water service. During this project this matter will have to be consulted with the concerned officials in each project site to draw their attention and to ask for efforts to enlighten the awareness of the residents.

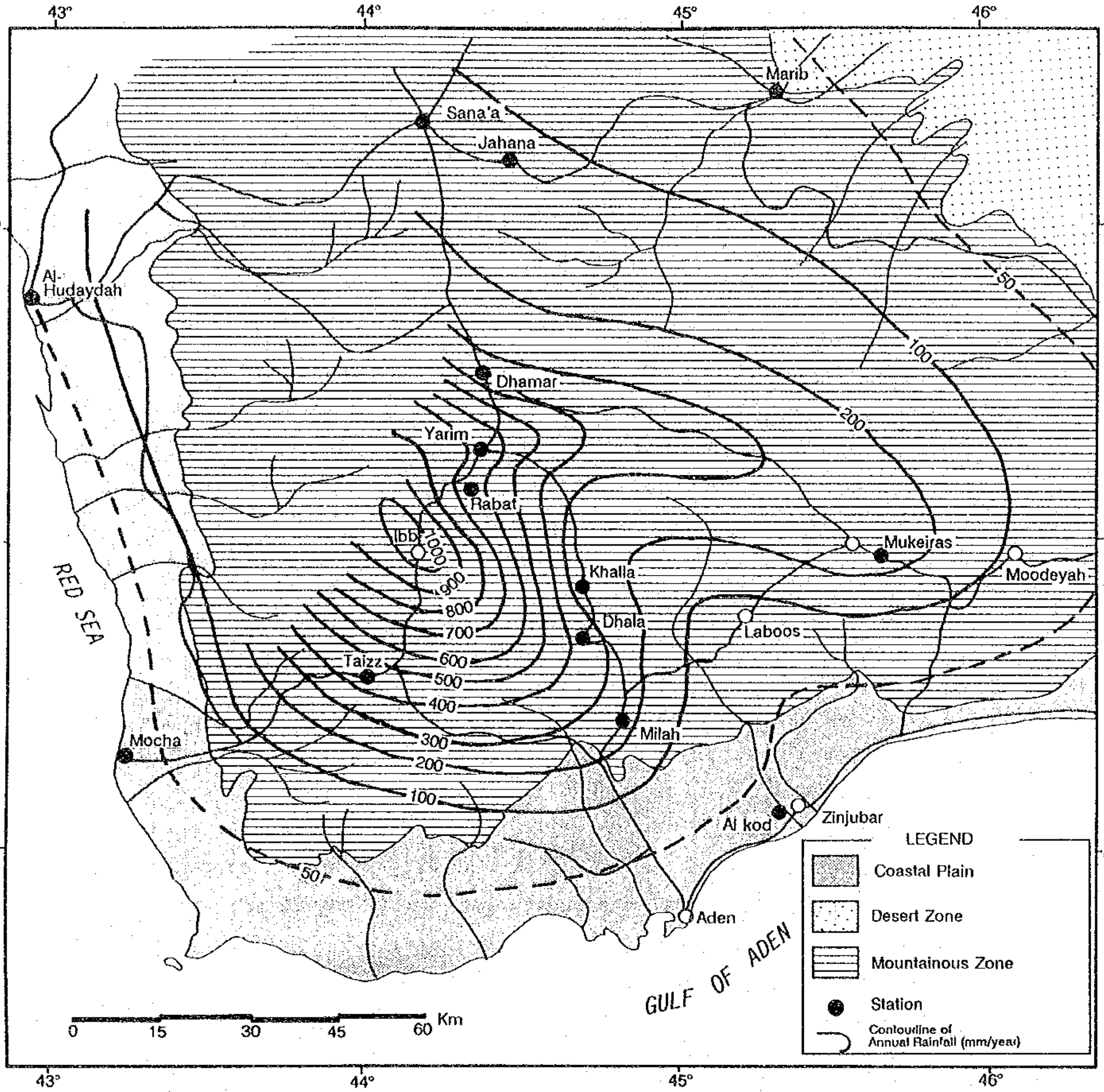
3.1.5 Natural Environment

(1) Climate

The southern part of the Republic of Yemen is located in the north latitudes, from 12 - 30" to 19 - 00." In terms of overall latitude, Yemen is located within the tropical and subtropical zones. Nevertheless, there are striking variations in the climate based on the topography of the region. Generally speaking, the climate is divided into an intense heat from April to October and a mild period from October to May. The average temperature during the former is 30°C to 40°C, and 20°C to 30°C during the latter. Aden, a port city, once recorded a temperature of 54.4. In the mountainous area in the west, the minimum temperature during the winter is 0°C, and the daytime/night-time temperature difference reaches 30°C.

The rainy season continues from February to March, although there is some rain during the monsoon season during July to September. Although the regional characteristics of rainfall cannot be detailed due to the unavailability of weather data, the mean annual precipitation across the southern part of Yemen reportedly is 76 mm: 200 mm - 700 mm/year in the northwest mountain area; 40 mm - 100 mm/year in the coastal plain along the Gulf of Aden; and 50 mm - 76 mm/year in Hadramout in the northeast. Five consecutive years without a drop of rain are said to have been experienced in this part of the country. Humidity in the Wadi Hadramout is 35% during the summer and 54% during the winter.

The seasonal changes in climate are responsible for the northeast monsoon predominant period (November to March) and the southwest monsoon predominant period (May to September) which occur as a result of the trade winds and the seasonal movement of the equatorial convergence zone.



STATION	LENGTH OF RECORD	PRECIPITATION (mm/y)
Sana'a	1984 - 1988	135.6
Jahana	1984 - 1988	112.5
Dhamar	1984 - 1988	321.9
Taizz	1984 - 1988	404.9
Al Hudaydah	1984 - 1988	50.1
Mocha	1984 - 1988	40.8
Marib	1984 - 1988	76.7
Yarim	1969 - 1981	690.0
Rabat	1975 - 1977	610.0
Mukeiras	1977 - 1979	240.0
Khalla	1972 - 1979	258.0
Dhala	1972 - 1979	370.0
Milah	1972 - 1978	202.0
Al kod	1967 - 1981	31.0

Fig.-3.1 The Map of the Annual Rainfall in Souther Part of the Republic of Yemen

(2) Topography

The topography of the southern part of the Republic of Yemen (South Yemen) can be divided as follows. (Refer to Figure-3.2)

1. Coastal Plain
2. Wadi Plain
3. Desert
4. Highland Platform
5. Mountains

1. The "coastal plain" faces the Gulf of Aden and extends east and west. The plain at its widest is 30 km covering an extensive area from Aden to Lahj; other areas are commonly 5 km to 10 km wide. In some locations there are 2 to 3 stages of terraces 5 m to 10 m in relative height. Sand dunes running in the direction of east and west, 2 m to 5 m high are widespread (small-scale back-marshes are seen behind the sand dunes between Aden and Zinjbar (capital of Abyan governorate). Between Ahwar and Shuqrah, respectively located 220 m and 100 m east of Aden, basaltic lava and scoria from Quaternary volcanic activity lie 1 m to 3 m thick on the alluvial sand. White sand containing animal remains (mainly coral and shellfish), blown in from the ocean, is observed in the area surrounding Bir Ali, a fishery base which borders Shabwa and Hadramout governorates.

2. The "wadi plain" is represented by a fan of floodplain formed along the big wadis such as the Wadi Tuban, Wadi Ahwar, Wadi Hajar, Wadi Al Masilah and Wadi Dahawan where these wadis cut exit from the mountains. Although much smaller in scale, the alluvium deposit forms belts of plain along the channels of the wadis as another example of this type of plain. In some locations such as Moodeyah in Abyan governorate and Seiyun in Hadramout governorate, flood plains are extensive, with a width up to 2 km. As Sadarah along the Wadi Hajar in Hadramout is a longitudinal tectonic basin (south-north approximately 20 km x east-west 4 km - 5 km).

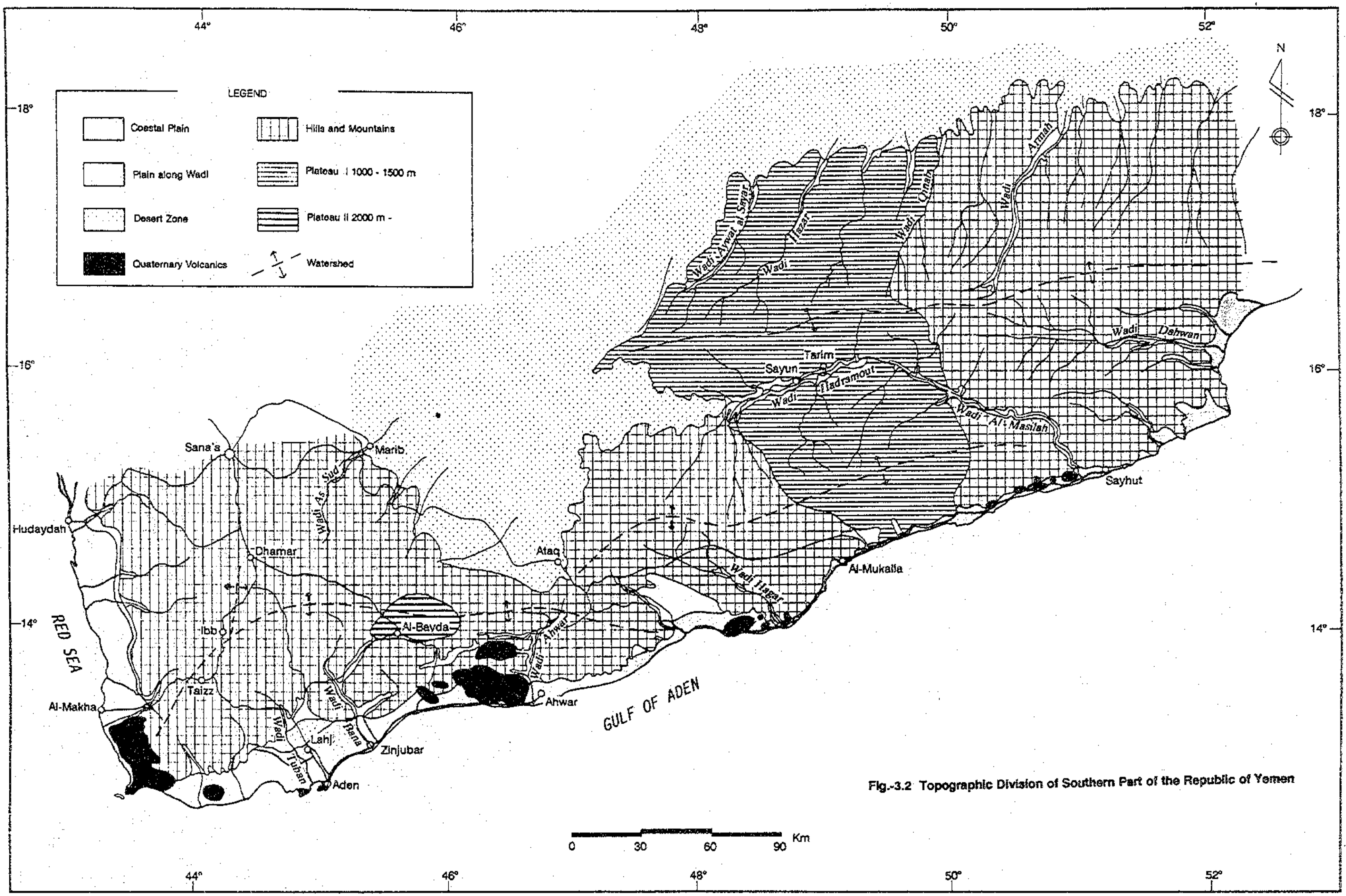


Fig.-3.2 Topographic Division of Southern Part of the Republic of Yemen

3. The southern limit of the "desert" lines the north of Ataq, the capital of Shabwa. The Rub Al Khali desert is a mighty desert, occupying a vast sandy area along the border of Saudi Arabia. Small-scale deserts are distributed north of the Aden coastal plain.

A gently rolling platform located between the Wadi Mayfaan and the Wadi Al Masilah is called "Jol", which extends a vast plateau constituted of limestone of the Tertiary Eocene period. This structure of Jol is divided into two platforms in the north and the south by the Wadi Hadramout, which is upstream of the Wadi Al-Masilah. The northern platform running east and west is called the North Hadramout Arch, while the other one in the south, the South Hadramout Arch running in parallel with the Northern Arch. Through these two anticline structures the Wadi Hadramout forms the Hadramout-Jeza axis of the syncline. The top of the platform is a limestone stratified plain and forms 2 to 3 stages of erosional terraces, indicating that the plateau surface is dominated by the geological structure. Both sides of the Wadi Hadramout and its tributaries form steep cliffs nearly 100 m higher than the wadi beds, resembling the Grand Canyon, though much smaller in scale.

