YEMEN ARAB REPUBLIC
MINISTRY OF PUBLIC WORKS

THE RURAL WATER SUPPLY PROJECT
PART II

TECHNICAL REPORT
HYDROGEOLOGY

FINAL REPORT

May 1980

JAPAN INTERNATIONAL COOPERATION AGENCY

YEMEN ARAB REPUBLIC
MINISTRY OF PUBLIC WORKS

THE RURAL WATER SUPPLY PROJECT
PART II

TECHNICAL REPORT
HYDROGEOLOGY

FINAL REPORT

May 1980

JAPAN INTERNATIONAL COOPERATION AGENCY

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The principal objective of this technical report is to identify the feasible water sources and to estimate the magnitude of the available water sources for the rural water supply schemes. The project survey sites distribute over a wide range of dry areas which receive annual precipitation less than 500 mm/year. At present the available hydrometeorological data is only limited in these areas.

Although water sources taken from the surface water requires various kinds of treatment in many cases for domestic purposes, on the other hand, groundwater sources obtained based on the prudent hydrogeological considerations provide potable water for domestic purposes without any significant treatment devices. Accordingly, an emphasis was given to the groundwater sources for the project in order to provide potable and stable water sources for the urgent requirements of the rural water supply schemes.

In the following section of the report, the general condition of hydrogeology in the Republic is discussed and the specific condition of hydrogeology at each survey site is analyzed. Based on the above discussion and analysis, the safe yield of each proposed borehole was estimated.

Since most survey sites are located in rather dry areas domestic and cattle watering purposes is increasing, it is expected that the shortage of water will also be prevalent in future.

In order to meet the future demand of water alternative water sources were proposed in some sites. As these alternative water sources require further data and field investigation, they are not recommendable for immediate purposes; however, consideration should be given to these alternatives for the future development.

CHAPTER II

GENERAL DESCRIPTION OF THE SITES

2-1 Geomorphology

The Yemen Arab Republic (YAR) is located at the south western corner of the Arabian Peninsula between latitudes 13°00'N and 17°30-N and longitudes 46°30'E and 46°10'E, bordering Saudi Arabia in the north and the People's Democratic Republic of Yemen in the south. The YAR faces the Red Sea in the west and extends into the great desert of Ar-Rub' Al-Khali in the east, where the border line is not clearly defined. The YAR lies in the highest altitudes of the Peninsula with a total land area of approximately 195 thousand km^2.

The YAR is divided into four topographical zones according to altitude and relief. These four zones are roughly aligned from north to south as long belts.

Each zone is shown in Fig. 2-1 as follows from west to east; the Tihama low pressure zone, Central mountain zone, Highlands and Desert zone (a continuation of the Ar-Rub Al-Khali). The central mountain zone with many peaks of 3,000 m altitude is distinctly separated from the Tihama Low Pressure Zone in the west by precipitous cliffs of approximately 2,000 m relative height. The central zone, however, extends into the desert in the east with gentle slopes, changing from steep hills to desert plain through transitional table lands. This type of relief is commonly called a "one-sided mountain".

River systems are clearly divided by the Central Mountain Zone into the easterly flowing system and the westerly flowing system. The western system, which flows into the Red Sea, has rapids and shorter river courses whereas the eastern system has gentle and longer river courses. Except for a few westerly flowing rivers, rivers (called wadis) are not permanent and

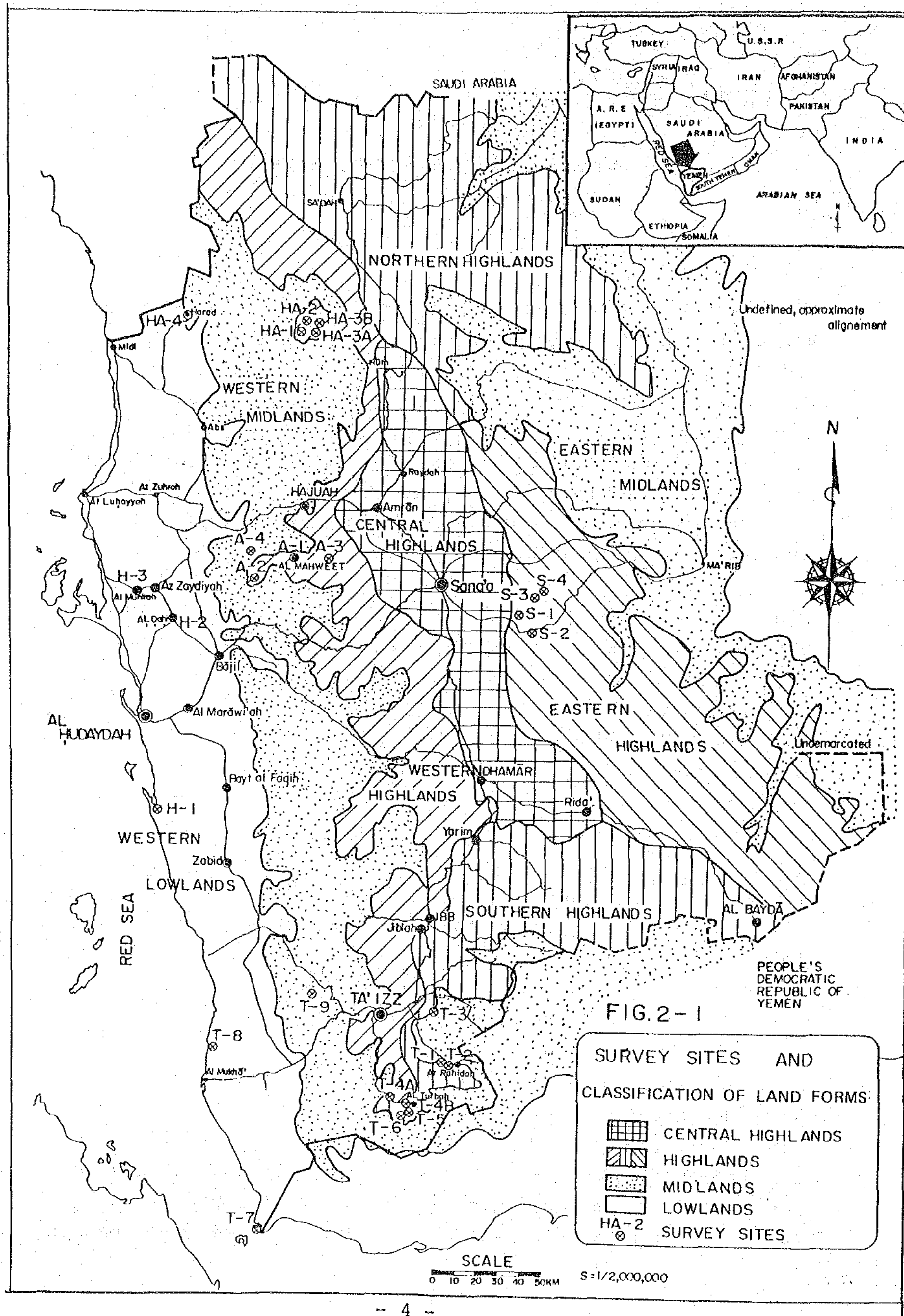

TURKEY
U.S.S.R
SYRIA
IRAQ
IRAN
AFGHANISTAN
PAKISTAN
A. R. E
(EGYPT)
SAUDI
ARABIA
RED SEA
YEMEN
SOUTH YEMEN
OMAN
INDIA
SUDAN
ARABIAN SEA
ETHIOPIA
SOMALIA
SAUDI ARABIA
SA'DAH
NORTHERN HIGHLANDS
Undefined, approximate alignement
HA-4
Harad
HA-2
HA-3B
HA-1
HA-3A
Midi
WESTERN
MIDLANDS
Abs
EASTERN
MIDLANDS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

Table 2-1

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	Harad	
A - 1	Al-Mahweet City	Al-Mahweet	AL-MAHWEET (A)
A - 2	Hufash	Al-Mahweet	
A - 3	Al-Rajam	Al-Mahweet	
A - 4	Al-Khobet	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-Dahl	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-Buraihl	
T-4-A	Hadad, Qahfa	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

intermittently flow during short periods after the rain.

2-1-1 Tihama Low Pressure Zone

This is a vast and flat region, extending from south to north about 400 km and from east to west approximately 50 km, located between the Red Sea and the Central Mountain Zone. The average slope of the area between 250 ~ 300 m altitude and the Red Sea Coast is 1/100 ~ 1/200 (i.e. a moderate gradient).

This zone can roughly be subdivided into two regions: one is the desert region covered by eolian sand and the other is a fan-like geomorphic surface region formed by the wadis further inland. The exact position of the border between the two subdivisions meanders and is not clearly defined. In the desert region, sand hills of 10 ~ 20 m height occur, spaced at rather regular intervals of 500 ~ 600 m and aligned from east to west. In the central part of this zone, there are smaller hills of approximately 50 m height. Near the coast, rock salt deposits are also found in this locality.

2-1-2 Central Mountain Zone

The Central Mountain Zone is formed of rugged spine-like ridges at the stage of maturity, rising as high as 3,000 m A.S.L, running from north to south. Mountain slopes are greatly dissected by wadis and many deep V-shaped valleys are found. Canyons are also prevailing features found in the western slopes.

In this zone, small river basins such as Sana'a, Dhamar, Yarim, Ibb and Taizz are located along the line extending from north to south. Particular attention should be drawn to the wide expanse of Quarternary lava plateaus spreading north of Sana'a, west of Dhamar and north of Taizz which holds good water bearing aquifers.

2-1-3 Highlands

The Highland Zone consists of gently undulating hilly terrain of 1,500 $\sim$ 2,000 m A.S.L, located between the Central Mountain Zone and the Desert Zone. The Highlands gradually decrease in altitude to the east and change into the Desert Zone transitionally. The great wadis like the Wadi Al-Jawf, the Wadi Al'Adhanah etc., occur in this zone, usually with vegetation in the Wadi beds. In general, wadis in this zone are large in width, having many tributaries. The wadi banks are less dissected compared to the westerly flowing wadis.

