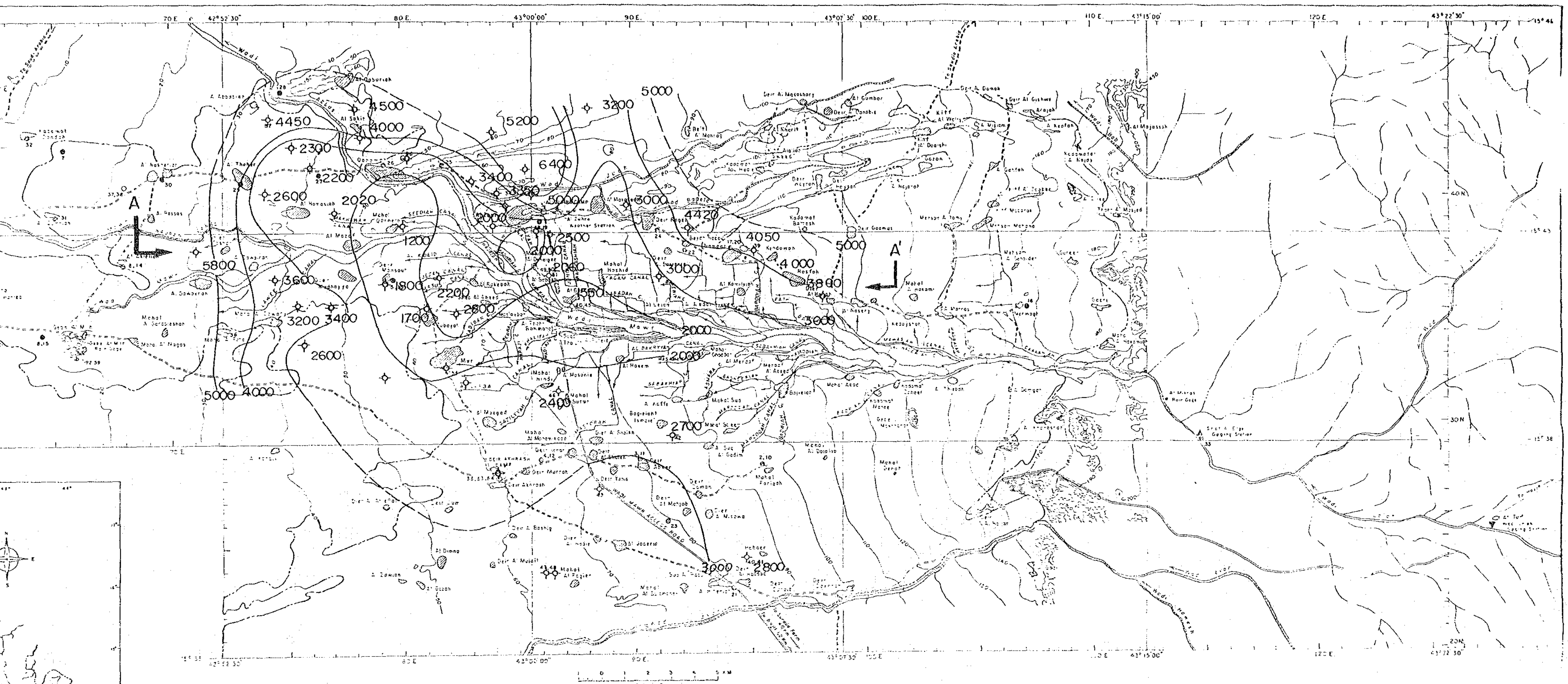
FIG. 3-8 Relationship Between Electric Conductivity and the Distance from the Sea Shore in Tihama Area




A
A'
5800
4450
4500
4000
2300
2200
2600
2020
3600
1800
2200
2800
1200
1700
3200
3400
2600
5000
4000
5200
3200
5000
6400
3400
5000
3000
4420
2500
4000
2060
1550
3000
4050
4 000
3890
5000
3000
2000
2000
2400
2700
3000
2800
NOTE
Base map data taken from maps prepared under the technical direction of the U.S. Geological Survey for the Central Planning Organization of the Yemen Arab Republic in 1974.
INDEX MAP
LEGEND
Settlement
Salt Marsh
Graveled Road
Unimproved Road
Canal
Wadi
Project Boundary
Test Well

FI

ELECTRIC



NOTE

Base map data taken from maps prepared under the technical direction of the U.S. Geological Survey for the Central Planning Organization of the Yemen Arab Republic in 1974.

LEGEND

- Settlement
- Salt Marsh
- Graveled Road
- Unimproved Road
- Canal
- Wadi
- Topographic Contour (meters)
- Project Boundary
- Test Well

FIG. 3-9

ELECTRIC CONDUCTIVITY CONTOURS

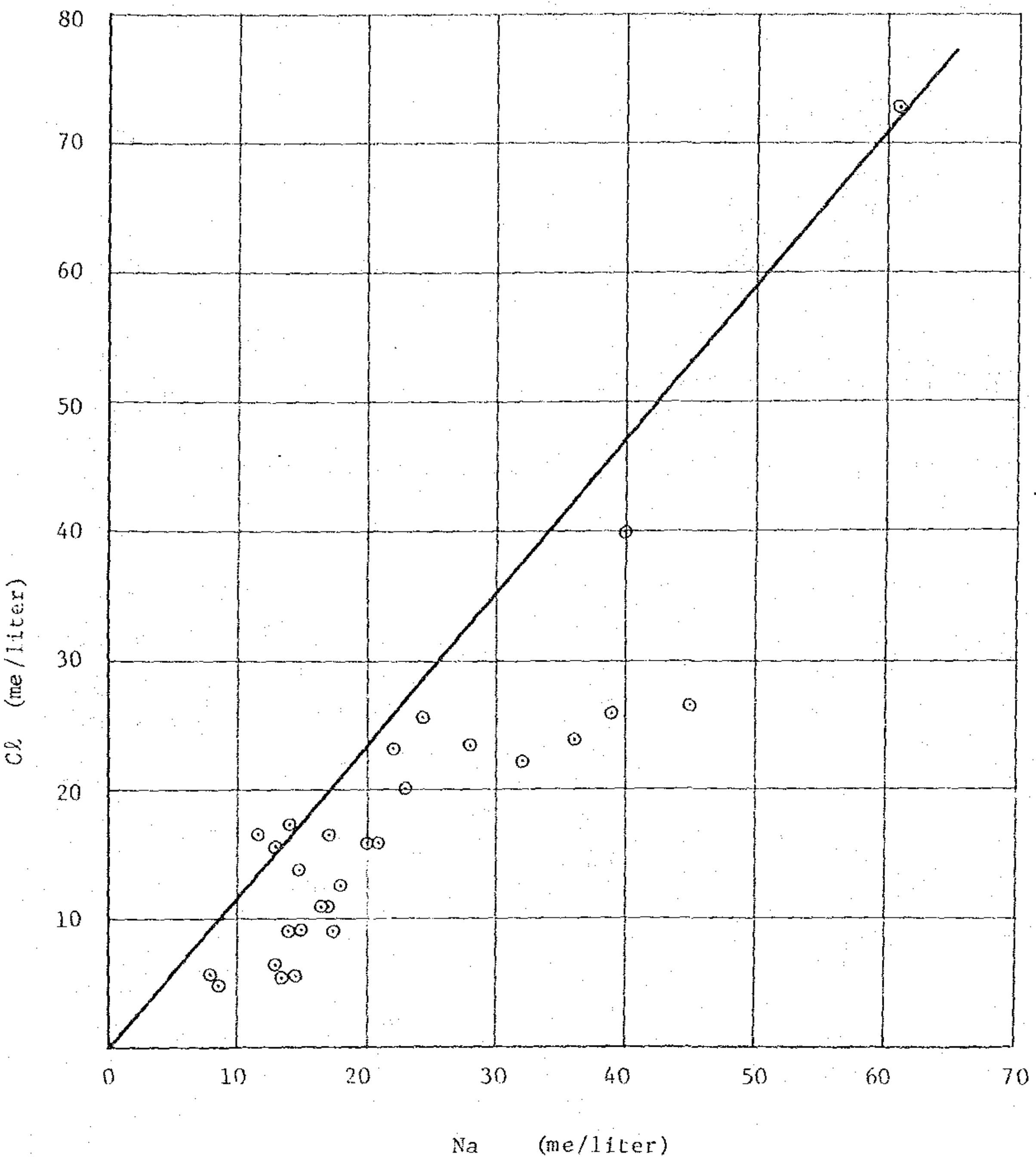
n)
50
0
-50
-100
-150

but are scattered widely. This may suggest the fact that the electrical conductivity of groundwater in the Tihama coastal region is not affected much by the present sea water.

Electrical conductivity data in the report done by Tipton and Kalmbach, Inc. Engineers, 1979 was plotted on a map with contours drawn. The result shown in Fig. 3-9, indicates that the distribution of electrical conductivity seems to be governed by the Wadi Mawr. In other words, electrical conductivity is lower than 2,000 $\mu \mho$/cm near the Wadi, but it increases as the site becomes the further from the Wadi. Within 20 Km from the coast, electrical conductivity has no clear correlation with Wadi locations in the downstream region.

Consequently, it may be concluded that groundwater in the Tihama Coastal region is replenished by the Wadi and diluted by the Wadi stream water (650 $\mu \mho$/cm in Wadi Mawr). The chemical equivalent ratios between Cl^- and Na^+ ion concentration in groundwater are shown in Fig. 3-10. The solid line in Fig. 3-10 represents a Cl^-/Na^+ ratio equal to 0.85 (i.e., the ratio in the mean ocean water). Most Cl^-/Na^+ ratios of groundwater are less than that of the mean ocean water.

FIG. 3-10 Equivalent Ratio Cl^-/Na^+



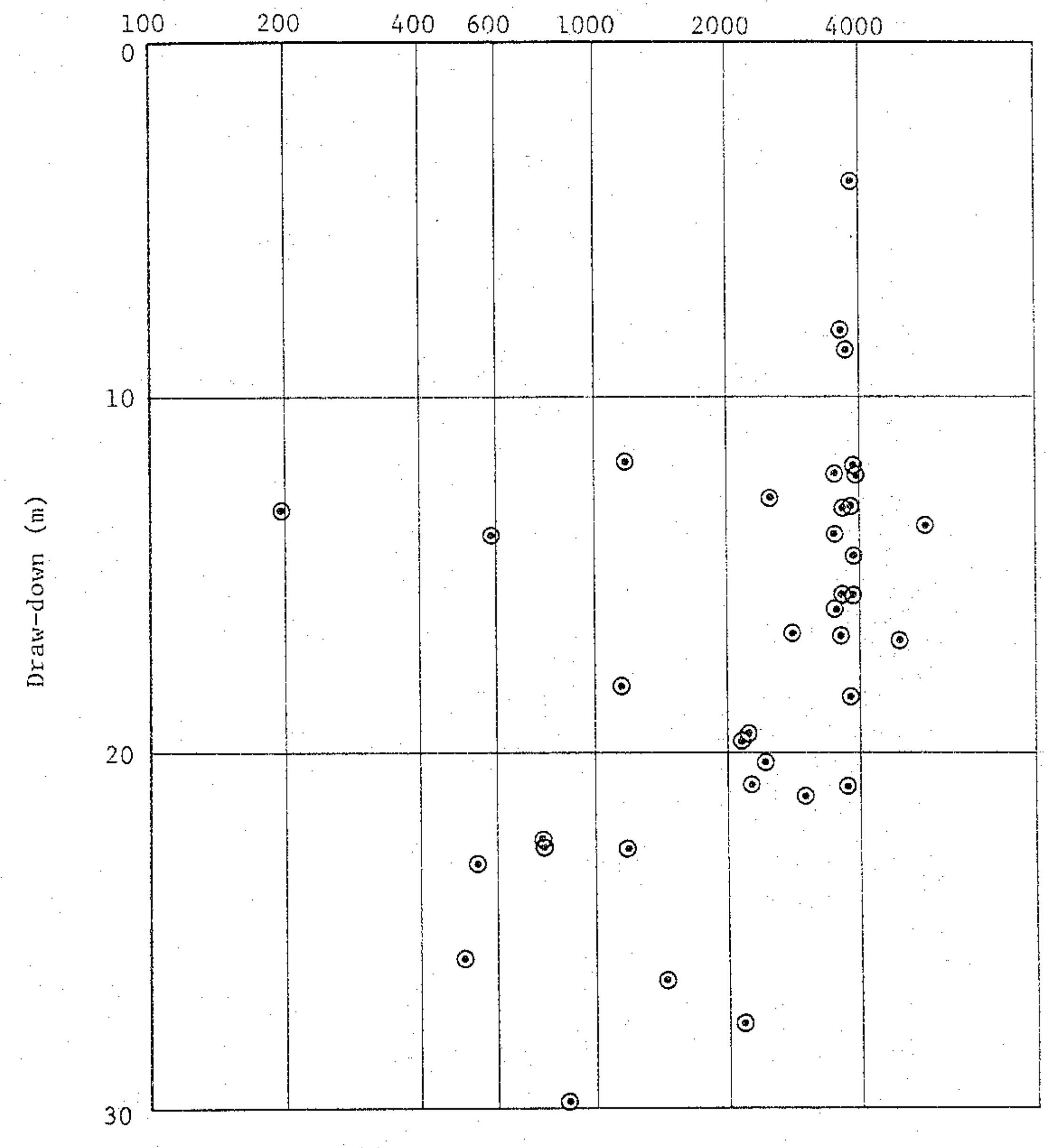
Tipton and Kalmbach. Inc. Eng. 1979

4) Pumping Rate and Drawdown

Until recently, well drilling rarely conducted stepwise pumping tests which provide data showing the relationship between pumping rate and drawdown in the survey area. Consequently, no established yield values ("attainable yield values") can be utilized.

However, the set of pumping tests in Wadi Mawr performed by Tipton and Kalmbach, Inc. Engineers, 1979 (see Fig. 3-11), are extensive enough to determined the local properties of the aquifer.
At first glance, the pumping data shows a large deviation in the yield values (i.e. from approximately 200 to 5,600 m^3/day). The most common pattern (70%) was found in the range from 2,000 to 4,000 m^3/day. The drawdown accompanying the pumping was within the 10 to 25 m range. Fig. 3-12 presents the analytical results of a pumping test conducted at a dug well in Al-Umari (1 m in diameter, 14.07 m deep). From this test, the transmissibility (T) was determined at about $2.5 \times 10^{-3} m^2$/sec and the permeability at about 5×10^{-2} cm/sec. These figures indicate that aquifers in Tihama Coastal region are of good quality and large yields can be expected with small drawdown.