The area from Tor Al-Bah to the right bank of the Wadi Ahwar is grouped as "mountains" ranging from 500 m to 2,000 m in elevation. This corresponds to the central highland zone and the central mountain zone in the northern part of Yemen. The topography is in a mature stage, with sharp ridges and deep valleys; however, a "peneplain" with an altitude of 2,000 m can be seen east of Al-Bayda city. There is a hilly terrain of 100 m to 500 m in altitude along the contact line of the mountains or platforms with the coastal plain. Round tail-shaped terrain caused by the flow of lava and scoria flows can be seen at the base of the Quaternary volcanos.

Part of wadis flow to the south into the Gulf of Aden, while others flow northward eventually merging into the Rub Al-Khali sand desert. However, some wadis, represented by the Wadi Hadramout, flow east and west, dominated by geographical structures. These wadis release floods vehemently during the rainy season, yet hardly have any surface runoff during the dry season. Year-round and interspaced surface runoffs are seen in the Wadi Tuban, Wadi Bana, and Wadi Hajar as rare types of wadis in this part.

(3) Geology

Yemen's geological structure is extremely complex because the country is located along one of the world's greatest mobile belts where the Aden Graben Belt, an eastern section of the Great African Graben Belt, and the Red Sea Graben Belt moving northward meet. Table-3.4 shows the diagram of geological stratigraphy, and Fig.-3.3 shows the geological map of the southern part of Yemen.

The geological structure in general consists of the Precambrian basement complex comprising crystalline schist, gneiss and granite, overlain by sedimentary and volcanic rocks from the Jurassic and Cretaceous Periods of the Mesozoic Era to the Tertiary Period and the Quaternary Period of the Cenozoic Era. base of Precambrian crystalline schist, gneiss, and granite.

The Precambrian rock series is composed of crystalline schist (such as biotite schist, sericite schist and chlorite schist), gneiss, granite, anphibolite and dolerite, the structure of which shows highly disturbed stratification and schistosity as well as folding and faulting affected by tremendous tectonic movements. The vast distribution of the Precambrian rocks is observed in the Western Mountains Zone and in the western part of Al-Mukalla.

The Jurassic rock series is distributed in the north of Ahwar and Rudun extending to Habban. From top to bottom it is divided into four groups: Naita Formation of dominantly limestone with sandstone and conglomerate (thickness 250 m); Madbi Formation, dominantly of sandstone interbedded with limestone (120 to 160 m); Shuqra Formation consisting only of limestone (100 m); and Kohlan Formation consisting of sandstone with highly developed crosslamina (about 100 m).

Table 3-4 Geological feature of southern part of Yemen

AGE		LOG	FORMATION		THICKNESS		LITHOLOGY	
Quaternary	Holocene		Quantrnary Deposits		5-100 m		Eolian sand, Sand, Gravel	
	Pleistocen		Quaternary volcaanics		2-200 m		Basaltic lava and scoria	
Tertiary	Miocene - Oligocene		Shihr Formation	Yemen volcanics	50 - 100 m	+2000 m	Sandstone, Coglomerate	Basalt, Andesite lava, Pyroclastic rocks and Dyke
	Mid - Upper Eocene		Habshiya Formation		20 - 100 m		Clay, Limestone interbedded Dolomite	
	Mid Eocene		Rus Formation		200 m		Limestone, Dolomite	
	Lower Eocene		Jeza Formation		0 - 90 m		Limestone	
	Paleocene		Umm Er-Rudhuma Formation		25 - 300 m		Limestone, Dolomite	
Cretaceous			Mukalla Formation		650 m		Sandstone interbedded shale	
Jurassic			Naita Formation		250 m		Limestone, Limestone with sandstone & conglomerate in lower part	
			Madbi Formation		120 - 160 m		Predominantly Sandstone interbedded Limestone	
			Shugra Formation		100 m		Limestone	
			Kohlan Formation		10 m		Sandstone prevalence of crosslamina	
Pre-Cambrian			Pre-Cambrian system		?		Granite, Gneiss, Crystalline schist, Amphibolite, Dolerite	

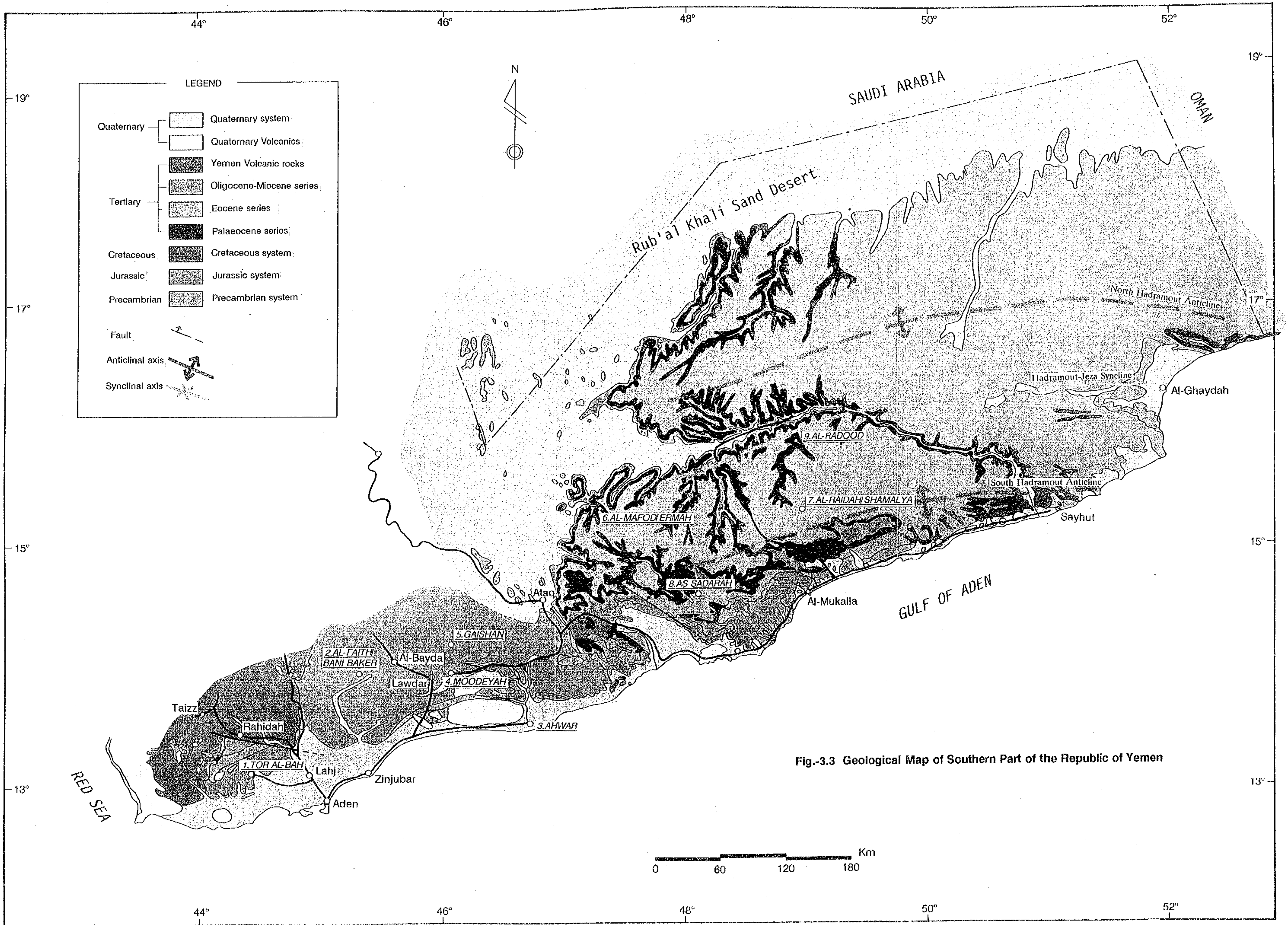


Fig.-3.3 Geological Map of Southern Part of the Republic of Yemen

The Cretaceous series is broadly distributed in Tor Al-Bah, Ataq, Al-Mukalla, and the Wadi Hadramout. A major group called Al-Mukalla Formation consists of sandstone of coarse to medium grains interbedded with shale, which is comparable with Tawilah Formation in the northern part of Yemen. Its thickness is more or less 650 m.

The Tertiary series is classified from bottom to top into the following groups: Umm Er-Rudhuma Formation of the Paleocene Epoch consisting of limestone and marl (thickness 250 m - 300 m); Jeza Formation of the Lower Eocene, consisting of limestone containing dolomite nodules (0 m to 90 m); Rus Formation of the Middle Eocene, consisting of limestone and marl (approximately 200 m); Habshiya Formation of the Middle and Upper Eocene, consisting of limestone interbedded with clay and marl; Shihr Formation of the Oligocene to the Middle Miocene Epoch, consisting of sandstone, conglomerate, and mudstone. Part of the terrace deposits along the big wadis possibly belong to the Pliocene. Basaltic lava and pyroclastic rock massively occurring in the south of Taizz, which is northeast of Aden, are called Yemen Volcanic Rock. Although distributed widespread all over the northern part of Yemen, this series of volcanic rocks is hardly seen in the southern part except for limited distributions in the western mountainous area. A vast area of the Tertiary rock series, the highland platform in Hadramout has a large-scale structure composed of two large anticlines (North Hadramout Anticline and South Hadramout Anticline) with the Hadramout-Jeza Syncline running in between east and west. At present this area is the focus of attention for oil exploration.

The Quaternary series is largely divided into basaltic lava and scoria scattered along the coast and sand and gravel forming the coastal and wadi plains. Quaternary volcanic flow was mobile basaltic lava and scoria which flowed down the coastal plains and the wadis. Its distribution is wide, yet in many places is only 2 m - 3 m thick. There are neither cones or craters, only fissure craters scattered, as are observed west of Ahwar. Deposits on the coastal plain and the wadi plain are mainly of sand and gravel and the surface is entirely covered with eolian sand.

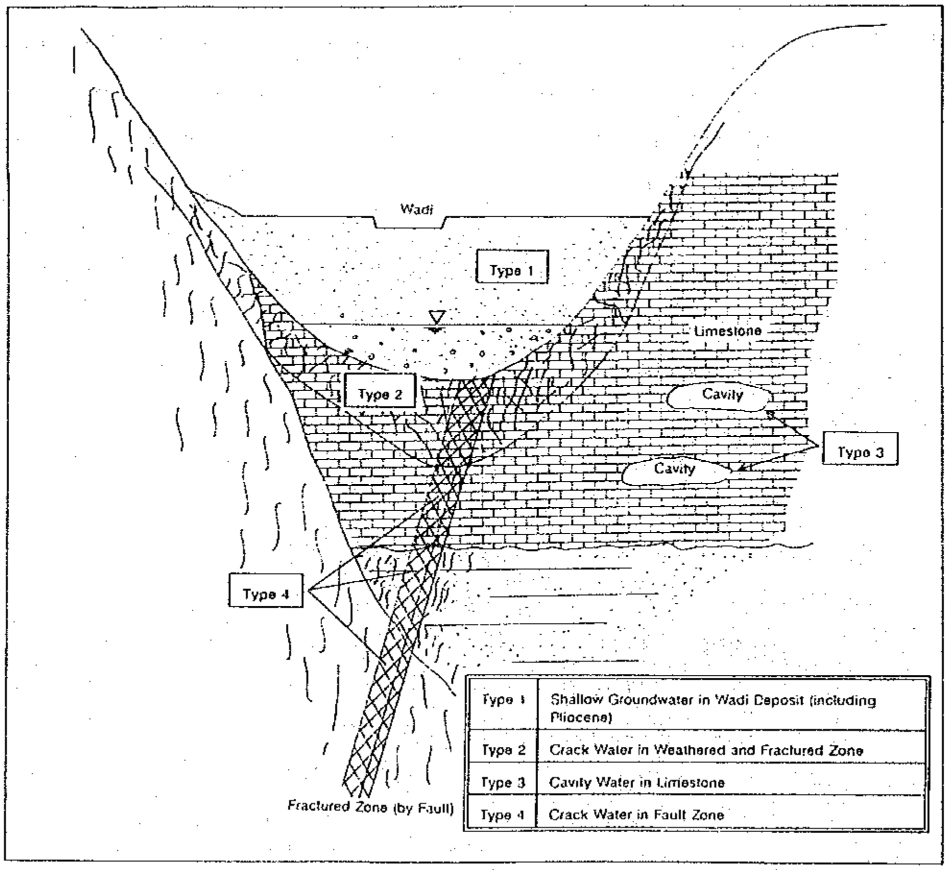
Fault systems mainly run north and south, and fissure craters of Quaternary volcanos follow the direction of the fault system.