2-1-4 Desert Zone

The Desert Zone is the continuation of the great Ar-Rub' Al-Khali Desert and the barren desert zone. Although most wadis in the Yemen Arab Republic are located either in the easterly or westerly flowing system as determined by the Central Mountain Zone, in the south, some wadis flow southerly towards the People's Democratic Republic of Yemen. Western and southern wadis have shorter courses and more rapid flows, forming deep V-shaped valley with steep cliffs. A significant number of them maintain permanent flow. On the other hand, eastern wadis with longer courses and wider valley beds, are filled by water flow only during the rainy season. A classification of wadis according to the direction of flow is presented in Table 2-2.

Table 2-2
List of Major Wadis

Westerly flowing wadis	Southerly flowing wadis	Easterly flowing wadis
Wadi Mawr	Wadi Aden	Wadi Jawf
" Surdud	" Bana	" Abrad
" Siham		" Harib
" Rima		" Jonnah
" Zabid		

2-2 Geology

The geology of the Yemen Arab Republic is principally composed (in upward sequence) of Pre-Cambrian rock as basement, Ordovician, Jurassic and Cretaceous sedimentary rocks, and igneous rocks of the Tertiary Trap series, which crop out extensively, with granitic and basaltic intrusions of the Quarternary period in some localities. The Quarternary basalt lava forms a wide expanse of lava plateau over the foregoing strata in the regions north of Sana'a, west of Dhamar and north of Taizz. Alluvium covers the surface of lowlands along wadis and of basins. Eolian sands are extensively distributed in the Desert Zone and in a greater part of the Tihama Lower Pressure Zone.

The stratigraphic sequence in the Yemen Arab Republic is shown in Table 2-3 and geologic map in Fig. 2-2.

Table 2-3

Stratigraphic Sequence

Geologic Period		Stratum	Constituents
Cenozoic	Quarternary	Eolian Formation	sand
		Alluvium	gravel, sand mud
		Aden Volcanic series	basalt andesite
	Tertiary	Intrusive rock	basalt, granite
		Trap series	basalt, andesite rhyolite, tuff
		Madj Zir Series	sandstone conglomarate
Mesozoic	Cretaceous	Tawilah group	sandstone conglomarate
	Jurassic	Amran series	limestone
		Kohlan series	sandstone conglomerate
Paleozoic	Ordovician	Wajid Sandstone	sandstone
Pre-Cambrian		Pre-Cambrian rock	granite gneiss schist

2-2-1 Pre-Cambrian Rock

Pre-Cambrian rocks comprize various rock species such as granite, gneiss, mica schist, green schist, slate etc. and crop out extensively in the western part of the Central Mountain Zone and the Highlands from south to north. However, they are not exposed along the Hodeidah Highway over approximately 130 km travelling distance or within about 70 km north and south of the wadi Al-Jawf, which flows eastwards. Although there are some local exceptions, generally granite and gneiss are predominant on the western side of the Central Mountain Zone. A considerable number of occurrences of pegmatite dykes intruding into granite are found in the hilly area west of Saadah. In the Highlands gneiss and schist occurrences prevail while granite occurrences diminish. Among schist rocks, biotite schist and sericite schist occurrences are overwelmingly the majority. This zone indicates strong metamorphism with complicated small-scale foldings generally along north to south axes. Although faults on a small-scale are frequent, heavy faulting is mainly located in the north (Saadah province) and in the south (Taizz province).

2-2-2 Wajid Sandstone

There is a wide distribution of Wajid sandstone in Saadah province. Wajid sandstone is composed of well-sorted medium to fine grain quartz sands, and occasionally accompanies granule lenses. In outcropping areas, the surface is cemented by calcareous material so rigidly that even by geological rock hammer, often it cannot be broken. By referring to probing records of dug-wells and deep wells, this formation is described to be interbedded alternatingly by compact and hard sandstone layers and by poorly cemented loose ones. The latter is regarded as a good aquifer.
In Majada province north west of Saadah, this formation has remarkably developed intraformational folding and cross

lamina, often accompanied by hematite lenses. This formation is believed to be formed from shallow marine deposits during the Ordovician period.

2-2-3 Kohllan Series

Major components of this series are sandstone and shale covering Precambrian rocks with unconformity under lain by the basaltic conglomerate. This series distribute in the central mountain zone in the north west from Sana'a.

Most probably this series represents the Lower Jurassic indicating a cycle of sedimentation.

2-2-4 Amran Series

The Amran series is an upper Jurassic formation, which extensively crops out from the northern part of Sana'a to the southern part of Saadah both in the Central Mountain Zone and the Highlands. This series is mainly composed of limestone. At the outer fringe of the Central Mountain Zone south of Sana'a, some of this formation discontinuously crops out. In the Tihama Low Presure Zone, extending to the south of the Hodeidah Highway, a group of hills of this formation rises and accents the otherwise monotonous landscape.

2-2-5 Tawilah Group, Madj Zir Series

No differentiation has so far been made between the Tawilah group and Madj Zir series. Both of them are composed of alternating strata of medium to fine grain sandstone and shale. which are unconformably over lain by the Upper Trap series and occur discontinuously at the margin of the Central Mountain Zone. Arkose sandstone is predominant among the sandstones in these formations. Tawilah group is thought to be Cretaceous and Madj Zir series, a Tertiary sedimentary rock.

2-2-6 Trap Series

Trap series crops out in a wide region covering most of the Central Mountain Zone south of Sana'a. The formation is made of Tertiary volcanic rock which overlies Pre-Tertiary formations unconformably. There is an out crop of this formation, 80 Km long from south to north and 50 Km wide from east to west, in the hilly region south of Saadah. Amran series of Jurassic period is overlain by this formation in that locality. The main constituent rocks are basalt, rhyolite, andesite lava with intrusive basalt dykes through the andesite lava. These rocks are sometimes interbedded by tuff, shale, sandstone and conglomerates. The rocks indicate small-scale micro-foldings, but are generally characterized by the almost horizontal sedimentation faces with a thickness presumed to be more than 1,200 m.

2-2-7 Intrusive Rock

Intrusive rocks are scattered in the Central Mountain Zone and are of Tertiary origin. They are roughly classified into basic rocks (mainly basalt) and the acidic rocks (granite, diorite, etc.). Basic intrusive rocks crop out on a minor scale on the western slope north of the Central Mountain Zone. On the other hand, intermediate and acidic rocks form continuous and magnificent out crops in the piedmont and foothill regions between Hodeidah and Taizz. They have additional minor occurrences in the mountain region.

2-2-8 Aden Volcanic Series

The Aden volcanic series is comprized mainly of basalt which form Quarternary lava plateaus with occasional occurrences of intermediate to acidic rocks such as andesite, rhyolite, etc. Lava plateaus and many volcanic cones are located in the basins of Pre-Quarternary rocks north and west of Sana'a and north of Dhamar and Taizz. Three prominent lava plateaus formed at slightly different times have been identified in Dhamar province. Each plateau has a 10-20 m relative difference in height. Among the cones which produced the lava to form the plateaus, the largest one has a 500 m wide diameter and a height of 30-50 m. The sizes are not too large, but they still maintain their original shapes with crators at their centers. In some crators, a central cone can be identified. This series crops out south of the Tihama Low Pressure Zone as a group of hills with height differences of 50-100 m. The group of hills is recognizable along the Mocha-Taizz Highway and in the vicinities of Dubab and Umari. The lavas of the Aden Volcanic series are porous in general.

2-2-9 Alluvium

Wide distributions of Alluvium were observed in wadis and river basins located in Tihama Low Pressure Zone, Desert Zone, Central Mountain Zone and Highlands. Alluvium can be subdivided into the following groups according to the form of its occurrence.

Alluvium - A : Occurrence is in belts along the wadis in Central Mountain Zone and Highlands. The major constituents are fine sands, occasionally with silt and gravel interbedding. Gravels are unweathered and angular without extensive continuous stratification. Thickness is presumably not more than 20 m (i.e., thin layered).

Alluvium - B : Occurrence is in isolated portions near the surface of river basins in the Central Mountain Zone and Highlands. Sand, silt, clay and gravel are main constituent elements. Most of the surface elements are the eolian fine sands. The largest scale of alluvium - B is in the Sana'a basin, where thickness is not less than 100 m. Its gravel layer bears a promising amount of groundwater.

Alluvium - C : Occurrence is along the eastern fringe of the Tihama Low Pressure Zone. It mainly consists of gravel and forms fan-like geomorphic terrain. In the region where wadis flow out of the mountaineous region to the Tihama Low Pressure Zone, one or two river terraces can be clearly recognized. This alluvium is overlain by the widely distributed eolian sand in the lowlands along the Red Sea coast. Italconsult has reported the thickness reached 150 m. There are two separate gravel beds in it which form important aquifers. It is doubtful whether the overall strata of this particular group consist of Alluvium. The lower part may be of Dilluvium origin.

Alluvium - D : Occurrence is in the main part of the Tihama Low Pressure Zone and in the Desert Zone. Its constituents are eolian sands. In Desert Zone it is an integral part of the great of Ar-Rub' Al-Khali Desert.