FIG. 3 - 11



Distribution of Drawdown
At Tihama Area

(Tipton and Kalmbach.
Inc. Engineers, 1979)

FIG. 3-12 (1) Analysis of Pumping Test at Al Umari

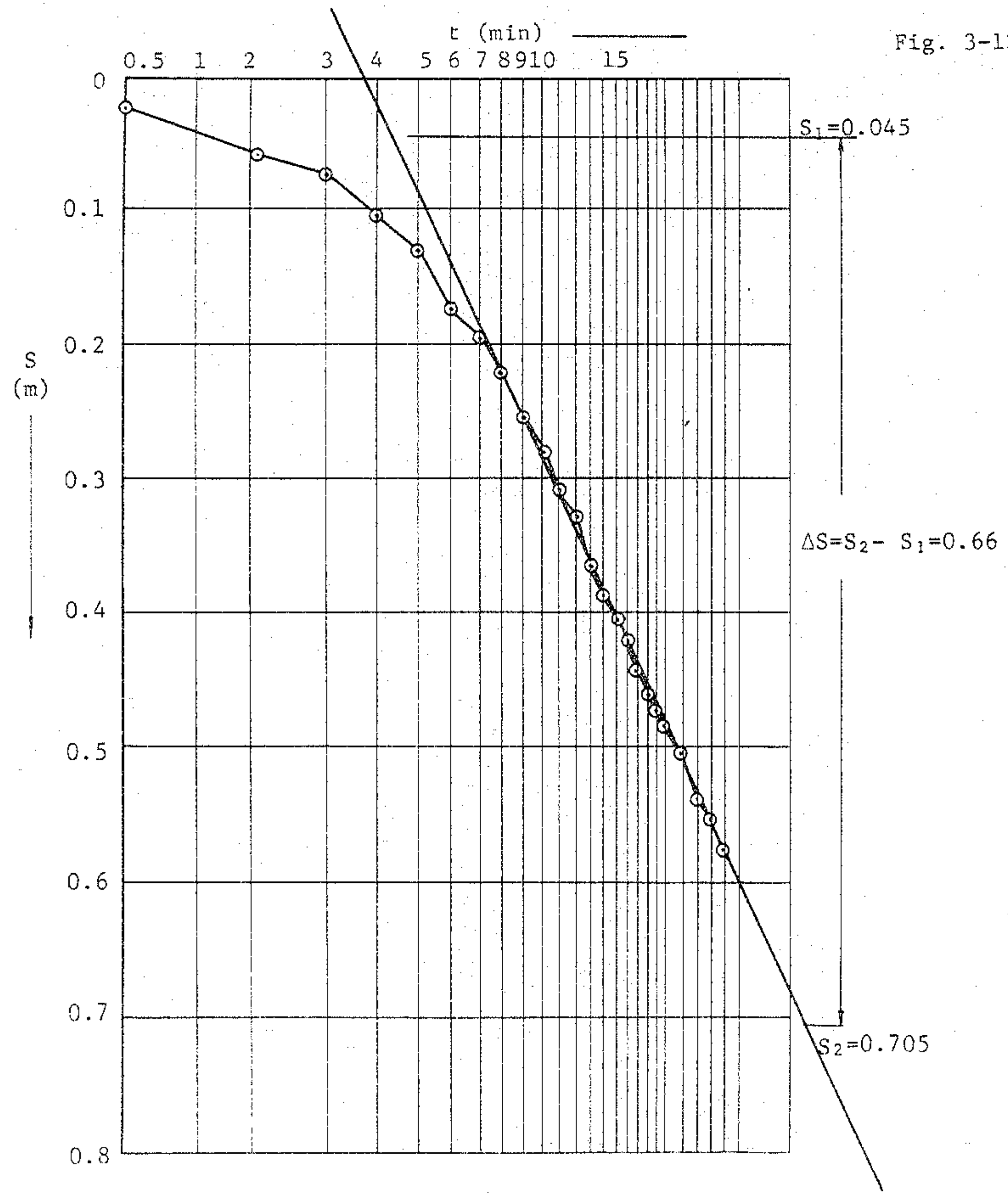


Fig. 3-12(1) Analysis of Pumping Test at Al Umari (Jacob Method)

Static Water Level 9.27m

Pumping Rate 500ℓ/min

$Q = 500ℓ/min = 8.33 \times 10^3 m^3/sec$

$\Delta S = 0.66m$

$b = 4.80m$

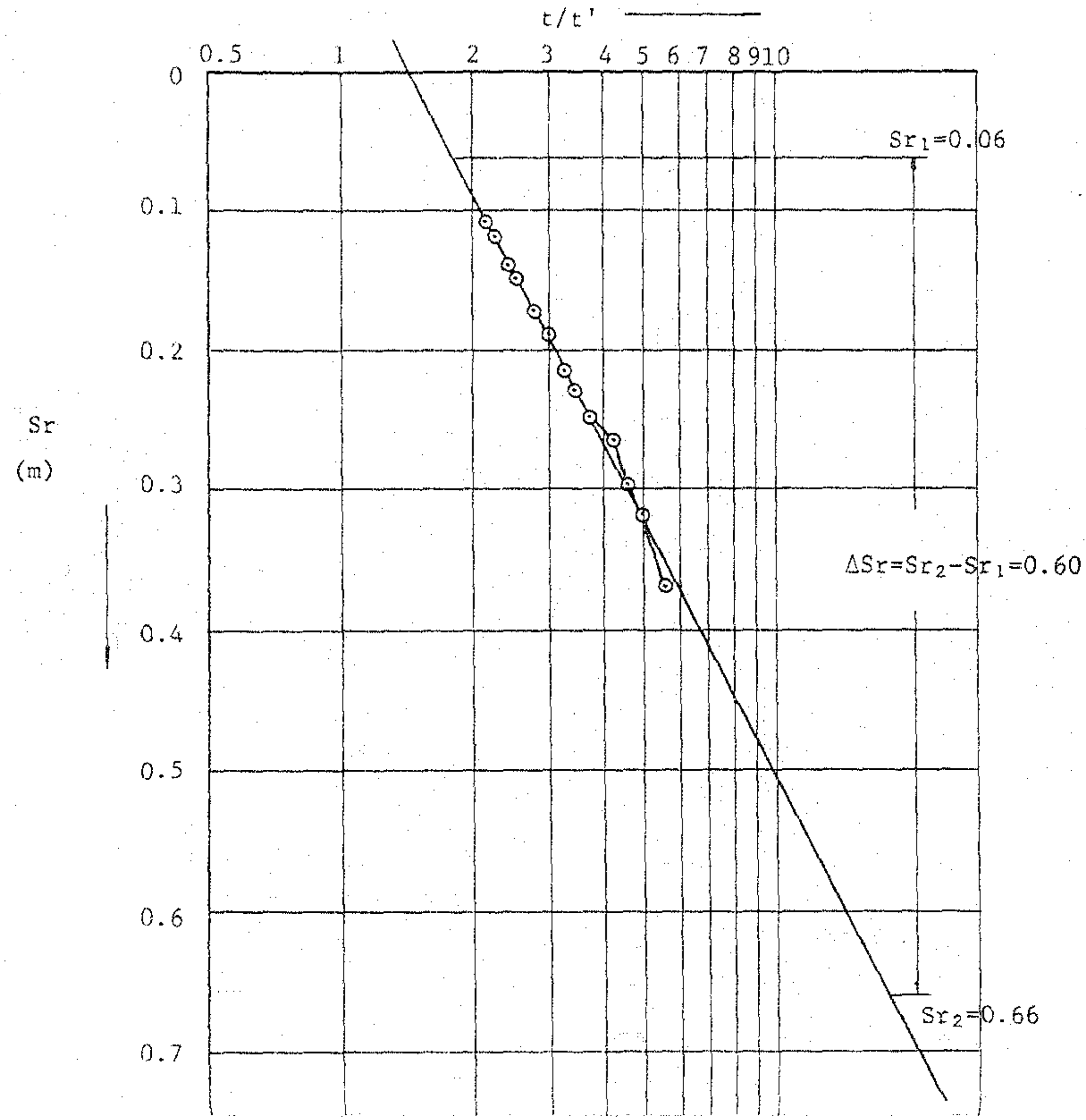
$$T = \frac{0.183Q}{\Delta S} = \frac{0.183 \times 8.33 \times 10^3}{0.66}$$

$$= 2.31 \times 10^3 m^2/sec$$

$$K = \frac{T}{b} = \frac{2.31 \times 10^3}{4.80} = 4.81 \times 10^4 m/sec$$

$$= 4.81 \times 10^2 cm/sec$$

FIG. 3-12 (2) Analysis of Pumping Test at Al Umari
(Recovery Method)



$Q=500\ell/min=8.33x10^3 m^3/sec$

$\Delta Sr=0.60m$

$b=4.80m$

$$T=\frac{0.183Q}{\Delta Sr}=\frac{0.183 \times 8.33 \times 10^3}{0.60}$$

$$= 2.54 \times 10^3 m^2/sec$$

$$K=\frac{T}{b}=\frac{2.54 \times 10^3}{4.80}$$

$$= 5.30 \times 10^4 m/sec$$

$$= 5.30 \times 10^2 cm/sec$$

CHAPTER IV

TYPE OF EXISTING GROUNDWATER FACILITIES AND FUTURE DEVELOPMENT

4-1 Existing Groundwater Facilities

The existing groundwater facilities were classified into 4 major types according to their water-exploiting mechanisms: Tube wells, hand-dug wells, collecting basins and cisterns.

4-1-1 Tube wells (Deep wells)

These are machine-drilled wells of 60 ∼ 500 m depth designed for deep groundwater exploitation, Extraction is done by motor-pumps to storage tanks for consumption. There are many such well facilities installed with U.S. and Saudi Arabia aid. Besides these, an increasing number of such facilities financed by local funds have come into use in recent years.

4-1-2 Hand-dug wells (Shallow wells)

These are the wells of 1 ∼ 2 m in diametre and 30 m or less in depth. Well holes are walled with stone work. These wells tap the shallow groundwaters. Most of the wells are used without motor pumps, and instead, a rubber bucket tied at the end of a long rope is used manually to draw the water up. These wells are often dug in wadi beds in the hilly region, and the bottom may reach the baserock or slightly deeper depth than this, judging from the depth of existing wells. Accidents during well construction and afterwards involving infants have been reported. In addition to this, the wells are not clean since many objects have fallen or been dumped into them.

4-1-3 Water Collecting Basin

These are made for collecting and storing spring waters in the hilly region. Collecting basins are sometimes built out of stone and cement and sometimes carved in the base rock. In places with poor springs, the amount of stored water was negligible even 1 ~ 2 months after the end of rainy season. On the other hand, in the rich spring region, a great amount of water was observed flowing out without any utilization because of the insufficient design of the facilities.

4-1-4 Cisterns

Cisterns are one of the traditional water storage facilities in Y.A.R. In hilly regions, cisterns are built in natural depressions and constructed on mountain slopes with stone mounds to collect surface runoff. The sizes of cistern range from several meters to 100 meters in diameter. They have no cover and so they become polluted with algae growth and an admixture of human waste.

Although the general scheme of the present groundwater facilities in Y.A.R. are as stated above, some localities have configurations of these facilities in hilly regions, hand-dug wells and cisterns are the major elements, although water collecting basins are used only in those places where spring waters are available; hand-dug wells and tube wells are main groundwater facilities in the Tihama coastal region.

4-2 Considerations for the Development of Future Water Resources

This section presents a general classification of water resources exploitable in the future based on the results at each survey site. The details of the results for each site have been described in Chapter VI. Since the focus of this project is principally on instantaneously available, stable and good quality water the most attention was given to deep and shallow groundwater and subsurface reservoirs as the target water resources.

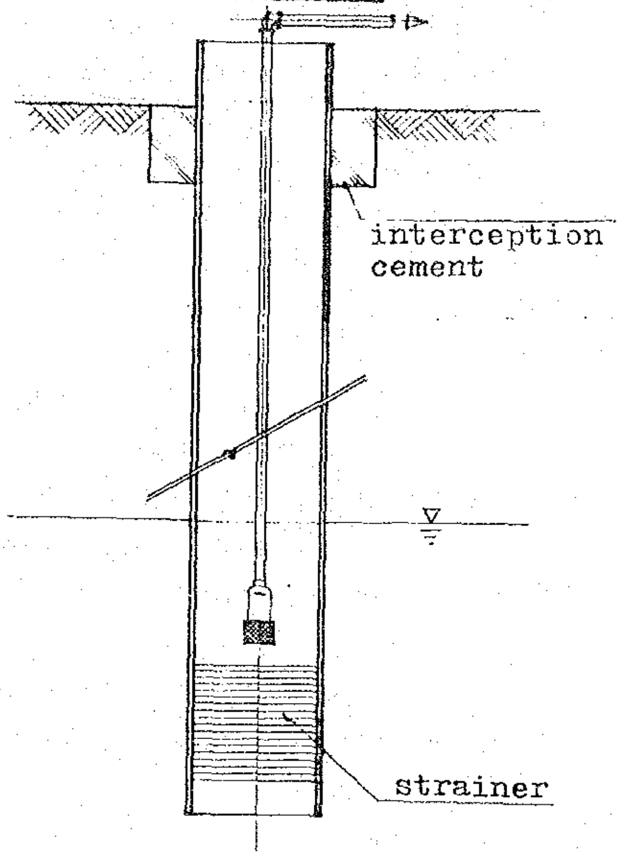
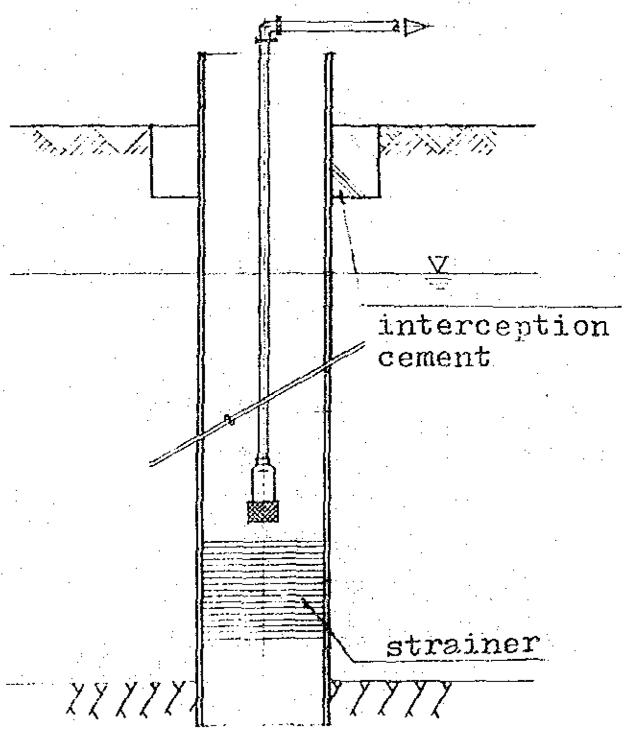
On the other hand, those types of water resources specified in Fig. 4-1 should be taken into consideration for planning for the future development projects.

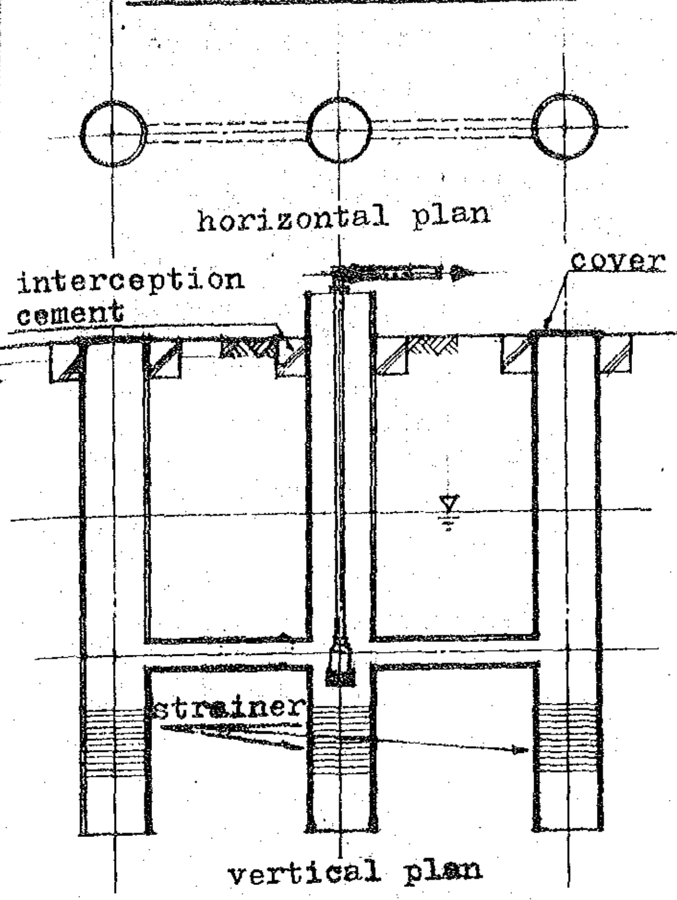
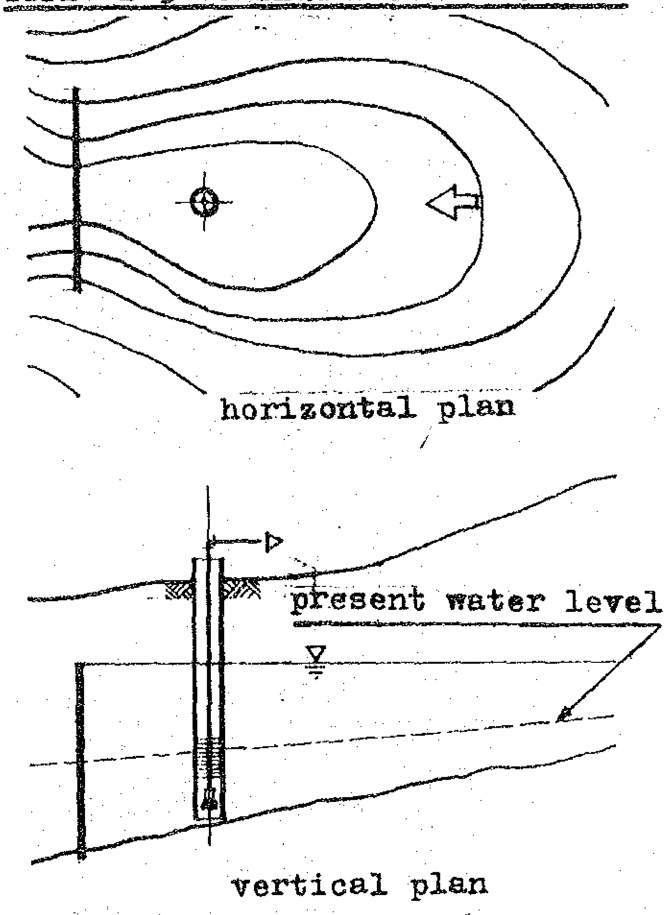
Water resources in Y.A.R. can be divided into two types Ii.e. groundwaters and surface flows). Groundwaters determine the water exploiting facilities according to their occurrences: whether they are deep groundwaters or shallow groundwaters.