(4) Hydrogeology

Groundwater means water filling interstices of formations and cracks or fractures of rocks. According to the types of its occurrence, it is divided into "free water" (water moving by gravity or pressure) and "retained water" (water not easily moved by gravity or pressure, such as pellicular water and capillary water). The former is the target of groundwater development, and this is generally referred to as groundwater.

Groundwater in the southern part of Yemen is largely divided into "stratum water" and "fissure water", and is further classified into the following four groups. Fig.-3.4 shows the classification of groundwater based on the types of its occurrence.

Fig.-3.4 Classification of Ground Water based on the Types of Occurrence



Type 1: This type of groundwater occurs in aquifers of coarse-grained sand and gravel of the Quaternary sedimentary formations (sediments in the coastal plain or along the wadi). However, the unconsolidated gravel formation of the Pliocene period sometimes becomes a major aquifer, as is the case with the deepwells drilled in the agricultural project for the site of Ahwar by the former U.S.S.R., which were surveyed under this basic design study. Where the Quaternary sediment is thin, the yield of this type of groundwater tends to be affected by the climatic change. In Moodeyah, another site under this study, the Quaternary sediment reaches 70 m in thickness.

Type 2: This type of groundwater moves through a network of cracks in the weathered zone of the basement rock.

A major part of rocks forming the land of Yemen are those of the Tertiary period or earlier, most of them tightly-cemented. As the effective porosity is extremely small, stratum water is not contained in these rocks. However, where a network of cracks is developed on the horizon of the basement on the wadi bed, fissure water moving through the cracks network takes a similar form of occurrence as stratum water. A part of the candidate sites provide examples of this case: The Wadi Uddamar at the site of Gaishan in Abyan governorate is the product of erosion of fault fractured zones through the Precambrian rock series. While a major part of faults have been reduced to impervious zones by clogging with fault clay or breccia, networks of cracks running in parallel with faults are active and provide good passages of groundwater: At the site of Al-Radood in Hadramout, small cracks striking NW or NNW abound in the brecciated limestone as a lower formation of the Umm Er-Rudhuma Formation of the Tertiary Paleocene period, providing an excellent passage of fissure water: Hot springs in As Sadarah in Hadramout fall into the zone of small cracks in NW direction.

Type 3: Groundwater moving through openings in limestone

The area such as the highland platform in Hadramout where limestone is thickly and widely distributed requires development specifically targeting this type of groundwater. The existing well drilled by UNDP at the site of Al-Raidah/Shamalya seems to have penetrated limestone, drawing some quantity of this type of groundwater.

Type 4: Fissure water moving through the fault fractured zone in the cemented rocks

Groundwater does not always exist in all fractures and fissures. This type of groundwater is possible to occur in the formations of the later geologic times with their fissures left open enough for the movement of groundwater. Since the Precambrian rock and limestone are transformed into clay with the energy associated with the fault movement, the occurrence of this type of groundwater in these rocks is very rare. In contrast, sandstone has a viscosity so low that it is easily torn apart, producing plenty of cracks when force is applied. Because of this characteristic, sandstone of the Cretaceous and Jurassic periods is said to be an excellent aquifer across Arabia and Africa. Although sandstone has a nature of forming fractures better than other rocks, this does not necessarily mean groundwater can be found in all sandstone. While one of the existing wells (W-1) in the site of Al-Raidah/Shamalya is judged to have successfully tapped limestone of Al-Mukalla Formation, one of the two existing wells in the site of Al-Mafod /Ermah, which reportedly penetrated Al-Mukalla Formation, could not obtain water. (The other well in Al-Mafod/Ermah is considered to hit a small cracks zone in limestone belonging to Rus Formation.)

3.2 Field Survey Sites for the Basic Design Study

The 20 project sites for the rural water supply project in the southern and eastern governorates, as requested by the Yemen government, broadly differ in their natural and socio-economic environments, but they have one factor in common that they are acutely in need of safe and stable water, with their urgency for water supply facility real. The water sector in Yemen, on the other hand, has been faced with diverse problems such as complex natural environment and hard-hit social conditions to overcome in order to meet the demand of rural communities. In view of the circumstances under which this project is to be executed, the following factors deemed critically important to be examined with each of the candidate sites for the purpose of establishing an effective water supply plan with grant aid through the selection of the most relevant project sites: (1) the possibility of securing water sources in the sites; (2) various conditions of the sites for project implementation; and (3) levels of capital investment effectiveness. Based upon this strategy, the results of "Project Formulation Study" were examined prior to the field survey under this basic design study. Furthermore, a variety of information was collected and interviews were conducted in regard to the current situation of the candidate sites. The results are shown as follows:

Group 1: Sites located in the Precambrian region (8 sites)

Lahj and Abyan governorates in the western part of the former South Yemen, particularly the mountainous area bordering with the territory of the former North Yemen, are mostly a Precambrian region where groundwater occurs mainly in the shallow underground zone along reaches of the wadis. The vast majority of water sources in this region tend to be unstable and are affected by precipitation. Part of Shabwa governorate bordering Abyan is another member of the Precambrian region. The water sources in this region are normally anything but enough except for rare cases. The water supply projects in this region, particularly large-scale ones, are likely to suffer from lack of relevant sources.

Eight sites among the 20 project sites belong to this category: All of the four sites in Lahj; two in Abyan (Rosud and Gaishan); and two in Shabwa (Jaba/Al-Hanak and Hadinat Ba Qatmi).

As a result of an examination of the present situation in each site, the sites which have a stable water source(s) already developed and the sites which have the wadi(s) with probable potential for development in the surrounding neighborhoods were selected as the targets for the field survey under this study. Furthermore, the social position of the sites was taken into account. The results of the selection are presented as follows:

1. Al-Faith/Bani Baker (Lahj governorate)
2. Tukar (same as above)
3. Gaishan (Abyan governorate)

Group 2: Sites located in the coastal plain (5 sites)

This group involves five sites: Ahwar in Abyan governorate; Mayfa in Hadramout; and three sites in Al-Mahara. These sites are all suffering from lack of sources with good water quality, as may be suspected. Ahwar, however, was judged to remain in the list of the field survey sites, since it owns the existing wells drilled by the former Soviet Union project along the reaches of the Wadi Ahwar, which could be the possible water sources for the project. Its significant position as the center of a subdistrict was also taken into account. Mayfa, on the other hand, was canceled as it had little possibility of successfully hitting aquifers with good quality of water, although its natural environment and social stance are similar to those of Ahwar.

Among the three coastal communities in Al-Mahara governorate, two sites were planned for groundwater development for their water sources, but the possibility of success was judged to be decisively low. The remaining one site had given up to try to get water in the coastal environment and switched to a plan to bring fresh water from a spring in a remote mountainous area through a long pipeline. Al-Mahara governorate, where these sites are located, still remains a remote, underpopulated region, about 1,500 km drive from the former capital of Aden, with a great majority of the settlements still being left underdeveloped. Although the three communities have the prospects of thriving fishing industry in the future, they were judged not to qualify as the field survey sites due to not only the difficulty of ensuring relevant water sources but their lower ranks of cost effectiveness of investment (ratio of cost per beneficiary) in comparison with the candidates in other governorates.

The examination of the sites in the coastal plain thus resulted in the selection of one site as follows:

1. Ahwar (Abyan governorate)

Group 3: Other sites (7 sites)

The remaining seven sites have either existing water sources or a possibility of developing them without much difficulty. In the process of cost effectiveness evaluation, however, Shroog Bakily in Shabwa governorate (population 1,400) and Bor in Hadramout (3,500) were excluded from the list.

The following five sites are the ones selected through the process:

1. Moodeyah (Abyan governorate)
2. Al-Mafot/Ermah (Shabwa governorate)
3. Al-Raidah/Shamalya (Hadramout governorate)
4. As-Sadarah (same as above)
5. Al-Radood (same as above)

Through the process of the examination of the candidate sites, nine sites were agreed to be assigned as the field survey sites. During the final stage of the process, however, the Lahj government came up with a request to switch the site of Tukar in its governorate to Tor Al-Bah, a district capital, because the water supply facility in the latter has currently been reduced to a poorer shape than the one in the former. The GAREW acting as the executing agency supported this request. The subsequent inquiry by the study team about the real situation in both sites revealed that a significant portion of the facilities has already been constructed in Tukar with the support of the PWC as well as the Lahj government, including the water source facilities, and it was agreed to replace Tukar with Tor Al-Bah among the concerned parties. The nine sites thus designated are listed as follows:

Table-3.5 List of the Field Survey Sites for the Basic Design Study

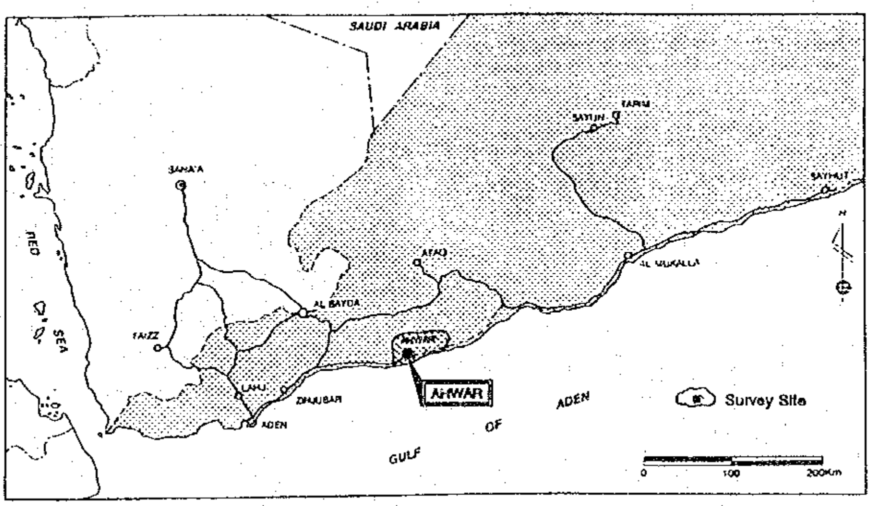
Number	Site Name	Governorate	District	Markaz
1.	Tor Al-Bah	Lahj	Tor Al-Bah	-
2.	Al-Faith/ Bani Baker	Lahj	Al-Abous	Al-Hadda
3.	Ahwar	Abyan	Khanfar	Ahwar
4.	Moodeyah	Abyan	Moodeyah	-
5.	Gaishan	Abyan	Moodeyah	Gaishan
6.	Al-Mafod/Ermah	Shabwa	Ermah	-
7.	Al-Raidah/ Shamalya	Hadramout	Ash Sheher	Qairbin-Yemen
8.	As Sadarah	Hadramout	Hager	As Sadarah
9.	Al-Radood	Hadramout	Seiyun	Tarim

The technical field survey for this basic design was conducted at the above-listed nine sites. The outlines of the survey results at these sites are presented in the following section.

3.3 Water Sources and Present Water Supply Conditions of Survey Sites

3.3.1 Ahwar

Site Number	3	Site Name		Ahwar	
Administrative Division		Governorate : Abyan District : Kanfar Sub-district : Ahwar			
No. of Villages	17	No. of Houses	1,927	Present Population	33,029
Planned Area	42 km^2	Population Density		785 persons/km^2	
Income Sources	Rank 1: Agriculture (50%) Rank 2: Daily Imcome (40%) Rank 3: Wages/Salaries (10%)			Average Monthly Income	YR3,500
Medical Facilities	Hospitals/ Clinics	1	Educational Facilities	Primary School	8
	Medical Staff	86		Intermedi-ate School	1
	No. of Beds	48		Secondary School	
Shops/Restaurants			Mosques		13
Water Purchase Practice	Quantity	lit/ day/ persons: lcd			
	Price	YR / lit : YR /m^3			
	Source				
Existing Water Facilities	Water Source	Deepwell x 1 No. (Constructed in 1960)			
	Reservoir	1 No. x 36,000gal. (Constructed in 1980)			
	Pipeline	4" - 2"			
	Water Rate	YR60/month/House			
	Consumption	40 lcd			
Power Facility		Generator (500kw) x 1 No.			



1. Location

Ahwar is the capital of Ahwar subdistrict in Abyan governorate, located on the coastal plain approximately 230 km east of Aden. The number of villages in the Ahwar subdistrict exceeds 20, with a population for a planned water service over 40,000. The water office at the Ahwar branch of the district office plans a new system to serve a population of roughly 33,000 as a minimal level.

For this region, the former Soviet Union carried out an agricultural development plan in the 1970s, including the construction of an earth dam and a network of irrigation canals taking advantage of the running water of the Wadi Ahwar, which flows through the region to the Gulf of Aden. The former PWC formulated an Ahwar regional water supply plan in 1990. Yet the plan has since been suspended because drilling failed to provide water sources of an acceptable quality.

