APPENDIX B

GEOLOGY AND GROUNDWATER

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B.1 Topography and Geology

B.1.1 Topography

The study area is situated in the southern flank of Himalayan mountain range and can be largely divided into two units in terms of geomorphological aspect. One is the mountains that mainly cover north eastern part of the study area and the other is so-called "Potwar plateau".

In the mountains, many steep mountain ranges are running in SW-NE direction consisting of the Margala hills, Murree Mountains and Hazara Mountains (highest summit some 9,000 ft) as shown in Figure B-1-1. The river system in the mountains shows a dendric pattern elongating in the same direction. These mountain ranges reduce their height toward southwest and sink into Potwar plateau.

Potwar plateau occupies central to eastern part of the study area. Potwar plateau is subdivided into 7 geomorphological units in the study area as shown in Figure B-1-1. Generally Potwar plateau is composed of comparatively low hill ranges running in a WSW-ENE direction with broad valleys and badland topography of highly dissected plain spreading widely in the lower plains where the severe soil erosion is taking place.

B.1.2 Geology

The study area is a northern marginal part of geosynclinal trough known as Indo-Gangetic synclinorium with an ENE-WSW axial trend. In the study area various layers exposed and they widely range from Precambrian to Holocene in age. The geological compile map of the study area is shown in Figure B-1-2.

(1) Stratigraphy and Lithology

Based on the existing studies, the stratigraphy of the study area is described in Table B-1-1. The descriptions of the layers are mentioned next.

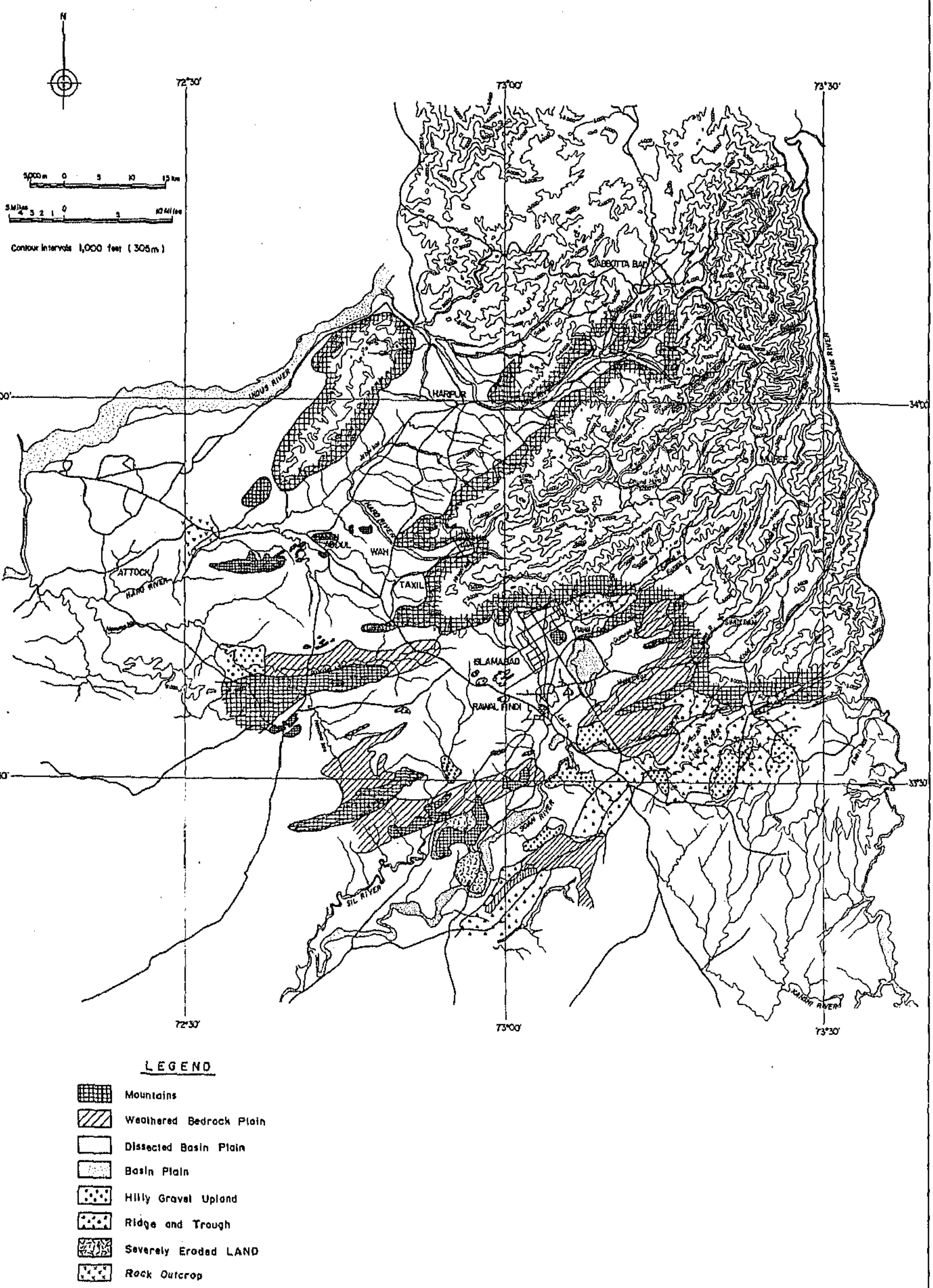
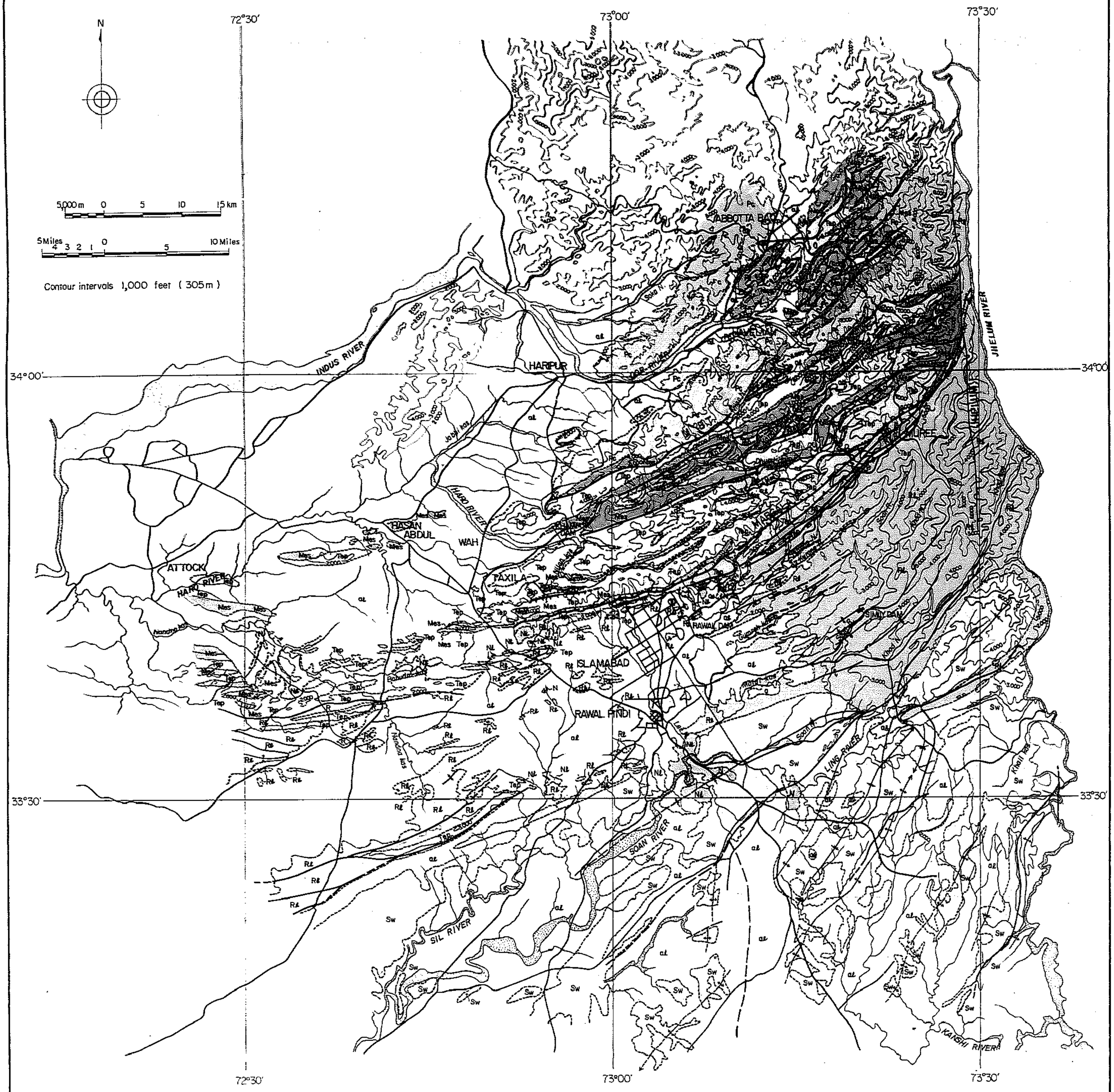


Figure B-1-1 Geomorphological Units of the Study Area



LEGEND

QUATERNARY	aℓ	Alluvial Deposits
	Nℓ	Lei Conglomerate
TERTIARY	Sw	Siwalik Group (Claystone. Sandstone. Conglomerate)
	Rℓ	Rawalpindi Group (Sandstone alternating with red Shale)
	Tep	Eocene to Paleocene Series (Limestone. Marl. Shale. Sandstone)
	Mes	Mesozoic Rocks (Limestone, Marl with Shale, Sandstone)
	Pz	Paleozoic Rocks (Shale, Sandstone, Conglomerate, Dolomite)
	Pc	Precambrian Rocks (Low Grade Slate with Limestone)

Geological Boundary
Fault (Thrust Fault)
Anticlinal Axis
Synclinal Axis

B-1-2. Geological Map of the Study Area

Table B-1-1 Stratigraphy of the Study Area

TIME		UNITS	STRATIGRAPHIC UNIT Group	Formation	LOTHOLOGICAL ABSTRACT
CENOZOIC	QUATERNARY	HOLOCENE			- Sand, Silt, Clay, Gravel - Loessic Clay, Gravel, Sand
		PLEISTOCENE		LEI CONGLOMERATE	Conglomerate, Sandstone, Siltstone, Clay
	TERTIARY	PLIOCENE	SIWALIK	SOAN	Claystone, Sandstone, Conglomerate
				DHOK PATHAN	
				NAGRI	
		MIOCENE		CHINJI	
			RAWALPINDI	KAMLIAL	Sandstone alternating with red Shale
				MURREE	
		OLIGOCENE			
		EOCENE	CHHARAT	KOHAT	Limestone, Marl, Shale
				KULDANA	
				CHORGALI	
				MARGALA HILL LIMESTONE	
		PALEOCENE	MAKERWAL 1)	PATALA	- Shale with Marl, Limestone Sandstone
				LOCKHART LIMESTONE	- Limestone,
				HANGU	- Sandstone, Siltstone
MESOZOIC	CRETACEOUS				
				LUMSHIWAL	- Sandstone, Shale
				CHICHALI	- Sandstone, Shale
	JURASSIC			SAMANA SUK	- Limestone with Marl, Shale
				DATTA	- Sandstone, Shale, Siltstone, Mudstone
				?	
	TRIASSIC			KINGRIALI	- Dolomite, Dolomitic Limestone
				CHAK JABBI LIMESTONE	- Limestone
				MIANWALI	- Marl, Limestone, Dolomite, Sandstone, Siltstone
PALEOZOIC				?	
	CAMBRIAN? 2)			ABBOTTABAD 2)	- Sandstone, Shale, Conglomerate, Limestone, Dolomite
	PRE CAMBRIAN? 2)				- Low-grade Slate with intercalation of Limestone band

1) MAKERWAL F. was not authorized in "Lithostratigraphic Units of The Kohat-Potwar Province, 1973"

2) Stratigraphy of so-called Precambrian to Cambrian System in Hazara area has been under discussion and not yet been authorized.

(a) Precambrian to Paleozoic Rocks

Precambrian to paleozoic rocks exposed in Hazara mountains situated in the northern part of Main Boundary Thrust (M.B.T). Precambrian rocks consist of black to green low-grade slate with intercalation of limestone layers. Paleozoic rocks consist of sandstone, shale, conglomerate, limestone and dolomite.

They are relatively hard and compact. The main part of the Dor river basin is composed of these layers.

(b) Mesozoic Rocks and Eocene to Paleocene Series

Mesozoic rocks and Eocene to Paleocene series exposed in Hazara mountains and Margala hills occupying the northern to central part of the study area. They are composed of various layers as shown in Table B-1-1 and among them calcareous facies (mainly limestone) particularly predominant. They are, in general, black, hard and compact. However, it is highly corroded along the bedding planes and cracks and many cavities have been formed. They occasionally intercalate shale and it is oftenly highly sheared and shows fault-like features. The main part of the Haro river basin consists of these layers.

(c) Miocene to Pliocene Series

Exposures of Miocene to Pliocene series have been widely distributed in the southern part of the study area. The lithology of the Miocene to Pliocene series is an alternation of sandstone and shale. Miocene to Pliocene series can be divided into two groups. as shown in Figure B-I-1. One is Murree group of Miocene age and the other is Siwalik group of Pliocene age. The lithological features of both groups are very similar and they are generally weak, highly weathered and not able to endure erosion well. Among them, the shale is highly sheared and has turned into very weak red clay. The Soan river basin is composed of these layers.

(d) Quaternary System

Quaternary system, that widely distributes on Potwar plateau, is composed of highly cemented conglomerate named Lei conglomerate and unconsolidated Alluvial deposits. Lei conglomerate is composed of highly consolidated gravel layers by the deposition of $CaCO_3$. It has no specific horizon and sporadically distributed with several tens meter in maximum thickness. Alluvial deposits consist of unconsolidated silt, sand, gravels and boulders and they bear main aquifers in the study area. Their maximum thickness is supposed to be more than 300 m.

Because materials become coarser toward the mountains, high yield aquifers are distributed along the foot of the mountains.

(2) Geological structure

The bedrocks in the study area are highly folded, faulted and over thrusted because of himalayan uplift during Pliocene epoch. The deformational axes are running in ENE-WSW direction. Among the many deformational units, on the following three main faults special attention should be paid for facility design in the study because they must have considerably wide fractured zone accompanied with many derivative faults and moreover some epicenters of earthquake have concentrated along certain part of these faults.

-: Main Boundary Thrust (M.B.T.) in ENE-WSW trend
-: Jhelum Fault in N-S trend
-: Margala Fault in ENE-WSW trend

B.2 Groundwater

B.2.1 Hydrogeological Structure of the Study Area

The potwar plateau in the eastern part of the study area was formed through the filling-up of the ancient mountains and basins with Quaternary deposits composed of unconsolidated clay, silt, sand and gravel layers.

The aquifer in the study area are mainly borne in the unconsolidated Quaternary deposits and the bedrock forms the unpervious groundwater containers (groundwater basins).

As it is seemed that the Quaternary deposits get coarser toward the foot of the mountains, high yield aquifers distribute mainly in the eastern part of Potwar Plateau.

Six main groundwater basins can be detected in the study area as shown in Figure B-2-1. As shown in this figure, the groundwater basins are elongated in WSW-ENE direction controlled by the main trend of the geological structure. The outline of the groundwater basins is listed in Table B-2-1.

The storage volume of groundwater is calculated based on the assumption that the effective porosity of the deposits is 10% and the depth of the groundwater basins is around 300 m.