As shown in Fig. 4-1, spring water is included in groundwater for it can be regarded as a local variety of groundwater. The springs which were surveyed in the present work were, with the exception of the Al-Mapan Spring, of extremely small discharge with a large seasonal variation. Consequently, it is not realistic to install intake facilities that utilize only the present amount of spring flow because of its unstable capacity. As a solution to this problem C_1 and C_2 type facilities shown in Fig. 4-1 are proposed, where local groundwaters around a certain spring are actively collected and stored.

In the case of surface flow exploitation, ground surface dams, constructed in valleys in hilly region, are conceivable. During the field survey, several topographically suitable places were found, but with insufficient planning data on precipitation, evapotranspiration and hygienic restrictions for drinking water. As this project has been planned for the very near term implementation, dams are excluded from the plan. However, for further planning such dams should be considered, especially in localities with relatively high precipitation. For this purpose, data collection of hydrometeorology is urgently required.

Figure 4-1. PROPOSED WATER SOURCE FACILITIES

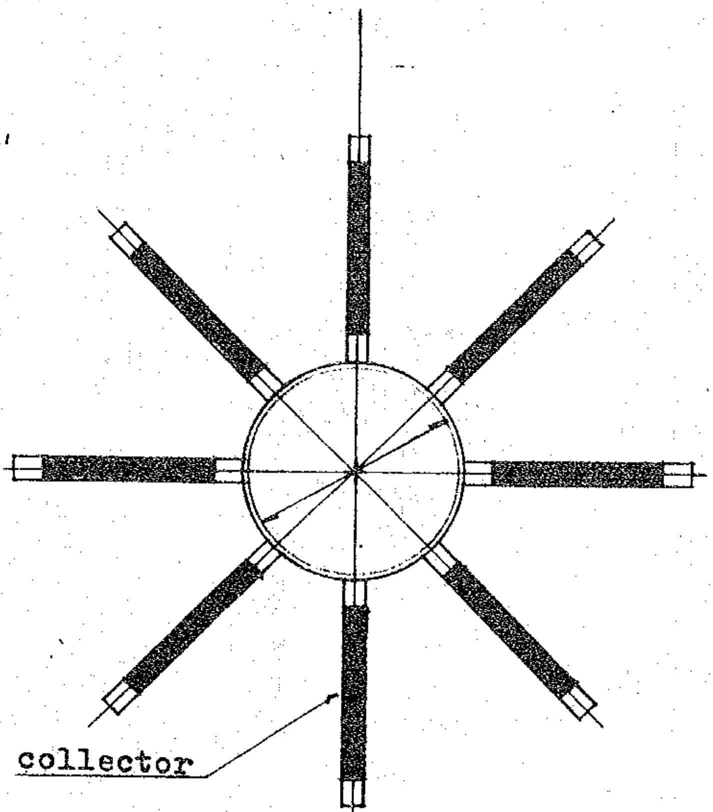
SCHEMATIC PLAN	REMARKS
TYPE'A' DEEP GROUND WATER BORE HOLE 	Supporting hydrogeological data are required to ensure the necessary amount of yield. In addition, accessibility of heavy machinery is important. This type of water source is proposed at several sites as follows: Al Madan, Al Man, Sihara, Dare Bany Shaker/Bait Abo Sabaa, Bait Abo Hashem, Al Sheab Alaswad, Bany Farhan/Bany Sariaa, Al Mashgab, Al Manar/Al Dukm, Al Maydan, Shebd Hamud/Al Jubail, Hadad/Qahfa, Aldahi, Almunayra, Yahkhtol and Makbana.
TYPE 'B-1' SHALLOW WELL 	The thickness of water holding strata has to be more than 20m from the ground surface to the impermeable strata at the bottom. Required minimum hydraulic gradient. Feasibility study of this type of water source is proposed at Shohat/Al Kadash, Al Munayra and Yahkhtol.

SCHEMATIC PLAN	REMARKS
TYPE 'B-2' SHALLOW WELL 	This type of water source is applicable where ground water level is sufficientry high (less than 5m) and sufficient amount of recharge is expected although the yield of a single hole is insufficient. This type of water source is proposed at Ghulayfagah and Yahkhtol.
TYPE 'B-3' UNDERGROUND RESERVOIR 	Suitable topography and site geology is required. Supporting data are necessary to ensure the sufficient subsurface storage capacity. This type of water source is proposed at Shohat/Al Kadash.

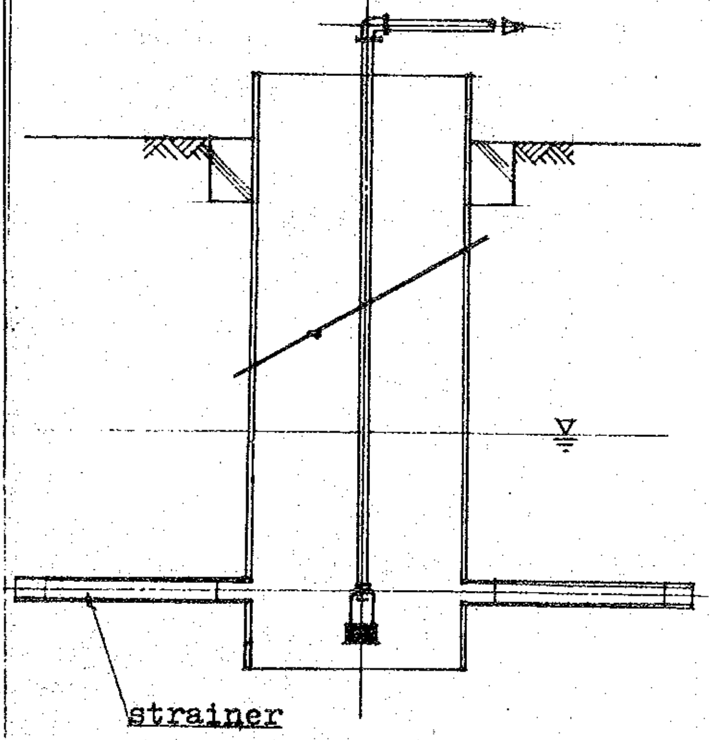
Continued

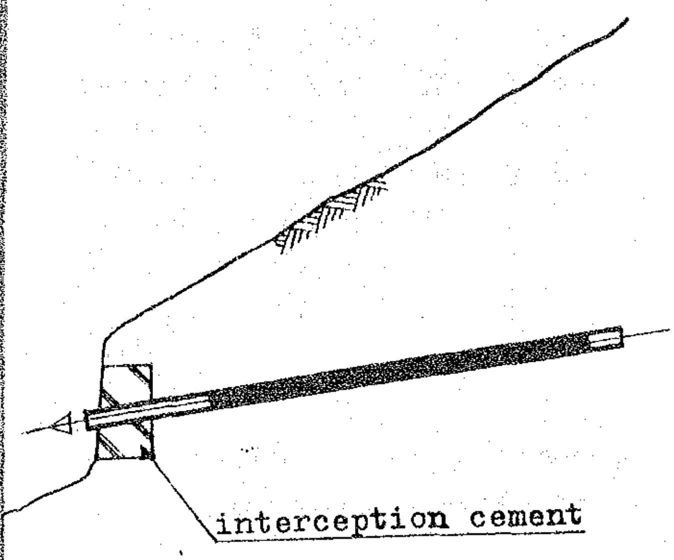
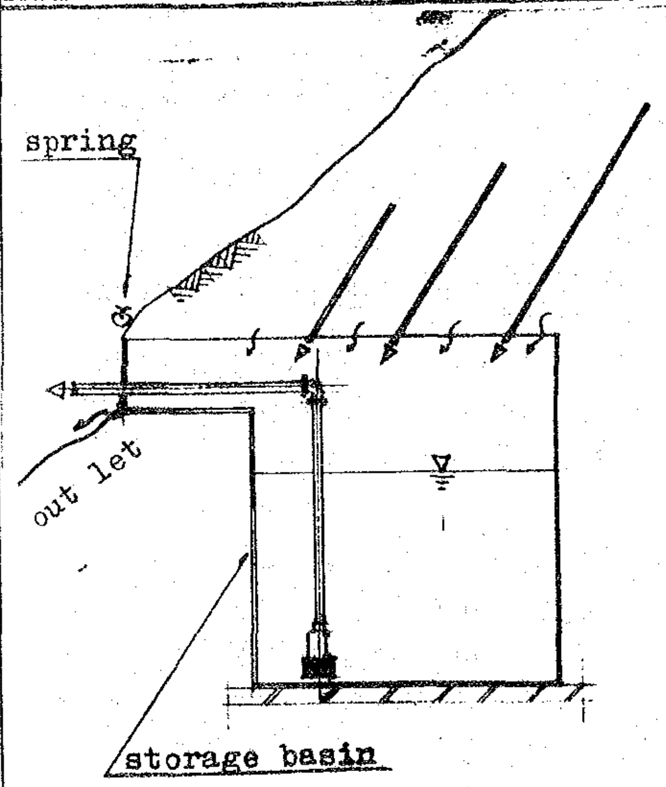
SCHEMATIC PLAN	REMARKS
TYPE 'B-4' COLLECTING WELL	This is applicable at Wadi where the yield of a single well is insufficient while the width of the Wadi is sufficiently wide (more than 200m wide). Feasibility study for this type of water source is proposed at Al Kodha/ Al Hagl, Ghulayfagah, Almunayra and Yahkhtol.

horizontal plan

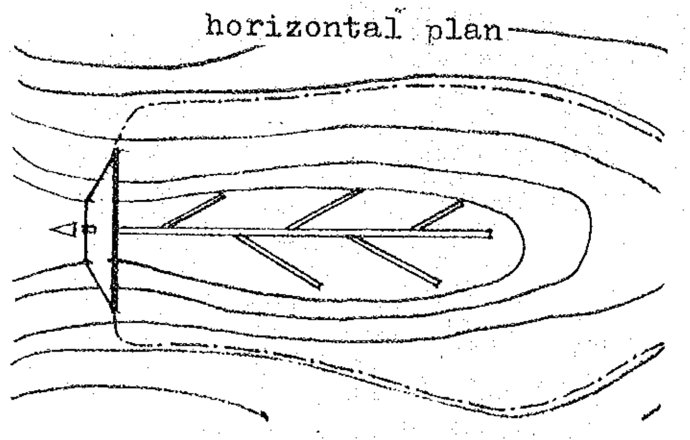
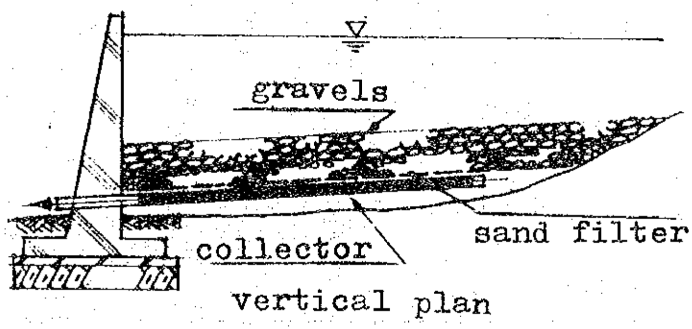
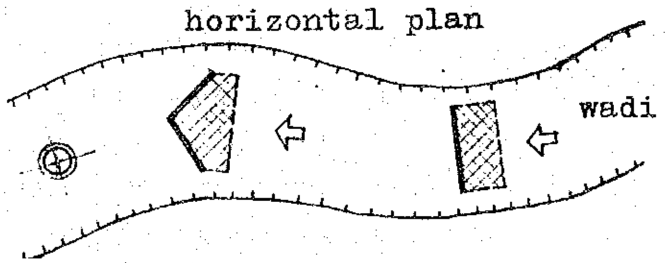
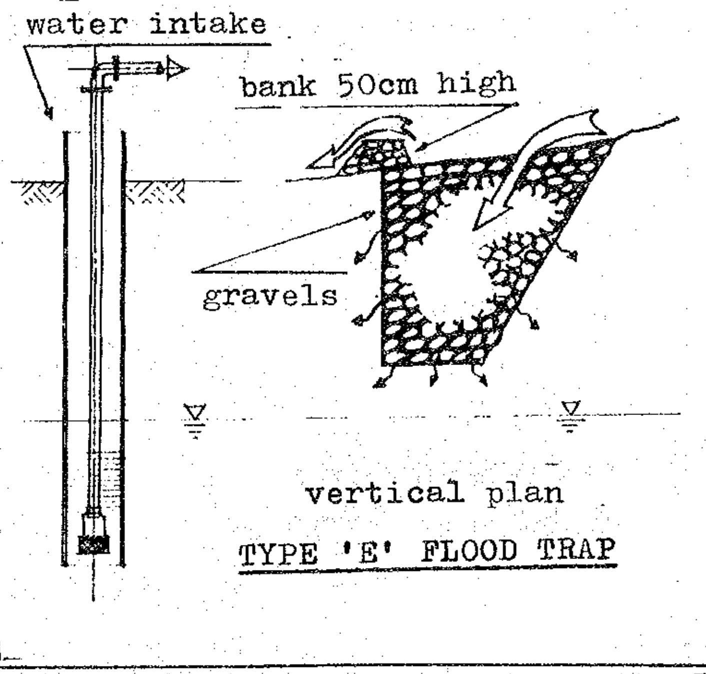


vertical plan



SCHEMATIC PLAN	REMARKS
TYPE 'C-1' HORIZONTAL DRILLING 	Horizontal drilling is applicable where water is obtainable from structure zone along fault or dykes. Supporting data are required to ensure the amount of water available. Feasibility study is proposed at Al Madan, Elman, Sihara, Bany Shaker/Bait Abo Sabaa and Al Zakirah for future water source.
SUB-SURFACE STORAGE BASIN TYPE 'C-2' SUB-SURFACE STORAGE BASIN 	An improvement of spring utilization. Supporting data are required to ensure the amount of spring yield. Feasibility study is proposed at Al Madan and Al Zakirah for future water source.

Continued

SCHEMATIC PLAN	REMARKS
 TYPE 'D' RESERVOIR 	Suitable topography and geological condition are required and also sufficient yield from the catchment is necessary. Feasibility study is proposed at Bany Shaker/Bait Abo Sabaa, Al Sheab Al Aswad and Hadad/ Qahfa for the future water source.
  TYPE 'E' FLOOD TRAP	Objective of this facility is to trap flood water with banks provided at rectangular direction to the flow. Feasibility study of this type of structure is proposed at Al Madan and Shohat/Al Kadash.