2. Present Water Supply Condition

The water services in this area are operating in Ahwar, capital of the Ahwar subdistrict (markaz), in Al-Hanad and in Al-Shaga. (Refer to Fig.-3.5.) These communities are respectively operating their facilities to serve the residents including those of several nearby villages. The village of Al-Rawad owns another facility including a network of distribution line, but in the wake of damage to its pumping unit, the operation has been suspended. Other villages depend either on water vending or nearby open wells from which the family members, mostly women and children fetch water. Groundwater in this region, however, has a problem in its quality because it ordinarily contains high salinity due to its location near the coast.

a. Ahwar Water Supply Facility

The current water source for the Ahwar water system is a single deepwell. Two wells were operating until March 1993, when a pump in one of them was broken down due to an inflow of sand, leaving the other a sole source to serve the area. An elevated water tank of steel construction, 12 m high with a capacity of 36,000 gal., was constructed near the deepwell in 1980. Although the entire structure of the tank has by now been run down and leaks heavily, it continues to serve the area. The distribution network in the town of Ahwar was installed during the same period as the tank. It consists of main line of 4" asbestos cement pipe and main and

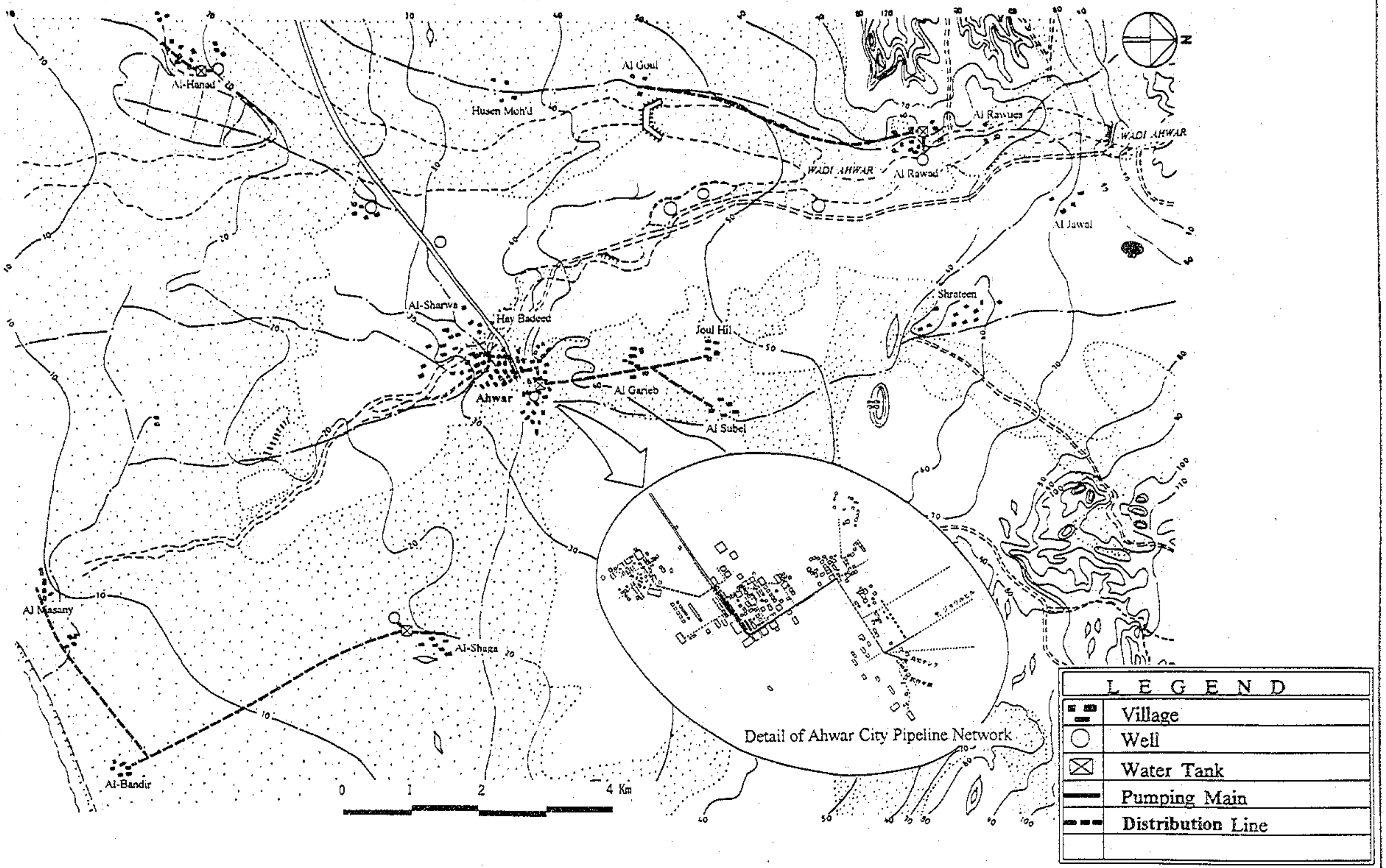


Fig.-3.5 Existing Water SUpply System at Ahwar branch lines of 3" to 1-1/2" steel pipe. These lines have also entirely been deteriorated due to heavy corrosion and clogging caused by salinity contained in served water reaching as high as 4,950 μS/cm in electrical conductivity. Leakage is widespread, and damaged sections have been left with a temporary measure of wrapping strips of rubber tubes of used car tires around. Water service does not reach about one third of the town's households, particularly those in higher locations, because of insufficient height of the water tank, the shortfalls in network layout and dilapilated conditions of entire facilites.

While the population in the Ahwar service area is more than 10,000, the production of a single source is at present approximately 230 m^3/day with the well operating for 16 consecutive hours. If the daily water consumption is assumed to be 40 liters/capital/day and the current water leakage is estimated at an level of 30%, the volume of water to meet the demand is required to be in a range of 600 m^3, about 3 times the present production. This calculation typcally illustrates the chronic water shortage of the Ahwar service system. Although the distribution network extends to three surrounding villages of Al-Garieb, Joul Hil and Al-Subel to the northeast of the town, the valve on this line was closed five years ago because of acute shortage of water and the water supply to these villages remains suspended.

Water is being served at a flat rate of YR 60 per household per month. Although the Ahwar water office is responsible for about 600 households in this area, part of water bills reportedly remain unpaid due to the aforementioned conditions of current service. A major part of collected bills are spent in daily operation and maintenance of the facilities, with wages of the water office staff mostly compensated by the district branch office.

3. Water Sources

a. Natural Environment

Ahwar is situated in the coastal plain about 200 km east of Aden. The elevation of the region is approximately 35 m above mean seal level. To the west of the town runs the Wadi Ahwar southward, its alluvial river bed sided with river terraces 3 to 4 m higher than that. The plain slopes toward the sea by 1/250 on average. In the northern area of the region are hills scattered around the Al-Rawad village about 7 km north of Ahwar town as well as behind the village of Al Subel north to east of the town. The hills are interspaced, rising about 40 to 100 m higher than the surrounding terrain. Near the Shrateen village are enclaves of small hills 20 to 40 m higher than the river terrace.

Ahwar and its nearby area are entirely mantled with Quaternary sediment (alluvial and terrace deposits), while Precambrian granite, gneiss and schist as well as Jurassic Kohlan Formation are cropped out in the northern hillsides. Kohlan Formation and Tawilah Formation strike roughly NE60° and dip 20° to 40° southeasterly, with normal faults estimated to be present along an axis of NW30° (line connecting Shrateen and Al-Subel) and another of NW50° obliquely crossing the former, respectively dipping eastward or northeastward.

Underground geologic information obtained through drilling a well on the left of the Wadi Ahwar under the regional agriculture development project by the former U.S.S.R. (No. 1 well) is as follows:

0 - 3.7 m	Alluvium
3.7 - 20.46 m	Terrace deposits mainly consisting of sand and gravel with clay
20.46 - 50.8 m	Pleistocene-Pliocene sand and gravel/clay
50.8 - 70.03 m	(well bottom) Miocene-Oligocene clay with gravel/clay

The aquifers for the existing wells in this region, both deepwells and open wells, are terrace deposits and pleistocene-Miocene sediments.

The typical lithology of the Ahwar region is illustrated in Table-3.6.

Table-3.6 Geological Features of Ahwar

AGE		FORMATION	LITHOLOGY
Quaternary	Holocene	Alluvium	Sand, Gravel,Clay
	Pleistocene	Terrace deposit	Sand, Gravel, Clay
Tertiary	Pliocene	Pleistocene - Pliocene series	Sandstone Conglomerate
	Miocene - Oligocene	Miocene - Oligocene series	Clay
Cretaceous		Tawilah Group	Sandstone Conglomerate
Jurassic		Kohlan Formation	Sandstone Conglomerate
Precambrian		Precambrian system	Schist, Gneiss, Granite

b. Hydrogeological Features

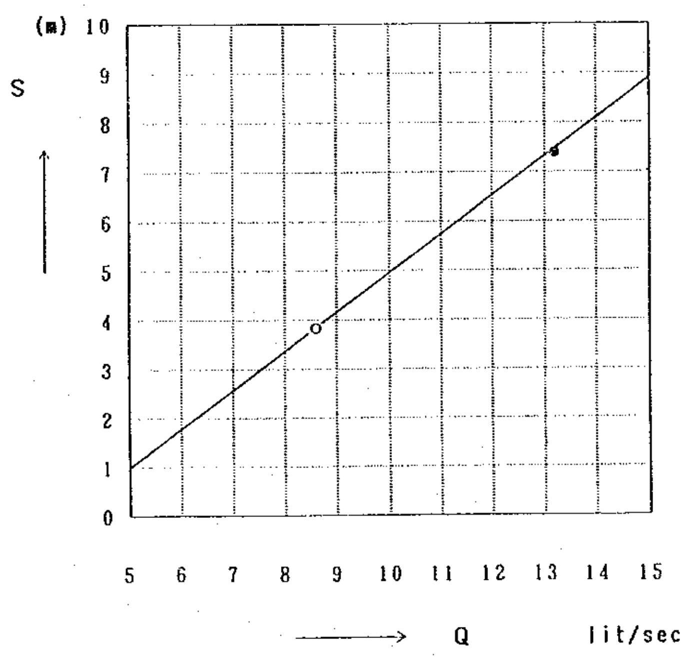
The characteristics of the existing wells in this region are summarized in Table-3.7, including 9 deepwells and 5 open wells. The deepwells, currently working, are the Well No. 1 for the Ahwar public water system and the Well No. 12 for another public system for Al-Hanad area, while the Well Nos. 2, 4 and 5 have been left closed after they were installed under the U.S.S.R's agricultural project. The Wells Nos. 7 and 8 installed recently by the government have been abandoned due to inferior quality of water containing high salinity, and the operation of the Well No. 9 for Al-Rawad water supply currently remains suspended because of the damage with the pumping facilities. The open wells are in service for domestic water as well as for irrigation in the surrounding villages.

The aquifer for these deepwells is Miocene sand and gravel, while the one for the open wells is alluvium and terrace deposits, featuring electrical conductivity ranging from 876 μS/cm to 4,966 μS/cm at 25°C. The regional characteristics of electrical conductivity are typically shown in Fig.-3.7, where various levels of conductance, corrected at 25°C, are mapped. According to this map, there is a belt along the Wadi Ahwar with a low range of electrical conductivity, beyond which it grows progressively higher. The low conductance in the wadi belt is interpreted to stem from contribution by floods running through the channel of the Wadi Ahwar during the rainy seasons, which percolate underground and dilute groundwater containing heavily-condensed salts due to a continued process of extremely high evapotranspiration over the region.

The two Russian wells (Nos. 2 and 4) are planned to be used as the water sources for this Project, the former (No. 2) showing 1,788 μS/cm of electrical conductivity and the latter (No. 4), 876 μS/cm. Groundwater in these two wells is by far better than the one from the present deepwell for Ahwar (Well No. 1) with a level as high as 4,046 μS/cm, which is located within the town.

Fig.-3.6 shows a relation between the pumping rates and drawdowns during the pumping test at Well No. 2 performed by the U.S.S.R project.

Fig.-3.6 The relation between the pumping rates and drawdons at Well No.2 Performed by the U.S.S.R project



During the testing, the maximum rate was about 800 lit/min (13.2 lit/sec) associated with a drawdown of 7.4 m. For this Project, however, a safe yield is proposed to be employed in order to keep the water level reasonably high so that the highly saline water in the surrounding aquifer may not be drawn into the well. A proposed rate is 75% of the test discharge of 800 lit/min, namely

(800 x 0.75 = 600 lit/min = 10 lit/sec). Nevertheless, this rate must further be controlled when the accurate yield is established in the future through the pumping test to be undertaken for the Project.