Table B-2-1 Features of the Groundwater Basins in the Study Area

Groundwater Basin	Depth to Groundwater Surface (m)	Capability of Aquifers	Degree of Groundwater Development	Assumed Volume of Groundwater ($x10^9$ m^3)
A	5 - 70	high to medium	medium	4
B	5 - 30	high to medium	medium	3
C	5 - 20	high to medium	high	2
D	10 - 30	low to medium	low	1
E	10 - 30	low	low	1
F	5 - 20	low to medium	low	3

Source: GE-1, GE-4

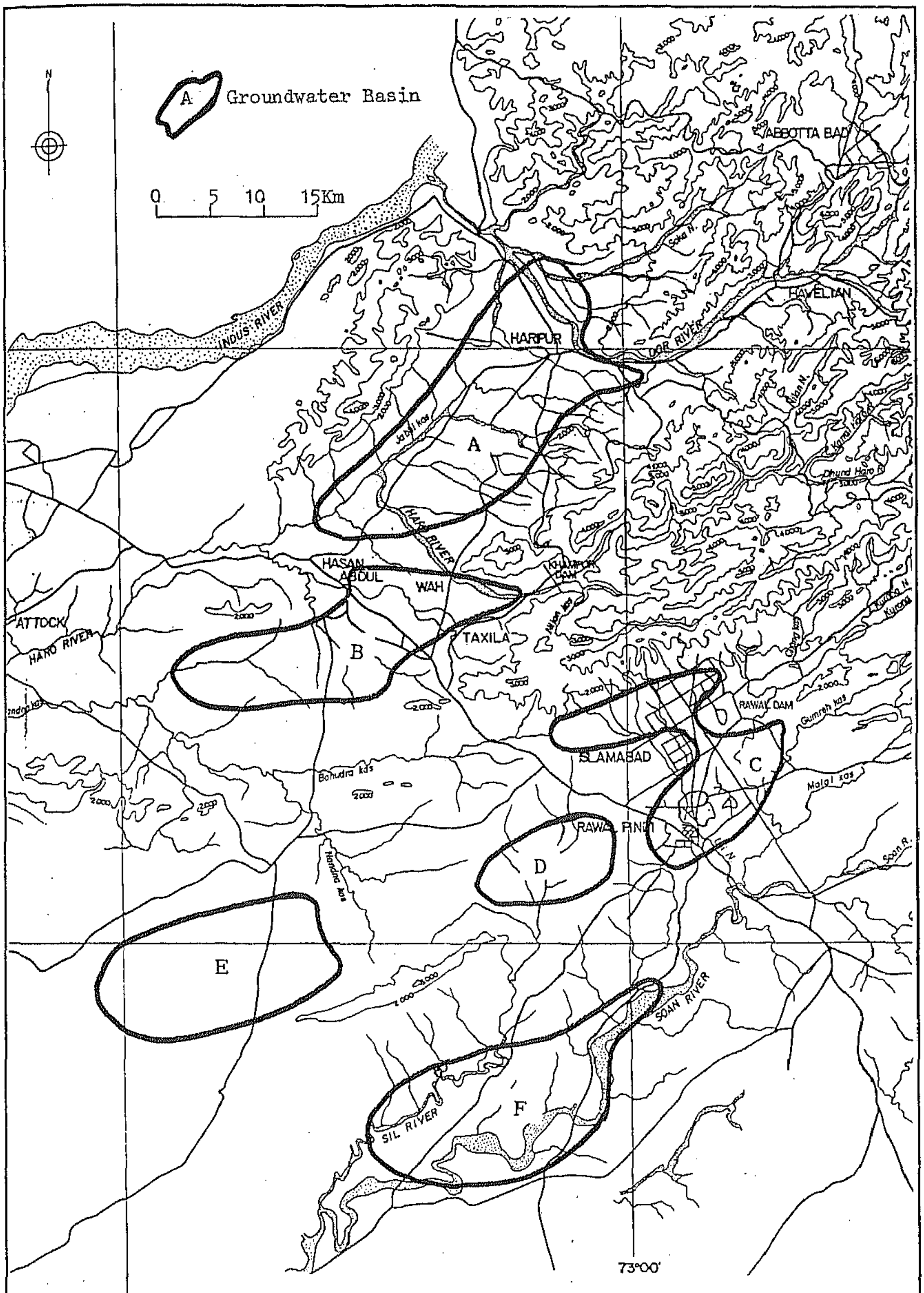


Figure B-2-1 Groundwater Basins in the Study Area

B.2.2 Subject Areas of Groundwater Development

The three groundwater basins of B, C and D are selected as the subject areas of groundwater development based on the following reasons;

: The existence of high yield aquifers is anticipated because they situated near the mountains.
: They have huge groundwater basins.
: They are situated near by the capital area.

Therefore, the studies have been done for the three groundwater basins mentioned above.

(1) Hydrogeological Structure

(a) Islamabad and Rawalpindi area (Capital Area), Groundwater basin C and D

Features of groundwater basins

The specific characteristic of the groundwater basins in the capital area is that they can be further subdivided into six groundwater basins as shown in Figure B-2-2.

The depth to the bedrock is assumed to reach 300 m in the central parts of the basins and the capability of aquifers differs basin to basin as shown in Figure B-2-3. The existing aquifer test results are shown in Table B-2-2.

The groundwater basin in the Islamabad sectoral area (C-I) can be further subdivided into three groundwater basins as shown in Figure B-2-2. The first one distributes F-7 to F-9, the second one is F-9 to 1-8 and the third one is F-10 to F-14. The first and third groundwater basins elongated in NE-SW direction along the foot of Margala hills. The second groundwater basin is located in NW-SE direction connecting the two groundwater basins mentioned above to the National Park groundwater basin. According to the existing well

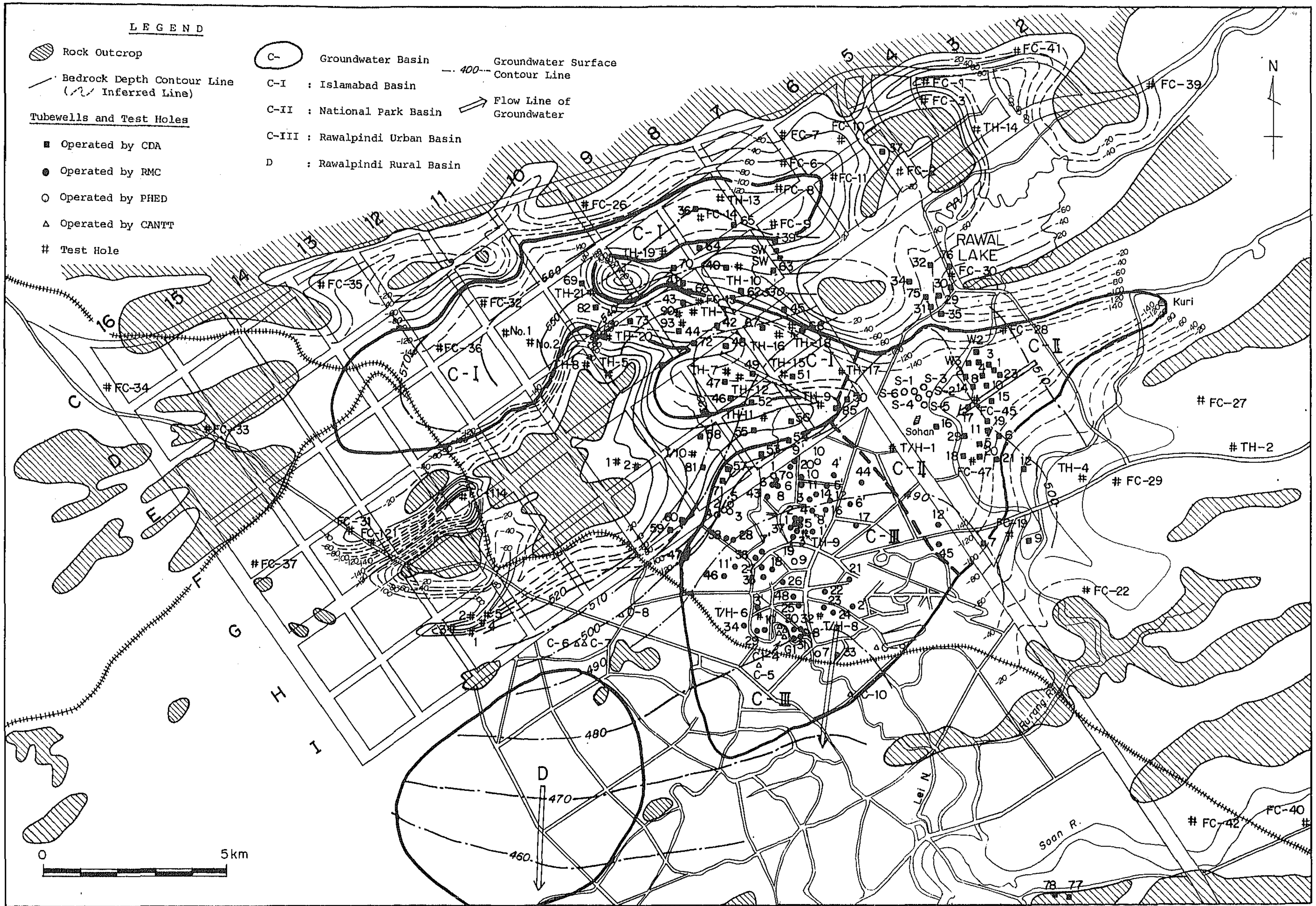


Figure B-2-2 Hydrogeological Map of Islamabad and Rawalpindi Area

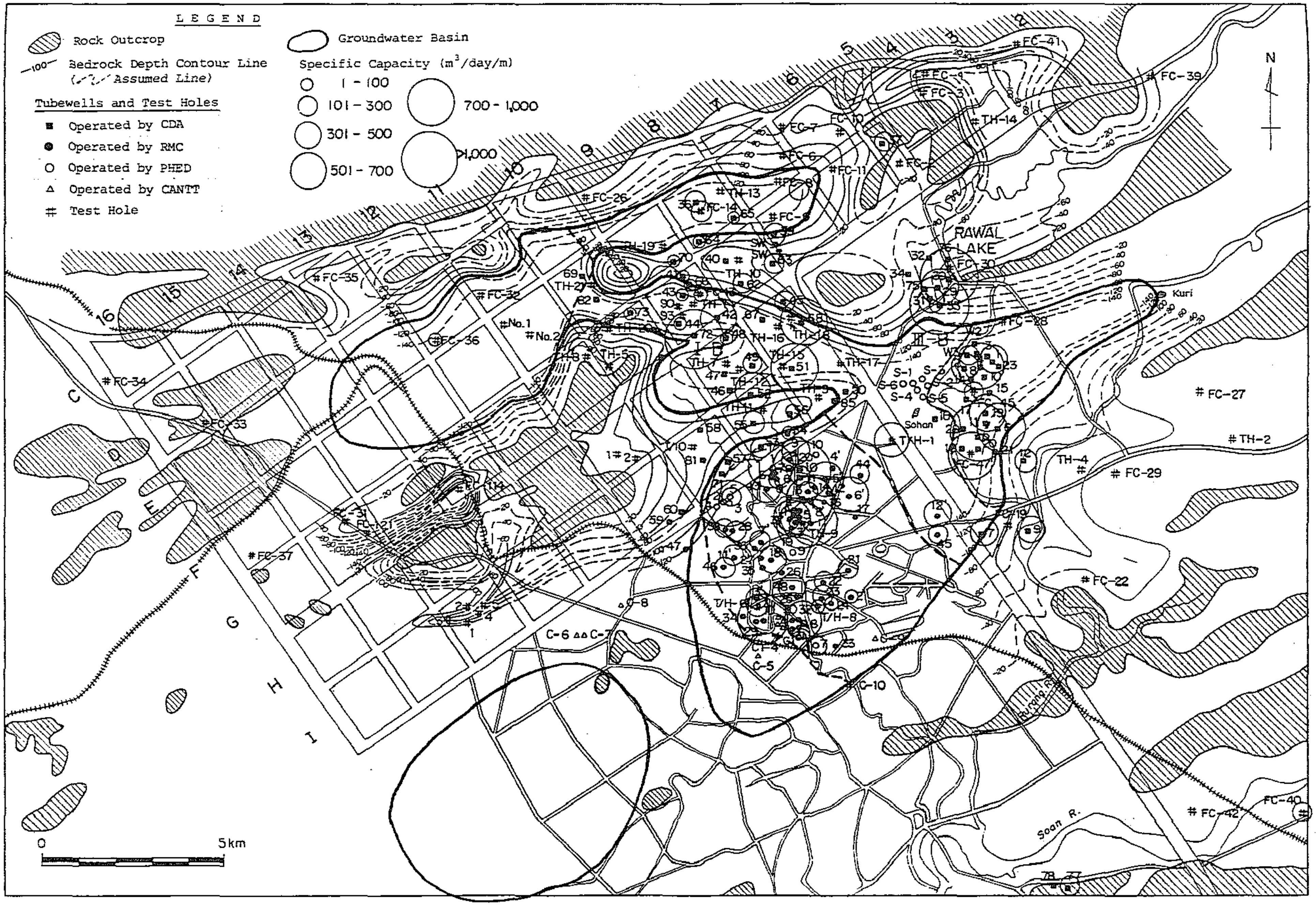


Figure B-2-3 Specific Capacity of the Tubewells in Islamabad and Rawalpindi Area

Table B-2-2 Existing Aquifer Test Results

Location		Test Well No.	Transmissivity (m^2/sec)	Permeability Coef. (cm/sec)	Storage Coef.	Specific Capacity ($m^3/day/m$)
ISLAMABAD CITY AREA	E-11	FC-32	2.3×10^{-4}	1.7×10^{-3}	-	32-35
	E-12	FC-36	1.7×10^{-4}	1.3×10^{-3}	-	34-39
	F-8	FC-14	9.3×10^{-4}	4.5×10^{-3}	-	98-114
	G-9	TH-1	$1.4\text{-}8.4 \times 10^{-2}$	-	$2.7 \times 10^{-5} \sim 6.2 \times 10^{-3}$	-
	G-9	FC-13	1.1×10^{-3}	7.6×10^{-3}	-	97
NATIONAL PARK AREA		FC-23	7.4×10^{-3}	6.1×10^{-2}	-	325-447
		FC-45	1.9×10^{-3}	-	-	227
		FC-47	5.6×10^{-2}	-	-	5,772
SOAN RIVER AREA		FC-40	1.8×10^{-2}	-	-	227
RAWALPINDI CITY AREA		T/H-1	1.5×10^{-2}	5.6×10^{-2}	7×10^{-2}	607
		T/H-6	3.6×10^{-3}	1.5×10^{-2}	2×10^{-3}	116
		T/H-8	1.4×10^{-3}	6.9×10^{-3}	2×10^{-4}	51
		T/H-9	1.3×10^{-2}	4.6×10^{-2}	5×10^{-2}	840

data and test hole informations, the transmissivity is assumed around 100 to 500 m^2/day in the Islamabad sectoral area. These groundwater basins receive groundwater inflow from Margala hills.

Golf course area is situated just downstream of the Rawal dam's saddle dam. In Golf course area, there are many springs and large amount of groundwater has been discharged in spite of its small groundwater basin. It can be concluded that the groundwater originated from Rawal lake seepage water.

National Park groundwater basin (C-II)is the most abundant area in groundwater. Many wells are under the artesian condition. There distribute continuous high yield aquifers composed of coarse gravels and boulders and their transmissivity shows high value ranging 500 to more than 1,000 m^2/day. The National Park groundwater basin receives the groundwater inflow from Murree mountains.

Rawalpindi Urban groundwater basin (C-III) situated at the confluence point of groundwater inflows from C-I and C-II groundwater basins. This groundwater basin opens toward the southern direction and the groundwater is assumed to flow-out toward Soan river. The transmissivity greatly differs well to well and it ranges from 100 to more than 1,000 m^2/day in this area.

Rawalpindi Rural groundwater basin (C-IV) has only few tubewells and the enough hydrogeological informations for hydrogeological analysis are not available. This groundwater basin, however, is assumed to have wide and deep groundwater basin because the bedrock exposures can be rarely found in it.

Groundwater flow

The groundwater table contour lines are shown in Figure B-2-2. This figure shows that two groundwater flow, one of which is from Margala hills and another is from Murree Mountains, confluence together at the National Park basin and after the confluence the groundwater flows toward southern direction. This figure also suggests that the Rawalpindi Rural Area basin is separated from other groundwater basins in terms of the groundwater flow.

The schematic model of groundwater flows in the capital area is shown in Figure B-2-4 based on the findings mentioned above.

(b) Wah and Taxila area, Groundwater basin B

Features of groundwater basin

Groundwater basin of Wah and Taxila area shows a belt shaped feature elongating ENE to WSW direction with width of about 10 km. The depth of the groundwater basin is assumed to be more than 300 m in the central part.

Three groundwater channels can be inferred from the concaves of the groundwater surface contour lines and the existence of springs as shown in Figure B-2-5. Their transmissivity reaches to several thousands cubic meter per day. It is considered that such high permeable zones might be ancient river courses in which the coarser materials accumulated.