CHAPTER V

SELECTION OF WATER SOURCE FOR THE RURAL WATER SUPPLY PROJECT

Based on the hydrogeological analyses done in the preceding chapters, data on the type of water source, quantity and estimated safe yield are summarized in Table 5-1 for each site. Most of the types of water sources were finally decided to be deep groundwater for the following reasons:

(1) The present survey was made for the rural water supply project planned for the immediate implementation.

(2) Shallow groundwaters and springs exist at some of the proposed development sites. However, feasible values seasonal variations of spring discharge could not be determined. Such deficiency in the available data present serious uncertainties to determine the scale of water source in order to evaluate the stability of the water source and its quantity.

(3) Dam construction was excluded among water sources under the project, however, proposed for water sources to utilize surface flow in future because of insufficient hydrometeorological data to enable calculation of the storage capacity and the size of the dam at present. In order to take advantage of the countless number of suitable dam sites, thanks to the rough topographic land features in Y.A.R., it is strongly recommended to initiate and continue collection and compilation of the basic data.

For the reasons above, deep groundwater development, which has been well experienced in Y.A.R., was chosen as the planning focus. The scale of water sources was determined based on the local geography, hydrogeological conditions, electric probing etc.

In order to estimate the safe yield of the proposed borehole, reference was made to the following aspects:

(1) Whether sufficient back up data of the aquifer is available with recorded yield of existing boreholes,
(2) Whether the results of electric prospecting can the prospecting yield of boreholes,
(3)
yield of boreholes, and
(4) hether uality of the groundwater is potable especially at Tihama Plain.

Generally, the yield of a single borehole in Alluvium, Quaternary Volcanics and Trap Series appears to be relatively stable in the Republic as shown in Table 3-3. Especially at Tihama area, the yield of a single borehole ranges between 2,000 and 4,000 m^3/day. (Fig. 3-11) Also in the alluvial deposits of wadis which has a large catchment area and thick accumulation of deposits, the yield of a single borehole is large at Al Mashjab and Al-Manara/Al Dukum. The groundwater source in these types of aquifer is classified as category A in terms of the availability of water.

On the other hand, although the yields of the same type of aquifer are recorded satisfactory production wells, no record is obtainable in the vicinity of the location of the proposed borehole in Hajja, Al Mahweet and Sana'a.
In this case, the availability of the groundwater is classified as category B. It is also classified as category B where the yield of boreholes varies in a wide range although the borehole is drilled the same type of aquifer as shown in Table 3-3.

In Turbah area, the survey site is located on the high cliff with more than 1,000 m relative height and the catchment area has only a limited extent. Accordingly, the availability of groundwater is extremely low which is classified as category C. The classified availability of groundwater is summarized in Table 5-1.

Table 5-1

Type of Water Source and Yield

Number	Survey Site	Classification of Yield	Diameter (mm)	Depth (m)	Pumping Head	Yield (m^3/day)	Future Water Source Development
HA-1	Al-Madan & 8 Villages	B	200	300	200	300	A,C1,C2,E
HA-2	Elman & 4 Other Villages	B	200	300	200	300	A,C1
HA-3-A	Sihara	B	200	300	200	300	A,C1
HA-3-B	Thari	B	200	200	150	300	A
HA-4	Harad	A	200	120	100	1,000	A
A-1	Al-Mahweet City	B	200	200	150	300	A,C1
A-2	Hufash	B	200	200	150	300	A,B3
A-3	Al-Rajam	B	200	300	200	300	A
A-4	Al-Khabet	B	200	200	150	300	A,B3
S-1	Bany Shaker & Bait Abo Saba'a	B	200	200	150	200	A,C1,D
S-2	Bait Abo Hashem	B	200	200	150	200	A
S-3	Al-Sheab Al-Aswad	B	200	100	100	300	A,D
S-4	Bany Farhan & Bany Saria'a	B	200	100	100	300	A

Continued

Table 5-1 (Cont'd)

Number	Survey Site	Classification of Yield	Diameter (mm)	Depth (m)	Pumping Head	Yield* (m^3/day)	Future Water Source Development
H-1	Ghulayfagah	B	200	30		100	A,B2,B4
H-2	Al-Dahi	A	200	80	50	1,000	A,B4
H-3	Al-Mounirah (to supply Ebn-Abbas and Al-Harunia)	A	200	60	50	1,500	A
T-1	Al-Mashjab	A	200	110	100	400	A
T-2	Al-Manara & Al-Dukum	A	200	110	100	400	A
T-3	Al-Maydan, Al-Jubail Sheiba Hamud	B	200	200	150	700	A
T-4-A	Hadad, Qahfa	A	200	180	150	500	A,D
T-4-B	Al-Kudha, Al-Hagl	C	200	250	200	100	A,B4
T-5	Shohat, Al-Kadash	C		10	50	200	B3,B1,E
T-6	Al-Zakira	C	200	250	200	100	A,C1,C2
T-7	Bab-Al-Mandab	A	200	(85)	50	500	A,B4,E
T-8	Yahkhtol	A	200	100	50	1,000	A,B4
T-9	Makbana	A	200	300	200	700	A

The depth of wells in the hilly region was chosen in order to collect waters from the all available fissures since most groundwaters are presumably born in fissure zones. On the other hand, the well depth in the Tihama coastal region was determined as down to the mean sea level in general, although electric probes did not indicate any sea water intrusion.

The estimated attainable yields are based on the data previously obtained and discussed in Chapter III (Hydrogeology) and judgement of the hydrogeological conditions at each site.

CHAPTER VI

HYDROGEOLOGY OF THE SITES AND CONSIDERATIONS FOR THE FUTURE WATER RESOURCE DEVELOPMENT

The location of each site is shown in Fig. 6-1.

6-1: Al-Madan and eight neighbouring villages (HA-1)

6-1-1: Geography (Fig. 6-2)

The areal extents of the sites are mostly around 10 Km^2 and the altitudes variety from 1,300 m A.S.L. at the wadi bed to 2,300 m at top of the hill. Precipitous cliffs rise for hundreds of meters from wadi to hill top. Local communities are distributed mainly on the mountains, located between the summits and the 2,000 m altitude zone.

These residential areas are relatively gentle in surface gradient with a high concentration of valleys.

6-1-2: Hydrogeology

Trap series are predominant at this site. Rock species are rhyolite, tuff, andesite, etc. The andesite formation is tens of meters thick and crops out at several levels between the hill top and the wadi bed. There are 14 springs, called Al-Maaian, in total, distributed around the center of the villages and scattered on the gentle slopes to the south east. These springs come from between the andesite and tuff. The andesite is hard and has a number of joints in the vertical direction. The tuff in contrast is soft and relatively free of joints; the stuff therefore is regarded as an aquiclude relatively speaking. People store water in collecting basins. The basins are not covered and therefore algae and micro-zooids proliferate and foreign water and dirt is dumped into eventually causing them to become deteriorated from a sanitary point of view. Much of the water flows away without being fully utilized due to the small volume of the basins. Only the Al-Maaian spring group is found to belong to this hydrogeological system at the site. Another spring (S-1) is observed to issue

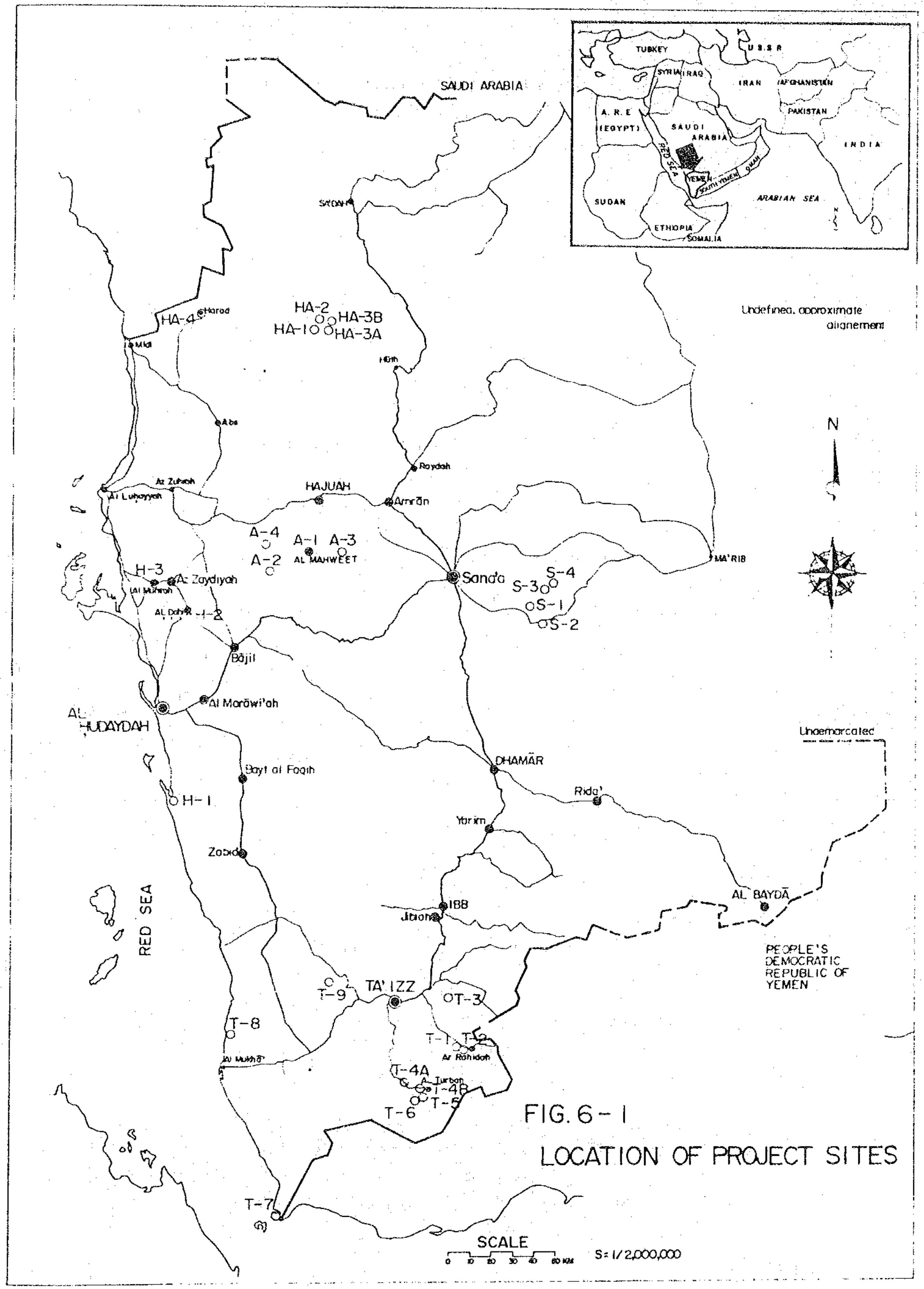


FIG. 6-1

LOCATION OF PROJECT SITES

LIST OF PROJECT SITES

NUMBER	SURVEY SITE	DISTRICT	GOVERNORATE
HA-1	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	Haradh	
A-1	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-1	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-1	Ghulayfagah	Duraihmi	HODEIDAH (H)
H-2	AL-Dahi	Hodeidah	
H-3	AL-Mounirah (to supply Ebn-Abbas and AL-Harunia)	Zuhrah	
T-1	AL-Mashjab	AL-Sulou	TAIZ (T)
T-2	AL-Manara & AL-Dukum	AL-Sulou	
T-3	AL-Maydan, AL-Jubail Sheibd Hamud	Kadier AL-Buraihi	
T-4-A	Hadad, Qahfe	AL-Turba	
T-4-B	AL-Kudha, AL-Hagl	AL-Turba	
T-5	Shohat, 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

from the rhyolite formation on the mountain slope in the eastern part of the site. It discharges along the joints aligning N40° - 50°W. However the discharge is very small. Faults and dykes are not intensive in the Trap Series.

6-1-3: Recommended water source

The recommended water sources in this site are as follows:-

The water source of the project

Type A: Deep Ground water

1. Up stream from Wadi Gaaman is recommended as a drilling site. From there easier supply systems are anticipated, since the service areas are located on top of the precipitous cliffs of 2,000 m A.S.L. and surrounded by extremely rough topographic relief.

2. The road must be widened and improved at two sections between the village and the water source.

3. Well location should be determined relative to the mutual disposition instead of geological feature, since prevailing faults or joints exist.

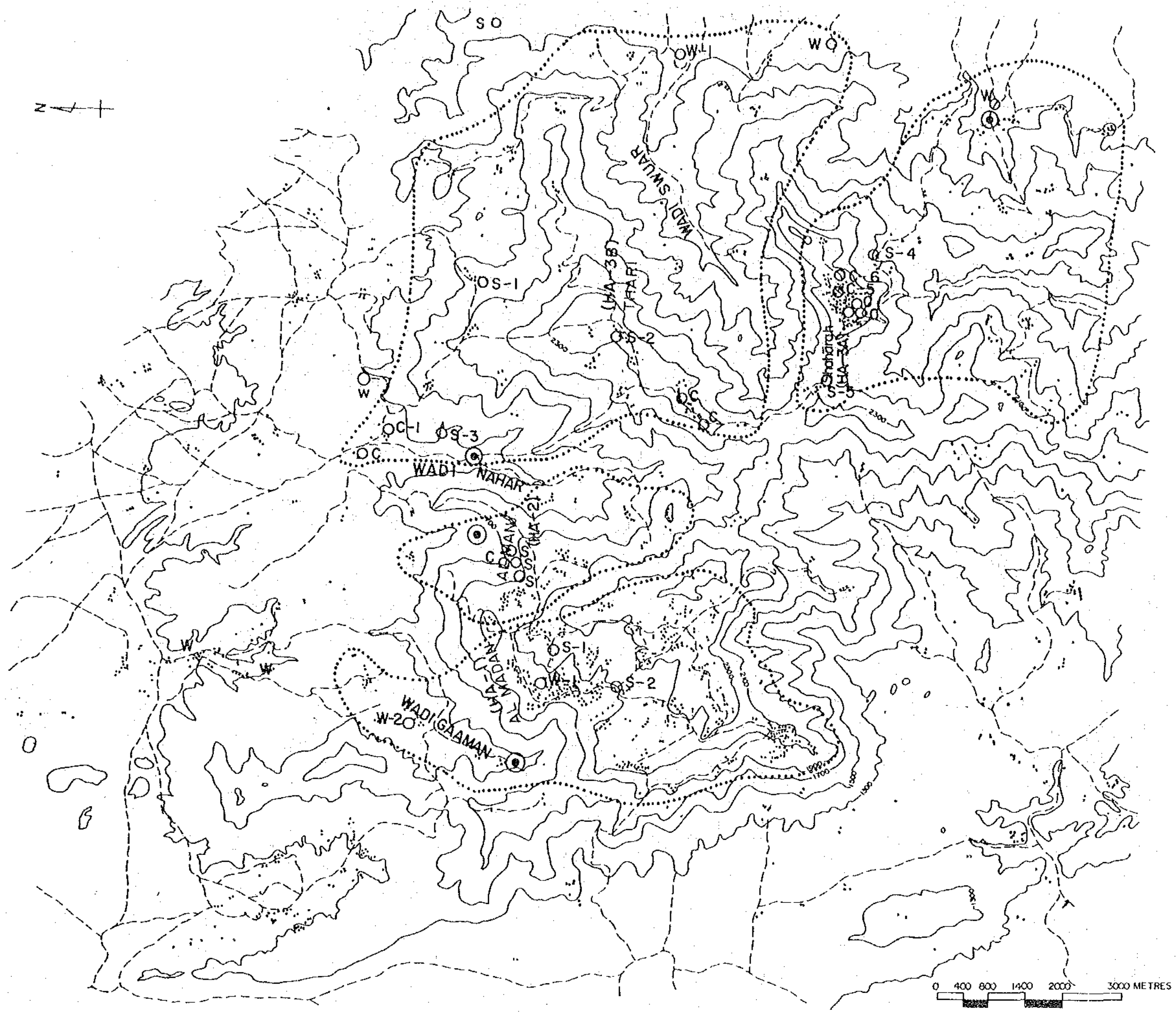
4. Operational waters can be supplied from dug wells nearby.