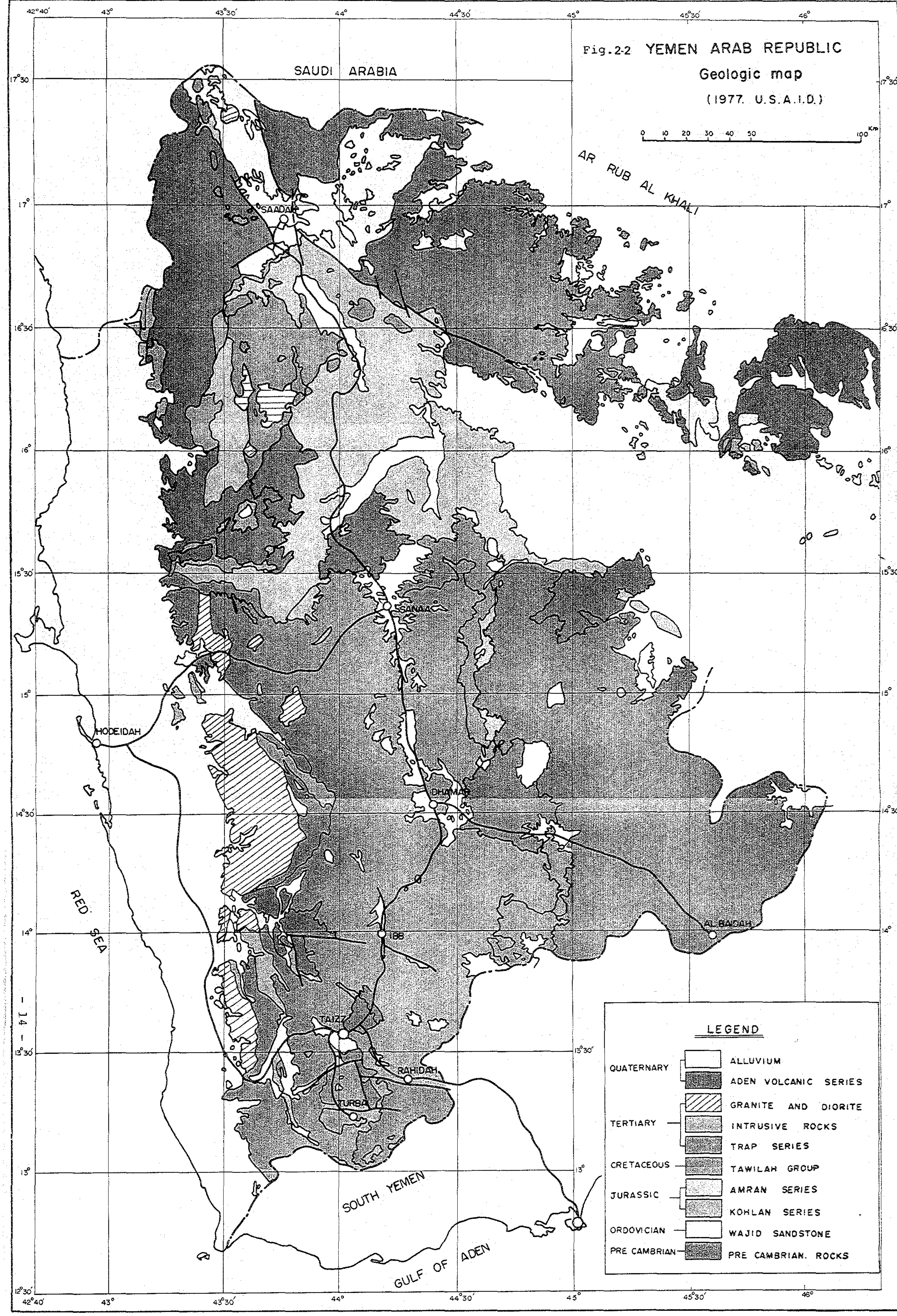


Fig.2-2 YEMEN ARAB REPUBLIC
Geologic map
(1977. U.S.A.I.D.)
0 10 20 30 40 50 100 Km
SAUDI ARABIA
AR RUB AL KHALI
SAADAH
SANAA
HODEIDAH
DHAMAR
IBB
AL BAIDAH
TAIZZ
RAHIDAH
TURBA
RED SEA
SOUTH YEMEN
GULF OF ADEN
LEGEND
QUATERNARY
ALLUVIUM
ADEN VOLCANIC SERIES
TERTIARY
GRANITE AND DIORITE
INTRUSIVE ROCKS
TRAP SERIES
CRETACEOUS
TAWILAH GROUP
JURASSIC
AMRAN SERIES
KOHLAN SERIES
ORDOVICIAN
WAJID SANDSTONE
PRE CAMBRIAN
PRE CAMBRIAN. ROCKS

2-3 Hydrometeorology

Although the Yemen Arab Republic is located at the southern most corner of the Arabian Peninsula, it enjoys cool and comfortable climate due to the high altitudes (more than 2,000 m A.S.L.) of the highlands which constitute most of the YAR land area. However, in the Tihama Low Pressure Zone, it is very hot and humid. In Zabid, for example, the monthly maximum atmospheric temperatures never get lower than 34°C, and those of June to August are 43 ~ 45°C. On the other hand, the monthly minimum atmospheric temperatures are between 10°C and 25°C, with occasional lowering to 10°C in the months from November to December. In contrast to these conditions, the maximum average monthly atmospheric temperature in Sana'a (located in Central Mountain Zone) is 22°C and 27°C ~ 32°C in July and August. The monthly minimum atmospheric temperatures are lower than 7°C, and reach 0°C to 3°C during November to February. In addition, the average monthly maximum/minimum temperature difference throughout the year approaches 20°C and temperature difference between day and night is 15°C ~ 20°C. These characteristics are typical of a continental climate.

Precipitation in Y.A.R. is not great by world standards; however when compared with the other countries in the Peninsula, the Y.A.R. enjoys relatively frequent rainfall. The rainy season is from February to September and the dry season is from November to January with some local variations.
The Table 2-4 states the recent average annual precipitation for selected localities based on the records from 1970-1974.

Table 2-4 Average annual precipitation for selected localities

Locality	Geomorphological Zone	Precipitation
Sana'a	Central Mountain Zone	157 mm
Yarim	"	489
Ibb	" , western fringe	1,230
Zabid	Tihama Low Pressure Zone	127

As shown in Table 2-5, there is a great variation in annual precipitation from year to year. This indicates significant instability for regarding precipitation as water sources.

Table 2-5

Annual precipitation at selected localities

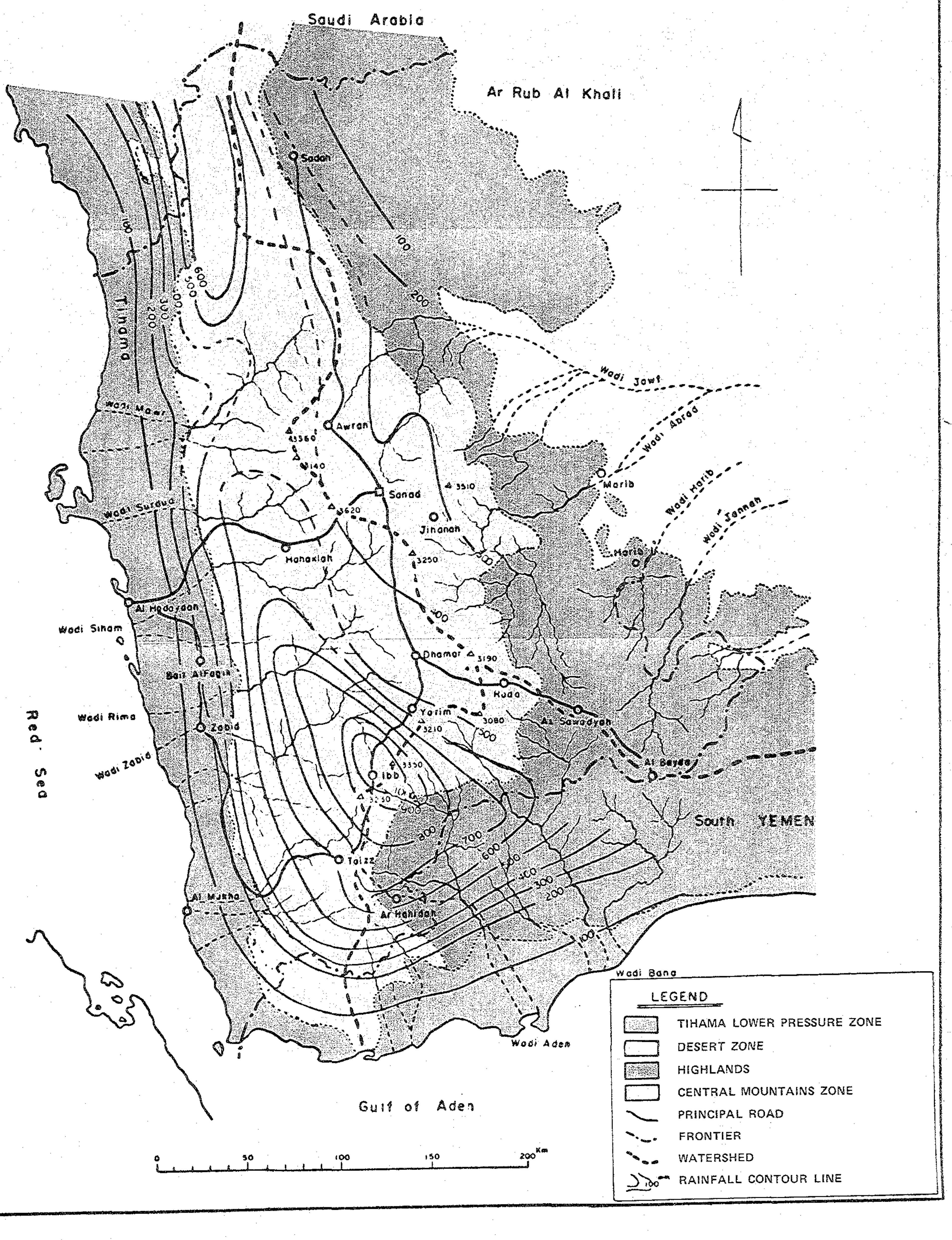
Unit: mm (No. of rainy days)

	1944	1974	1975	1976	1977	1978
Sana'a		215.4 (35)	350.6 (62)	154.2 (32)	335.6 (44)	167.1 (33)
Hodeidah				16.3 (2)	78.5 (13)	78.0 (2)
Taiz	528.4 (-)			359.6 (46)		

The magnitude of daily rainfall, calculated from Table 2-5, is small (5mm - 8mm) except for that of Hodeidah in 1978.