Another Russian deepwell (Well No. 5) was drilled to a depth of 300 m as a testing well for their project. Sampling in this well showed a relatively low electrical conductivity, and is likely to be used for this Project. This well, however, needs further testing to confirm its exact characteristics in both yield and quality.

The geological section of the region is referred to in Fig.-3.7. The lithologic data from the existing wells are shown in Appendix.

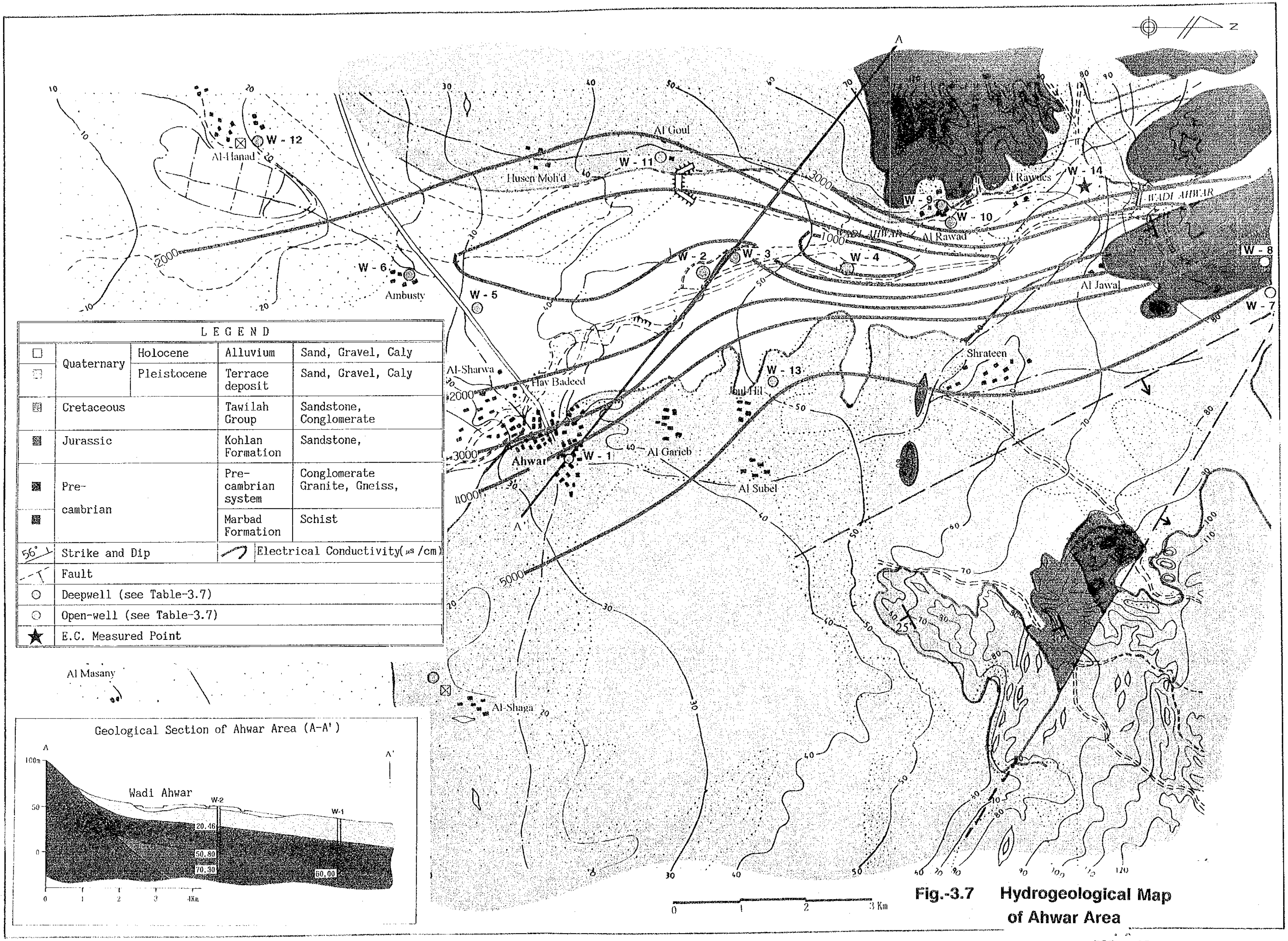


Fig.-3.7 Hydrogeological Map of Ahwar Area

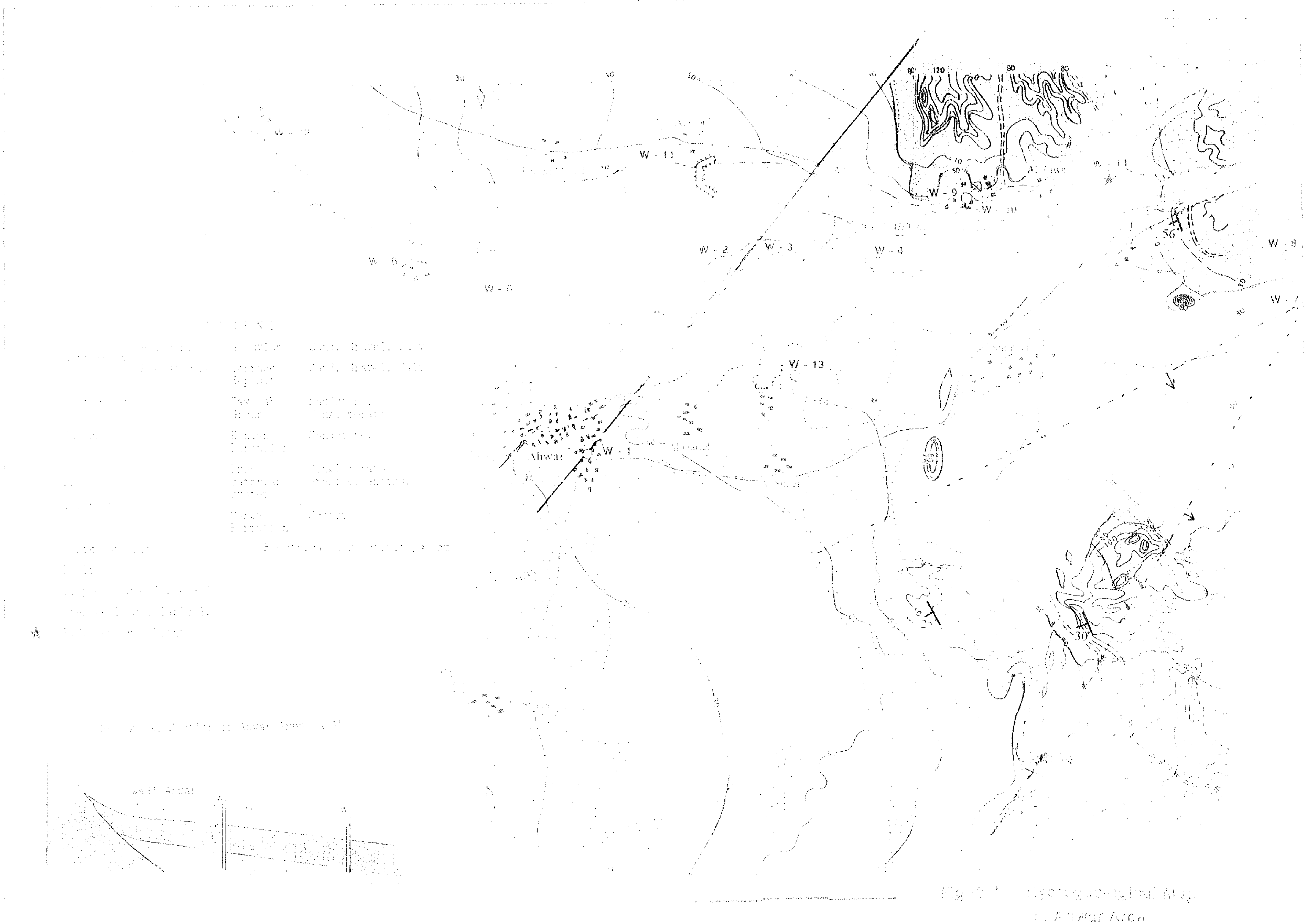


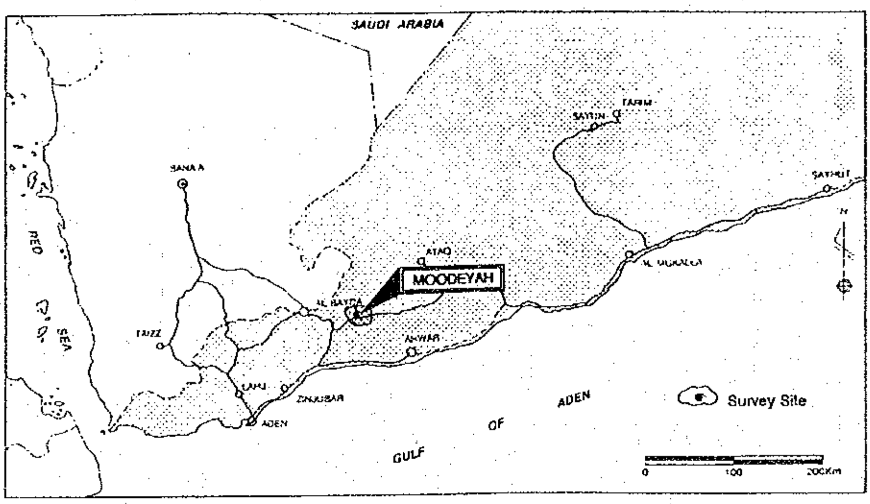
Fig. Hydrogeological Map of Ahwar Area

Table-3.7 List of Existing Wells (Ahwar)

No.	Type	Source	Dia. (")	Depth (m)	Pump	Aquifer	SWL (m)	DWL (m)	Q (l/min)	T (°C)	pH	EC(μS/cm)		Remark
												Measured	Corrected at 25°C	
W1	Deepwell	Well of water source for Ahwar	8"	60.0	Bore-hole pump	Pliocene				33.7	7.8	4,750	4,046	Water source for Ahwar
W2	Deepwell	U.S.S.R. No.1 well for agriculture	8"	70.3	-	Pliocene	10.90	18.3	792	33.1	9.0	2,078	1,788	unused
W3	Open well	Private well or agriculture		30.0	Bore-hole pump	Terrace deposit				30.8	8.5	2,480	2,222	Agricult. use
W4	Deepwell	U.S.S.R. No.2 well for agriculture	8"	70.0	-		9.71			30.4	8.7	971	876	unused
W5	Deepwell	Test well	12" 12"	90.0 300.0	-	Pliocene Pliocene	17.16 16.49			37.6 35.5	7.8 7.4	3,080 2,220	2,460 1,835	unused
W6	Open well	Ambusty well		24.0	Bore-hole pump	Alluvium Terrace deposit	18.20			32.7	7.4	2,067	1,791	Agricult. use
W7	Deepwell	PWC No.7	8"	200.0	-	Tawilah Group						6,000 ?		Abandan
W8	Deepwell	PWC No.8	8"	200.0	-	Precambrian						6,000 ?		Abandan
W9	Deepwell	Al-Rawad	8"	100.0	-	Precambrian						?		not operating
W10	Open well	Al-Rawad	8"	10.0		Alluvium				30.5	7.3	3,720	3,351	Domestic use
W11	Open well	Al-Jawal		15.0	Bore-hole pump	Terrance deposit	8.00			30.9	7.2	2,100	1,469	Domestic use
W12	Deepwell	Al-Hanad	8"	57.0	Bore-hole pump	Pliocene	?			30.1	7.4	2,670	2,423	Domestic use
W13	Open well	Joul Hil			Bore-hole pump	Terrance deposit	?			33.8	7.4	5,840	4,966	Agricult. use
W14		Surface water								30.5	7.3	3,720	3,351	unused

3.3.2 Moodeyah

Site Number	4	Site Name		Moodeyah	
Administrative Division		Governorate : Abyan District : Moodeyah Sub-district : Moodeyah			
No. of Villages	21	No. of Houses	4,717	Present Population	37,120
Planned Area	48 km²	Population Density		736 persons/km²	
Income Sources	Rank 1: Agriculture (70%) Rank 2: Daily Income (10%) Rank 3: Wages/Salaries (20%)			Average Monthly Income	YR3,000
Medical Facilities	Hospitals/ Clinics	14	Educational Facilities	Primary School	13
	Medical Staff	106		Intermediate School	5
	No. of Beds	48		Secondary School	
Shops/Restaurants			Mosques		32
Water Purchase Practice	Quantity	2,000 lit/30day/12persons: 5.51 lcd			
	Price	YR26/200 lit : YR130 /m³			
	Source	Moodeyah, Al-Qurath			
Existing Water Facilities	Water Source	4 Nos. (deepwells)			
	Reservoir	3 Nos.(50,000gal x 1 No./40,000gal x 2Nos.)			
	Pipeline	6" - 1"			
	Water Rate	YR52/month/House			
	Consumption	35 lcd			
Electric Power Facility		1 No. (Deisel generator, 500Kw)			



1. Location

Moodeyah is a district capital of Abyan governorate, located just 200 km east of Aden along the national highway linking Aden to Al-Mukalla, the second largest city next to Aden, and extending farther inland to Seiyun city in Hadramout governorate. With its location as one of the major stops along the highway as well as its stance as the center of the regional administration, Moodeyah has developed into a community having features of a secondary town in the southern part of Yemen. The entire region of Moodeyah and its vicinity, however, has long been suffering from lack of domestic water mainly due to problems with the water sources. All the citizens have been looking forward to the advent of a new project which may alleviate their current hardships connected with water service.