For the future water source development.

Type Cl: Horizontal drilling

1. The recommended site is somewhere near (S-1) spring (situated at the foot of the mountain and installed with a pump). The spring is restricted to the direction along the joints aligned N40°-50°W, therefore a set of drilled wells can be arranged crossing the joints direction in order to collect water.

2. There is a fear among the people that the existing collecting basin systems with pumping and storage facilities may be influenced by the newly introduced well systems.



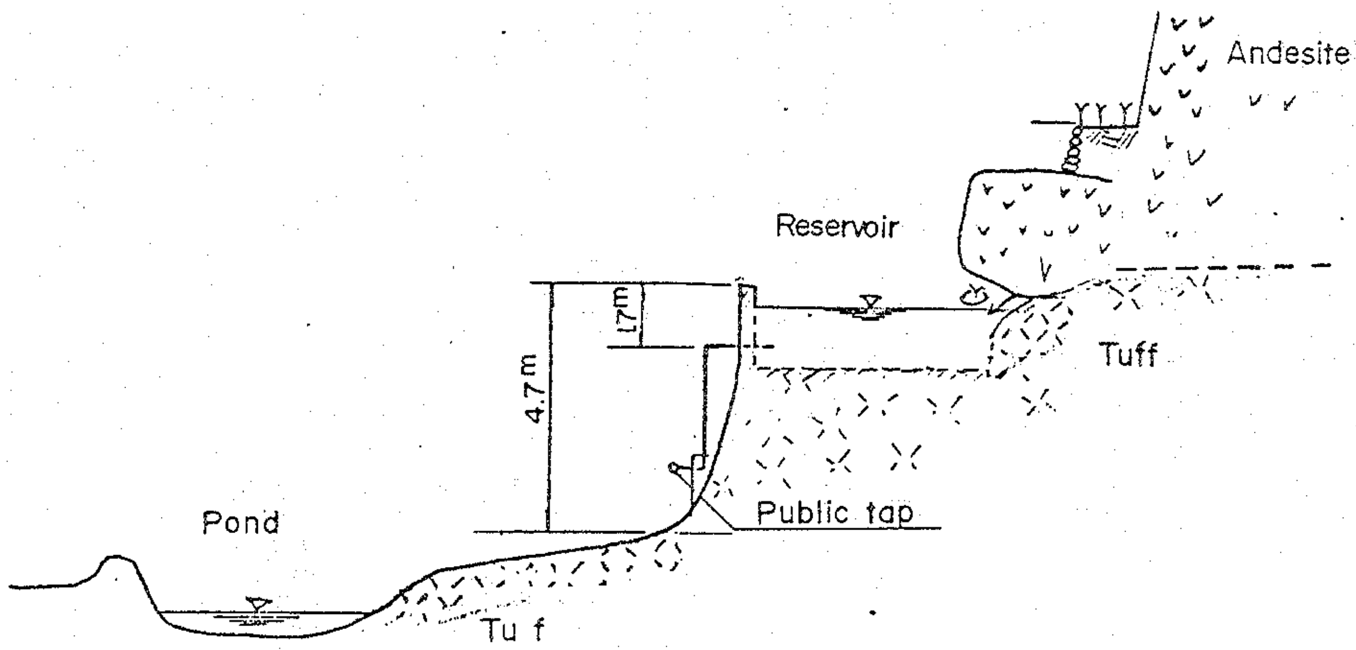
LEGEND	
O W	WELL
O C	CISTERN
O S	SPRING
(dotted line)	BOUNDARY
⊙	PROPOSED BOREHOLE

Fig. 6-2

MINISTRY OF PUBLIC WORKS YEMEN ARAB REPUBLIC
THE RURAL WATER SUPPLY PROJECT PART- II
LOCATION MAP OF HAJJA AREA (HA-1 , HA-2 , HA-3A, HA-3B)
DESIGNED BY Pacific Consultants International
DATE SCALE 1: DRAWING No.
JAPAN INTERNATIONAL COOPERATION AGENCY, TOKYO, JAPAN

FIG. 6-3 SKETCH MAP OF WATER SYSTEM

(A) Spring with reservoir



3. Judging from the topographical relief, many springs may disappear as the result of new wells, being installed the estimation of collectable water volume is difficult.

4. As water source for this site it is not adequate and further study is necessary on the recharge mechanism of the spring water.

Type C2: Subsurface Reservoir

1. The recommended site is the Al-Maaian spring area (a valley with 14 springs).
2. At present there is only a 1.5 m wide road along the valley, so a new road must be constructed prior to drilling.
3. The volume of the subsurface reservoir is to be determined according to the required supply amount, however a subsidiary reservoir could be constructed at the ground surface.
4. The discharge quantity is comparatively large, judging from the topography, geological structure (the axises of valley are in good accord with the regional dip and the valleys are dense) and information from the local people. The night discharge, (not used at all) is supposedly equivalent to the day time consumption.

Type E: Other types

1. It is conceivable to recharge the surface flow from Wadi Gaaman artificially into the ground.
2. This type will be effective only when the shallow ground waters of Wadi Gaaman can be exploited.
3. Since the precipitation and the water shed area are not large enough, the shallow ground water table may not be capable of coping with the local water demand.
4. The new system can be expected to supplement the local shallow aquifer which sustains the existing wells in the Wadi. Necessary further study on hydrology.

6-2: Elman and four neighbouring villages (HA-2)

6-2-1: Geography (Fig. 6-1)

The site is located on the mountain slope between 1,500 - 2,100 m A.S.L. up-stream from the Wadi Nahar and the villages are bordering on the precipitous cliffs which are 250 m height at their lower level. The local communities are built on the top of hill and on the mountain slope and they can be subdividable into three groups according to the valley where they belong.

6-2-2: Hydrogeology

The geological formation is again the Trap Series and the major rock type is rhyolite. There are several storage basins for the small springs along the valley located at the center of the village. The spring water seems to crop out from joints and weathered layers developed in the rhyolite, however the quantity is very small. The areal extent of the watershed also suggests such a small amount.

6-2-3: Recommended water source

Water sources available at the site are listed below. The C1-type however, is not considered the most suitable water source from the standpoint of stability of discharge.

Type A: Deep ground water is proposed for the water source of the project.

1. Recommended site is up-stream from the Wadi Nahar.
2. There is one road section 200 - 300 m length, where widening and improvement is necessary, between the Village and the site. New road construction is mandatory for the section of 3 Km along a tributary of the Wadi Nahar before the reach to the site.
3. The site consists completely of the Trap series and is not accompanied by any heavy faults or joints. This hydrogeological condition is regarded to be uniformed.
4. The operational waters must be transported from outside the site.

Type C1: Horizontal drilling for the future development.

1. The recommended site is around the existing spring along the joints and weathered zone aligned with a N40°-50°W axis, which is developed in the tuff and rhyorite. Further study is necessary to determine the safe yield.

2. Even from the existing spring the discharge is extremely small so that a large and consistent water discharge cannot be expected. The geographical condition also suggests the small yield.
3. Man power can only be applied to the transportation between the road and the recommended site. The distance is about 300 m.

6-3: Sihara (HA-3A)

6-3-1: Geography (Fig. 6-2)

Villages are located from 1,300 m a.s.l. at the foot of the mountain to 2,500 m a.s.l. at the summit. Major villages are found on the summit higher than 2,300 m A.S.L. The valleys are deep and steep cliffs rise above in steps. In order to approach the major villages on the summit we must follow the mountain road on the eastern slope. This road however is so narrow and steep that only four-wheel-drive vehicle can reach the destination. However, the villages are fortified by a wall preventing motor vehicles from to coming inside. The aerial extent of the site is approximately 18 km2.

6-3-2: Hydrogeology

As at other sites, the site consists entirely of the Trap series. In the eastern part, however an andesite dyke, running from south to north, prevails. The small valley, which is conspicuous with a small stone bridge built over it at the ridge near the summit, is parallel with the dyke. At the present time, cisterns predominate in the area with about 50 of them having been built. The subsurface cistern is shown in Fig. 6-4. This cistern is dug out undergound, strengthened and the water sealed with stone works. Only one hole for removal of water and a round hole of 1 m in diameter were built in it for access from the outside. There are springs at several locations. All of them issue from the boundary between the land slide debris and base rock or from the weathered zone of base rock. Their discharge is very small.

6-3-3 Recommended Water Source

The recommended water sources are as shown below.
The quantitiative potentiality and stability for the C1 type exploiting springwater along the dykes is still unknown. Further survey is necessary to estimate these values.

Type A: Deep Groundwater-recommended for the water source of the project-

1. The major consumers are the residents on the hill summits above the 2,300 m A.S.L. LEVEL.

2. The recommended drilling sites are located in the wadi bed at 1,200 - 1,250 m A.S.L. in the east, based on consideration of the hydrogeological conditions and transportation of materials.

3. The location of borehole should be determined based on other facilities and the local topography.

4. Operational waters can be drawn from dug wells in the wadi.

Type C1: Horizontal Drilling-proposed for future development-

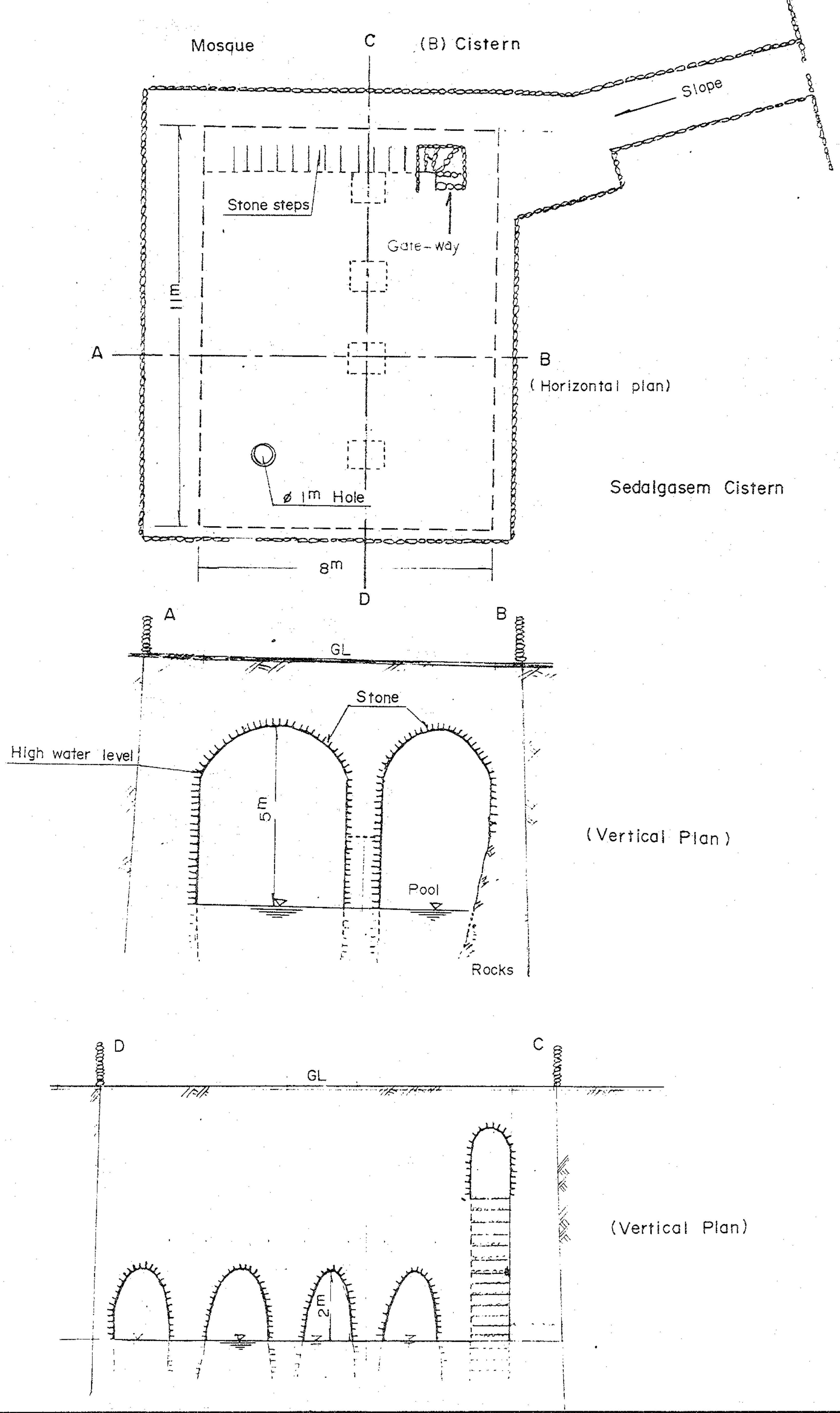
1. The drilling directions should be set in the east to west direction in general, because dyke rocks are aligned from north to south with almost vertical inclination and the ground surface is sloping to the east.

2. Dykes prevail from the foot of the western mountain up to the level of 1,700 m A.S.L. The dykes are located several hundreds meters apart.

3. A single bore hole may penetrate 1 or 2 dykes because of construction convenience.

4. The existing roads are only passable with four-wheel-drive small vehicles, so road construction is inevitable once this type of water source construction is decided.
In addition detailed study is necessary to estimate the safe yield.

Fig.6－4 SKETCH MAP OF WATER SYSTEM CISTERN



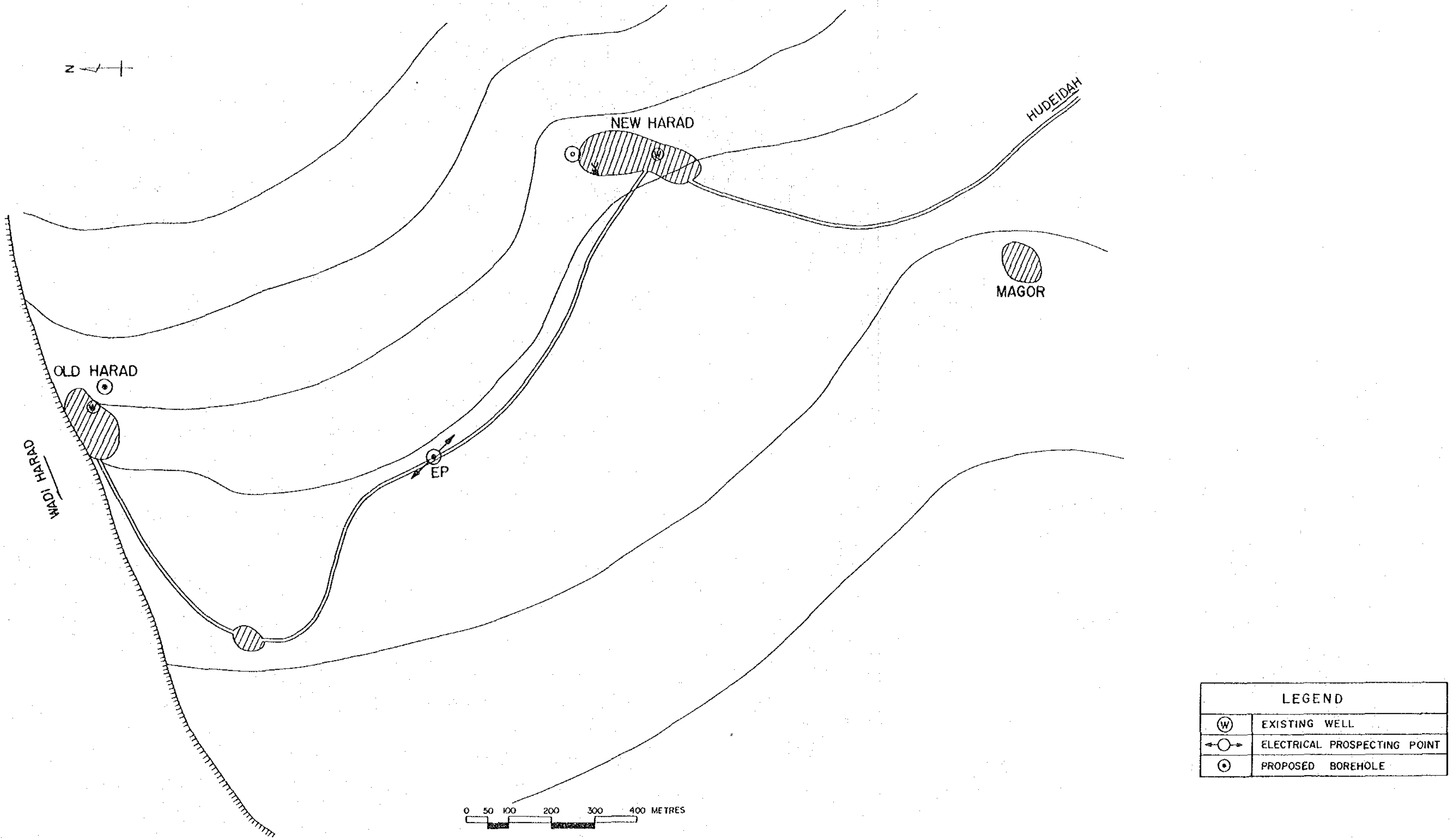


Fig. 6-5

MINISTRY OF PUBLIC WORKS
YEMEN ARAB REPUBLIC

THE RURAL WATER SUPPLY PROJECT PART-II

LOCATION MAP OF HARAD (HA-4)

DESIGNED BY Pacific Consultants International

DATE | SCALE 1: | DRAWING No.