The isohyet map of Y.A.R. in the 1973 Italconsult report is reproduced in Fig. 2-3. In this map, a 1,000 mm zone centering around Ibb together with a 600 mm zone near the border of Hajja province form an isohyetal ridge on the western slope of Central Mountain Zone. This high precipitation zone in mainly attributed to the humid westerly winds which blow from the Red Sea and are blocked by the Central Mountains where they produce rains. Permanent streams, flowing into the Red Sea, are consequently maintained by this meteorological system. In the neighbouring zone, on the eastern slope of Central Mountain Zone (200 ~ 500 mm) annual precipitation is still observed, and this can be regarded as replenishing groundwater through the wadis.

Fig. 2-3 YEMEN ARAB REPUBLIC ISOHYET MAP OF ANNUAL RAINFALL



CHAPTER III

HYDROGEOLOGY

3-1 General Condition of Hydrogeology

As already stated, the hydrological conditions of the Yemen Arab Republic are divided into two separate regions: the Tihama coastal region along the Red Sea and the Mountain region east of it. Two methods of water resource development were considered as follows: exploiting groundwater and spring water, and storing rain water and surface water. In the Yemen Arab Republic both methods of developing water sources are currently used. However, the examinations in this report focus on the development of groundwater which is relatively stable in quantity and quality, for the following reasons:

1) This survey is a part of the Rural Water Supply Project planned for operation in the near future in the Yemen Arab Republic,
2) The selected survey sites are distributed on a nationwide scale,
3) Precipitation is generally low and varies from year to year; it is also accompanied by high evapotranspiration, and
4) Water treatment techniques for hygiene are still inefficient.

This chapter will discuss the hydrogeological conditions in the Mountaineous region and the Tihama Coastal region in separately.

3-1-1 General Condition of Hydrogeology in Mountaineous Region

Until now the following deep well drilling projects listed in Table 3-1 have been conducted.

Table 3-1

Deep Well Drilling Projects in Y.A.R.

Project	Number of Wells	Total Drilled Depth (M)	Average Depth (M)
USAID Project	60	10,682	178.0
IRAQI Project	22	1,967	89.4
SAUDI Project	38	9,497	249.9
George Stow. Co.	21	3,008	143.2

A considerable number of wells have been drilled in addition to those in the table, but statistics on the exact number of wells and depth are not available.

In order to estimate the approximate attainable yield for single bore hole wells in the Mountaineous region of Y.A.R., a histogramme was made as shown in Fig. 3-1. Although the wells considered in Fig. 3-1 differ in structure, pumping method, tapped aquifer, etc., the greatest number (25%) have a daily pumping rate which fall in the range 200-300 m^3/D per well. It is noteworthy that 29 of the wells (22%) are empty (i.e., have a zero rate).

1) Yield of Boreholes by Aquifer

The distribution of the existing wells is shown in Fig. 3-2. Most wells are found in the Central Mountain Zone and comparatively near the main highway connecting Sadah-Huth-Amran-Sana'a-Yarim-Ibb. Since information on the hydrological characteristics of the region is insufficient to discuss the region generally, discussion is limited to sites with sufficient data as listed in Table 3-2. The pumping rates according to the strata are given in Table 3-3, and attainable yields for single borehole wells are grouped in 200 m^3/D classes. Although many empty wells were found in the Amran Series,