2. Present Water Supply Condition

Moodeyah and the surrounding communities have four large water service areas, each with their own independent water supply facility. These areas are the Moodeyah service area (21,000 people); the Zyoar water area (6,000); the Al-Qurath area (4,000); and the Al-Habir area (2,400). In addition to these four areas, another independent systems are now under operation for several communities.

a. Moodeyah Service Area

The water source for the area consists of two deepwells drilled within the town of Moodeyah. Water is directly pumped to a distribution reservoir (40,000 gal.) installed at the top of a hill near the north end of the town, and is distributed to the households through a network of distribution line. The water production from these two wells, however, has been merely 90 m^3 per day, scarcely enough to meet just the basic demand of the population of no less than 13,000 in this service area. The district water department, which operates the water facility, further divides the total area into three zones, and water rationing of only 30 min/day has been imposed alternately in the three zones. Table-3.8 shows the schedule of water rationing.

The pumping mains from the wells to the reservoir are 4" steel pipe and the town's distribution network consists of 6" main from the reservoir, 2" to 1" branches and 1/2" house connections. Pipe maintenance is relatively good. Valve boxes are laid out at each

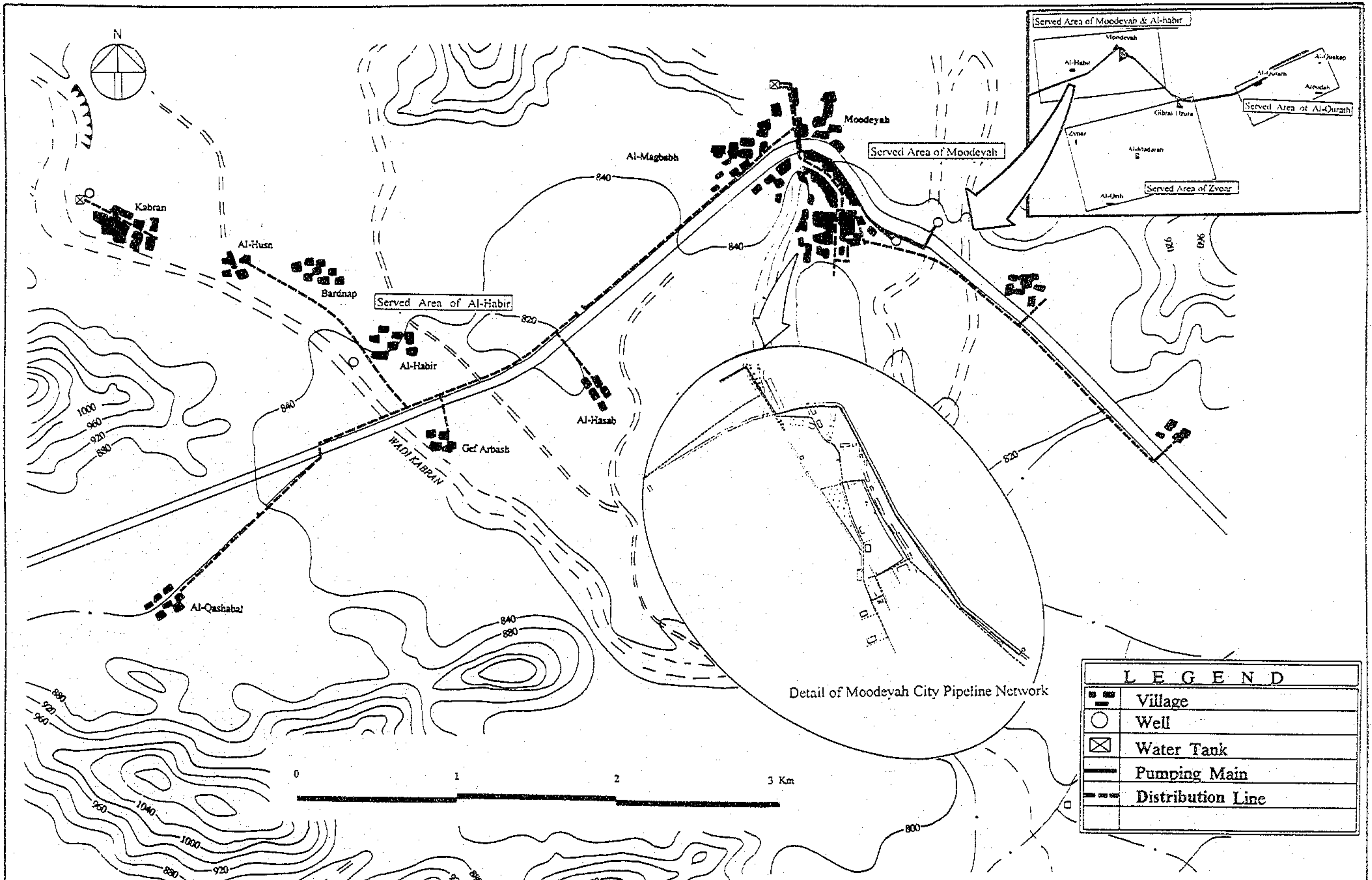


Fig.-3.8 Existing Water SUpply System at Moodeyah and Al-Habir

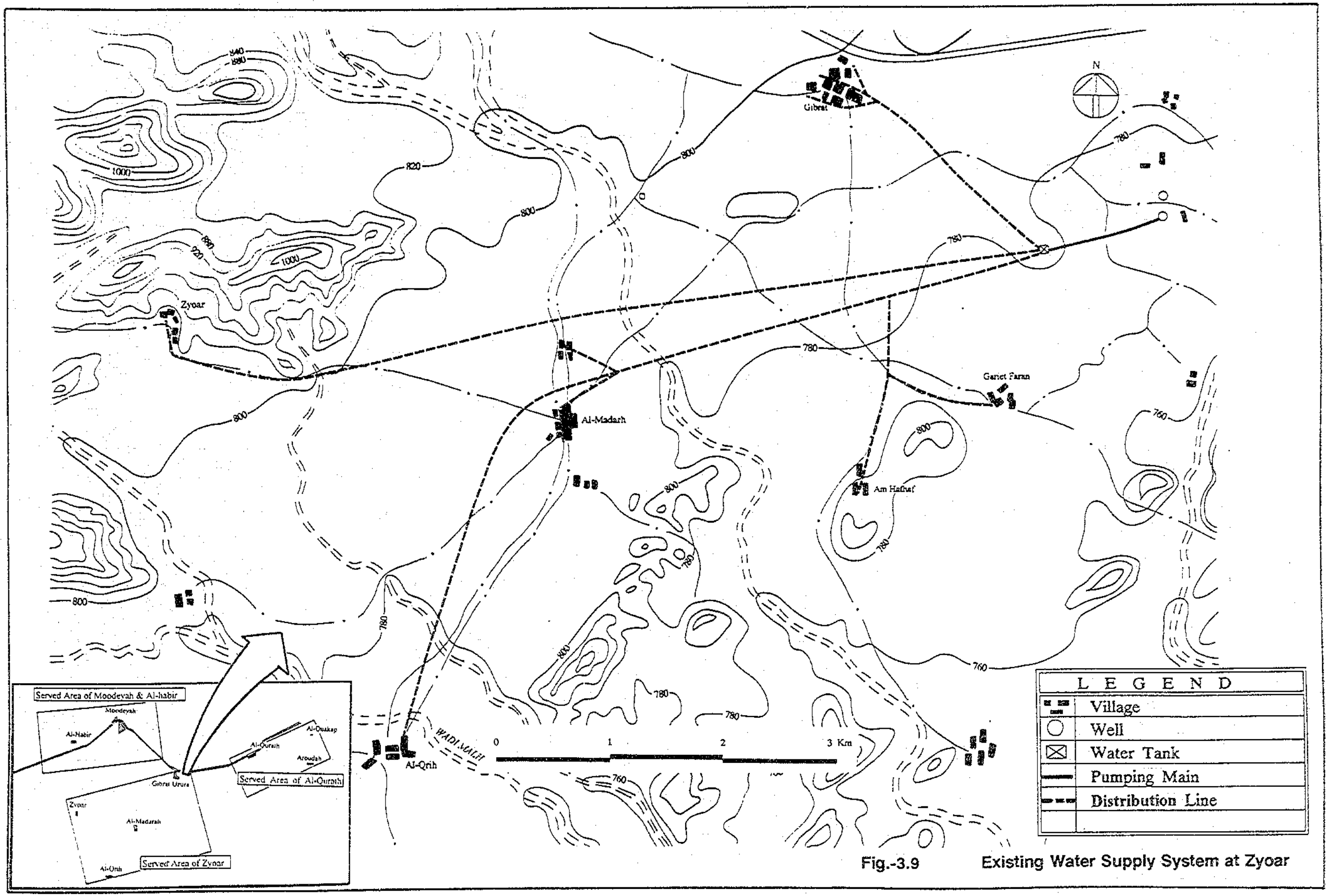


Fig.-3.9 Existing Water Supply System at Zyoar

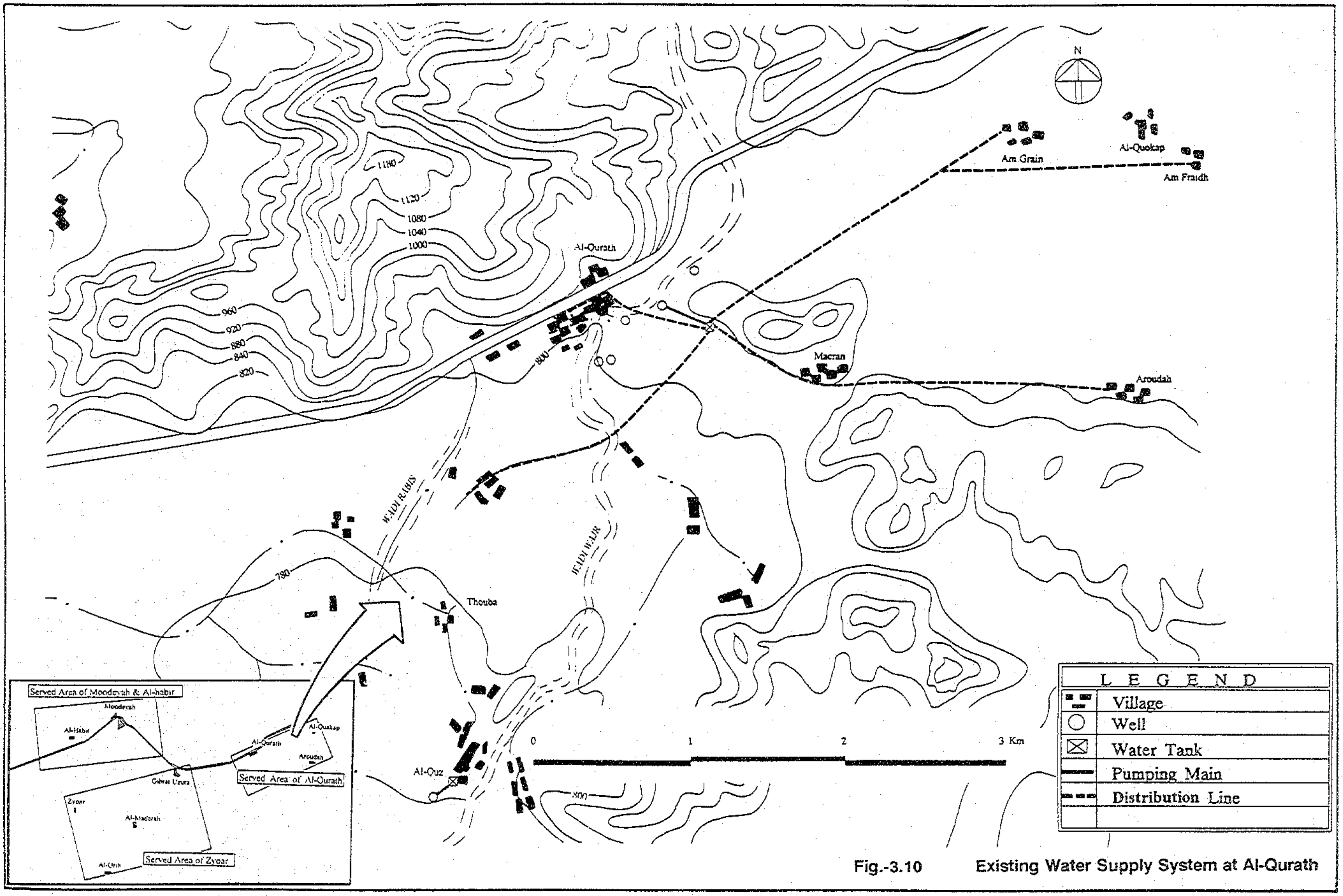


Fig.-3.10 Existing Water Supply System at Al-Qurath

Table-3.8 Current Water Rationing in Moodeyah Service Area

Service Day(*)	Pumping Time	Service Time	Service Area(**)
First Day	5:00 - 24:00	6:00 - 6:20	6" pipe area
Second Day	5:00 - 18:00	6:00 - 6:30 12:00 - 12:10	4" pipe area (Al-Magbabh area)

(*) Alternate supply to each area every two days.
(**) See Fig.-3.8.

important point, and the service zones can be changed by daily valve operation. Major lines within the town are buried 3 feet beneath the ground, whereas the pipes outside of the town are all exposed.