JAPAN INTERNATIONAL COOPERATION AGENCY, TOKYO, JAPAN

6-4 Thari (HA-3B)

6-4-1 Geography

Villages are located from the foot of the mountain at 1,300 m A.S.L. to the summit at 2,500 m A.S.L. Most of the villages are located at the summit. Major valleys are the Wadi Nahar and Wadi Swnar west and east of the site respectively. The slopes of both wadis become steep above 1,500 m A.S.L. The precipitous cliffs rise above that level in steps. This is the largest site in this region, i.e. roughly 36 km^2 (See Fig. 6-2).

6-4-2 Hydrogeology

The site geology consists of andesite, rhyolite and tuff (partially green tuff), i.e. Trap Series. Regional strikes are NE-SW and slight dips are in the NW direction. Fan deposits, consisted of round gravels ranging from several centimeters to tens of centimeters in diameter, are found on the piedmont table mountains near the Wadi Swnar in the east. The elevation is about 1,200 m A.S.L.

The main water source is cisterns, however, some springs can be added subsequently. The springs were either dried up or without any appreciable amount of discharge during the survey period. These springs issue from debri deposits or joints between the rocks. Since they have a narrow watershed area, it will be difficult to secure a stable discharge.

6-4-3 Recommended Water Source

Only a deep groundwater well is recommended at this site. Considering the distance to the place of consumption and the topographic relief, a location 1,400 m A.S.L. zone along Wadi Nahar is presumably the best location of the borehole.

6-5 Harad (HA-4)

6-5-1 Geography

Harad is located on the Tihama coastal plain at a level of 100 m A.B.L. Harad is a twin village, with Old Harad and New Harad, 1.5 Km apart from each other. Wadi Harad flows in a westerly direction north of Old Harad. The villages of Harad are situated on the left bank of Wadi Harad or at the fan top. There are cultivated fields with high furrows (50-100 m high) around the village. A mountain mass consisting of sandstone, limestone, andesite, etc. outcrops about 5 Km east of New Harad. (Fig. 6-5)

6-5-2 Hydrogeology

Electric probing was carried out halfway between Old and New Harad (See Fig. 6-5). The ρ-a curve tends to up lift in the zone deeper than 120 m. The well depth could be limited to 120 m, based on this data. The wadi bed is covered by a mud layer several meters in thickness, but below this layer the wadi deposits are sand and gravel including round gravels.

Electrical conductivity of the existing well waters is less than 900 $\mu\mho$/cm, indicating that the groundwater in the Tihama region is of good quality.

6-5-3 Recommended Water Source

Groundwaters from a deep aquifer are recommended.

Type A: Deep Groundwater

1. There are high furrows along the wadi which are constructed to intercept storm waters for agricultural use. The road crossed these furrows and lorries' ground clearance is not sufficient to go over the furrows in some places. At such locations grading of the furrows is necessary.

2. Construction can not be commenced in the rainy season with any success due to the fact that several wadis cross this site. During the present survey the stream depth of Wadi Maur, the largest wadi, was 20-30 cm.

3. Base rock depth was estimated to be 120 m based on the electric probing.

4. Operational water is available within the site.

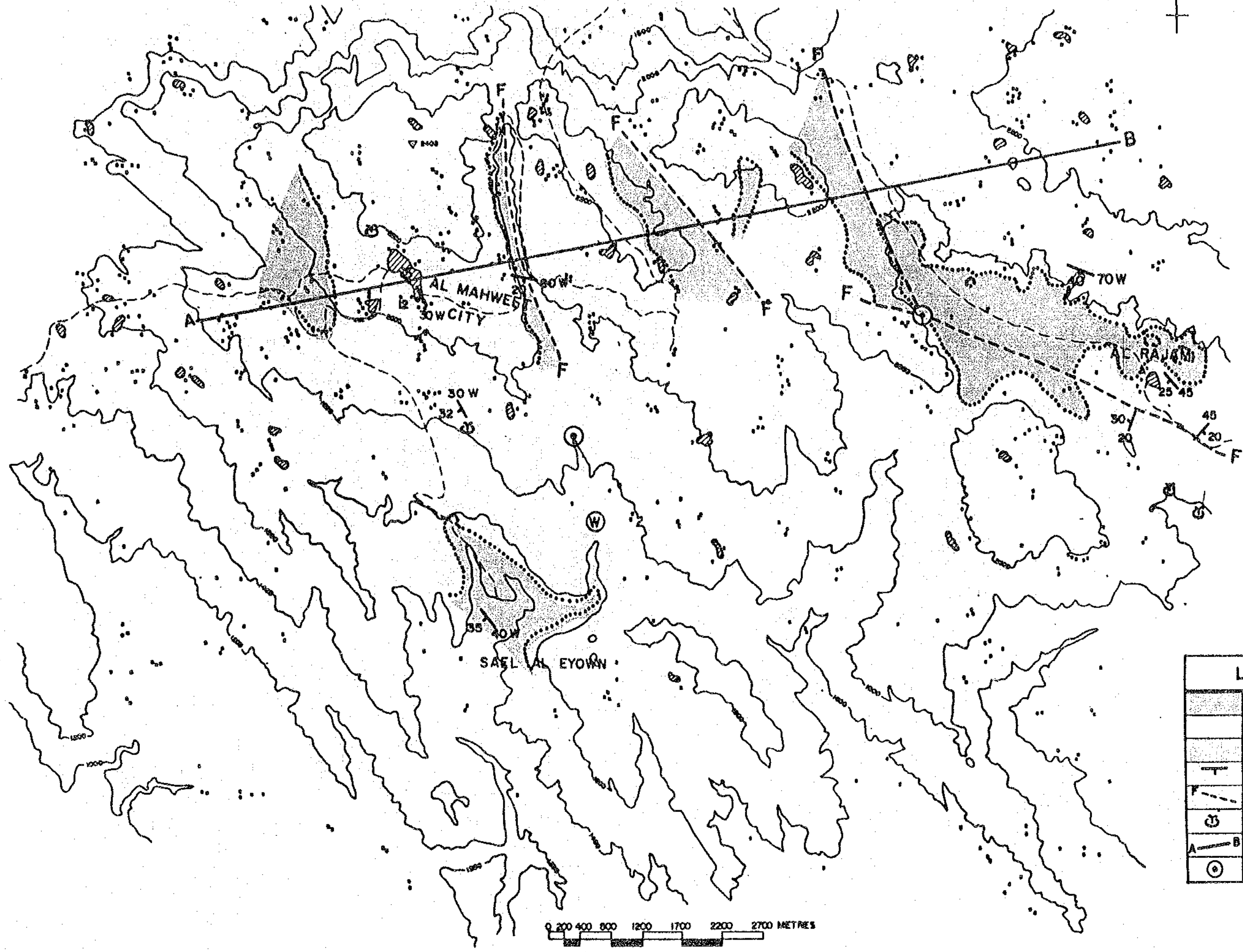
6-6 Al-Mahweet City (A-1)

6-6-1 Geography

Al-Mahweet city is located on a gentle mountain slope at 2,000-3,100 m A.S.L. A steep cliff line, sloping northward, is extends from east to west about 2 Km north of the city. The southern slope on the other hand has a gentle gradient, whereas the deep valleys run in a N30-40W direction. Water streams sometimes appear in these valleys (See Fig. 6-6).

6-6-2 Hydrogeology

Fig. 6-6 shows geological occurrences around Al-Mahweet and Fig. 6-7 shows a geological cross section in the E-W direction. According to these profiles, arkose sandstones crop out in the southern slope and an underlying formation, i.e. limestone of Amran Series crops out window like in valleys. The strikes of both formations are N30°-40°W regionally and their dips are 10-20S. These formations seem to be conformably layered, but the assumed geological cross-section indicates block movement caused by the faults, i.e. lifted up in the western portion and drawndown relatively in the eastern portion. The faults are supposedly running along the valleys and the valley formations may be closely related to the faults. Following the Sael Al-Eyown valley (stream flow confirmed), located south of Al-Mahweet city, to up stream, a straight valley formed by a fault is located.

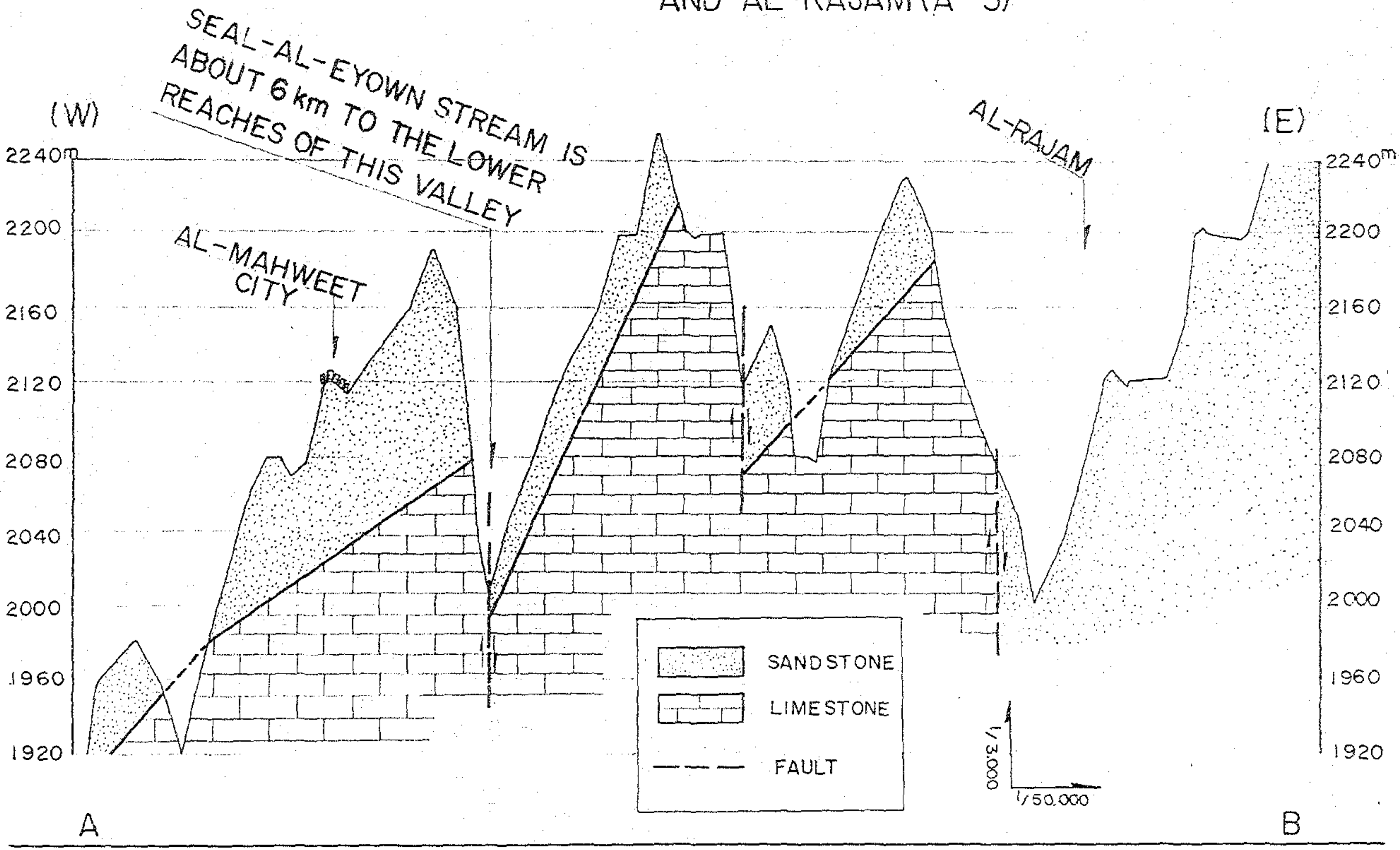


LEGEND	
	ALLUVIUM
	SANDSTONE
	LIMESTONE
	STRIKE, DIP
	FAULT
	SPRING
	GEOLOGICAL SECTION LINE
	PROPOSED BOREHOLE

Fig. 6-6

MINISTRY OF PUBLIC WORKS YEMEN ARAB REPUBLIC	
THE RURAL WATER SUPPLY PROJECT PART-II	
GEOLOGICAL MAP OF AL-MAHWEET CITY (A-1) AL-RAJAM (A-3)	
DESIGNED BY	Pacific Consultants International
DATE	SCALE 1: DRAWING No.
JAPAN INTERNATIONAL COOPERATION AGENCY, TOKYO, JAPAN	

FIG. 6-7 GEOLOGICAL PROFILE BETWEEN AL-MAHWEET CITY(A-1) AND AL-RAJAM(A-3)



The general aspects of the local hydrogeological settings can be summarized as follows:

1. Porous and well jointed sandstones are functioning as aquifers in comparison to the underlying limestones. The formations are dipping to SW and valleys formed by the faults are running almost perpendicular to this direction. Groundwater in the sandstone is invariably issued at the valley bottom interrupted by the aquicludes (limestone) at relatively shallow levels. Similar geologic structures can be conceived for the springs in the neighbouring localities in the same region.

6-6-3 Recommended Water Source

WHO launched a project to introduce Sael Al-Eyown's stream flow to the Al-Mahweet City water, however, there is no continuous river flow record. The river bed bears large boulders of several meters in diameter, and the local people informed us that floods happen about 20 times every year. Accordingly the construction of the intake facility for the wadi stream will be quite difficult.

Although the amount of yield is insufficient, spring at south of the city can be another object of development as a supplementary water source.

Accordingly, groundwater development is proposed for the project water source at the fault valleys. For this purpose not only the boundaries between the sandstone and limestone but also water draws from the limestone aquifer in connection with faults is worth consideration.