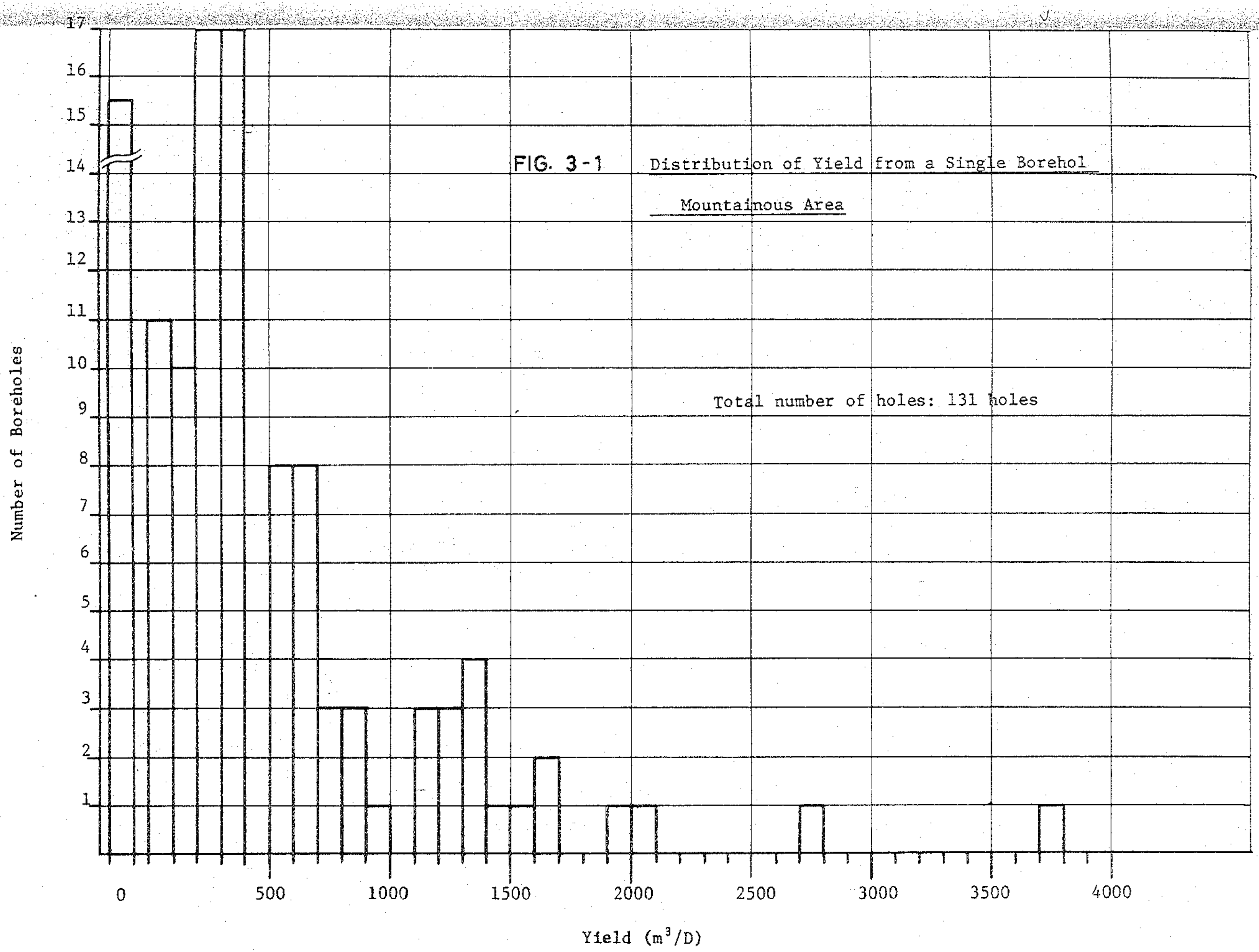


FIG. 3-1 Distribution of Yield from a Single Borehol

Mountainous Area

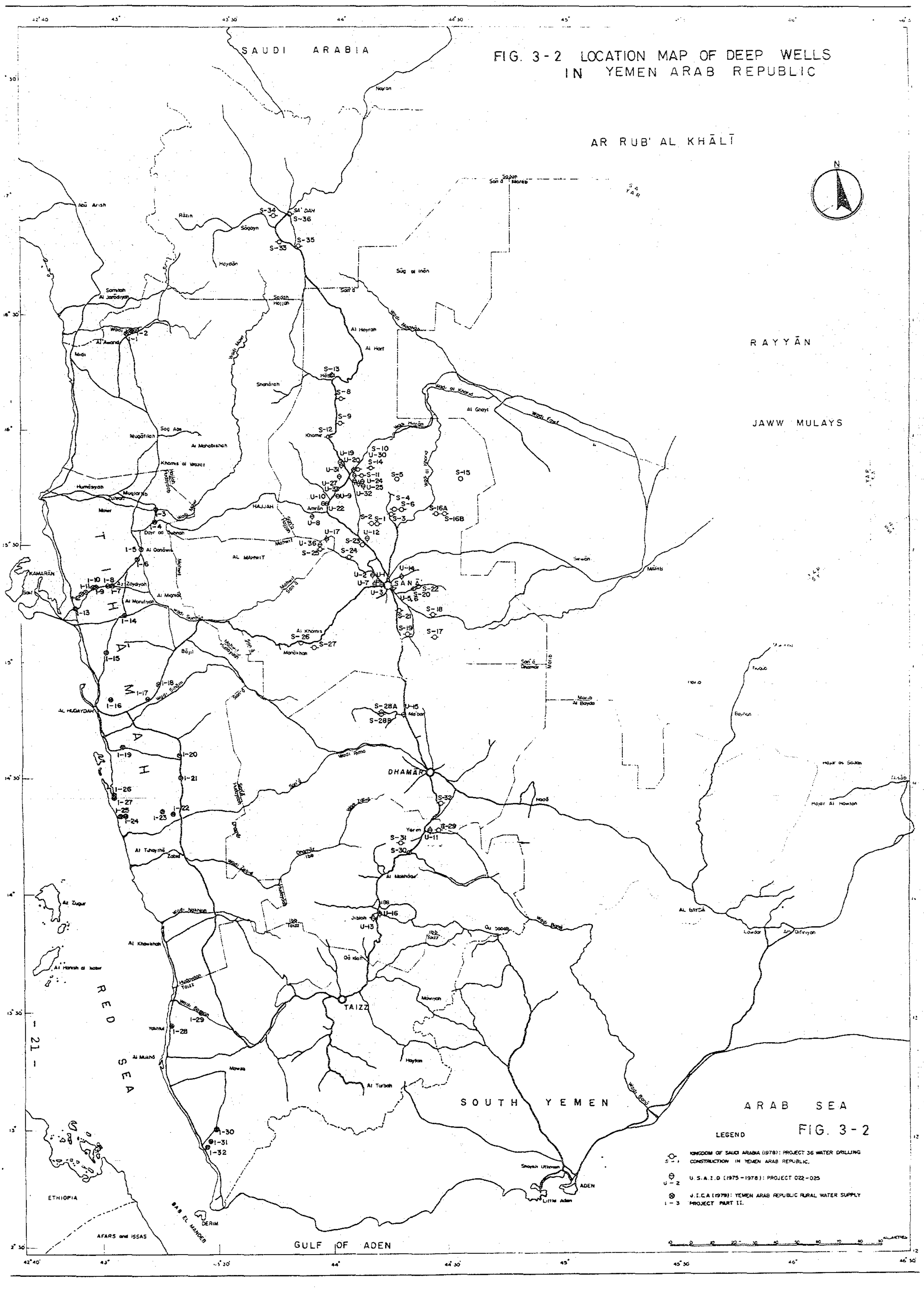


FIG. 3-2 LOCATION MAP OF DEEP WELLS IN YEMEN ARAB REPUBLIC

Table 3-2

Yield of Existing Boreholes

	Well No.	Yield (m^3/day)	(m^3/day/m)	Conductivity (μ℧ /cm)
Alluvium	U-4	801	20.9	368
	U-5	627	102.8	385
Quaternary Volcanics	S-10	662	33.5	480
	S-11	1,252	907.2	360
	S-23A	0	0	-
	S-23B	1,183	1,820	340
	S-24A	87	2.2	300
	S-24B	90	2.2	260
	U-12	245	-	-
	U-30	218	-	-
Trap Series	S-17A	0	0	-
	S-17B	307	4.6	820
	S-18	75	0.5	1,350
	S-19	1,951	145.9	800
	S-20	316	9.8	420
	S-21	295	20.6	590
	S-22	1,183	17.7	960
	S-26	503	6.4	1,050
	S-27	60	0.6	440
	S-28A	0	0	-
	S-28B	1,384	790.9	400
	S-29A	0	0	-
	S-29B	1,657	67.3	400
	S-30A	0	0	-
	S-30B	328	4.2	280
	S-31	593	13.7	390
	S-32	2,071	344	-
	U-1	327	-	-
	U-2	327	8.8	-

Table 3-2 (Cont'd)

Trap Series	U-3	300	14.1	-
	U-5	3,816	-	-
	U-6	894	86	400
	U-7	92.7	-	-
	U-9	273	-	-
	U-11	273	-	-
	U-13	245	10.7	365
	U-14	382	-	-
	U-16	2,715	119	-
	U-32	382	390	-
	U-33	832	-	-
Tawilah Group	J-P-14	1,232	722	620
	J-P-16	959	416	410
Amran Series	S-1	237	262	925
	S-2	0	0	-
	S-3	221	5.8	520
	S-4A	0	0	-
	S-4B	691	17.7	500
	S-5A	0	0	-
	S-5B	0	0	-
	S-6	613	12.9	1,050
	S-7	0	0	-
	S-8	0	0	-
	S-9	160	4.2	520
	S-12A	256	3.3	130
	S-12B	388	12.0	1,000
	S-13	361	3.3	750
	S-14	0	0	-
	S-15	42	0.4	1,580
	S-16A	0	0	-
	S-16B	165	2.6	2,200

Table 3-2 (Cont'd)

	S-25A	0	0	-
	S-25B	38	0.2	480
	S-35	818	28.5	760
	U-8	512	-	-
Amran Series	U-10	48	48	700
	U-17	0	0	-
	U-19	354	-	-
	U-24	0	0	-
	U-25	654	18	-
	U-31	0	0	-
Wajid Sandstone	S-33	164	2.7	1,220
	S-34	1,400	139	600
	S-35	818	28.5	760

Table 3-3 YIELD OF BOREHOLE BY CLASSIFIED AQUIFER

Geologic Strata		Classified Yield (m^3/day)								Total No. of Wells
		0	1 - 200	201 - 400	401 - 600	601 - 800	801 - 1000	more than 1000	Total Average	
Alluvium	No. of Wells					1	1		714	2
	Percentage					50	50			
	Average Yield					627	801			
Quaternary Volcanics	No. of Wells	1	2	2		1		2	467	8
	Percentage	12.5	25.0	25.0		12.5		25.0		
	Average Yield	0	89	232		662		1,420		
Trap Series	No. of Wells	4	3	12	2		2	7	721	30
	Percentage	13.3	10.0	40.0	6.7		6.7	23.3		
	Average Yield	0	76	316	548		867	2,111		
Tawilah Group	No. of Wells						1	1	1,096	2
	Percentage						50	50		
	Average Yield						959	1,232		
Amran Series	No. of Wells	12	5	6	1	3	1		199	28
	Percentage	42.9	17.9	21.4	0.4	10.7	0.4			
	Average Yield	0	91	303	512	653	818			
Wajid Sandstone	No. of Wells		1					2	1,001	3
	Percentage		33.3					66.7		
	Average Yield		164					1,218		

the Trap series has only about 13% empty wells, with the majority producing water at the rate of 201-400 m^3/D and 23% of these producing more than 1,001 m^3/D. In Quarternary volcanics, the majority of the produce 1-400 m^3/D, but in some cases 1,000 m^3/D or more water is produced. Less data is available for other strata, so it is difficult to determine the properties of other formations to the same degree of accuracy; however, rough average yield values for all strata are summarized below for reference:

<u>Average Daily Pumping Rates for Geologic Strata</u>

Aluvium	- 700 m^3/D
Quarternary volcanics	- 450 m^3/D
Trap series	- 700 m^3/D
Tawilah group	- 500 m^3/D
Amran series	- 200 m^3/D
Wajid sandstone	- 1,000 m^3/D

2) Water table

The data for hydrostatic water level contour in the Sana'a region is available with higher regional concentration and is shown in Fig. 3-3.

According to the water table contour, groundwater is apparently controlled by the surface topography. Groundwater levels are higher in the hilly district east, west and south of Sana'a which is the replenishing area for the Sana'a sloping to the north of Sana'a. In the region extending from Amran to Raydah, another groundwater basin exists. Water table gradient is steep in the hilly district, but very gentle in valley district. Major geological formations in this region are Amran series, Tawilah sandstone, Trap series Quarternary Volcanics and Alluvium. Each formation has already been tapped. There is no eminent difference in water table level from the variations of each formation. The very noticeable contour indentation of