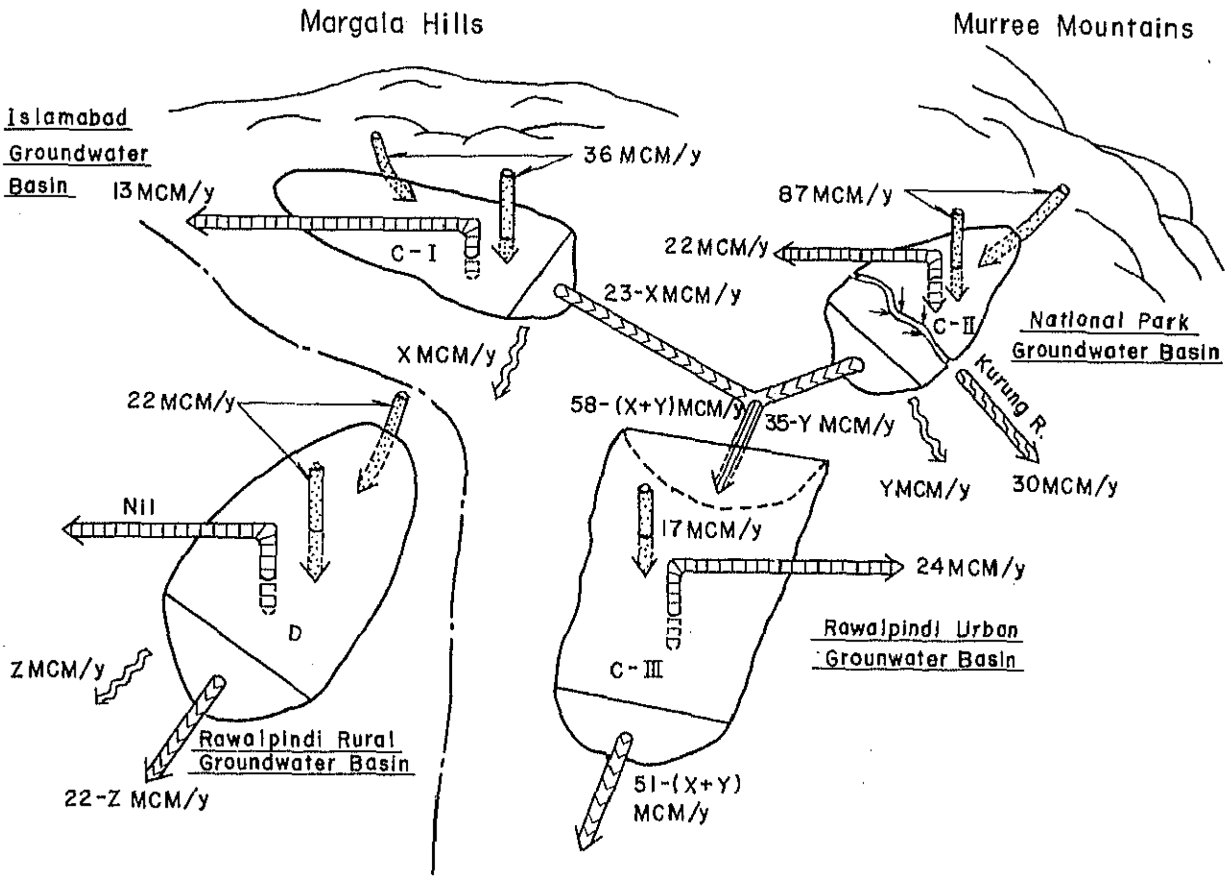
Groundwater flow

As shown in Figure B-2-5, the groundwater surface inclines toward the north-west direction. It means that the groundwater flows toward same direction and the flow beyond northern boundary of the groundwater basin is intercepted by the unpervious bedrock ridges.

The large-scaled springs, which are Bauhti spring, Hassan Abdal spring, Wah spring and Pathar Garh spring, are located in the north-western end of the high permeable zone as shown in Figure B-2-5. It is considered that the groundwater through the groundwater flow channels hits the unpervious bedrock ridges and is dammed up to be appeared on the ground surface as springs.

(2) Groundwater Table Fluctuations

The relationships between precipitation and groundwater level are shown in Figure B-2-7 and Figure B-2-8 and their locations are shown in Figure B-2-6. According to these figures, the groundwater level in the wells



L E G E N D

- Groundwater Divide
- Recharge from Precipitation (calculated from the results of the hydrological analysis)
- Outflow from Groundwater Basin
- Inflow to Groundwater Basin
- Effluent Flow to River System (from the actual measurements)
- Discharge by Tubewells
- Leakage into Bedrock

Figure B-2-4 Schematic Model of Groundwater Balance in Islamabad and Rawalpindi Area

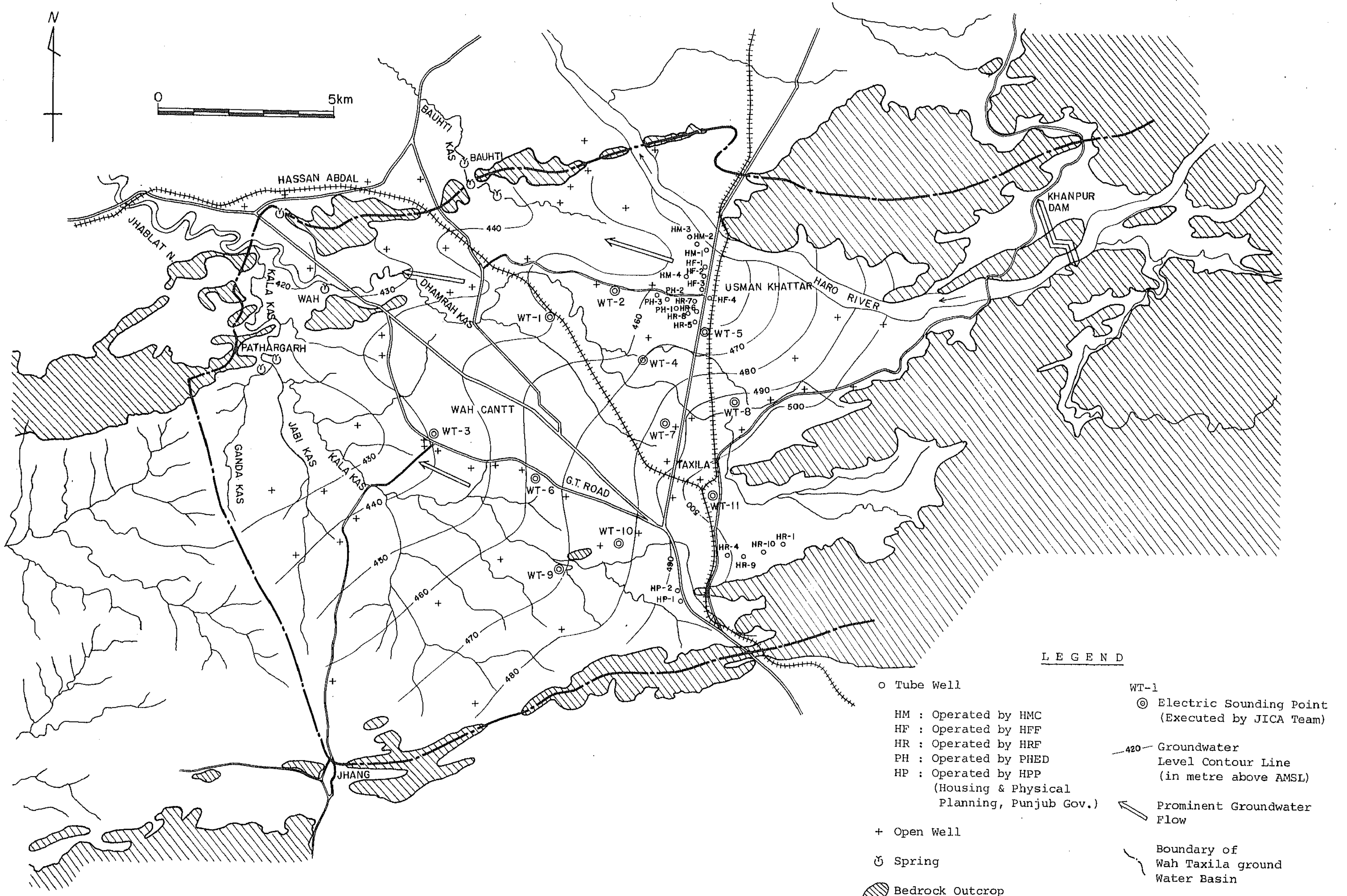


Figure B-2-5 Hydrogeological Map of Wah and Taxila Area

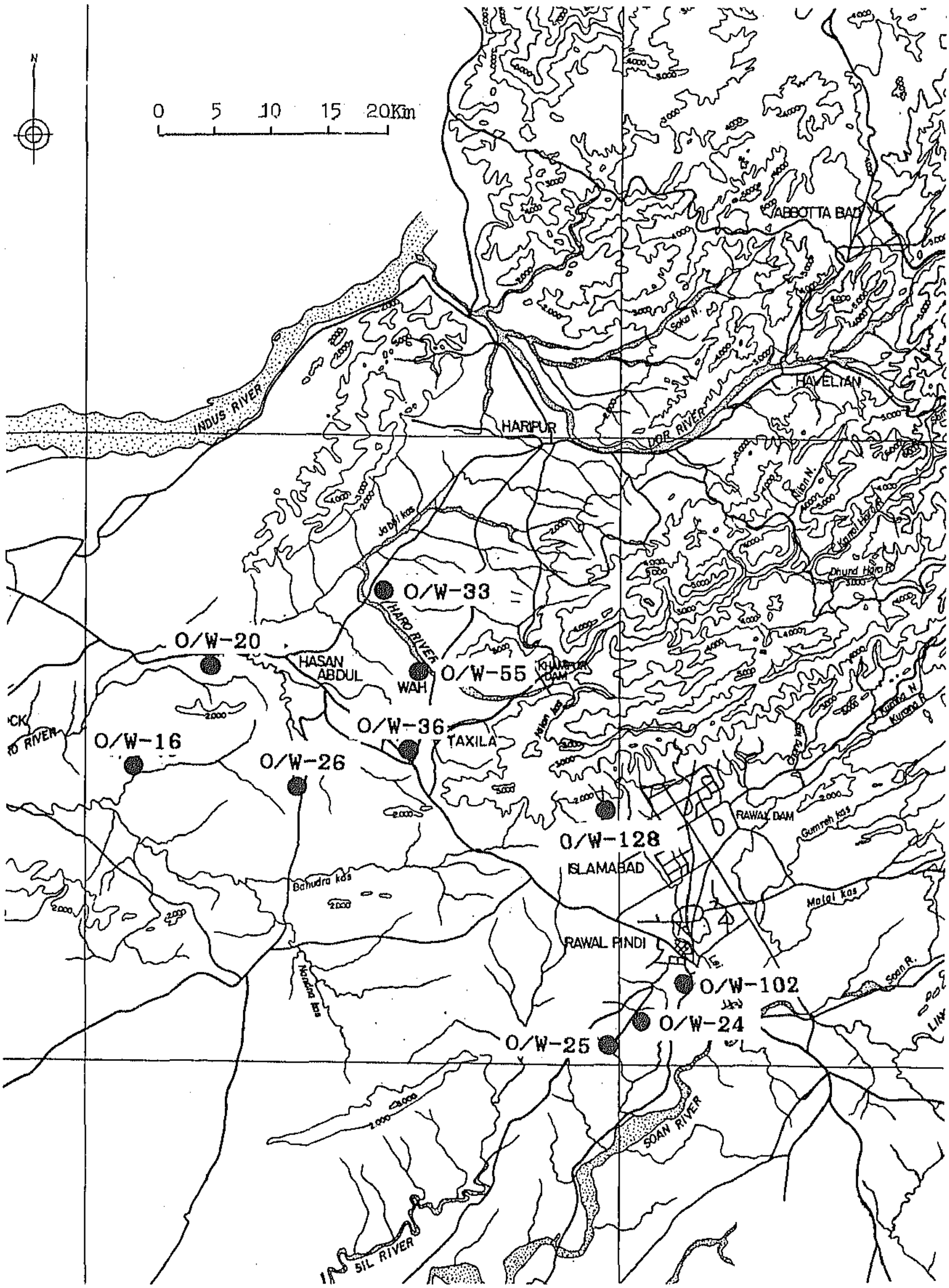
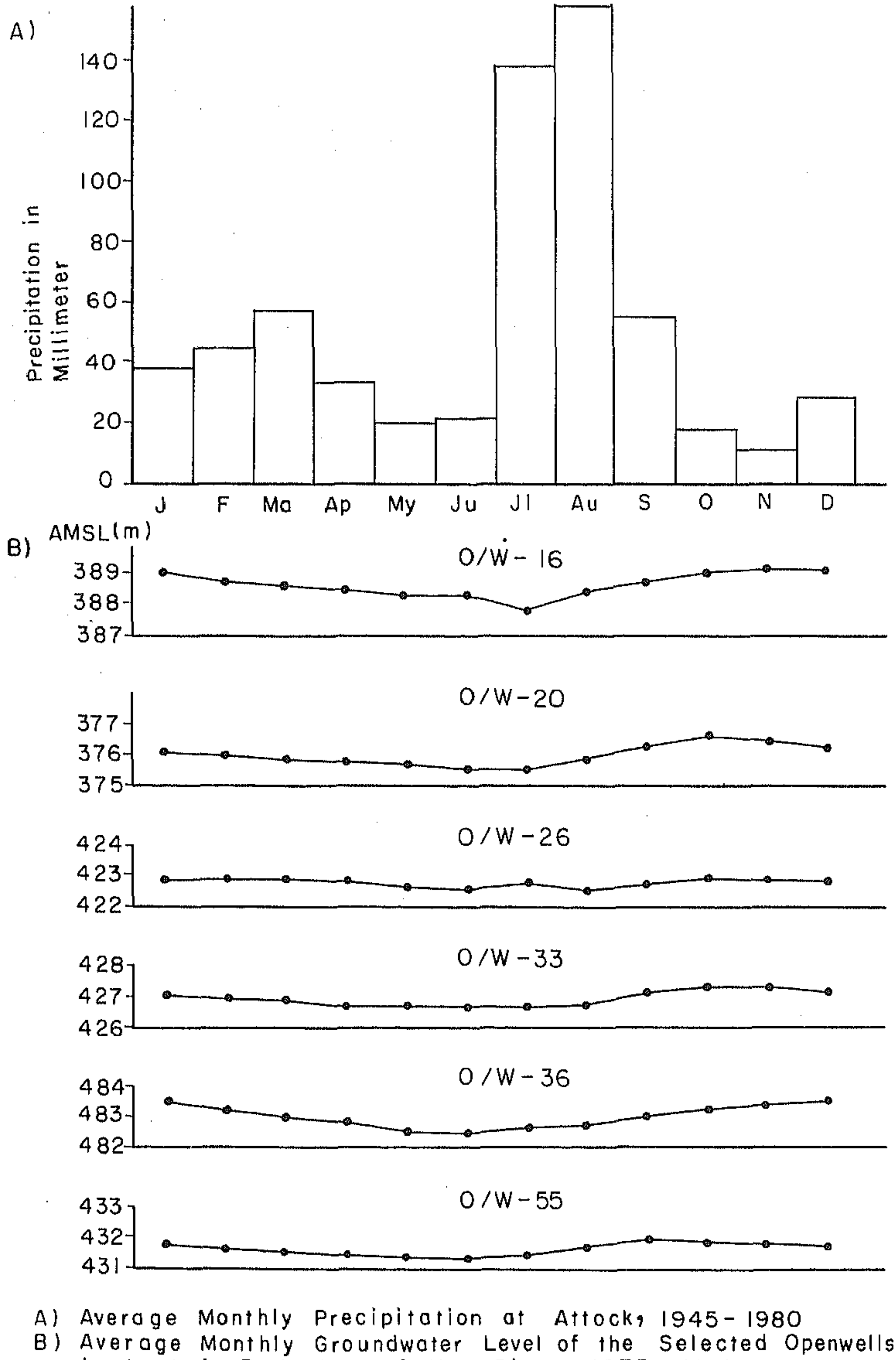