6-7 Hufash (A-2)

6-7-1 Geography

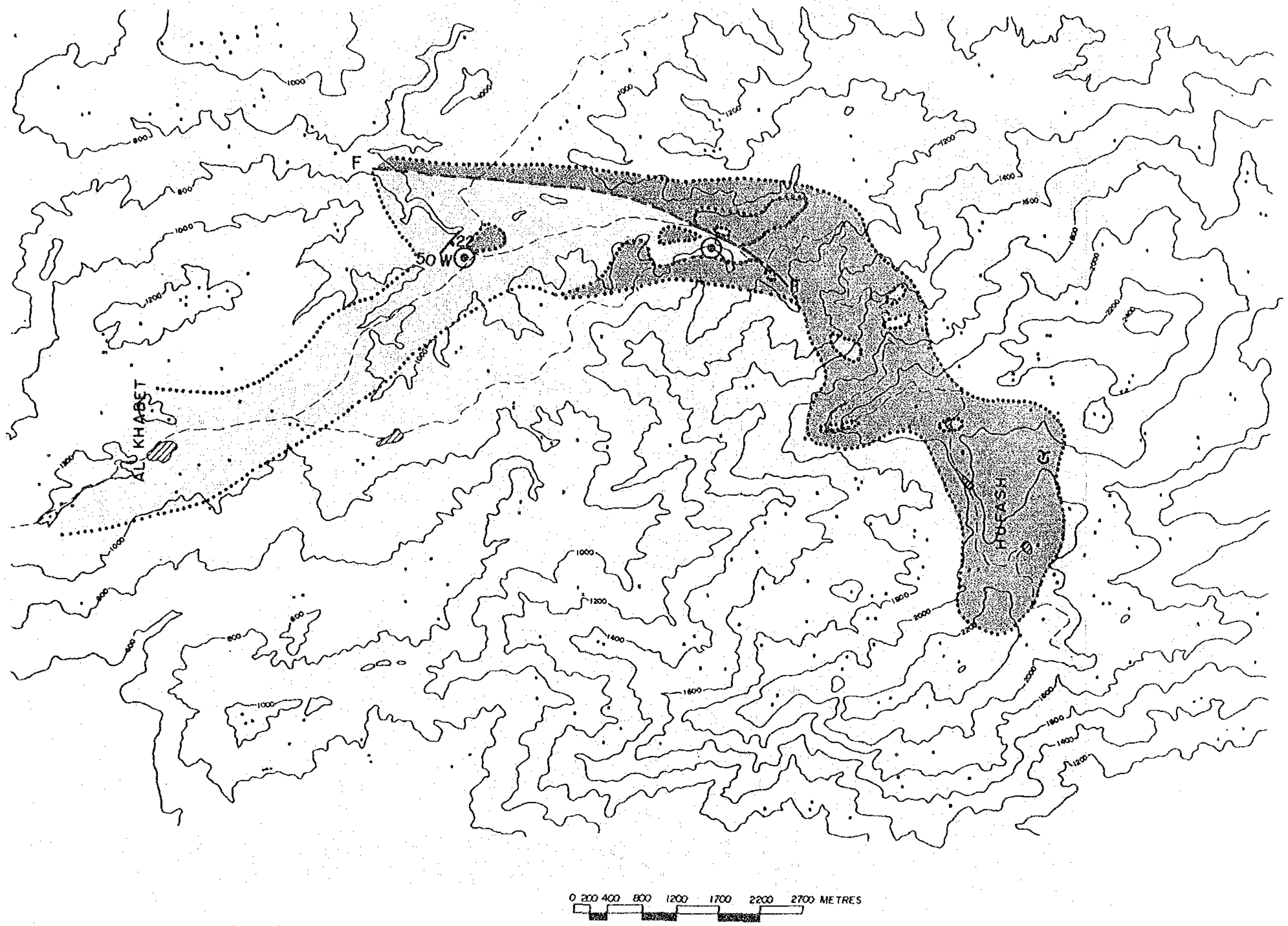
Hufash is spread out over a large area, and its center is situated at the summit 2,100 m A.S.L. The mountain slopes are very steep and they become almost vertical at some locations. There are several major wadis originating from this mountain mass: northward running Wadi Ayyan, southward running Wadi Urkh, northward running Wadi Sheahe in the eastern part of the mountain etc. Their river courses are straight. In these wadis stream waters are present (Fig. 6-9).

6-7-2 Hydrogeology

Most of the site consists of Trap Series, specifically andesite rocks and granite rocks intruding the former ones. In some places springs issue from the mountain slopes and from the summit, however, the issuing mechanism is still unknown. Arkose sandstone outcrops around Wadi Mosanaba in the north and sandy gravels, including pebbles, cover the table mountains upstream from the valley. On the left bank down stream, sandstone outcrops at the lower level and andesite at the higher level. On the right bank however, the outcrops of both formations are supposedly due to the faults. Andesite and granite boulders scattering along the wadi course may suggest seasonal large scale flooding.

6-7-3 Recommended Water Source

Development of the springs out-cropping near the summit should be considered. Uncertainty arises however, concerning the stability of discharge because of their location (i.e. near the summit) and the narrow watershed area. Therefore, deep groundwaters are to be developed for the project water source, a site at the estimated fault location which lies near Madeh and upstream from Wadi Sheahe is recommended, although it is located at a distant point from the residential center. Road construction or improvement is necessary for satisfactory project operation.



	LEGEND
	TERRACE DEPOSIT
	GRANITE
	YEMEN VOLCANICS
	SANDSTONE
	SPRING
F	FAULT
	PROPOSED BOREHOLE

Fig. 6-8

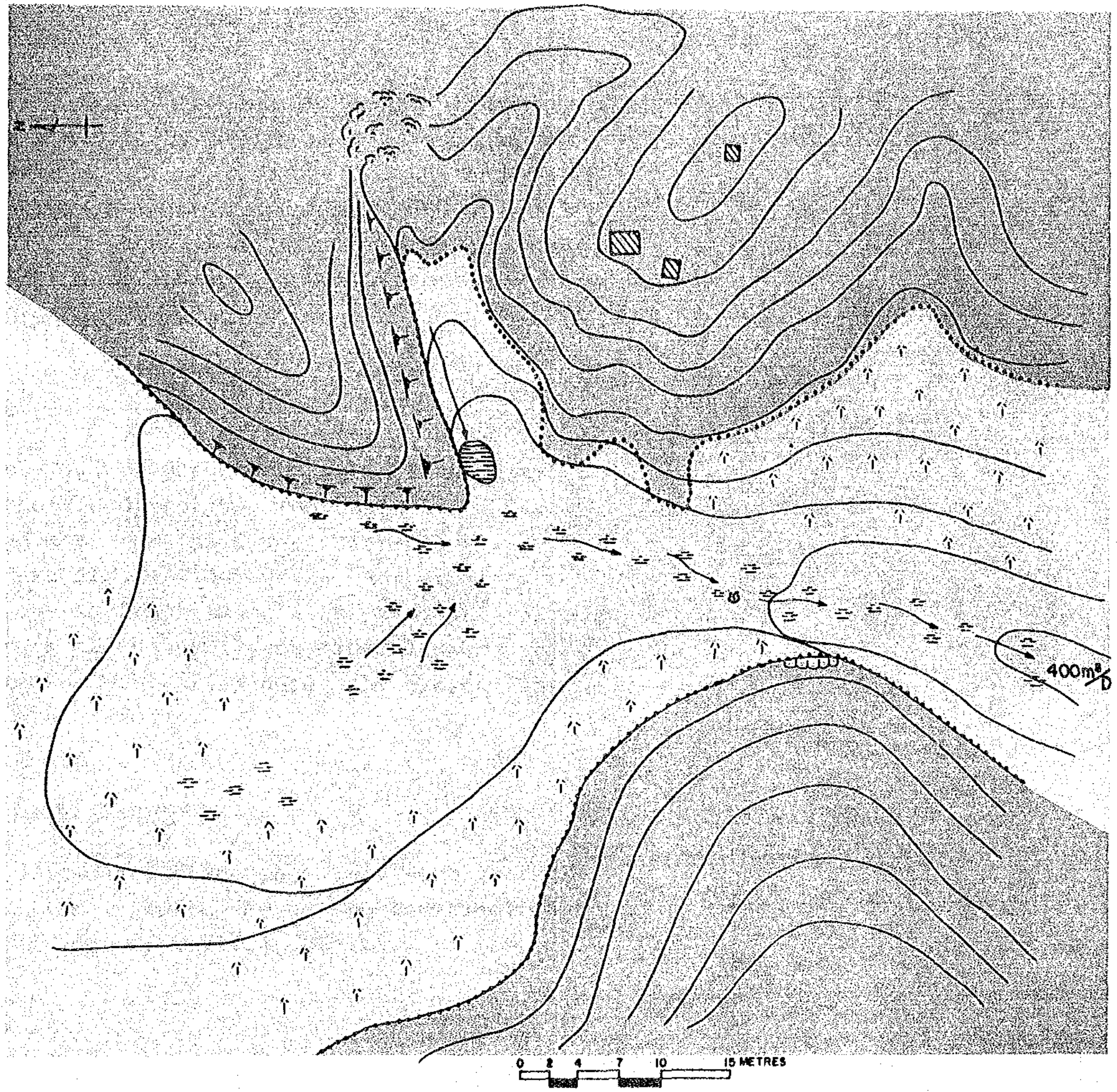
MINISTRY OF PUBLIC WORKS
YEMEN ARAB REPUBLIC

THE RURAL WATER SUPPLY PROJECT PART-II

GEOLOGICAL MAP OF HUFASH (A-2)
& AL-KHABET (A-4)

DESIGNED BY	Pacific Consultants International	
DATE	SCALE 1:	DRAWING No

JAPAN INTERNATIONAL COOPERATION AGENCY, TOKYO, JAPAN



LEGEND	
	ALLUVIUM
	YEMEN VOLCANICS
♁	SPRING
⩦	SWAMP

Fig. 6-9

MINISTRY OF PUBLIC WORKS YEMEN ARAB REPUBLIC
THE RURAL WATER SUPPLY PROJECT PART-II
GEOLOGICAL MAP OF HUFASH (A - 2)
DESIGNED BY Pacific Consultants International
DATE SCALE 1: DRAWING No.
JAPAN INTERNATIONAL COOPERATION AGENCY, TOKYO, JAPAN

6-8 Al-Rajam (A-3)

6-8-1 Geography

The site covers a very large area and its center is situated in a basin at 2,000 m A.S.L. The site is located east of Al-Mahweet City. Through the central part of the basin Wadi Magdara flows down from NE to SW. A valley south of the basin joins Wadi Har. 5 Km north of the basin center, precipitous cliffs, sloping northward, running from east to west (see Fig. 6-7)

6-8-2 Hydrogeology

Arkose sandstone outcrops at the ground surface and Amran series cannot be observed directly. Two fault lines, i.e. with south-north and east-west alignment respectively, are presumed. Springs are discharging at the northern fringe of the basin, and some springs issue in the southern valleys. These facts suggest an almost similar hydrogeological system to the Al-Mahweet region prevailing here. At present the main water sources are cisterns.

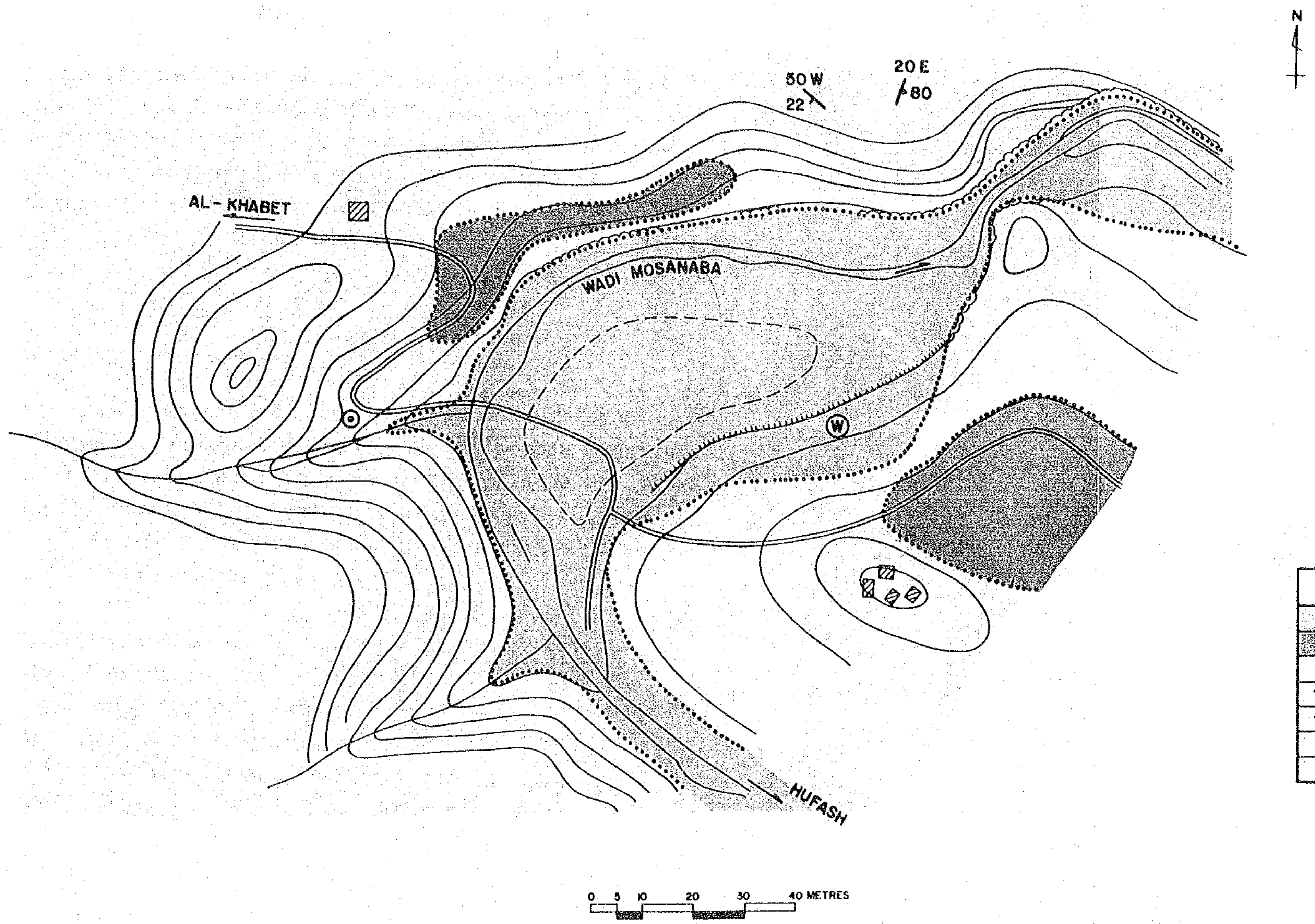
6-8-3 Recommended Water Source

The only feasible sources are obtainable from deep groundwater. The best drilling site may be at the intersection of two faults located west of the city center.

6-9 Al-Khabet (A-4)

6-9-1 Geography

Al-Khabet also spreads from wadi bed to the mountain top at thousand and some hundreds of metres A.S.L. It covers a very large area. The central part however, is situated on the flat summit at about 1,200 m A.S.L. West and east of this Wadi Ayyan and Wadi Mosanaba are running respectively. (see Fig. 6-10)



LEGEND	
	ALLUVIUM
	TERRACE DEPOSIT
	SANDSTONE
	STRIKE , DIP
	CRACK
(W)	WELL
(•)	PROPOSED BOREHOLE

Fig. 6-10

MINISTRY OF PUBLIC WORKS YEMEN ARAB REPUBLIC
THE RURAL WATER SUPPLY PROJECT PART-Ⅱ
GEOLOGICAL MAP OF AL-KHABET (A-4)
DESIGNED BY Pacific Consultants International
DATE SCALE 1: DRAWING No.
JAPAN INTERNATIONAL COOPERATION AGENCY, TOKYO, JAPAN

6-9-2 Hydrogeology

At present, the local people utilize cistern water and stream water in valleys. The geology of the site consisted of sandstone extensively. Regional strikes are N50°W and dips are 20°N. A fault aligned south to north is estimated between sandstone and Trap series 3.5 Km east of the center. Stream flow appears in Wadi Mosanaba. On the riverbed andesite and granite round gravels tens of centimeters in diameter are distributed. The fresh eroded stream banks in Wadi indicate that floods of a considerable magnitude occur in a certain season.

6-9-3 Recommended Water Source

The sub-surface stream of Wadi Mosanaba can be developed. There are, however, seasonal floods of considerable magnitude and river bed deposits indicate significantly large mud flows. In addition, the trunk road, which passes through this wadi for Khabet and Hufash, may be blocked by the construction of the sub-surface stream development.

Therefore, deep groundwater is proposed for the project water source, considering the occurrences of andesite dykes with two alignments (i.e. N70°W, 80°N; N30°E, 85°S) along the Al-Khabet road on the left bank of Wadi Monasaba and estimated faults east of these dykes.

6-10 Bany Shaker and Bait Abo Saba'a (S-1)

6-10-1 Geography

Bany Shaker is located in a small valley surrounded by mountains of about 2,300 m A.S.L. The branching road, about 2 Km long, connecting the village with the trunk road, is narrow and rough with bare base rock at the ground surface.