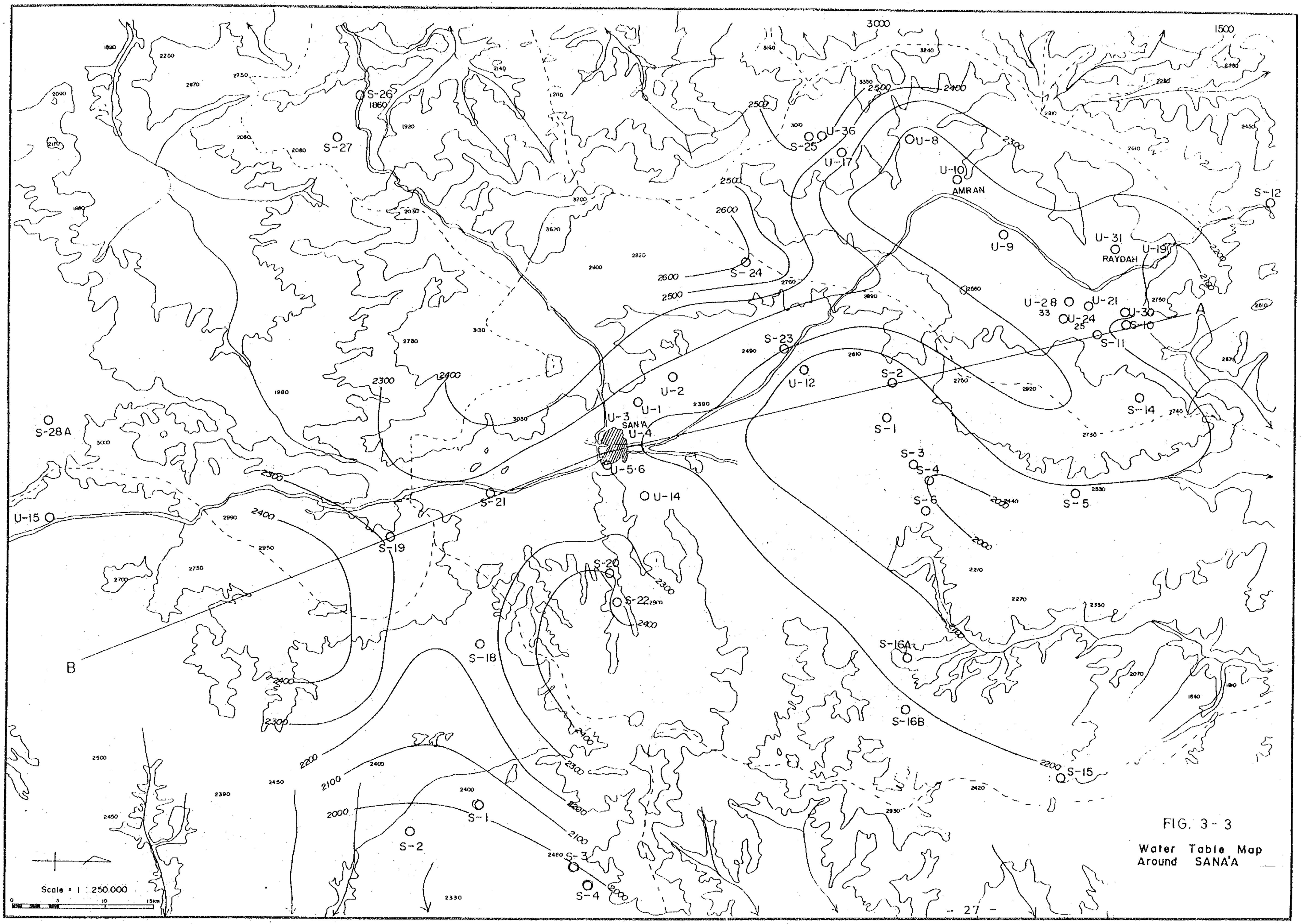


FIG. 3 - 3

Water Table Map Around SANA'A

FIG. 3 - 4 HYDROGEOLOGICAL PROFILE

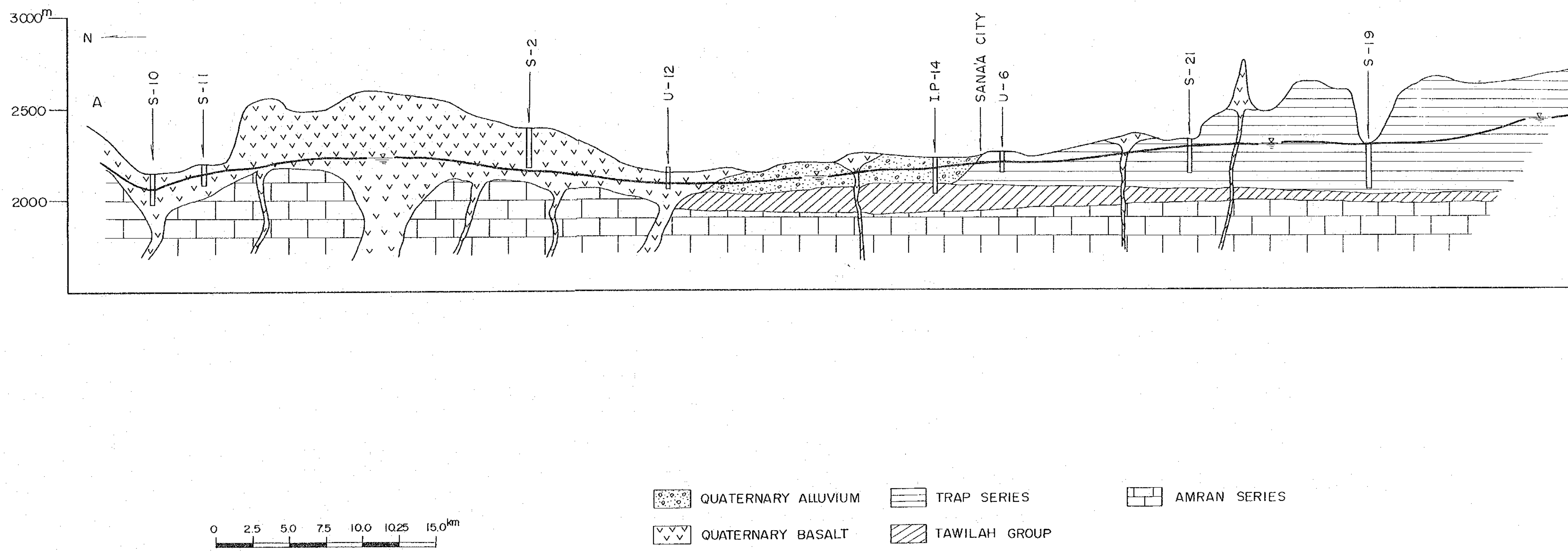
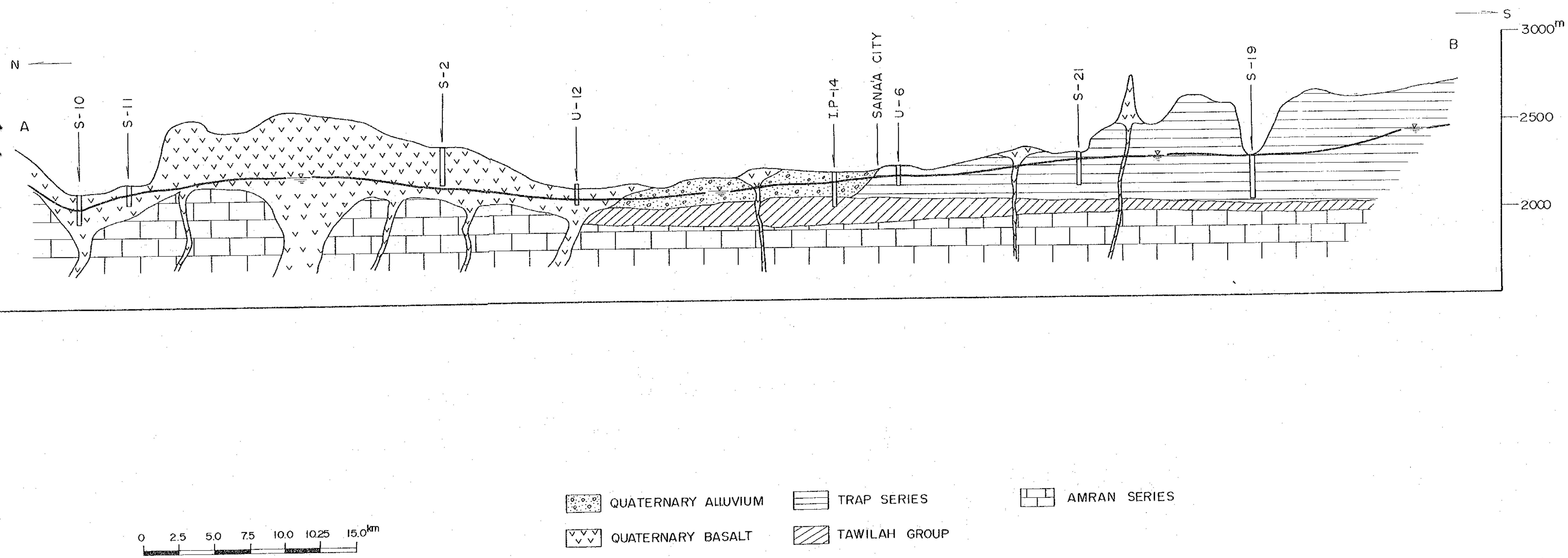


FIG. 3-4 HYDROGEOLOGICAL PROFILE



2,200 m into the Sana'a city area cannot be explained in detail, but the recent rapid lowering of the water table in this locality could be attributed to this feature in the groundwater contour map.

3-1-2 General Conditions of Hydrogeology in Coastal Region

A long belt of the Tihama Low Pressure Zone 50 Km in width spreads along the coastal region, located in the western part of the Y.A.R. and extends along the Red Sea. This region consists of eolian sands and wadi deposit transported from the mountaineous region to the west. Two kinds of exploration reports have been published so far concerning the groundwater in this particular region: one is for the major wadi region (Wadi Zabid: Awad, Toson M., and Hassan, Tawfik A., 1978; Wadi Mawr: Boros I.J., 1972, Tipton and Kalmbach, Inc. Engineers, 1979) and the other is for the vicinities of Hodeidah (Italconsult 1973).

In this section, the hydrogeology of this region is summarized based on the present survey and the survey report entitled "Development of Wadi Mawr" by Tipton and Kalmbach, Inc. Engineers in 1979, which gives a comparatively systematic and well summarized view of the groundwater behavior in the Tihama Low Pressure Zone.

1) Water Bearing Formation

Among the existing wells for groundwater supply, there are hand-dug wells tens of meters in depth and deep wells 100-150 m deep. According to the columnar sections, the main constituents of the formation are sand, silt, gravel, etc. Fig. 3-5 presents the east-west geological section, which follows approximately along the Wadi Mawr, based on columnar sectional data as well as electric probes in the bore holes. The schematic columnar section deducted from these data is shown in Table 3-4.

Table 3-4 Schematic Columnar Section of the Coastal Region

Depth (M)	Thickness (M)	Major constituents
0-23	11-23	Silt, mixed with find sand
11-56	19-45	Sand (containing silt in some localities)
39-70	4-15	Sandy gravel
54-95	29-55	Sandy gravel, mixed with silt
95-132	6-23	Sandy gravel
106, or deeper		Sandy gravel, mixed with silt

Judging from the above constituent elements, the main water bearing formations are presumably the sandy gravel strata at 39-70 m and 95-132 m depths.

These formations are layered parallel to the surface slope with a gentle gradient of 1/350 from east to west. The formations are extensively distributed throughout the region, varying in thickness from place to place. Italconsult also reported (1973) the occurrence of sandy gravel formations at around 50-60 m and 100 m depths in the Hodeidah area. However, the underground assemblage of the wells indicates that they are tapping out only these water bearing formations but other ones installing strainers there.

2) Water table

The water table in the Wadi Mawr river basin was determined as in Fig. 3-6 by Tipton and Kalumbach, Inc. Engineers, 1979. The figure clearly illustrates that Wadi Mawr is replenishing the surrounding aquifers. Nonetheless, the influence of an extensive irrigation system must be taken into consideration; however, the fact that Wadi Mawr is one of the rare Wadis with year round flow could also explain the underground flow system presented.