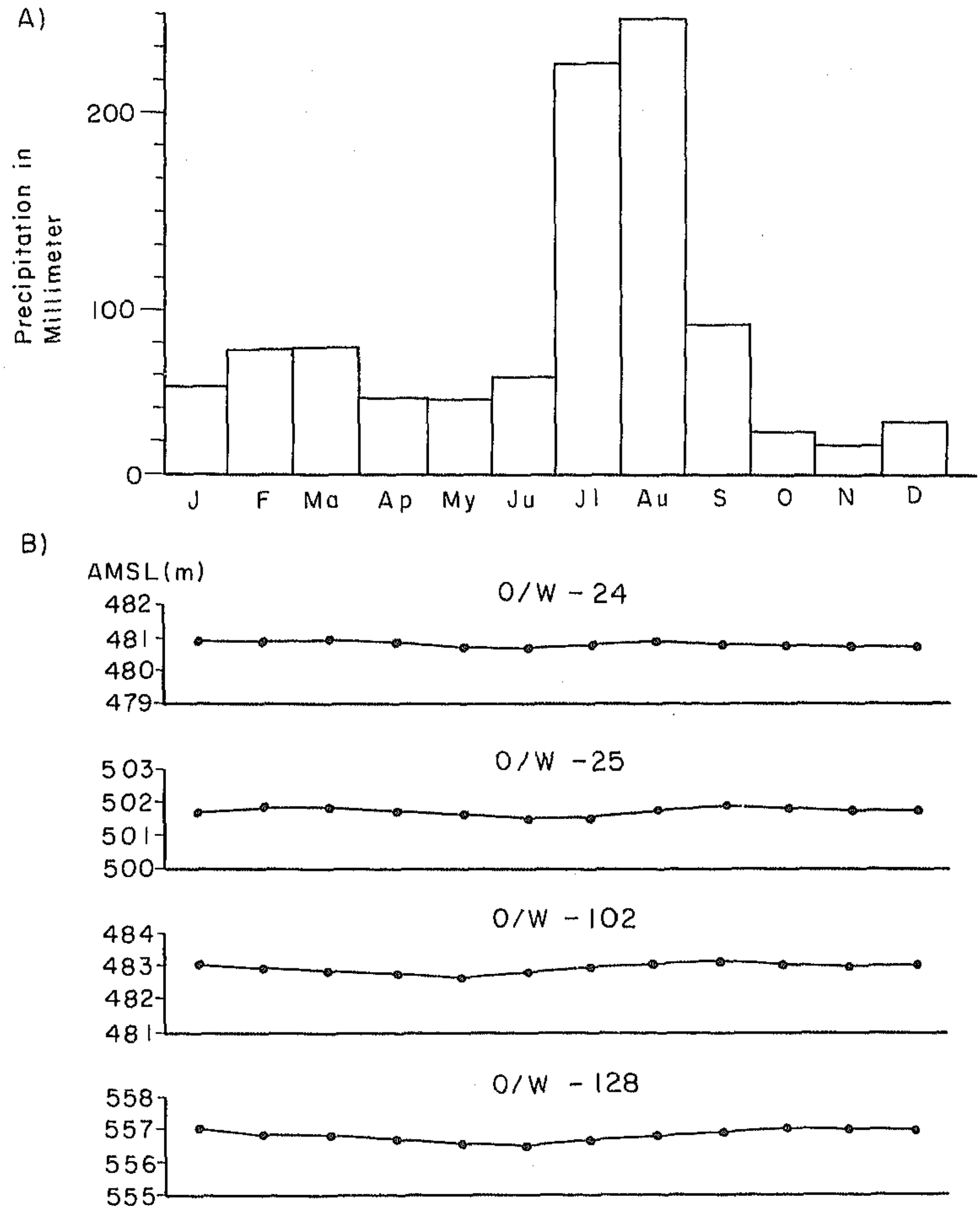
Figure B-2-6 Location of the Observation Wells



A) Average Monthly Precipitation at Attock, 1945-1980
B) Average Monthly Groundwater Level of the Selected Openwells in the Left Bank Area of Haro River, 1975-1981

(Based on the data from "HYDROGEOLOGICAL INVESTIGATION IN HARO BASIN, POTWAR PLATEAU, PUNJAB PROVINCE" WAPDA, April 1981)

Figure B-2-7 Relationship between Precipitation and Groundwater Level Fluctuation in the Left Bank Area of Haro River



A) Average Monthly Precipitation at Rawalpindi, 1960-1980
B) Average Monthly Groundwater Level of the Selected Openwells in the Capital Area, 1975-1981

(Based on the data from "HYDROGEOLOGICAL INVESTIGATIONS IN SOAN BASIN, POTWAR PLATEAU, PUNJAB PROVINCE" WAPDA, August 1982)

Figure B-2-8 Relationship between Precipitation and Groundwater Level Fluctuation in the Capital Area fluctuates in response to the precipitation, that is, the peak of precipitation which is detected in July and August can be correlated to the peak of groundwater tables in September to November. From such a phenomenon it is inferred that the aquifer systems in the study area are mainly recharged by the precipitation and they are under the unconfined condition in general.

The average fluctuation range is 0.4 to 0.5 m in the capital area and 0.7 to 1.5 m in the left bank area of Haro river including the Wah and Taxila area.

(3) Groundwater Depth

(a) Islamabad and Rawalpindi area

The depth of groundwater is shown in Figure B-2-9. From this figure followings can be inferred;

: The groundwater basins have different groundwater depth each others.
: Groundwater depth in Islamabad area is about 10 m.
: Groundwater depth in National Park area is generally 0 or artesian condition.
: The groundwater table is much higher than the river bed in the National Park area, so that great amount of groundwater may flow into the river.
: Groundwater depth in Rawalpindi Rural area is 10 to 15 m.
: Groundwater table is almost parallel with ground surface but slightly deepens toward south-west direction.

(b) Wah and Taxila area

The depth of groundwater is shown in Figure B-2-10. According to this figure, any specific characteristics as indicated in the capital area are not found. The groundwater table is almost parallel with the ground surface and groundwater depth ranges from 5 m to 30 m. The groundwater table lowers in the high permeable zones and the groundwater surface contour lines concave along them as shown in Figure B-2-10.

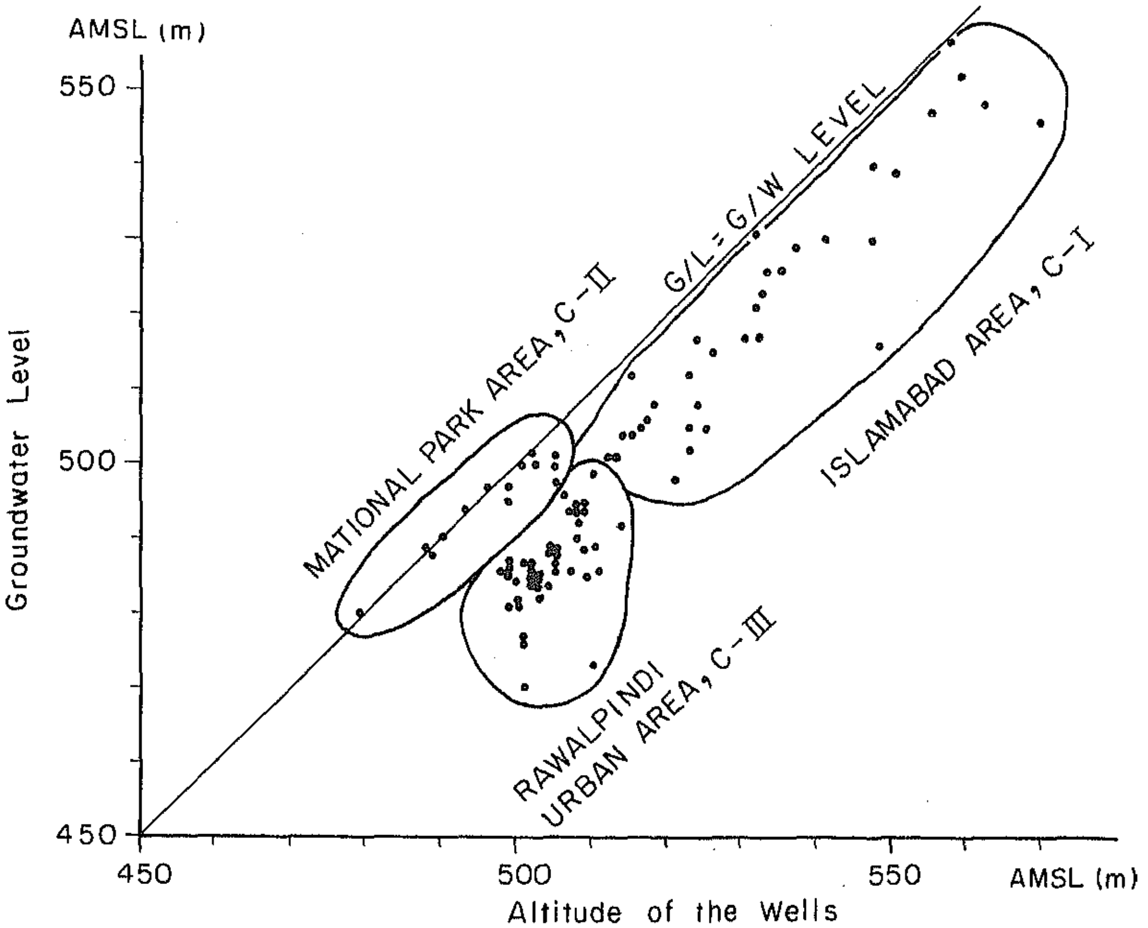


Figure B-2-9 Relationship between Altitude of the Tubewells and Groundwater Levels in the Capital Area

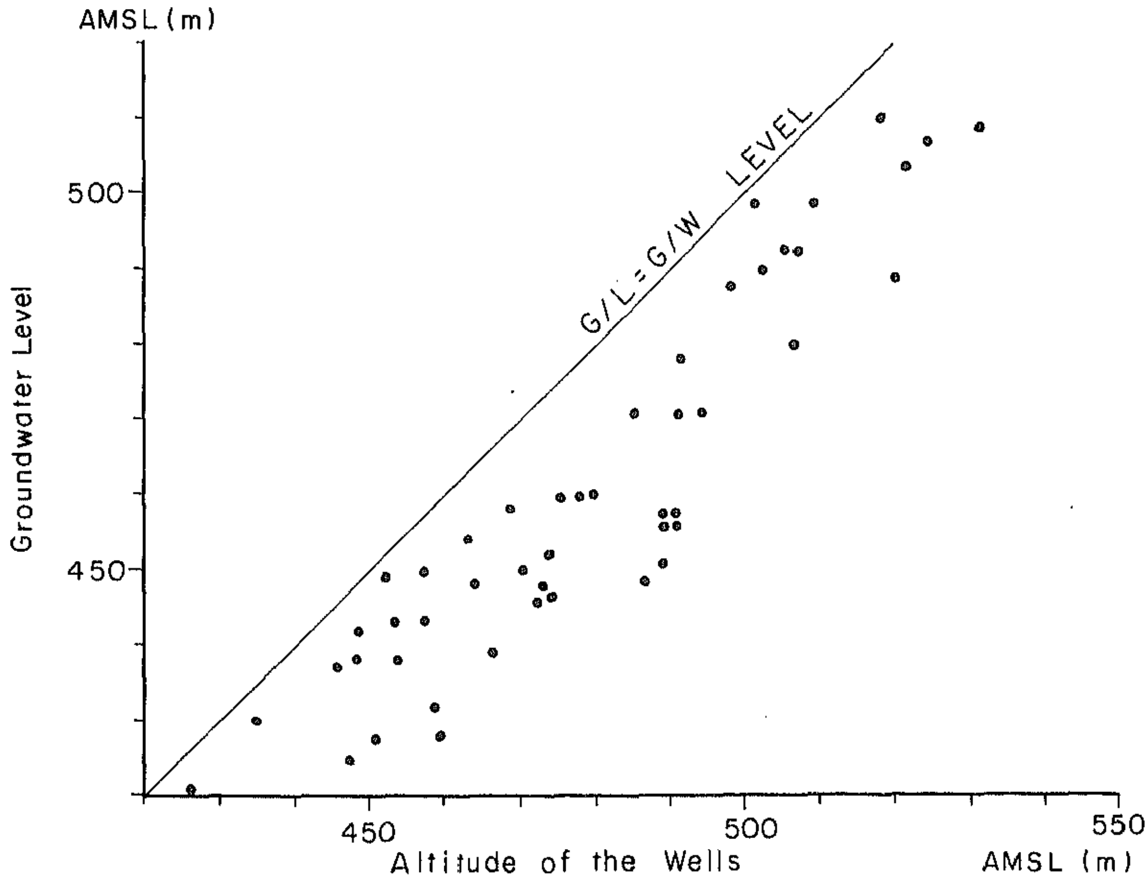


Figure B-2-10 Relationship between Altitude of the Shallow Wells and Groundwater Levels in Wah and Taxila Area

(4) Groundwater Abstraction

The lists of Tubewells are shown in Table B-2-5.

(a) Islamabad, Rawalpindi area

More than 150 tubewells have been installed in this area. The groundwater development has been highly concentrated in the central to western part of the capital area as shown in Figure B-2-2.

The well conditions in the each groundwater basins are shown in Table B-2-3. The possible daily discharge amount in this table includes the resting tubewells due to the maintenance, the actual working tubewells are around 80% of the total.

Table B-2-3 Tubewell Abstraction in the Capital Area

Groundwater Basin	No. of Tubewells	Possible Daily Discharge (m^3/day)	Average Well Capability (m^3/hour)
Islamabad C-I	37	43,469	60.2
National Park C-II (including Golf Course Area)	37	76,543	108.7
Rawalpindi Urban C-IV	78	85,142	61.0
Rawalpindi Rural D	few dugwells	Negligible	-
Total	152	205,154	-

Annual discharge amount, 21 MCM/year

Possible annual discharge amount: 75 MCM/year
Actual annual discharge amount : 59 MCM/year

In the left bank area of Lei Nalah in Rawalpindi Urban area decrease of groundwater table has been prevailing on the existing wells especially in summer season as the results of excessive discharging from the highly concentrated tubewells.

(b) Wah and Taxila area

The present groundwater discharge from the Wah and Taxila groundwater basin through the tubewells are listed in Table B-2-4. The tubewells in this area were fully working.

Table B-2-4 Tubewell Abstruction in the Wah and Taxila Area

Area	No. of Tubewells	Daily Discharge Amount (m^3/day)	Average Well Capability (m^3/hour)
Usman Khattar	13	20,768	100.0
Taxila Cantt.	4	3,264	51.0
Wah Cantt.	18	18,360	51.0
Others	15	15,638	-
Total	50	58,030	-

Annual discharge amount, 21 MCM/year

The decrease of groundwater table caused by the excessive discharging has not been recognized so far in this area.

(5) Potential Areas of Groundwater Development

Areas, in where large groundwater basins are located and the groundwater resources have not yet been highly developed, should be selected as the potential areas of groundwater development.

In the selected areas the geo-electric sounding has been carried out in order to get the hydrogeological conditions clearer.

Table B-2-5 (1) List of Tubewells in Islamabad

LOC.	NO.	YEAR OF COMP.	DEPTH (m)	SCREEN (m)	STATIC W/L (m)	PUMPING W/L (m)	SPEC.CAP. m^3/day/m	DIS. (m^3/h)	DIS. HOUR	DIS.AMOUNT A DAY (m^3)
NATIONAL PARK AREA	1	1971	54.6	22.3	5.3	13.2	367	121.3	22	2,669
	2	1971	70.0	24.4	4.6	6.8	431	39.5	22	869
	3	1971	69.5	23.2	-	-	-	201.5	20	4,031
	4	1971	62.2	23.2	0	3.4	914	129.5	22	2,848
	5	-	70.4	37.8	ARTESIAN	2.7	1,088	122.5	20	2,450
	6	1971	65.2	18.3	ARTESIAN	4.3	970	173.8	20	3,476
	7	-	69.5	18.3	-	12.4	408	57.8	20	1,155
	8	-	-	-	-	-	-	ABONDONED		
	9	1971	63.4	12.2	ARTESIAN	9.3	408	158.4	20	3,168
	10	-	76.2	21.9	-	-	-	27.3	20	546
	11	-	76.2	29.3	0	-	-	22.7	20	455
	12	1971	53.0	9.8	ARTESIAN	8.6	239	85.8	20	1,717
	13	1971	78.0	18.6	-	9.5	-	171.7	21	3,607
	14	1971	51.2	19.5	2.9	8.4	602	138.0	22	3,036
	15	1971	71.3	21.9	-	10.5	-	181.4	22	3,990
	16	1977	83.2	20.7	-	-	-	106.8	20	2,135
	17	1977	76.2	21.9	-	5.0	-	93.7	20	1,874
	18	1971	63.1	21.9	-	4.8	166.8	20	2,135	
	19	1977	82.6	12.2	0	3.1	633	81.8	22	1,799
	20	-	75.9	11.0	0	-	-	ABONDONED		
	21	1982	69.8	13.4	1.6	-	-	102.3	22	2,251
	22	-	-	-	-	-	-	ABONDONED		
	23	1980	62.2	24.4	5.6	10.6	622	129.6	22	2,851
	24	-	82.3	13.4	-	-	-	56.9	20	1,137
	W-I	1971	76.2	-	-	-	-	108.8	22	2,375
	W-II	-	76.2	-	-	-	-	ABONDONED		
	W-III	1971	76.2	-	0.9	7.9	190	55.5	21	1,165
GOLF COURSE AREA	28	1970	45.0	14.3	-	-	-	68.5	20	1,369
	29	1970	35.2	6.5	21.5	23.4	644	51.0	20	1,021
	30	1970	33.8	5.1	21.7	23.5	2,450	183.8	22	4,042