Particularly in the vicinity of the village entrance, the foot of the mountain slopes come closer and the valley becomes narrower with bare rock bed, being shaped just like a natural sub-surface dam.

In order to obtain a flat cultivation field, the people construct a rock mound of 5 m height down-stream in the valley.

6-10-2 Hydrogeology

The geology of the site consists entirely of sandstone. The sandstone is arkose sandstone containing considerable amount of cherty round gravels several centimeters in diameter. Regional strikes are N-S and slight dips are westward. A number of andesite dykes run from east to west. Near the village entrance two faults with different alignments, i.e. N70°E and N20°E respectively, cross the site.

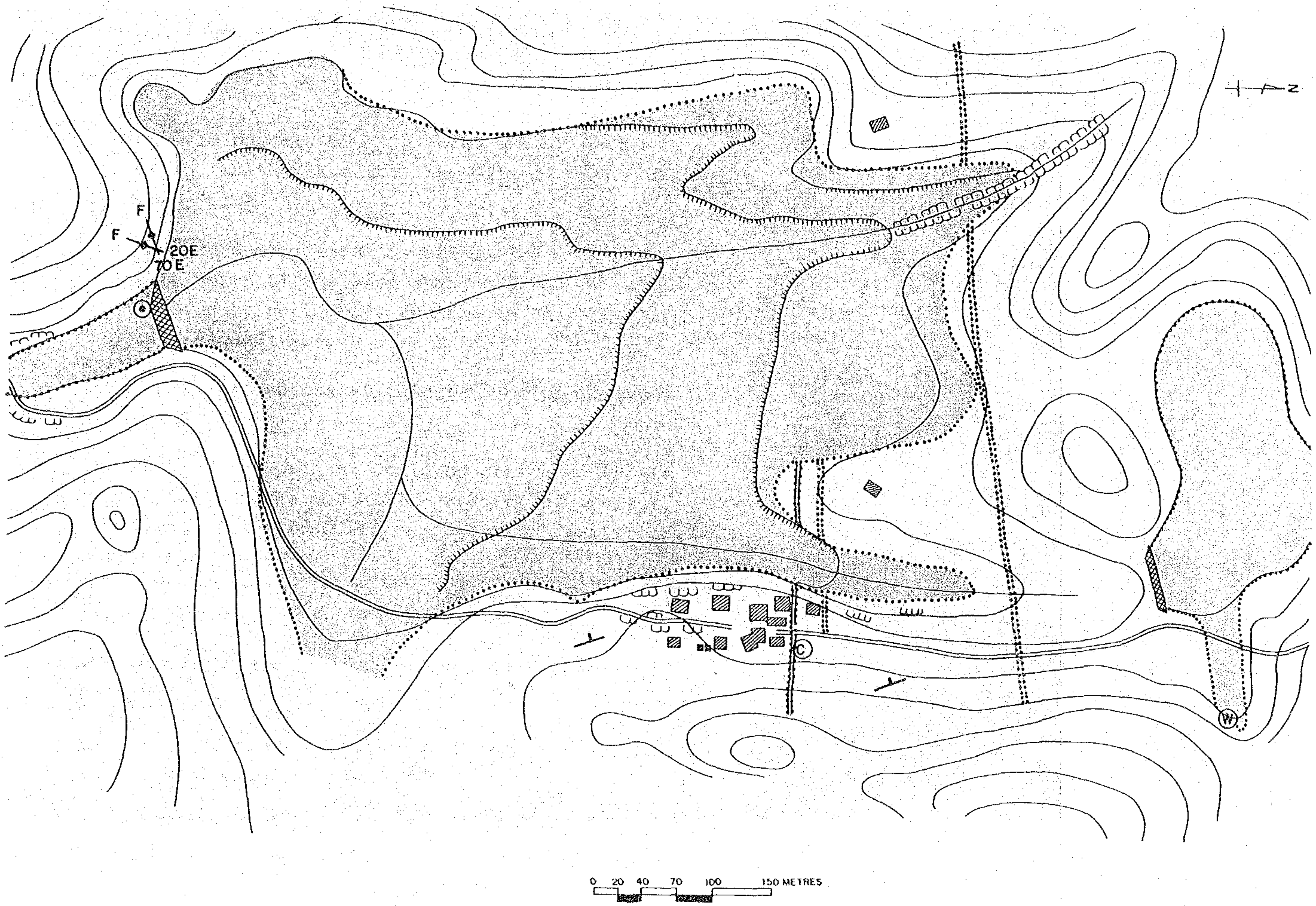
6-10-3 Recommended Water Source

The recommended water sources for development in this site are as follows; deep groundwater through faults, shallow groundwater by horizontal drilling into andesite dykes and surface waters by dams. A part of road construction is necessary for transportation of drilling equipment and material. The recommended water sources are listed below:

Type A: Deep Groundwater - proposed for the project water source.-

1. Near the intersection of the two faults at the entrance of Bany Shaker is recommended for drilling.

2. The approach road to the site is narrow and rough with bare rock at the surface. Road construction is in progress, however, a considerable number of days and labor is necessary before the completion.



LEGEND	
	ALLUVIUM
	ANDESITE DYKE
	SANDSTONE
(W)	EXISTING WELL
(C)	CISTERN
	STRIKE, DIP
(•)	PROPOSED BOREHOLE

Fig. 6-11

MINISTRY OF PUBLIC WORKS YEMEN ARAB REPUBLIC
THE RURAL WATER SUPPLY PROJECT PART-II
GEOLOGICAL MAP OF BANY SHAKER AND BAIT ABO SABA'A (S-1)
DESIGNED BY Pacific Consultants International
DATE / SCALE 1: / DRAWING No.
JAPAN INTERNATIONAL COOPERATION AGENCY, TOKYO, JAPAN

Transportation to the site is impossible at the present time.

Type C1: Horizontal Drilling - proposed for the future development -

1. Regional alignments of dyke rocks are in an E-W direction, so that the drilling direction should be North-South.

2. The recommended position is at the foot of the mountain north of the site and the drilling direction should be northward, restricted only by the geographic condition.

3. Dyke rocks are spaced at intervals of approximately 400-600m.

4. The risk of the project could be great due to the uncertainty of the potential capacity of aquifer, geological conditions and poor traffic facilities, stated above.

Type D: Dam - proposed for the future development -

1. The area surrounding the Bany Shaker entrance is recommended.

2. The water storage capacity could attain 5,000 m3 with a dam height of 5 m.

3. The watershed area is very small. Further study on hydrology is necessary.

6-11 Bait Abo Hashem (S-2)

6-11-1 Geography

The site is located at the north-western edge of the broad table-land at about 2,200 m A.S.L. A low wadi basin with 50 m relative height extends about 500 m north of the surveyed site. Villages are built in two localities: on the table-land and on the summit 30 m higher than the surrounding area. Valleys dissect the table-land with steep banks. No soil formation is observed on the table-land and sands and gravels cover the wadi bed (see Fig. 6-12)

6-11-2 Hydrogeology

Limestone (Amran Series) forms most of the table-land, however in the Survey Site Quarternary volcanics are predominant. Regional strikes and dips of the limestone are N20°-30°W and 5°S respectively, and the occurrence of the limestone is localized. The Quarternary volcanics cropout on the hills formed on the table-land and in the wadi beds and areas adjacent. Quarternary volcanics are compact basalts with well developed joints, forming small rock pieces. Faults may run through the minor valleys in a south-north direction. A geological cross section of the site is shown in Fig. 6-13.

6-11-3 Recommended Water Source

Deep groundwater is feasible for water source development when exploited from the faulted area. In such a case sufficiently deep drilling must be accomplished since the site is located on the table-land.

Type A: Deep Groundwater

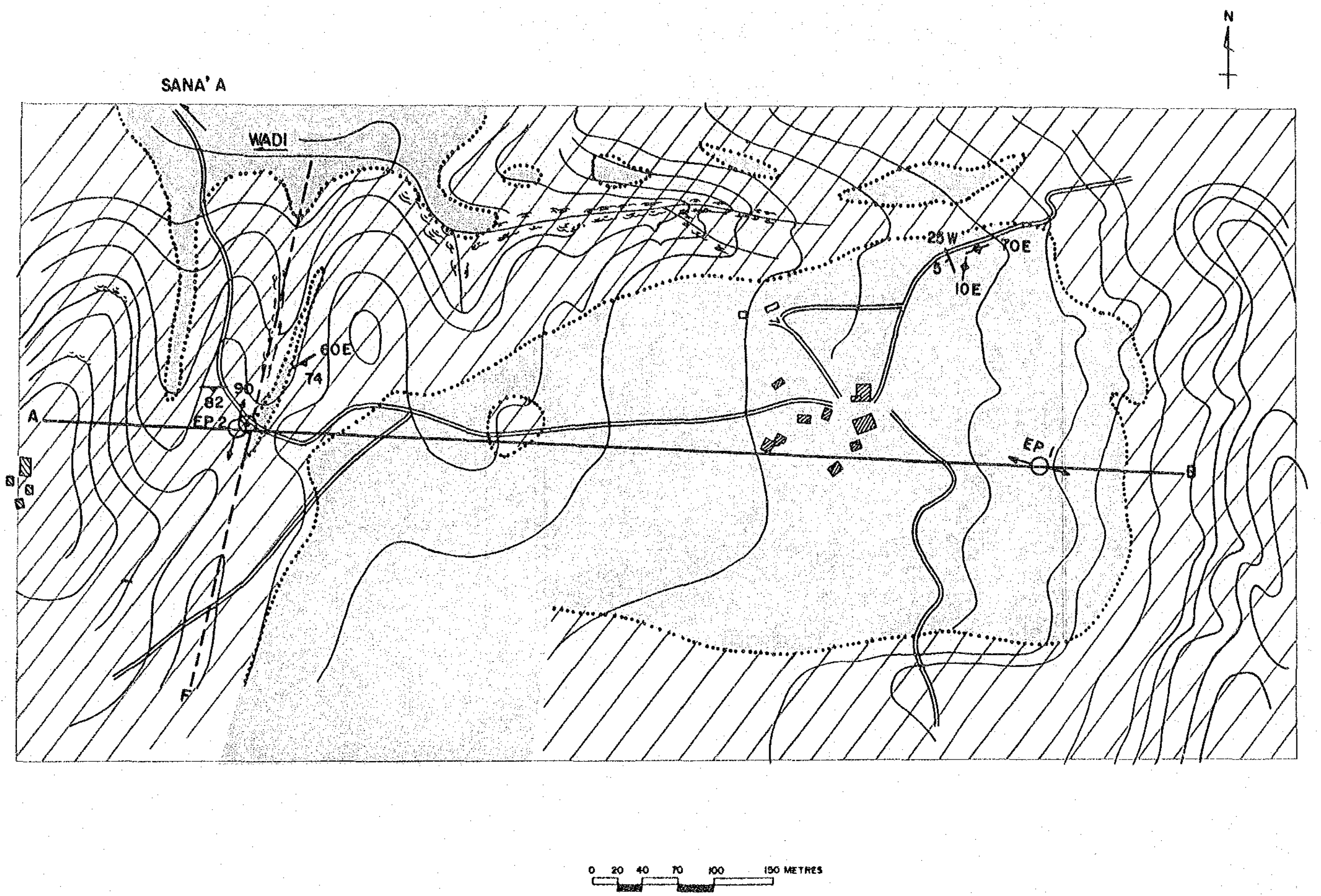
1. The saddle point between the two villages is the recommended site.

2. Faults are estimated along a N10°E direction.

3. Drilling depth is presumed to be 100-150 m as the relative height is 30 m around the wadi.

4. A road section of 500 m exists between the wadi at the front of the site and the entrance of the mountain trail.

5. Operational waters must be carried from out side the site.



LEGEND	
	ALLUVIUM
	LIMESTONE
	BASALT
E.P	ELECTRICAL PROSPECTING POINT
⊙	PROPOSED BOREHOLE
F---	FAULT
A—B	GEOLOGICAL SECTION LINE
	STRIKE, DIP
	CRACK

Fig. 6-12

MINISTRY OF PUBLIC WORKS YEMEN ARAB REPUBLIC		
THE RURAL WATER SUPPLY PROJECT PART-II		
GEOLOGICAL MAP OF BAIT ABO HASHEM (S-2)		
DESIGNED BY Pacific Consultants International		
DATE	SCALE 1:	DRAWING No.
JAPAN INTERNATIONAL COOPERATION AGENCY, TOKYO, JAPAN		

FIG. 6 - 13 GEOLOGICAL SECTION (BAIT ABO HASHEM)

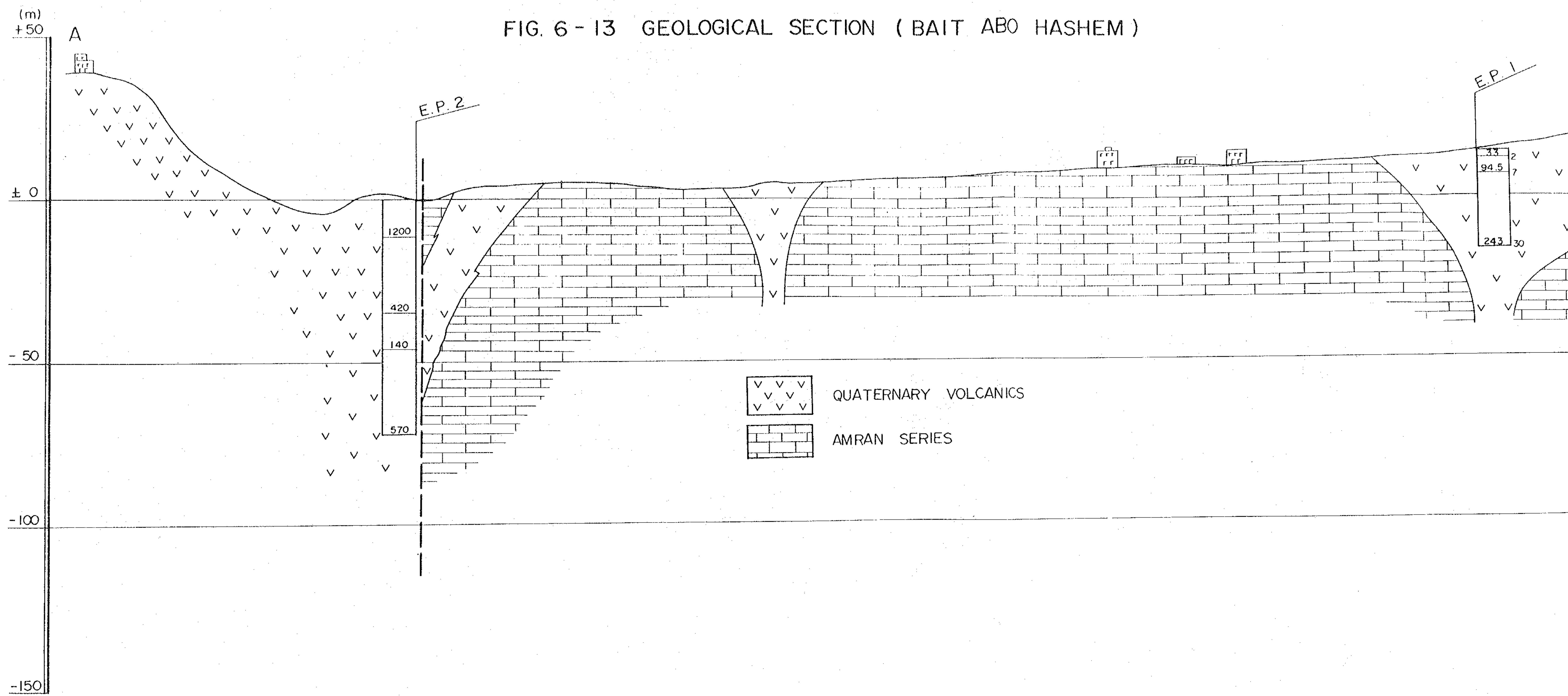


FIG. 6 - 13 GEOLOGICAL SECTION (BAIT ABO HASHEM)