FIG. 3-5 SECTION OF WADI MAWR

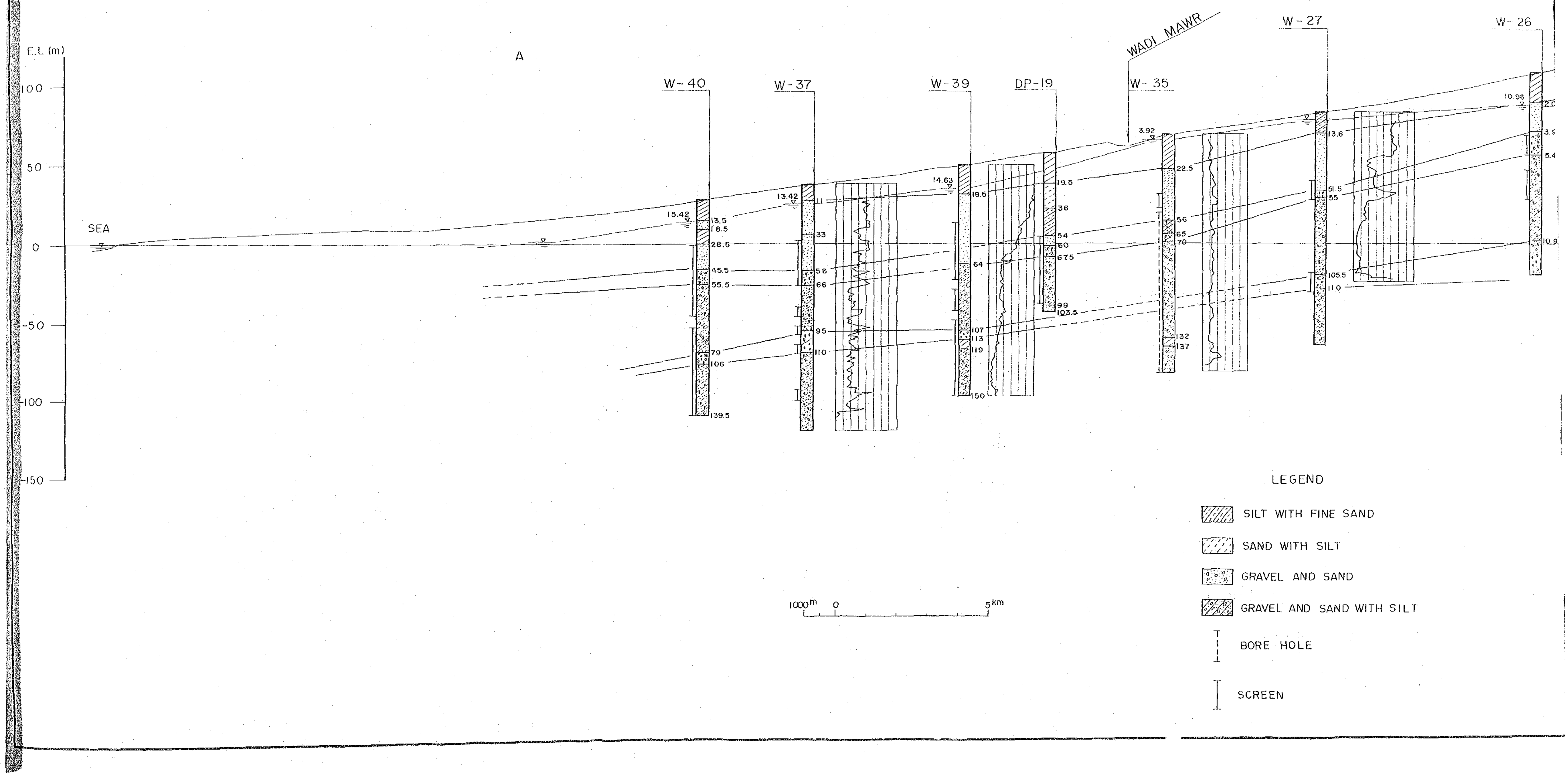
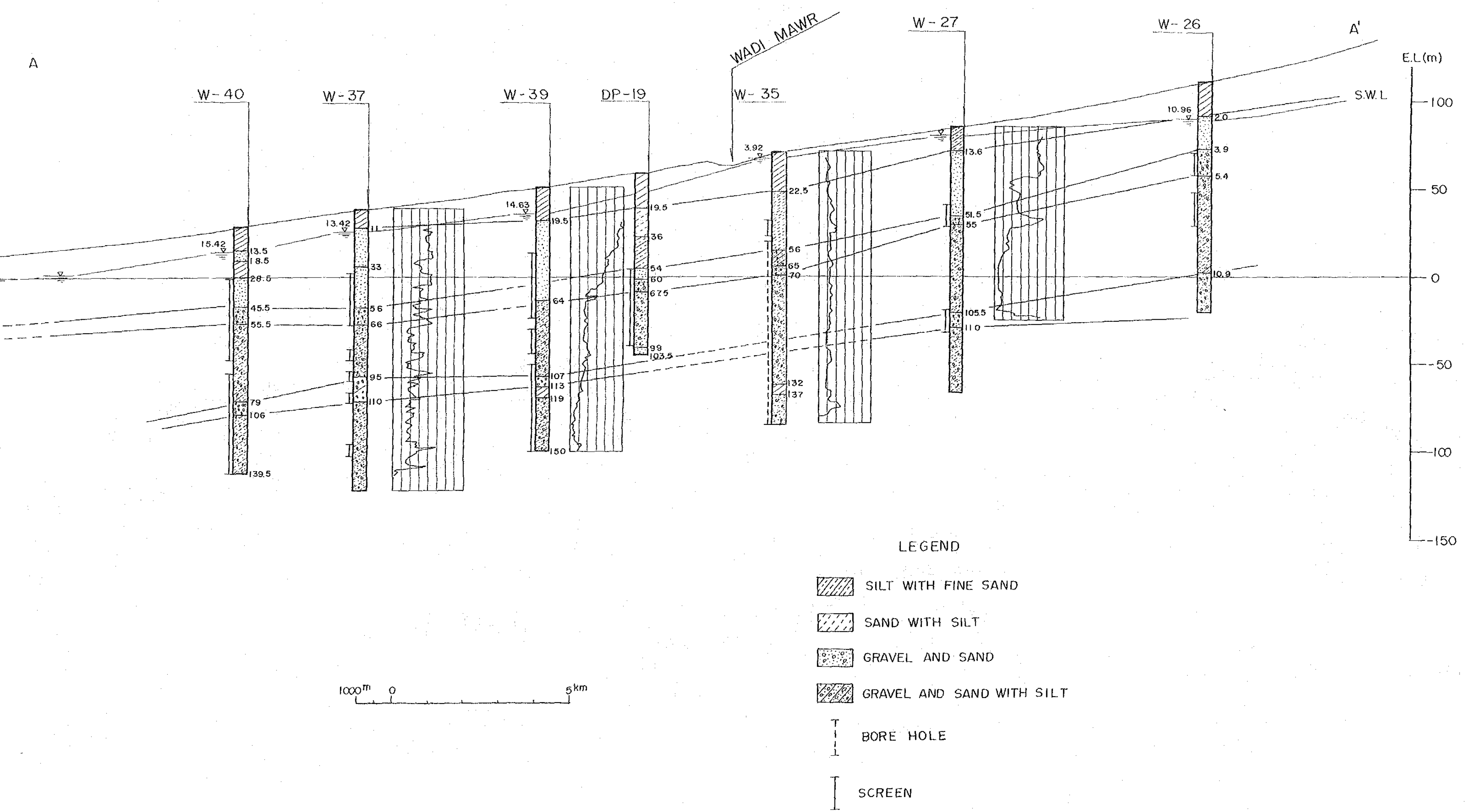
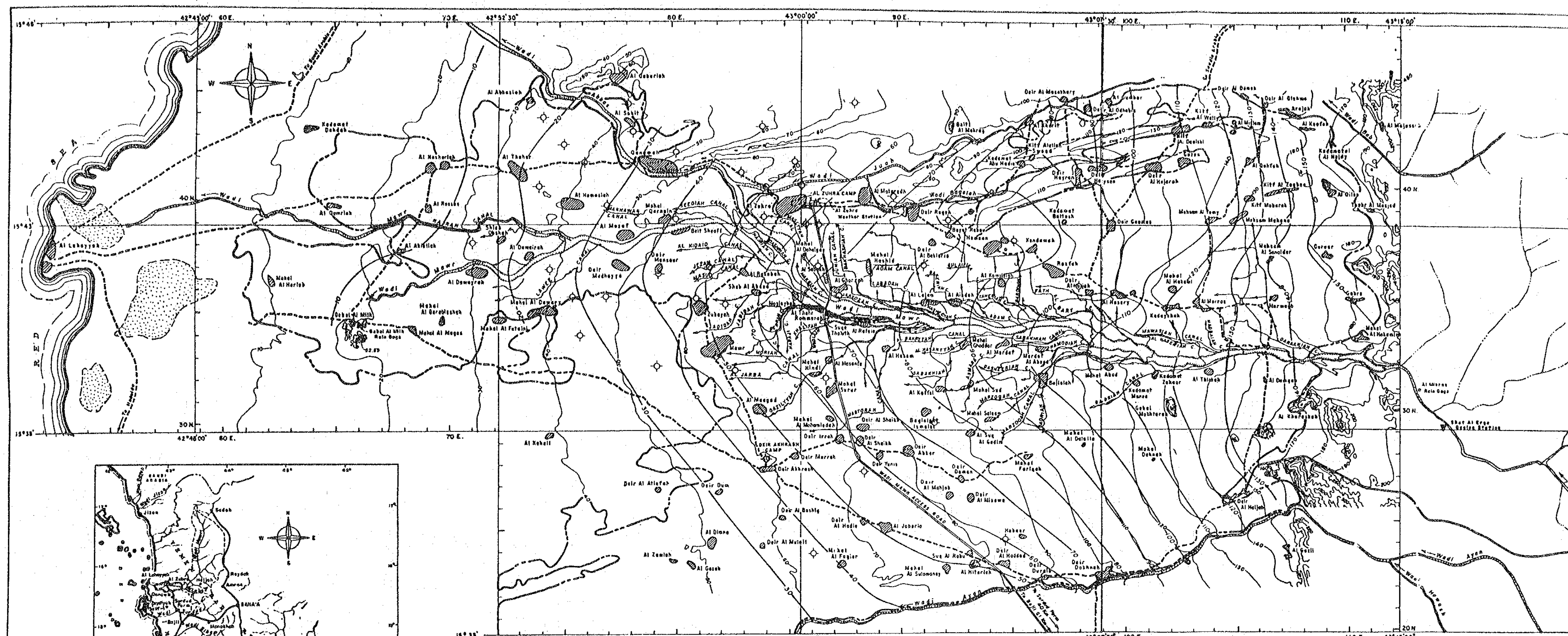
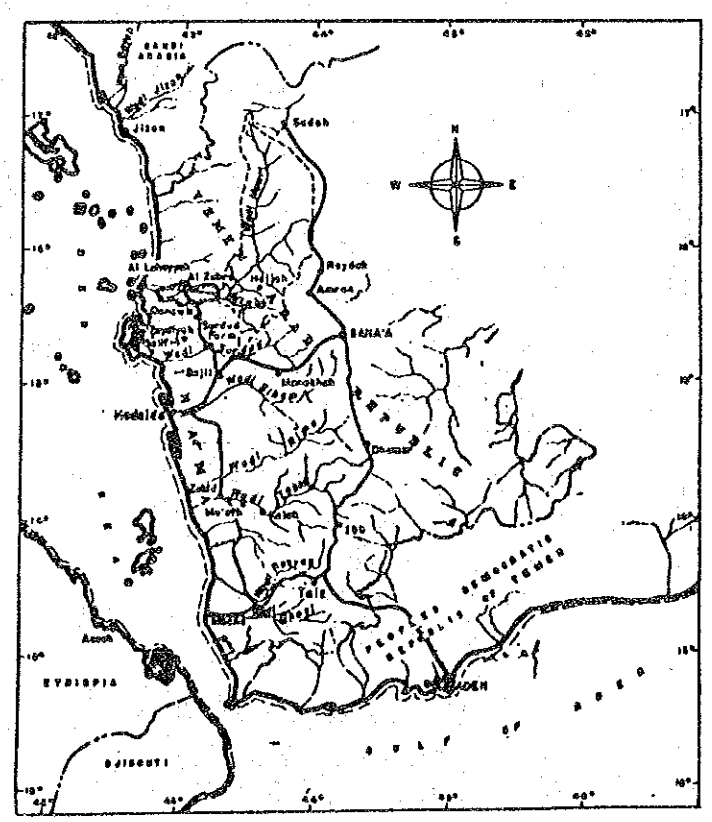