Table B-2-5 (2) List of Tubewells in Islamabad

LOC.	NO.	YEAR OF COMP.	DEPTH (m)	SCREEN (m)	STATIC W/L (m)	PUMPING W/L (m)	SPEC.CAP. m^3/day/m	DIS. (m^3/h)	DIS. HOUR	DIS.AMOUNT A DAY (m^3)
GOLF COURSE	31	1970	30.9	8.4	12.2	16.5	323	102.3	22	2,251
	32	1970	33.8	5.1	-	20.5	-	51.0	20	1,021
	33	1978	31.1	12.2	-	-	-	ABONDONED		
	34	1978	39.9	23.2	-	-	-	34.1	20	682
	35	1983	80.8	40.2	23.9	26.2	1,253	120.1	12	1,441
F-8	36	1980	181	-	25.1	32.7	187	59.3	20	1,187
G-5	37	1968	36.6	10.7	3.8	7.4	219	32.8	12	393
G-7	38	1964	-	-	5.3	-	-	19.8	20	396
=	39	-	26.8	-	0.6	2.3	279	19.8	12	238
G-8	40	1980	45.1	12.2	-	-	-	51.8	20	1,035
G-9	41	1978	80.5	21.9	12.5	22.2	74	30.0	21	631
=	42	1978	121.9	30.5	13.6	15.8	646	59.3	21	1,246
=	43	1980	86.9	30.5	12.1	20.9	81	29.7	20	593
=	44	1980	91.4	20.1	10.4	17.5	100	29.7	20	593
H-8	45	1981	114.3	-	11.0	22.5	170	81.8	22	1,799
H-9	46	1979	82.3	20.1	6.5	-	-	68.2	20	1,364
=	47	1980	103.6	23.2	16.6	-	-	54.5	10	545
=	48	1980	109.7	22.9	11.6	29.1	93	68.2	22	1,501
=	49	-	118.9	29.3	17.3	21.4	143	24.5	2	49
I-8	50	1980	59.4	16.2	-	-	-	68.2	20	1,364
=	51	-	90.8	31.7	10.9	13.2	802	126.8	20	2,537
I-9	52	1970	118.0	22.9	12.4	15.6	645	126.8	20	2,537
=	53	1970	79.6	21.9	11.6	17.2	253	59.1	20	1,182
=	54	1970	78.9	18.3	12.1	24.0	84.5	76.4	20	1,528
=	55	1980	91.4	19.5	11.6	24.9	151.1	100.4	20	2,008
=	56	1980	73.2	22.9	10.7	28.6	79	59.0	20	1,179
I-10	57	1976	86.9	22.9	-	-	-	59.1	6	355
=	58							ABONDONED		
I-11	59	1979	82.3	18.3	5.6	16.2	63	28.1	20	562
=	60	1979	82.9	21.9	-	11.1	-	59.0	4	236

Table B-2-5 (3) List of Tubewells in Islamabad

LOC.	NO.	YEAR OF COMP.	DEPTH (m)	SCREEN (m)	STATIC W/L (m)	PUMPING W/L (m)	SPEC.CAP. m^3/day/m	DIS. (m^3/h)	DIS. HOUR	DIS.AMOUNT A DAY (m^3)
G-7	61	1981	135.6	30.5	7.8	17.8	240	100.0	20	2,001
G-8	62	1981	74.1	19.5	8.4	20.0	112	54.5	20	1,091
=	63	1981	45.1	14.6	7.6	13.5	259	63.7	22	1,400
F-8	64	1981	89.3	26.8	9.5	28.4	37.4	30.9	20	617
=	65	1981	94.5	21.9	15.4	32.8	35.4	43.2	20	865
G-9	66	1981	51.2	14.6	8.4	19.5	547	25.3	20	507
H-8	67	–	71.0	18.3	–	–	–	102.3	20	2,046
=	68	1982	92.7	40.2	18.9	23.4	727	136.4	22	3,002
F-9	70	1982	88.4	30.5	12.4	35.7	56.1	24.5	22	539
F-10	69	1980	53.3	19.5	8.2	29.2	93	81.7	20	1,633
I-10	71	–	121.9	29.3	–	–	–	62.0	22	1,364
G-9	72	1981	91.4	24.4	16.5	19.2	1,131	127.3	22	2,801
G-10	73	1982	77.7	24.4	1.3	47.0	27.3	20	545	
=	74	–	66.8	17.1	–	–	–		ABONDONED	
Golf Course	75	–	61.6	21.9	–	–	–		ABONDONED	
–	76	–	60.4	17.9	–	35.4	–	81.8	20	1,636
Humak Sharki	77	1982	–	–	9.3	15.2	300	61.3	4	245
=	78	–	–	–	–	11.6	–	32.4	4	139
=	79						TEST	HOLE		
I-9	80						TEST	HOLE		
I-10	81		71.6	–	2.7	–		NOT YET FUNCTIONING		
F-10	82		99.4	18.3	3.3	–		NOT YET FUNCTIONING		
=	83						TEST	HOLE		
=	84						TEST	HOLE		
I-8	85		71.3	19.8	11.8	–		NOT YET FUNCTIONING		

Table B-2-5 (4) List of Tubewells in Islamabad

LOC.	NO.	YEAR OF COMP.	DEPTH (m)	SCREEN (m)	STATIC W/L (m)	PUMPING W/L (m)	SPEC.CAP. m^3/day/m	DIS. (m^3/h)	DIS. HOUR	DIS.AMOUNT A DAY (m^3)
RAWALPINDI CITY AREA	TW-1	1926	–	–	17.4	20.7	529	72.8	22	1,602
	= 2	1926	–	–	–	–	–	68.2	22	1,501
	= 3	1926	–	–	–	–	–	45.5	22	1,001
	= 4	1981	137.2	–	–	–	–	45.5	22	1,001
	= 5	1978	–	–	8.3	–	–	36.4	222	801
	= 6	1971	–	–	14.9	19.5	242	45.5	22	1,001
	= 7	1978	–	–	–	–	–	27.3	22	600
	= 8	1982	137.2	46.3	17.3	24.1	128	36.4	22	801
	= 9	1968	–	–	12.5	18.0	318	72.8	22	1,601
	= 10	1955	–	–	–	–	–	18.1	18	326
	= 11	1956	–	–	–	–	–	45.5	18	819
	= 12	1970	–	–	–	–	–	22.7	22	499
	= 13	1958	–	–	11.0	14.0	254	31.8	22	700
	= 14	1960	–	–	–	–	–	36.4	22	801
	= 15	1971	–	–	–	–	–		ABONDONED	
	= 16	1972	–	–	–	–	–	36.4	22	801
	= 17	1978	–	–	–	–	–	27.3	14	382
	= 18	1975	–	–	17.4	20.7	331	45.5	10	455
	= 19	1977	–	–	–	–	–	72.1	8	576
	= 20	1978	–	–	12.2	16.8	237	45.5	16	728
	= 21	1968	–	–	18.3	24.4	268	68.2	15	1,023
	= 22	1968	–	–	15.2	25.0	111	45.5	15	683
	= 23	1972	106.1	–	25.3	30.8	298	68.2	14	955
	= 24	1980	–	–	19.5	29.9	84	36.4	8	291
	= 25	1968	–	–	17.4	–	–	45.5	23	1,045
	= 26	1977	–	–	–	–	–	45.5	22	1,001
	= 27	1978	–	–	–	–	–	27.3	8	218
	= 28	1976	–	–	16.8	24.4	144	45.5	20	910
	= 29	1971	–	–	–	–	–	27.3	16	436
	= 30	1959	–	–	–	–	–	45.5	12	546

Table B-2-5 (5) List of Tubewells in Islamabad

LOC.	NO.	YEAR OF COMP.	DEPTH (m)	SCREEN (m)	STATIC W/L (m)	PUMPING W/L (m)	SPEC.CAP. $m^3/day/m$	DIS. (m^3/h)	DIS. HOUR	DIS.AMOUNT A DAY (m^3)
RAWALPINDI CITY AREA	TW-31	1956	-	-	14.6	-	-	18.1	12	218
	= 32	1983	121.19	-	19.5	25.0	595	136.4	4	546
	= 33	1968	-	-	25.9	-	-	36.4	23	837
	= 34	1968	-	-	-	-	-	6.8	2	14
	= 35	1982	-	-	-	-	-	45.5	20	910
	= 36	1983	135.6	-	-	-	-	45.5	20	910
	= 37	1981	137.2	-	17.4	20.7	264	36.4	20	728
	= 38	1983	-	-	18.3	274	120	45.5	12	546
	= 39									
	= 40		Centrifugal Pump							
	= 41									
	= 42									
	= 43	1986	137.2	17.7	13.7	17.1	321	45.5	22	1,001
	= 44	1986	-	-	14.9	21.0	179	45.5	18	819
	= 45	1984	-	-	18.0	22.6	237	45.5	11	501
	= 46	1986	-	-	21.0	25.3	254	45.5	12	546
	= 47	1985	-	-	23.2	35.1	92	45.5	10	455
	= 48	1986	-	-	19.5	21.9	455	45.5	13	592
	RW-1	1983	61.0	29.3	19.8	23.2	962	136.4	10	1,364
	= 2	1983	61.0	21.4	18.6	29.9	77	36.4	15	546
	= 3	1983	57.9	24.4	19.8	29.0	190	72.8	10	728
	= 4	1983	107.9	28.0	-	-	-	136.4	9	1,228
	= 5	1983	94.5	34.1	15.5	21.0	595	136.4	11	1,501
	= 6	1983	105.7	32.9	21.6	27.7	536	136.4	21	2,865
	= 7	1983	136.7	39.0	18.9	25.9	253	73.8	19	1,383
	= 8	1983	116.4	27.0	18.6	19.5	970	36.4	10	364
	= 9	1983	100.0	45.1	-	-	379	72.8	22	1,601
	= 10	1984	90.5	31.7	13.4	16.2	1,169	136.4	16	2,183
	= 11	1984	108.8	34.1	21.9	28.7	257	72.8	12	873
	= 12	1986	-	-	20.1	23.2	475	61.3	8	490
	G-1	1982	68.7	19.5	15.2	17.4	843	77.3	16	1,238

Table B-2-5 (6) List of Tubewells in Islamabad

LOC.	NO.	YEAR OF COMP.	DEPTH (m)	SCREEN (m)	STATIC W/L (m)	PUMPING W/L (m)	SPEC.CAP. m^3/day/m	DIS. (m^3/h)	DIS. HOUR	DIS.AMOUNT A DAY (m^3)
RAWALPINDI CITY AREA	PW-2	1986	62.2	26.2	>37	>37	–	165.7	16	2,652
	= 3	1986	67.3	21.9	21.0	24.4	892	126.3	16	2,021
	= 4	1986	86.5	30.5	25.9	>37	–	79.3	16	1,268
	= 5	1986	72.5	25.6	24.7	34.1	170	66.7	16	1,066
	= 6	1986	94.5	34.1	18.9	>37	–	126.1	16	2,018
	= 7	1985	118.9	29.3	12.8	22.6	261	106.6	16	1,766
	= 8	1985	126.3	30.5	–	–	–	152.8	16	2,444
	= 9	1985	94.5	31.7	32.0	>37	–	82.9	16	1,326
	= 10	1985	93.3	34.1	21.0	–	–	123.9	16	1,983
CANTONMENT AREA	C- 1	–	–	–	–	–	–	90.9	12	1,091
	= 2	1964	–	–	–	–	–	18.2	22	400
	= 3	1964	–	–	–	–	–	90.9	22	2,000
	= 4	1964	–	–	–	–	–	13.6	22	300
	= 5	–	–	–	–	–	–	9.1	2	18
	= 6	1984	–	–	–	–	–	27.3	10	273
	= 7	1985	–	–	–	–	–	100.0	6	600
	= 8	1984	–	–	–	–			ABONDONED	
	= 9	1964	–	–	–	–	–	18.2	22	400
	= 10	1985	–	–	–	–	–	22.7	10	227
SOHAN VILLAGE	S- 1	1974	61.0	31.7	–	–	–	102.3	20	2,047
	= 2	1974	64.6	28.0	–	–	–	128.0	20	2,558
	= 3	1984	(redrilled)		–	–	–	87.0	20	1,739
	= 4	1974	59.7	20.7	–	–	–	76.7	20	1,535
	= 5	1974	70.1	34.1	3.0	–	–	76.3	20	1,525
	= 6	1975	57.9	32.9	–	–	–	97.2	20	1,943

Table B-2-5 (7) List of Tubewells in Wah and Taxila

	LOC. NO.	YEAR OF COMP.	DEPTH (m)	SCREEN (m)	STATIC W/L (m)	PUMPING W/L (m)	SPEC.CAP. m^3/day/m	DIS. (m/h)	DIS. HOUR	DIS.AMOUNT A DAY(m^3)
TAXILA	HR-1	1974	85.3	24.4	22.0	33.0	111	51	16	816
	HR-4	1976	97.0	31.7	22.0	33.0	111	51	16	816
	HR-5	1977	65.2	21.9	32.7	33.0	8,160	102	16	1,632
	HR-6	1978	60.0	13.4	32.7	33.0	8,160	102	16	1,632
	HR-7	-	60.1	19.5	32.7	33.0	8,160	102	16	1,632
	HR-8	1978	61.0	19.5	32.7	33.0	8,160	102	16	1,632
	HR-9	1982	98.8	32.9	21.6	33.0	107	51	16	816
	HR-10	1984	106.0	31.7	22.0	33.0	111	51	16	816
			HRF TAXILA TOTAL							9,792
	HM-1	1968	61.9	-	35.8	36.4	3,800	95	16	1,520
	HM-2	1968	64.6	-	39.6	41.5	1,200	95	16	1,520
	HM-3	1968	53.3	-	21.9	31.0	251	95	16	1,520
	HM-4	1974	61.0	-	36.1	37.9	1,267	95	16	1,520
			HMC TAXILA TOTAL							6,080
	HF-1	1973	55.5	12.2	33.5	34.4	2,720	102	16	1,632
	HF-2	1973	56.4	11.0	33.5	34.4	2,720	102	16	1,632
	HF-3	1973	57.0	12.2	33.5	34.4	2,720	102	16	1,632
	HF-4	1973	-	-	33.5	34.4	2,720	102	16	1,632
			HFF TAXILA TOTAL							6,528
	PH-1	-	-	-	-	-	-	102		1,632
	PH-2		ABONDONED							
	PH-3		ABONDONED							
			PHED GOHDO MODEL VILIAGE TOTAL							1,632

Table B-2-5 (8) List of Tubewells in Wah and Taxila

LOC.	NO.	YEAR OF COMP.	DEPTH (m)	SCREEN (m)	STATIC W/L (m)	PUMPING W/L (m)	SPEC.CAP. m^3/day/m	DIS. (m/h)	DIS. HOUR	DIS.AMOUNT A DAY (m^3)
	HP-1	-	-	-	30.5	-	-	22.7	7	159
	HP-2	-	91.4	27.3	30.5	-	-	22.7	7	159
			HOUSING AND PHYSICAL PLANNING (PUNJAB GOV.) total							318

TAXILA

TAXILA MUNICIPALITY

2 Wells x 205m^3/h x 14 hrs/day = TOTAL 5,740 m^3/day

TAXILA TOTAL 30,090 m^3/day

WAH

WAH CANTONMENT (POF)

18 Wells (2 wells rest) x 51 m^3/h x 20hrs/day = TOTAL 18,360 m^3/day

HASSAN ABDAL IRRIGATION

11 Wells TOTAL 9,580 m^3/day

WAH TOTAL 27,940 m^3/day

(a) Islamabad and Rawalpindi area

As such potential areas explained above, following four areas are selected;

1. Western part of Islamabad sectoral area
2. Right bank area of Kurang river in the National Park
3. Western part of Rawalpindi city (Cantonment area)
4. Western rural area of Rawalpindi city

The selected areas listed above are shown in Figure B-2-11.

(b) Wah and Taxila area

As the groundwater development have not highly proceeded comparing with its enormous groundwater basin, Wah and Taxila area is judged to have significant potential of the future groundwater development.