The Moodeyah district water office is now operated by 14 staff consisting of a general manager, four operators, four plumbers, two bill collectors and three clerks. This office also directly manages the Zyoar service area. The water fee is a flat rate of YR 52/month/household. At present the water office can charge about 400 households. This revenue is mostly consumed for the fuel cost and facility maintenance. As the current supply is far below the demand, residents have no choice but to depend on water vending which costs them about YR 70 per 1 m^3.

The Al-Habir service area (to be discussed later) was formerly included in the Moodeyah service area. The pipe leading to the former area, however, was diconnected immediately after the extended service became impractical due to the abrupt decline of water production. Water is no longer supplied to Al-Habir from Moodeyah.

b. Zyoar Service Area

The Zyoar area is further divided into three service zones of Gibrat, Al-Madarah and Al-Zyoar, to which distribution mains are resepctively extended from a 50,000 gal. reservoir. The water source for this area is restricted to a single deepwell. The distribution mains are steel pipe of 4" size and reduces it to 2" to 1" at the entrances of the villages included in each service zone. Within the villages, house connections are 1/2" in size.

In this service area, the production of the well is again far less than the demand of the entire population, and water service to the three zones is alternated every two days. Even on the service day, however, water does not come enough as the residents may wish, with the houses at the far end of the villages receiving a trickle of water. Every house connection, therefore, is kept open on the service day to store water as much as possible. Because of such poor service conditions, most of house connections in the villages now have no taps, ready for receiving water whenever it comes. This situation has made the water shortage even more serious in this area.

c. Al-Qurath Service Area

Water is supplied to Al-Qurath and the other nine villages from a 40,000 gal. water tank with one deepwell as the water source. This area is further divided into three zones, each of which receives water every three days. Because the location of the tank is too low, water pressure is insufficient in areas where the ground level is higher. Approximately one third of the population suffers from a water shortage.

d. Al-Habir Water Supply Area

This area used to be served from the Moodeyah service area, but the scarcity of water production in the Moodeyah wells forced its water office to disconnect the distribution line to this area. This area now own another water system, with a deepwell drilled by the troops stationed in the northern part of Abyan in 1990 after unification and a distribution network covering 7 villages composing this service area, which was recently completed by the Moodeyah water office. Nevertheless, water from this well is so saline that the residents cannot drink. They simply use it for washing and other miscellaneous purposes, and depend entirely on water vending from the Al-Qurth area for drinking water (YR 300/ m^3).

The existing water supply facilities in each service area in the site of Moodeyah are shown in the table below.

Table-3.9 List of Existing Facilities in Moodeyah Project Area

Service Area	Water Source	Distribution Tank	Pumping Main	Distribution Line
Moodeyah	2 Deepwells	40,000 gal	6"	6" - 1"
Zyoar	1 Deepwell	50,000 gal	4"x1,464m	6"-1" x 5,822m
Al-Qurath	1 Deepwell	40,000 gal	4"x1,406m	3"-1" x13,444m
Al-Habir	1 Deepwell	-	6"	6" - 1"

3. Water Sources

a. Natural Environment

The district center of Moodeyah is 830 to 850 m in elevation, located where the mountainous area contacts the hilly area. To the south of the national highway stretches a vast floodplain formed by the Wadi Wajar, Wadi Rabis, Wadi Maran, Wadi Kabran, Wadi Malh and their tributaries, dotted with enclaves of hills 20 to 60 m high. The northern mountains are in the stage of maturity with their sharp ridges and deep V-shaped gorges, while the hills in the floodplain have been reduced to ones with gently sloped ridges and hillsides. The hills around the villages of-Al Quz and Am Hafhaf are Quaternary volcanoes constituted of basalt lava, still with their primary shapes well preserved. The floodplain slopes by 1/125 on average southeastward.

The region is composed of Pre-Cambrian rocks such as biotite schist, quartz schist, gneiss and metamorphic sandstone, Quaternary volcanic materials like basalt lava and scoria and ancient floodplain sediment deposited by the wadis. The wadis have belts of alluvium. Dr. Mezhelovsky, a former U.S.S.R's geologist, who carried out the survey in this area in 1985 classified the region's Precambrian rocks into four groups: *Wasr type* dominantly consisting of carbonaceous metamorphosed sandstone and gneiss; *Ads type* of biotite-quartz-feldspar schist; *Mashar type* of dominant biotite schist; and *Barak type* of biotite gneiss and biotite schist. Since these rocks are all of impermeable materials, such grouping has no direct connection with this study on the hydrogeological features of the region. Another typical outcrop of rock is basalt distributed around the villages of Al-

Quz and Am Hafhaf, which is part of a vast outcrop of Quaternary volcanic rock to the south and the east of the region. Yet since its distribution within the project site is limited, it is of little significance for this study as well.

The major part of the Project site is constituted of floodplain sediment consisting of sand, gravel and clay accumulated by the Wadi Wajar, the Wadi Maran and other wadis. Part of this series is judged to be older than basalt lava flows, since the former is overlain by the latter to the south of Al-Quz. As the Quaternary volcanic activity in this region is estimated to have taken place in Quaternary Pleistocene and Hollocene periods, sedimentation of floodplain is considered to have started around the middle of the Pleistocene period. The sediment is 60 to 70 m thick, providing most of groundwater for the region. On the other hand, alluvial sand and gravel is distributed on the bottom of the wadis, probably 5 to 6 m thick, mantled entirely with eolian fine sand as is the major part of the floodplain.

TABLE-3.10 Geological Features of Moodeyah

AGE		FORMATION		LITHOLOGY
Quaternary	Holocene	Alluvium		Sand, Gravel
	Pleisto-cene	Floodplain Deposit		Sand, Gravel Clay
		Basalts		Basalt lava, Scoria
Precambrian		Pre-Cambrian System	Wasr Formation	Metasandstone Gneiss
			Ads Type	Biotite-Quartz-Feldspar schist
			Mashar Type	Biotite Schist
			Barak Type	Biotite gneiss, Biotite schist

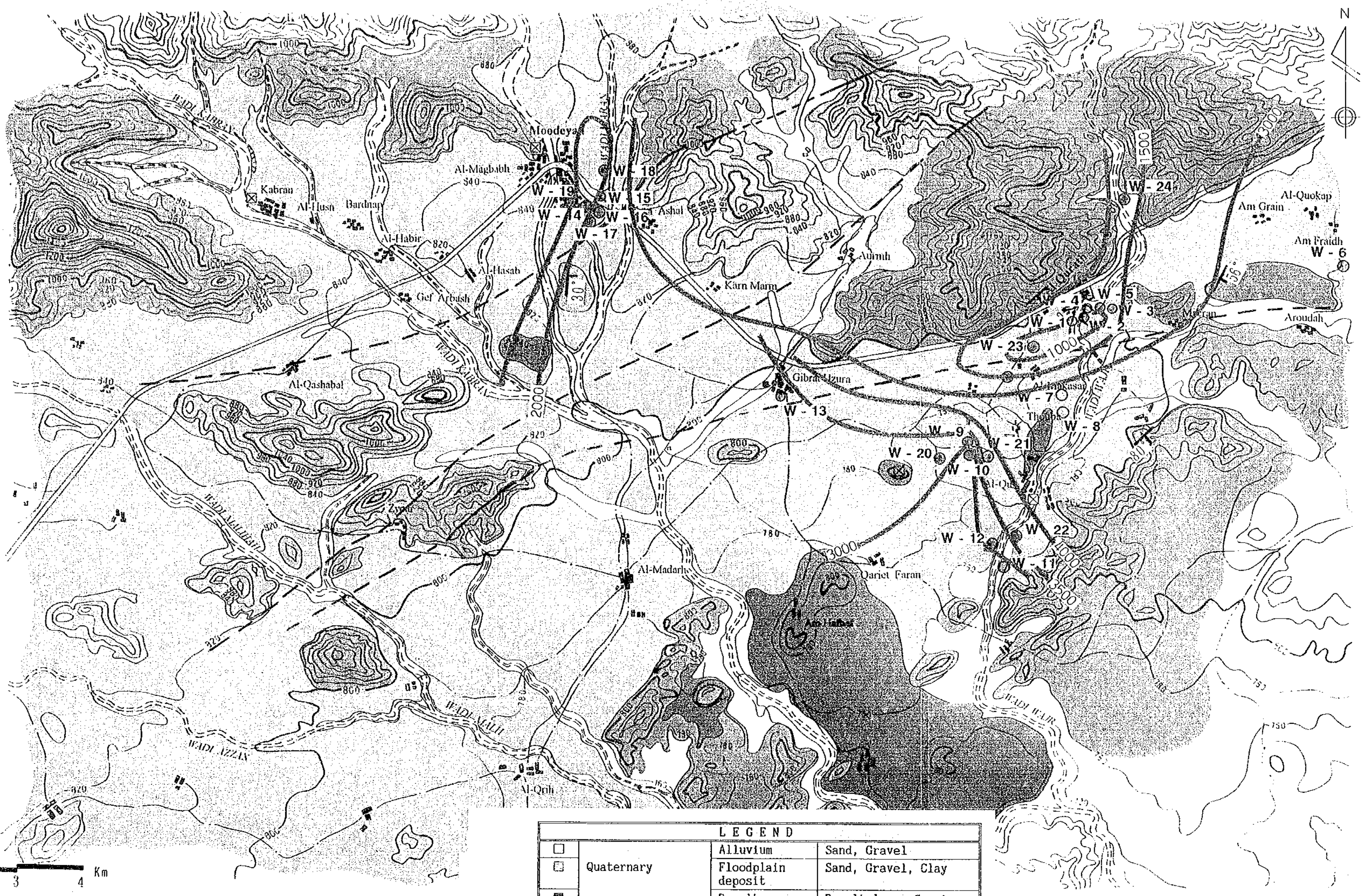
b. Hydrogeological Features

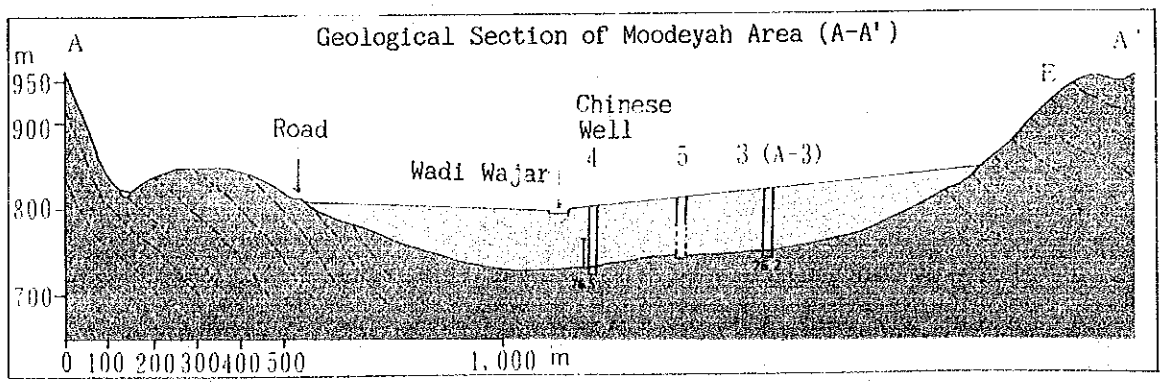
The region has 16 deepwells and more than 10 open wells. Aquifers of these wells are entirely floodplain sediment, in which groundwater has electrical conductivity ranging from 819 to 4,667 μS/cm at 25°C. The features of groundwater quality in this region are represented by the isoline map of electrical conductivity in Fig.-3.11, which indicates there is a zone of a lower range of electrical conductivity of 1,000 μS/cm within the site, encircled by a line connecting the existing wells, Nos. 1 to 5, 9 and 10. Higher electrical conductivity of 3,000 to 4,000 μS/cm prevails on either side of this zone. The lower electric-conductance zone is probable to be an ancient channel of the Wadi Wager cut into the Precambrian horizon, forming a passage of groundwater flow where salinity is diluted by ample recharge of fresh water. Another lower-range zone with its conductance at 1,400 μS/cm is observed to the east of Moodeyah town, but the current condition of the existing water sources for Moodeyah indicates the quantity of groundwater flow in this zone is so scarce that the development of new water sources there cannot be feasible. In contrast, groundwater is ample in quantity and good in quality in the former basin around the village of Al-Qurath where 5 wells (Nos. 1 to 5) exist. The area around the village of Al-Quz is in a similar hydrogeological condition.