FIG. 3-5 SECTION OF WADI MAWR







INDEX MAP

NOTE

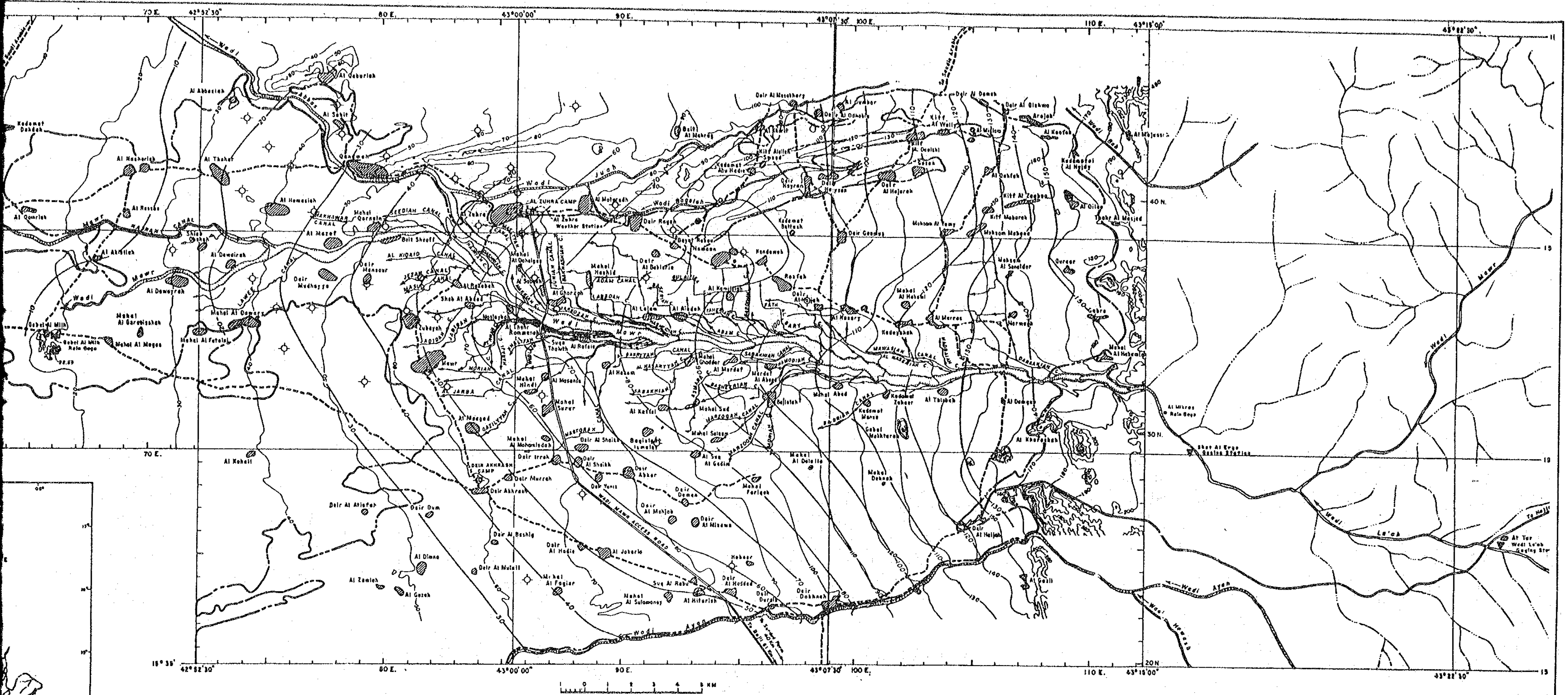
Base map data taken from maps prepared under the technical direction of the U.S. Geological Survey for the Central Planning Organization of the Yemen Arab Republic in 1974, and from maps prepared by the United Kingdom for the Yemen Arab Republic in 1974.

TIPTON AND KALMBACH INC 1979

LEGEND

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

WA



LEGEND

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

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, and from maps prepared by the United Kingdom for the Yemen Arab Republic in 1974.

TIPTON AND KALMBACH INC 1979

FIG. 3 - 6

WATER TABLE MAP AROUND WADI MAWR

50
0
50
100
150

Table 3-5 Hydrogeological Analysis of Existing Dug Wells in Tihama Costal Region

No.	Site	Depth (m)	Static Water Level (m)	Altitude (m)	Water Temperature (°C)	Electric Conductivity (at 25°C) (μ℧/cm)	Distance from the Shore Line (km)	Date of Sampling
1.	Old HARAD				29.0	735	29	
2.	New HARAD	17.6	17.0(63.0)	80	31.0	382	32	
3.	Wadi MAWR	-	-		24.0	665	48	11/27 18:00
4.	Dayr KHASHM	26.7	24.5(165.5)	190	23.5	2,585	47	" 18:21
5.	QANAWIS	32.0	-		29.5	2,730	38	" 19:35
6.	HASANABD ALLAH	20.0	18.5(61.5)	80	34.0	3,088	33	" 20:20
7.	AZ ZAYDIYAH	65.0	-	60	35.0	1,803	21	11/28 07:30
8.	"	19.5	18.7(41.3)	60	28.0	1,051	20	" 08:30
9.	MOUNIRAH	60.0	13.0(7.0)	40	[36.0]	2,818	13	
10.	"	20.0	16.0(24.0)	40	31.5	4,987	13	
11.	KAIR SOWED	11.9	11.4(10.6)	22	29.0	4,871	8	11/28 09:00
12.	TORKIA Well	5.7	5.0(8.0)	17	33.0	4,337	6	" 09:15
13.	SHOWLEE Well	9.5	8.7(8.3)	17	34.5	2,884	6	" 09:30
14.	AL DAHI	65.0	-	78	33.0	1,588	24	
15.	TORBAH	25.1	24.4(25.6)	50			12	
16.		100	-	40	[38.0]	2,566	6	
17.	MARAWIAH	(60.0)	-	65	25.5	2,621	22	
18.	QUTAY	50.0	20.0(83.0)	103	26.0	1,389	28	
19.	AD DURAYHIM	16.7	13.8(16.2)	30	30.5	2,186	7	
20.		24.0	10.9(119.1)	130	24.0	3,476	33	
21.	AL MOUSEA	38.4	37.0(113.0)	150	34.0	1,260	32	
22.	SHOWKAI BANI ROMEH	25.0	23.3(76.7)	100	32.5	1,219	26	
23.	KOBEH	25.8	25.4(44.6)	70	33.0	1,361	21	
24.	AL JAH	2.7	2.5(17.5)	20	30.5	2,159	5	
25.	AL JAHAR ASFAL	11.5	10.9(2.1)	13	33.5	1,432	2	
26.	GHULAYFAGAH	1.4	0.4(9.6)	10	26.5	1,839	1	
27.	"	4.4	1.9(8.9)	10	32.0	1,820	1	
28.	YAHKHTUL	3.3	3.0(2.0)	5	31.0	4,682	2	
29.	AL BAKERYA	27.0	17.0(143.0)	160	33.0	2,721	15	
30.	UMARI	14.1	9.3(130.7)	140	32.0	1,603	10	
31.	AL MUSALAS	18.6	16.8(133.2)	150	33.0	1,658	6	
32.		12.46	10.45					

[ ]: cooling water ( ): Static Water Level at m.A.S.L.