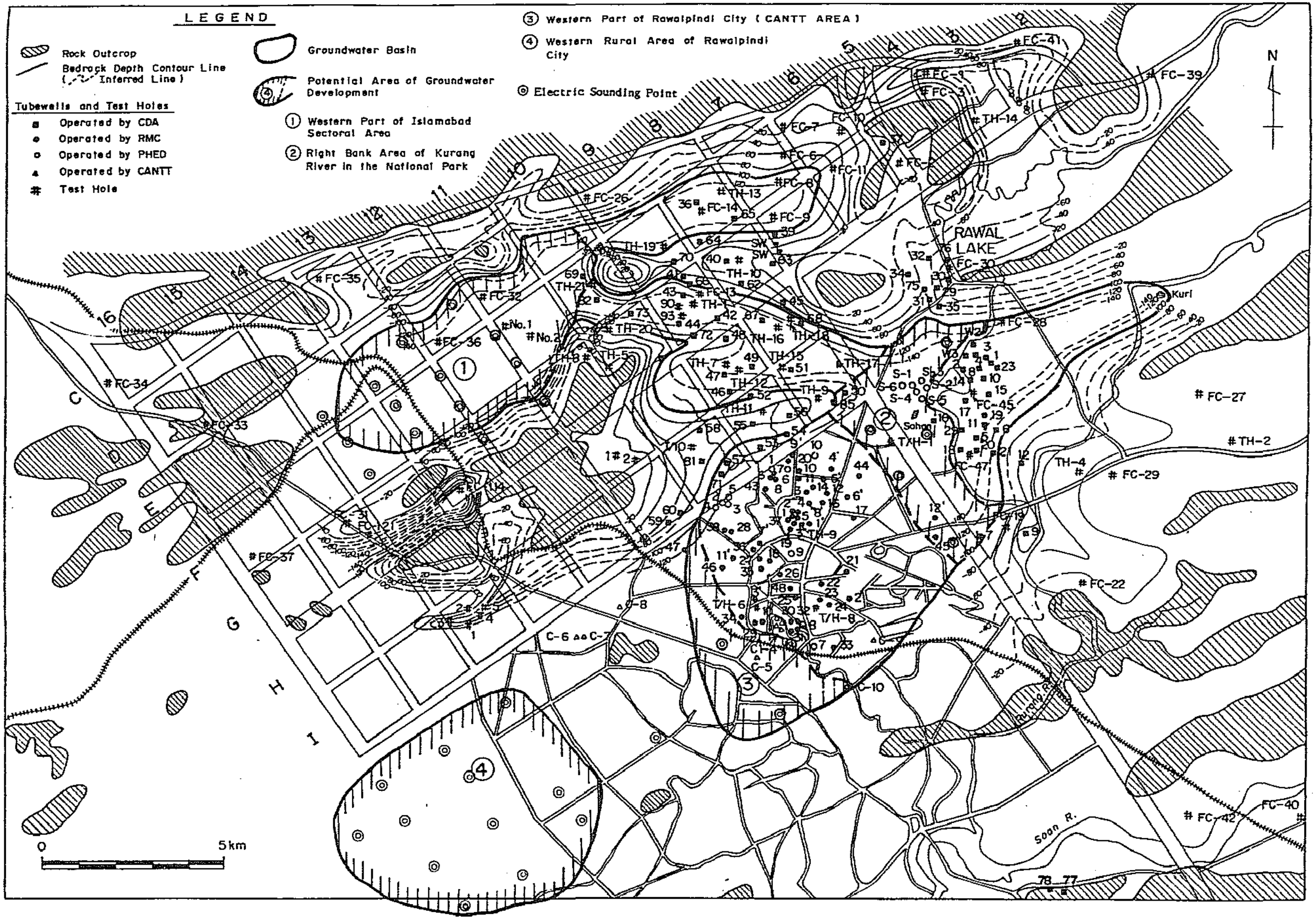


Figure B-2-11 Potential Areas of Groundwater Development in the Capital Area

B.2.3. Geo-electric Sounding

(1) General

Geo-electric prospecting was conducted by the JICA study team as well as geomorphological reconnaissance, cooperating with engineers of CDA. The potential areas of groundwater development were chosen the following five areas by reason of that the groundwater basins in these areas were widely and deeply, and furthermore much groundwater in the basins were undeveloped, namely, Wah-Taxila area, Islamabad area, National Park area, Rawalpindi Rural area and rawalpindi Cantonment area. The geo-electric prospecting points in these areas are shown in Figure B-2-12 to Figure B-2-13.

In each target area, a geomorphological and hydrogeological reconnaissance survey had been done at first to grasp a general physical condition and to make an actual geo-electric prospecting plan. Simultaneously, existing wells in the target area were checked by the JICA study team.

The prospecting depth was 200 m (prospecting steps are 30) in princeple. When the prospecting line was not able to be extended because of no space enough at the site, it was changed to be extended because of no space enough at the site, it was changed to the depth as deep as possible. When the space for extending the line was enough, the prospecting depth was extended up to 300 m.

Geo-electric prospecting applied in hydrogeological or civil engineering aspect is generally a resistivity method prospecting. The resistivity method geo-electric prospecting is classified into two major methods from a removing process of electrode system; a horizontal resistivity prospecting (resistivity mapping) and a vertical resistivity prospecting (resistivity sounding).

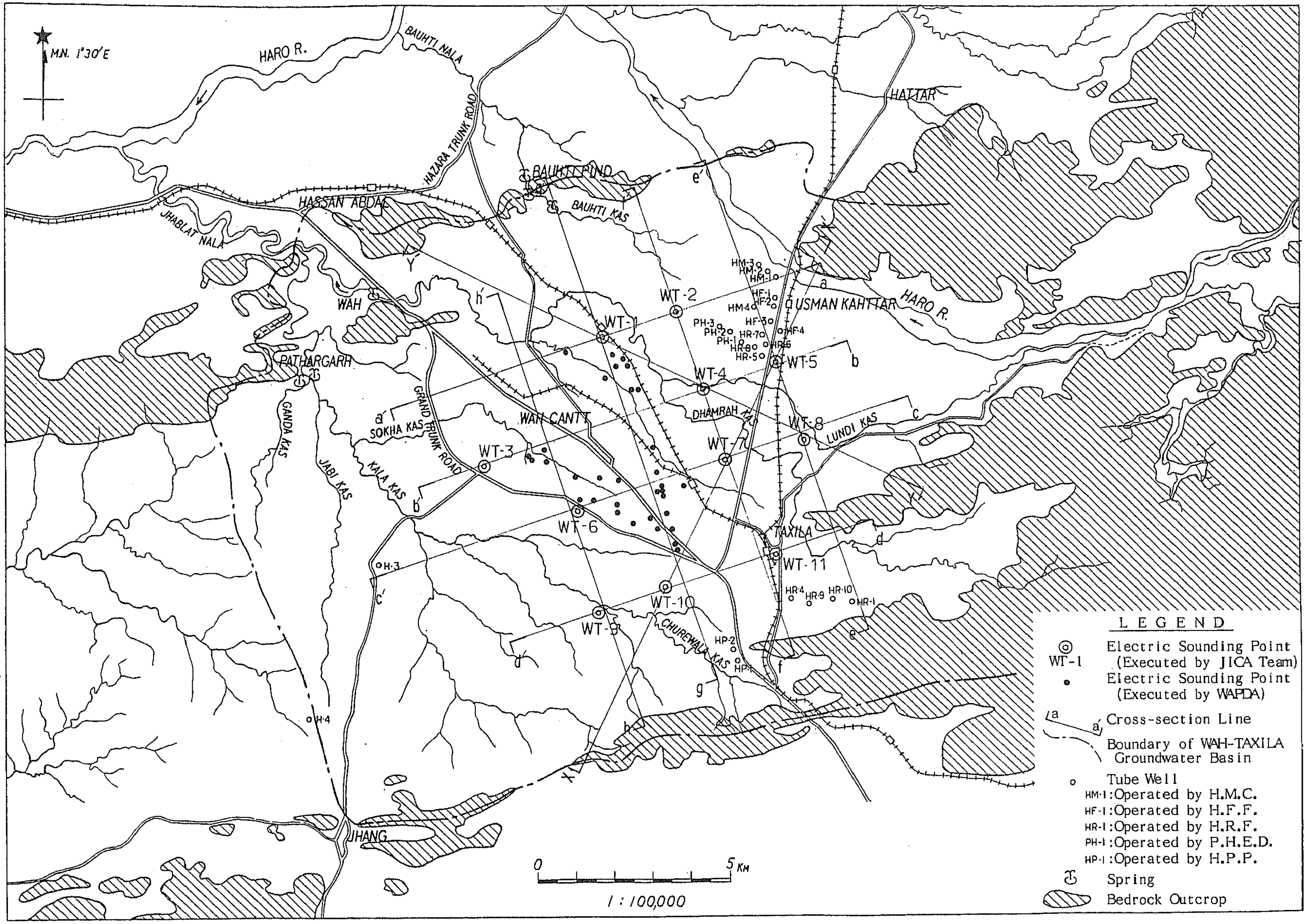


Figure B-2-12. Location Map of Electric Sounding (Wah-Taxila Area)

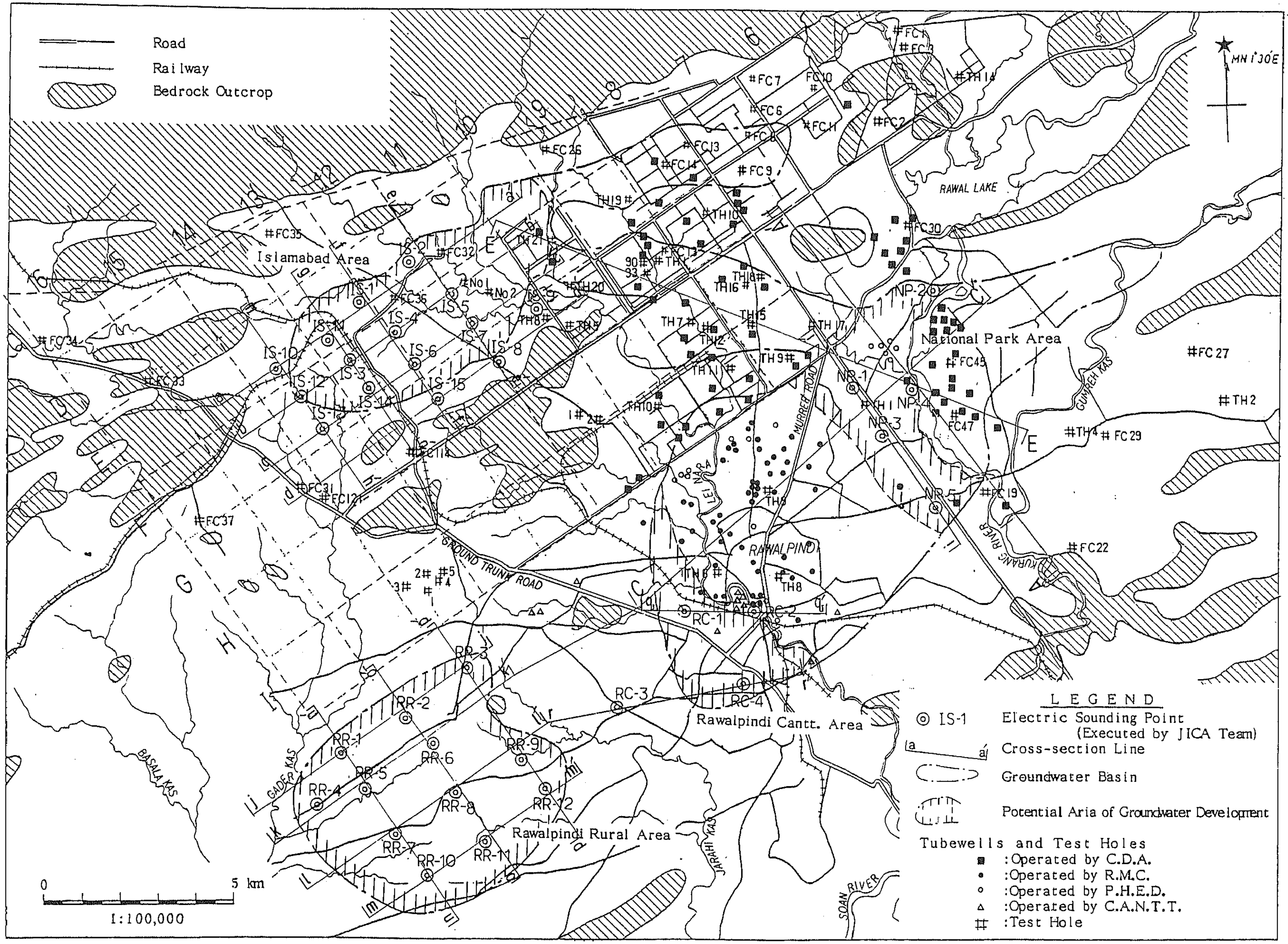


Figure B-2-13. Location Map of Electric Sounding (Capital Area)

A horizontal resistivity prospecting is the method that a fixed electrode system remove along the prospecting line, observating the resistivities of a certain depth. In a vertical prospecting, the center of electrode system (mid-point of symmetric electrode array) is fixed (called as prospecting station) and the electrode interval "a" is enlarged one by one, observation the resistivities of each depth.

The electrode system (electrode arrangement) is divided into three arrays from the number of electrode, and is farther classified into eight arrangements from its electrode configuration (see Figure B-2-14).

Figure B-2-14. Electrode Arrangement List

	Electrode Arrangement	Electric configuration facter (d*2)	Configuration
1	Pole-pole Array	a	C_2 C_1 P_1 P_2 + - - - - - +--------+ - - - - - - + |--- a ---|
2	Three-electrode Array		
2-1	CPP me.*1	2a	C_2 C_1 P_1 P_2 + - - - - - - - - - +------+------+ -- a --|-- a --|
2-2	Pole-dipole me.	n(n+1)a	C_2 C_1 P_1 P_2 + - - - - - +-------------+------+ |---- n a ----|-- a --|
3	Four-electrode Array		
3-1	Wenner's me.	a	C_1 P_1 P_2 C_2 +-----------+-----------+-----------+ |---- a ----|---- a ----|---- a ----|
3-2	Eltran's me.	3a	C_1 C_2 P_1 P_2 +-----------+-----------+-----------+ |---- a ----|---- a ----|---- a ----|
3-3	Stuggard's me.	(3/2)a	C_1 P_1 C_2 P_2 +-----------+-----------+-----------+ |---- a ----|---- a ----|---- a ----|
3-4	Schlumberger's me.	$\frac{(n+1)a}{2n}$	C_1 P_1 P_2 C_2 +-------------+------+-------------+ |---- a ------|--na--|------ a ----|
3-5	Dipole-Dipole me.	$\frac{n(n+1)(n+2)a}{2}$	C_1 C_2 P_1 P_2 +-------+--------------------+-------+ |-- a --|---------na---------|-- a --|

*1 me. : method

*2 $\rho a = 2\pi d \cdot \frac{V}{I}$, $\frac{1}{d} = \frac{1}{C_1P_1} - \frac{1}{C_2P_1} - \frac{1}{C_1P_2} + \frac{1}{C_2P_2}$

The four electrode array is commonly used, and among them, the Wenner's method (CPPC array) and the Schlumberger's method are prevailing in hydrogeological investigation. Taking the sounding depth into consideration, which extended to more than 200 m depth, the vertical prospecting method with the Schlumberger's electrode arrangement was adopted for this project.

The results of the sounding were analyzed roughly in Pakistan and finally analyzed and interpretated in Japan.

Main equipments for the electric sounding were carried from Japan by the JICA study team and some materials were purchased in Pakistan. The equipments used in the work are listed below;

-	Geo-electric Sounder (McOHM, OYO)	1 set
-	Cables (300 m and 50 m)	4 sets
-	Electrode (Iron bars)	4 pcs
-	Measuring Tapes (100 m)	6 pcs
-	Electric Tester	1 set
-	Tools	1 set
-	Battery (12 V)	1 pcs

(2) Field Work

The geo-electric sounding stations were selected in the sites based on geomorphological reconnaissance survey. The numbers of station in each target area range from 4 (at Rawalpindi Cantonment area) to 15 points (at Islamabad area).

In the case of the master plan, usually the sounding stations were allocated along 1 or 2 km grid as the wideness of each sounding area. Although the most of sounding stations were set on the side of roads, some were settled on corn fields or rough when the road net was not suitable for the sounding grid.

At each station, the center peg was set at first to the adequate point to settle an observation base. The measuring tape, with marks of all electrode positions separating current electrodes (C-poles) from potential electrodes (P-poles), was spread symmetrically to the center peg. Then, the observation work for resistivity of each depth (= electrode interval) performed one by one, from 1 m to 200 m (or to 300 m when the sounding site has enough space to extend the sounding line).

The data obtained by the field work; apparent resistivity " ρa" (ohm-meter), were rearranged in the relation with the distance from center peg to the current electrode "AB/2", called as ρ-a curve. In the case of Schlumberger's method, the distance from the center point to the current electrode means the sounding depth simultaneously, so that the ρ-a curve means the relation of apparent resistivity and the sounding depth. The ρ-a curve obtained by the field work are shown by using 1 mark in Figure B-2-17 to Figure B-2-20.

The location of geo-electric sounding stations for each target area are shown in the location maps of geo-electric sounding as Figure B-2-12 and Figure B-2-13. The figures also show the location of existing tubewells and test holes which geological logs were referred for this study.