The deepwell No. 4 is the public water source for the village of Al-Qurath, drilled under a Chinese project to a depth of 76.51 m. The floodplain sediment in this well was 65.59 m thick, followed by Precambrian bedrock. The static water level was as deep as about 40 m below ground level, as was confirmed by the team during this study. During the field study this time, therefore, the current conditions of two wells, No. 2 and No.4 were closely examined. This study has revealed both wells could continuously discharge a yield of 400 to 500 lit/min, 450 lit/min on average.

The Al-Qurath basin already has 5 deepwells, two of which are currently in service, one for private use for water vending and the other for the public water supply for Al-Qurath and other surrounding communities. The remaining 3 deepwells, currently closed, can be employed for this Project. These wells, however, are closely located, and it is feared that once pumping of all of these 5 wells starts, interference between each other would abruptly increase and might eventually induce into this zone highly saline water from the surrounding zone. Accordingly the pumping rate from one well is proposed to be restricted to a safe yield, which is estimated to be about 75 to 80% of 450 lit/min - the current production rate of the working wells, namely (450 lit/min x 0.75 = 340 lit/min = 5.7 lit/sec).

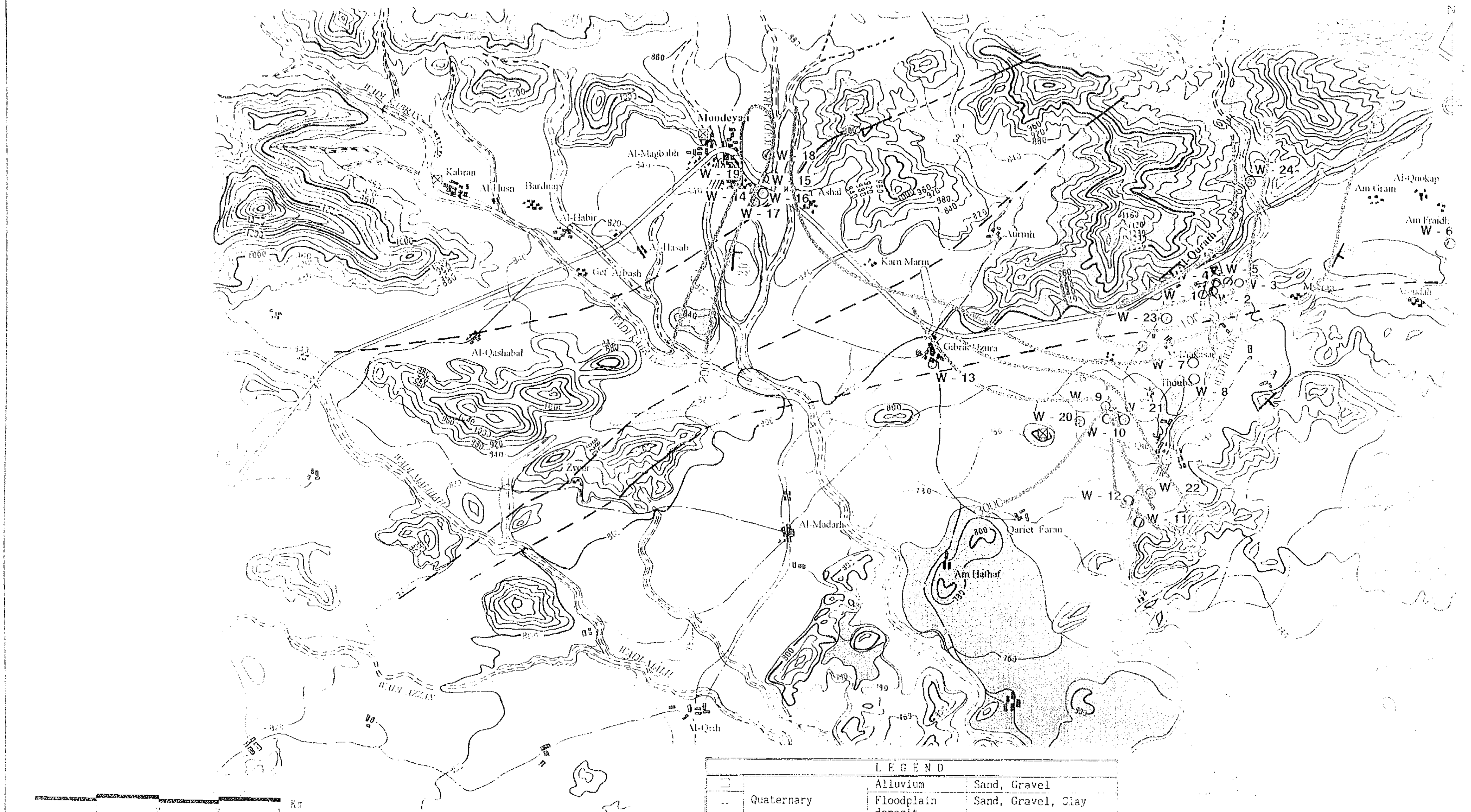
The proposed rate, however, is far from meeting even the immediate demand of the whole service areas in Moodeyah, not to mention the future one. In this view, one additional deepwell is planned to be installed for the Project. It is judged, however, that further development of this basin seems quite impractical due to its limited size. The future prospects remains yet to be revealed by a series of accurate pumping tests, which may be carried out under this Project.

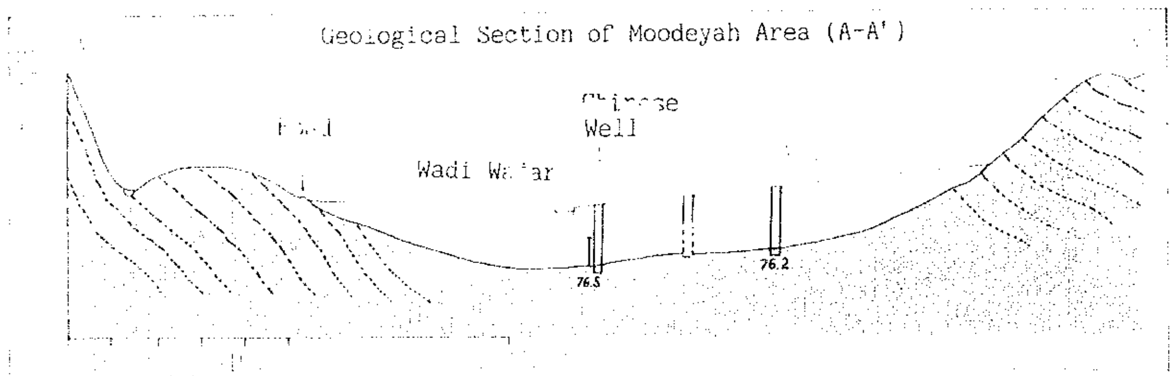




LEGEND				
	Quaternary		Alluvium	Sand, Gravel
			Floodplain deposit	Sand, Gravel, Clay
			Basalts	Basalt lava, Scoria
	Pre-cambrian	Pre-cambrian system	Wasr Formation	Metasandstone, Gneiss
			Ads Type	Biotite, Quarts, Feldspar schist
			Mashar Type	Biotite schist
			Barak Type	Biotite gneiss, Biotite schist
	Strike and Dip			Deepwell (see Table-3.11)
	Fault			Open-well (see Table-3.11)
	Electrical Conductivity (μs/cm)			Drywell (see Table-3.11)
				Project Well

Fig.-3.11 Hydrogeological Map of Moodeyah Area





LEGEND				
	Quaternary		Alluvium	Sand, Gravel
			Floodplain deposit	Sand, Gravel, Clay
			Basalts	Basalt lava, Scoria
	Pre-cambrian	Pre-cambrian system	Wasr Formation	Metasandstone, Gneiss
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	Strike and Dip			Deepwell (see Table-3.11)
	Fault			Open-well (see Table-3.11)
	Electrical Conductivity (μs/cm)			Drywell (see Table-3.11)
				Project Well

Fig.-3.11 Hydrogeological Map of Moodeyah Area

Table-3.11 List of Existing Wells (Moodeyah)

No.	Type	Source	Dia. (inch)	Depth (m)	Pump	Aquifer	SWL (m)	DWL (m)	Q (l/min)	T (°C)	Ph	EC(μS/cm)		Remark
												Measured	Corrected at 25°C	
W1	Deepwell	PWC A-1	8"	76.0	Bore-hole pump	Terrace deposit	44.2			34.4	7.1	1,786	1,503	Not operating
W2	Deepwell	PWC A-2	8"	76.0	-	Terrace deposit	43.50		600.0	35.3	7.7	1,098	910	"
W3	Deepwell	PWC A-3	8"	76.21	Bore-hole pump	Terrace deposit	45.73		152.0	28.1	7.3	1,360	1,281	"
W4	Deepwell	Chinese Well	8"	70.0	-		40.51		300.0?	29.9	7.5	1,244	1,133	Beside source of water supply
W5	Deepwell	Private well	8"	76.51	-		?		?	31.0	8.3	1,200	1,071	Selling water
W6	Deepwell	Kohban well	8"	?	Bore-hole pump	?	?			31.1	7.0	3,595	3,204	for washing
W7	Deepwell	PWC	8"	?	-									Empty well
W8	Deepwell	PWC	8"	?	-									"
W9	Deepwell	PWC	8"	?	-									Not operating
W10	Deepwell	PWC	8"	120.0		Terrace deposit				29.9	7.5	2,600	2,368	Water source for this area
W11	Deepwell	Al-quz well	8"	60.0?	Bore-hole pump	Terrace deposit	8.00			26.9	7.6	2,730	2,630	Operating
W12	Deepwell	Al-quz well	8"	60.0?	Bore-hole pump	Terrace deposit	?			24.0	7.5	3,160	3,224	"
W13	Deepwell	Gibrat well	8"	60.0?	Bore-hole pump	Terrace deposit	?			36.0	6.9	4,400	3,607	"

No.	Type	Source	Dia. (inch)	Depth (m)	Pump	Aquifer	SWL (m)	DWL (m)	Q (l/min)	T (°C)	Ph	EC(μS/cm)		Remark
												Measured	Corrected at 25°C	
W14	Deepwell	Moodeyah No. 1 well	8"	33.0	Bore-hole pump									The well is pumped within 5 minutes
W15	"	Moodeyah No. well	8"	108.0	"					29.7	6.7	2,740	2,505	
W16	"	Moodeyah No. 2, 3 well	8"	32.0		Terrace deposit								
W17	Openwell	Private Well for agricult.	120"	35.0	Bore-hole pump	"				28.2	7.4	2,920	2,744	Abandon
W18	"	"	120"	39.0?	"	"	35.50		200.0?	28.0	7.7	1,553	1,465	Operating
W19	"	Moodeyah Well of Mosque	120"	30.0?	"	"	28.70			28.5	6.9	2,950	2,757	" The well is pumped within 5 minutes
W20	"	Private Well for agricult.	200"	"	"	"	28.20			27.0	7.6	4,070	3,913	Operating
W21	"	"	200"	30.0	"	"	27.84			27.5	7.0	4,900	4,667	"
W22	"	"	140"	?	"	"	27.30			26.9	7.6	4,610	4,441	"
W23	"	"	200"	?	"	"	47.80			28.5	7.3	876	819	" Existing Tank
W24	"	"	120"	32.0	"	"	29.70			29.3	7.2	1,450	1,335	Operating