(3) Analysis and Interpretation

The arranged ρ-a curve were analyzed in the sites by Schlumberger's standard curve method. All data had been brought to Japan and the results of field analysis were checked by a curvefitting method using a computer.

The standard curve method is the most orthodox and simple analysis for the vertical resistivity prospecting. The analysis is done using a two-layer standard curves by Schlumberger and its supplemental curves by Ono (these are attached in Figuer B-2-15 and B-2-16. The ρ-a curve obtained is fitted with a certain curve on the standard curves to know the resistivities of the first and second layers, and the depth of the first layer from its match point (O_1 point). Then, the ρ-a curve is suited on the supplemental curves to know the allowance (or permissible range) of the match point shift. After that, the ρ-a curve; the next curve span exceeding from the first fitting curve, is fitted again with a certain curve on the standard curves adjusting the first match point on the allowance range gotten from the supplemental curves, to know the resistivity of the third layer from the second match point (O_2 point). Then, ρ-a curve is suited on the supplemental curve again to know the depth of the second layer and the allowance of the second match point. In these manner, the all ranges of the ρ-a curve shall be analyzed using the standard curves and the supplemental curves alternatively.

The curve fitting method using computer is a kind of try and error approach to analyze the ρ-a curve. When the depth and resistivities of each layer consisting the ground were known, the resistivities which should be obtained on the ground surface can be calculated theoretically by computer. In the method, at first, one supposed structure model (depths and resistivities) is put-in and the theoretical ρ-a curve according to the model shall be gained. If the calculated ρ-a curve is not fit to the original ρ-a curve,

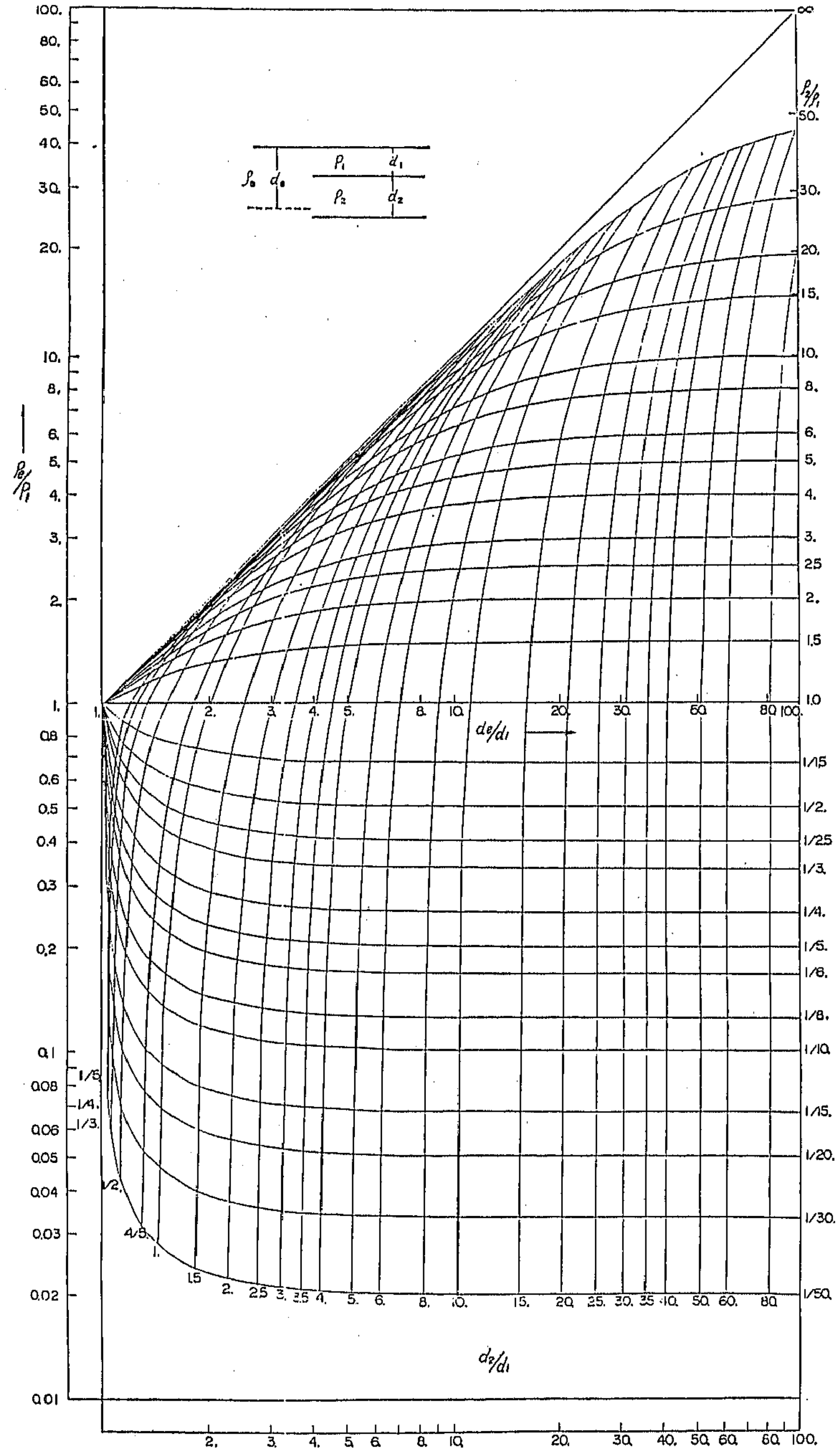


Figure B-2-15. The Supplemental Curves by Ono

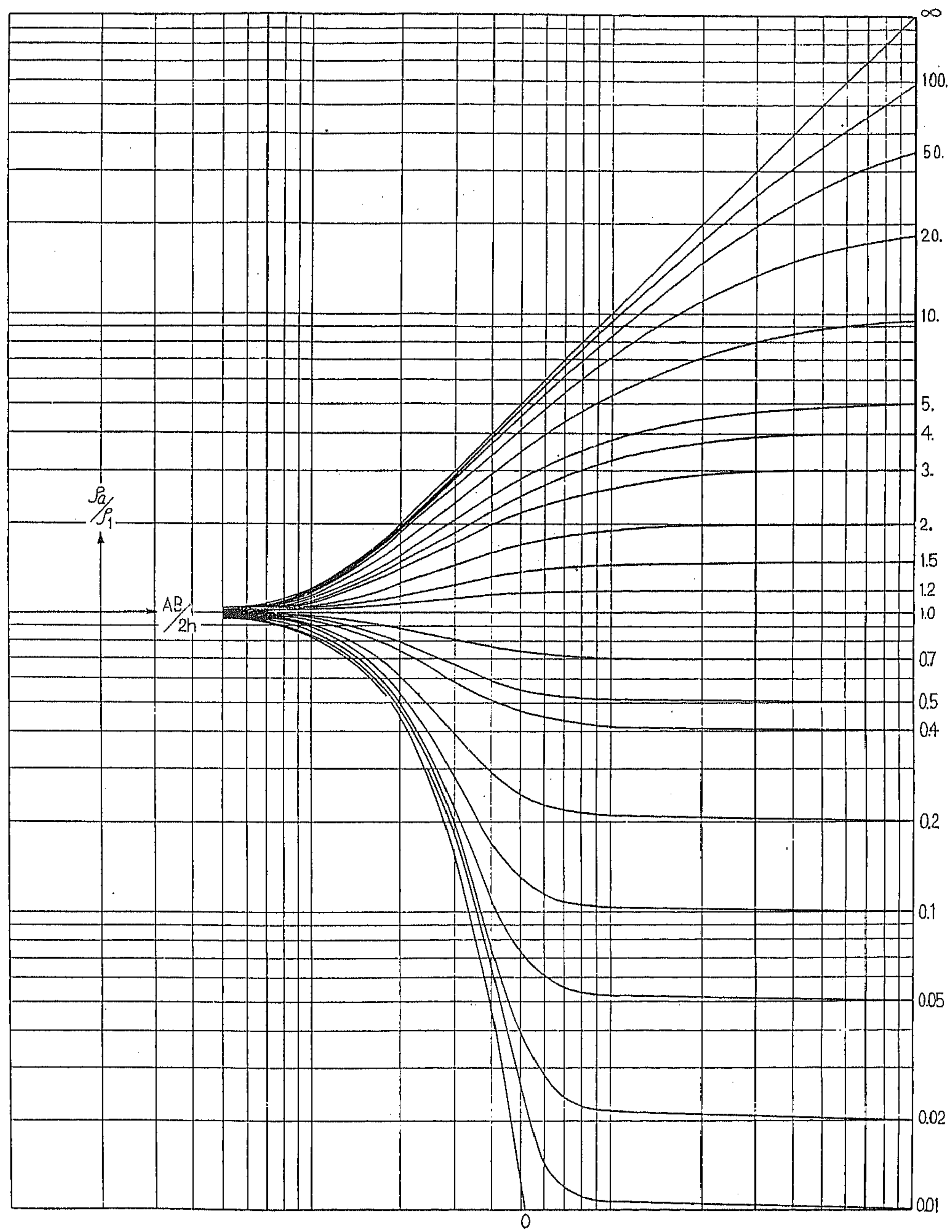


Figure B-2-16. The Two-layer Standard Curves by Schlumberger

WAH-TAXILA area

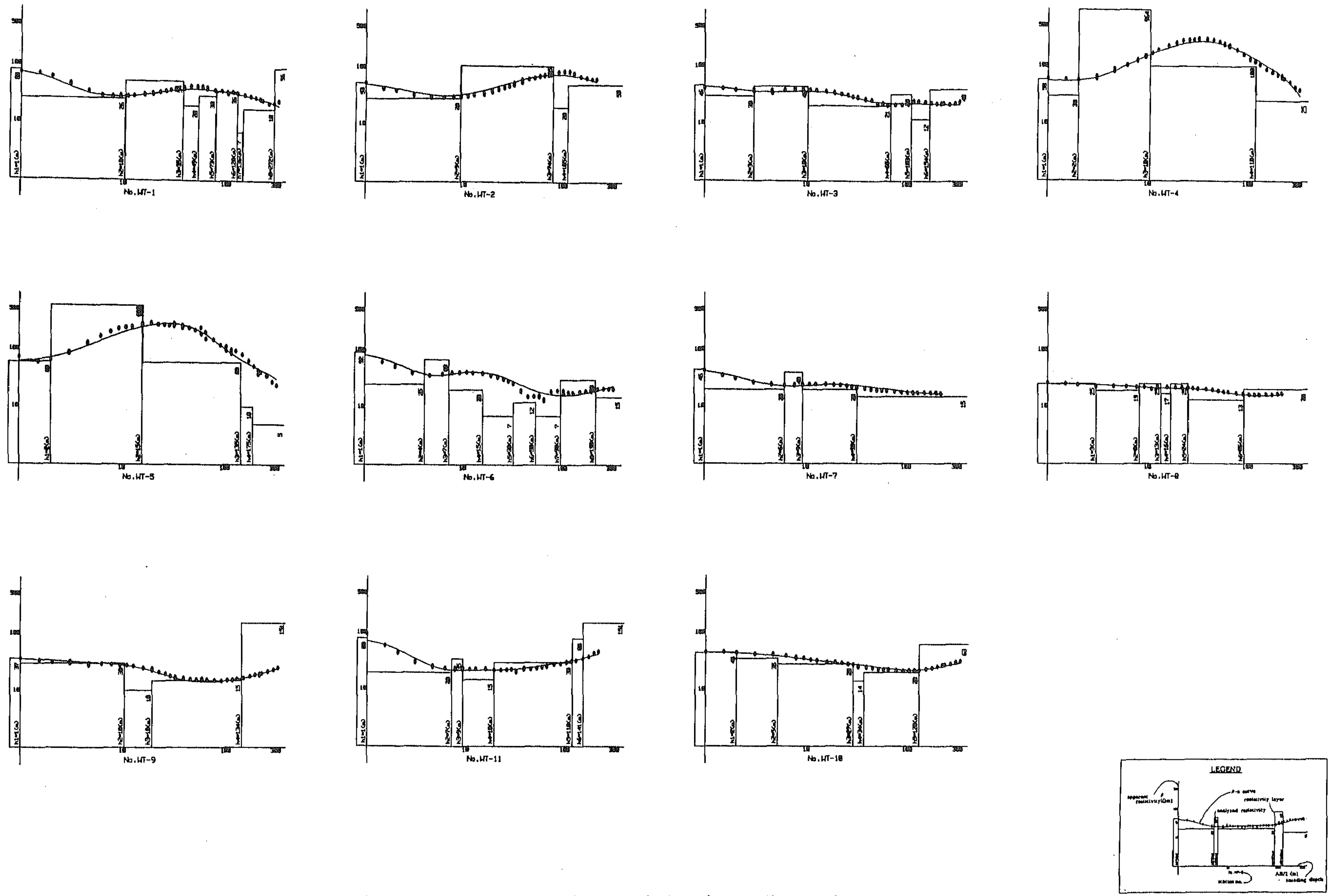


Figure B-2-17. ρ-a Curves (Result of Electric Soundings - 1)

ISLAMABAD area

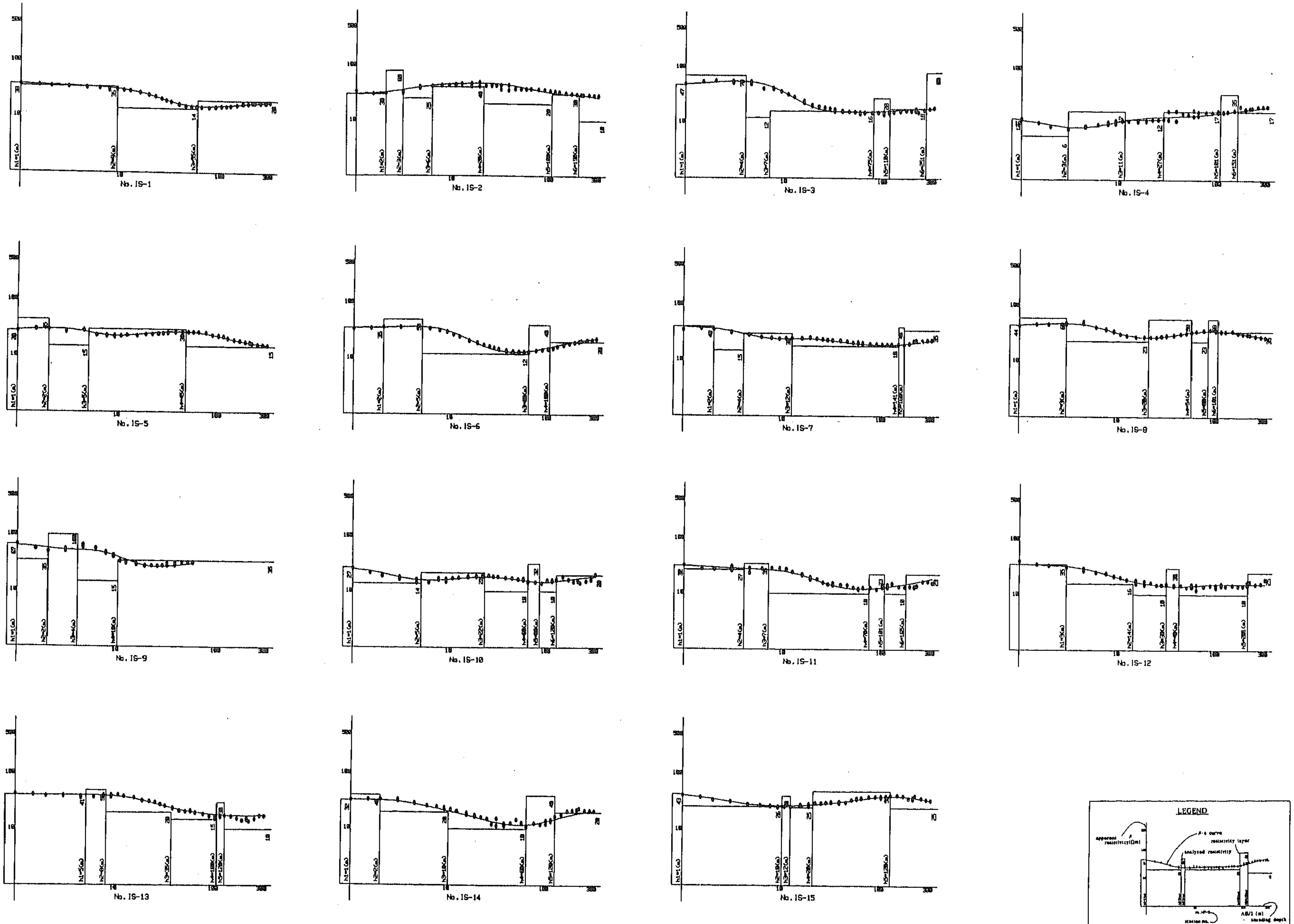
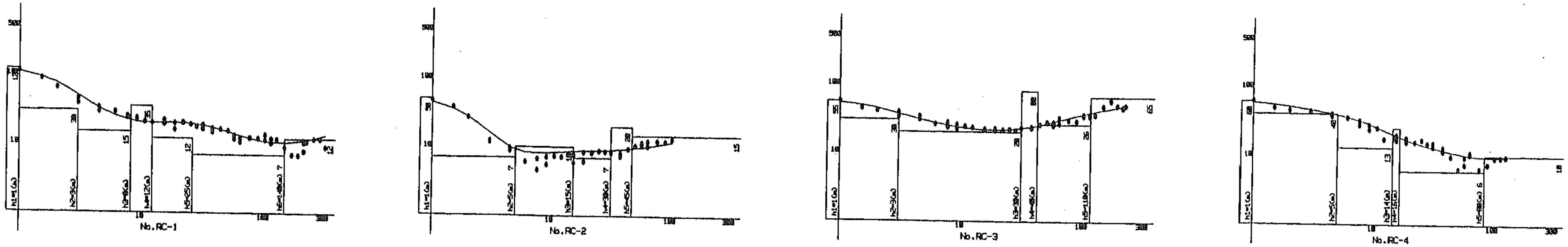
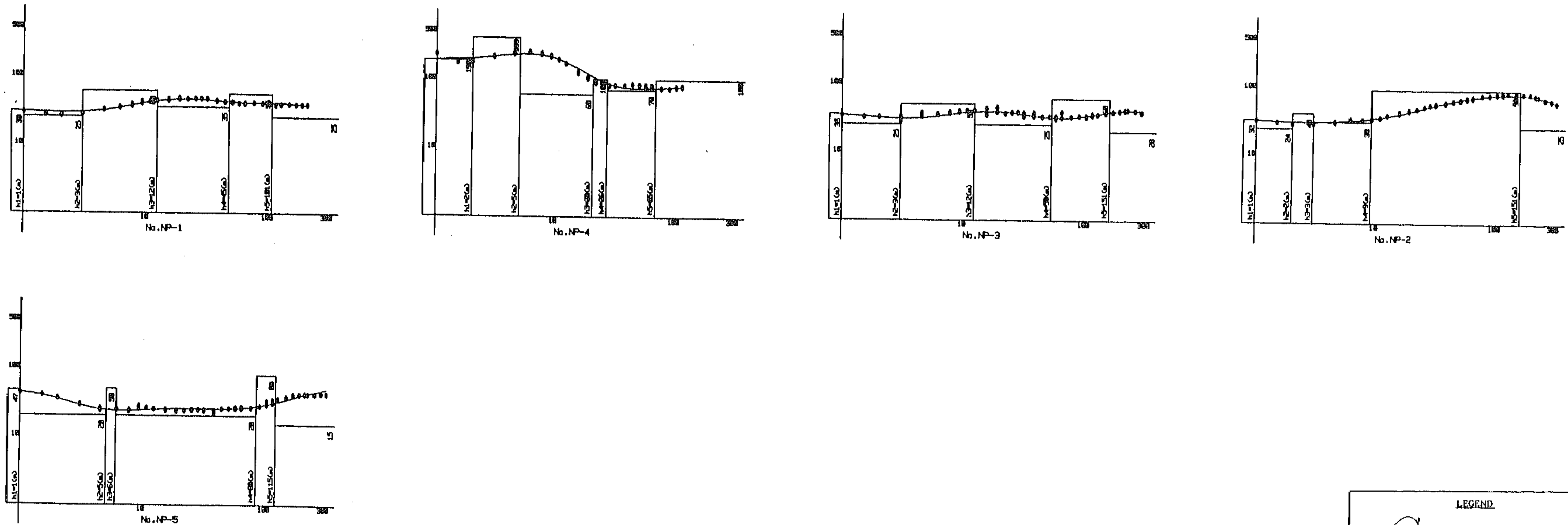


Figure B-2-18. ρ-a Curves (Result of Electric Soundings - 2)

RAWALPINDI CANTONMENT area



NATIONAL PARK area



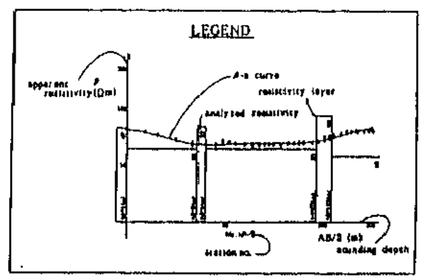


Figure B-2-19. ρ-a Curves (Result of Electric Soundings - 3)

RAWALPINDI RURAL area

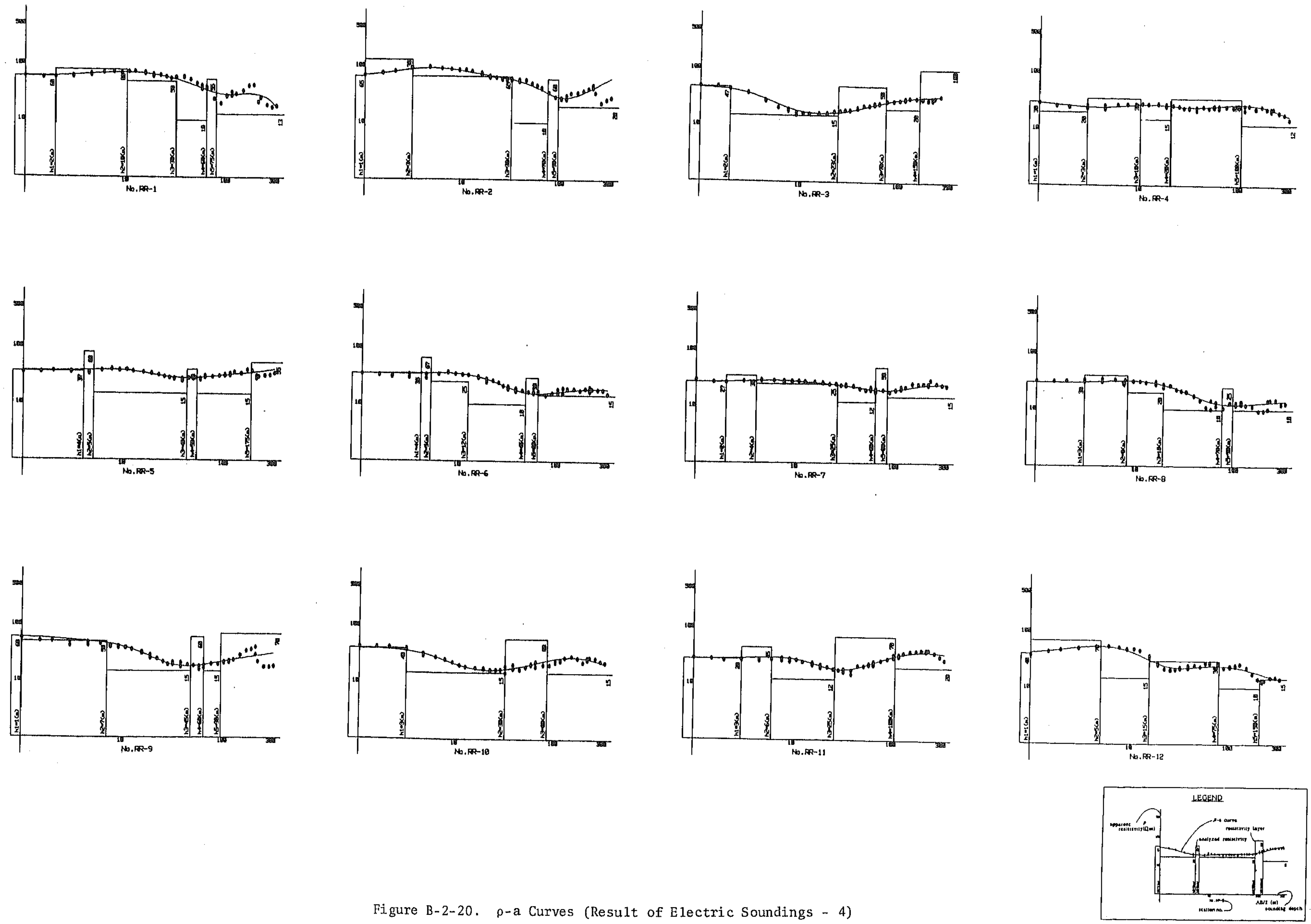


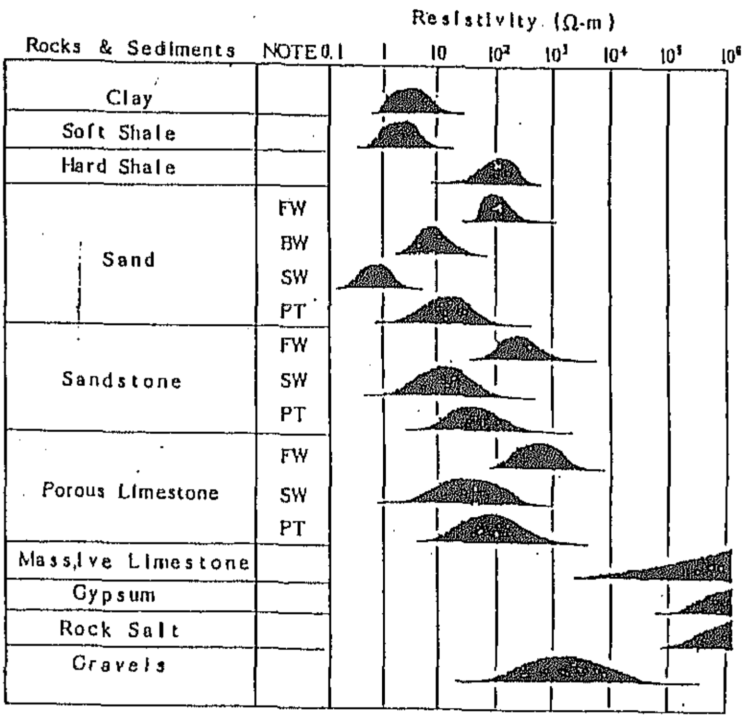
Figure B-2-20. ρ-a Curves (Result of Electric Soundings - 4)

the model shall be calculated again. Like this manner, the calculation of theoretical ρ-a curve shall be repeated until the curve shall fit to the original curve obtained by the field work within tolerable errors. The analyzing method is the one of the recent way to analyze the geo-electric prospecting, however, it has basical limitation that it hardly can analyze adelicate or fine structures and it can not fit up to the original curve when the ground is not homogeneous or not horizontally formed.

In this work, the result of electric sounding were analyzed mainly by the standard curves method, and totally checked by the curve fitting method to confirm a real resistivity and general structure. The results of curve fitting method are attached in Figure B-2-17 to Figure B-2-20 as out-put of the computer.

Generally, the resistivity ranges of some rocks and sediments are shown in Figure B-2-21.

Figure B-2-21. Resistivity of Rocks & Sediments



NOTE FW: fresh water
BW: brackish water
SW: salt water
PT: petroleum

In this project, the evaluated resistivity values have been interpreted as four electrical layers. As compared with the sub-surface materials which have been described in the geological log of the actual tubewells and test holes, these layers have been correlated as follows.

Low resistivity layer ----- Mainly clay or silt
($\rho < 30\ \Omega\cdot m$)

Medium resistivity layer ----- Clay or silt with gravels and sand
($30\ \Omega\cdot m \leq \rho < 50\ \Omega\cdot m$)

Medium to high resistivity layer --- Sand with gravels
($50\ \Omega\cdot m \leq \rho < 100\ \Omega\cdot m$)

High resistivity layer ------ Gravels, boulders with sand
($100\ \Omega\cdot m \leq \rho$)

Generally, an excellent aquifer consists of sand and gravels. So, the medium to high resistivity layer and the high resistivity layer are identified with the aquifer. As the result of analyzing the layers with high resistivity range are shown as gravels and sand, the layers with a low resistivity range are shown as clay and silt in the geological profiles (Figure B-2-22 to Figure B-2-25). The figures show the geological structure of the aquifer simultaneously. These conditions are explained briefly as follows;

a. Wah-Taxila Area

Concerning to the distribution of the analyzed resistivity layer, this area is separated into two characteristic area. One is the northeast area of the Wah Cantonment and another is the south and southwest area including the Wah Cantonment.

In the northeast area of the Wah Cantonment, which is between the Haro river and the Dhamrah Kas, high apparent resistivity values were obtained in the field. As the result of analyzing, the high resistivity layers were distributed at the 10 m to 35 m depth in WT-1, at the 9 m to 74 m depth in WT-2, at the 2 m to 110 m depth in WT-4 and at the 2 m to 135 m depth in WT-5. Depending the geological logs of existing tubewells and test holes, these high resistivity layers were identified the aquifer consisting of gravels and boulders. This aquifer extends in the direction of WT-2 station from WT-5 station (NW-SE) inferring from its distribution. This inferred extension of aquifers are endorsed by the existence of much tubewells in this zone.

In the Wah Cantonment and the south or southwest area of there, the low resistivity values about 10 Ω·m to 30 Ω·m were obtained and the excellent aquifer has not been identified. Therefore, the useful tubewell has been hardly existed in these area. But in the westward area from Wah Cantonment, the Kala Kas basin and the Jabi Kas basin, medium resistivity values about 40 Ω·m were obtained (at p-24, WT-3). This existence of the medium resistivity layer inferes the excellent aquifer which are extended from the southward of Taxila where the gravel layers have distributed in as the aquifer for tubewells at Taxila Cantonment.

b. Islamabad Area

In this area, low resistivity values about 10 to 50 Ω·m have been obtained at each sounding station, so that the low resistivity layers are distributed. The thin layers to consist of sand and gravels which are found in the existing tubewells and test holes are identified as interstratified layers with the medium resistivity layers at IS-2 station (6 m - 10 m, 100 m - 190 m), IS-4 station (100 m - 150 m) and IS-14 station (60 m - 120 m). These layers are inferred to be distributed as the interfingered layers with silty or clayey layer, so that the aquifer in the area is locally and discontinuously. It supported the undevelopment of the excellent aquifer that the existing tubewells in this area have low efficiency.

In the capital area, shale mainly underlies the alluvial as the bedrock. The resistivity of weathered shale are shows a similar resistivity range of clay. So, the top line of the bedrock can not be inferred by only the result of geo-electric sounding. In this project, the top line of the bedrock has been inferred to base on the geological reconnaissance survey for outcrops and the referential geological logs of tubewells and test holes. As the result of the interpretation for Islamabad area, the depth to the top of the bedrock is about 150 m at the central part of the basin.

c. National Park area

The medium to high resistivity layers which reisistivity values show more than 50 Ω·m are analyzed as the thick layers at each sounding station in the area. Above all at NP-2 station (9 m - 150 m) and NP-4 station (20 m - 26 m, 65 m - 108 m), the resistivity values are more than 90Ω·m. Depending on the geological logs of existing tubewells and test holes, the sand and gravels are generally distributed with the thickness of 20 m to 40 m in the area. Therefore, the excellent aquifers extend continuously in the area. It supports the development of the excellent aquifer that many tubewells with high efficiency exist in the southward part from the Rawal lake.

d. Rawalpindi Rural area

Although the resistivity values obtained in this area are generally low as less than 30 Ω·m, high resistivity layers are partly distributed in the part from the ground surface to the about 30 m depth in northern area of this target area (around RR-1, RR-2, RR-3 station) and the part of 50 m to 70 m depth at RR-1, 2, 7, 9, 10, 11 station. The high resistivity layer in the northern area is continuously toward the northeast and southwest, and also this layer extends to the northwest area out of the target area. The high resistivity layer in the deeper part is continuously in the southern area, but it becomes to be discontinuously and locally from central area to northern area. Although these resistivity layers are not identified definitely because of no geological data of tubewell and test hole, they can be inferred to consist of sand and gravels as compared with other target areas.

e. Rawalpindi Cantonment area

In this area, although the medium resistivity layer (20 - 40 Ω·m) are partly intercalated, the resistivity values generally show the low range less than 20 Ω·m. This area is located in the edge of the Rawalpindi Urban groundwater basin, so that it is inferred for silty and clayey materials to be distributed in this area.

(4) Estimation of the Potential Area

a. Capital area

According to the results of the geo-electric sounding, the right bank area of Kurang rive in the National Park area is the sole area where the high yield aquifers are supposed to be continuously distributed. In the other areas, promising aquifers might be seldom borne.

b. Wah and Taxila area

As the high permeable zones is inferred to distribute in the shallower portion along the assumed three groundwater flow channels, the potential of groundwater development might be high in these channels. In other areas, such a high yield aquifer may be rarely intercalated.

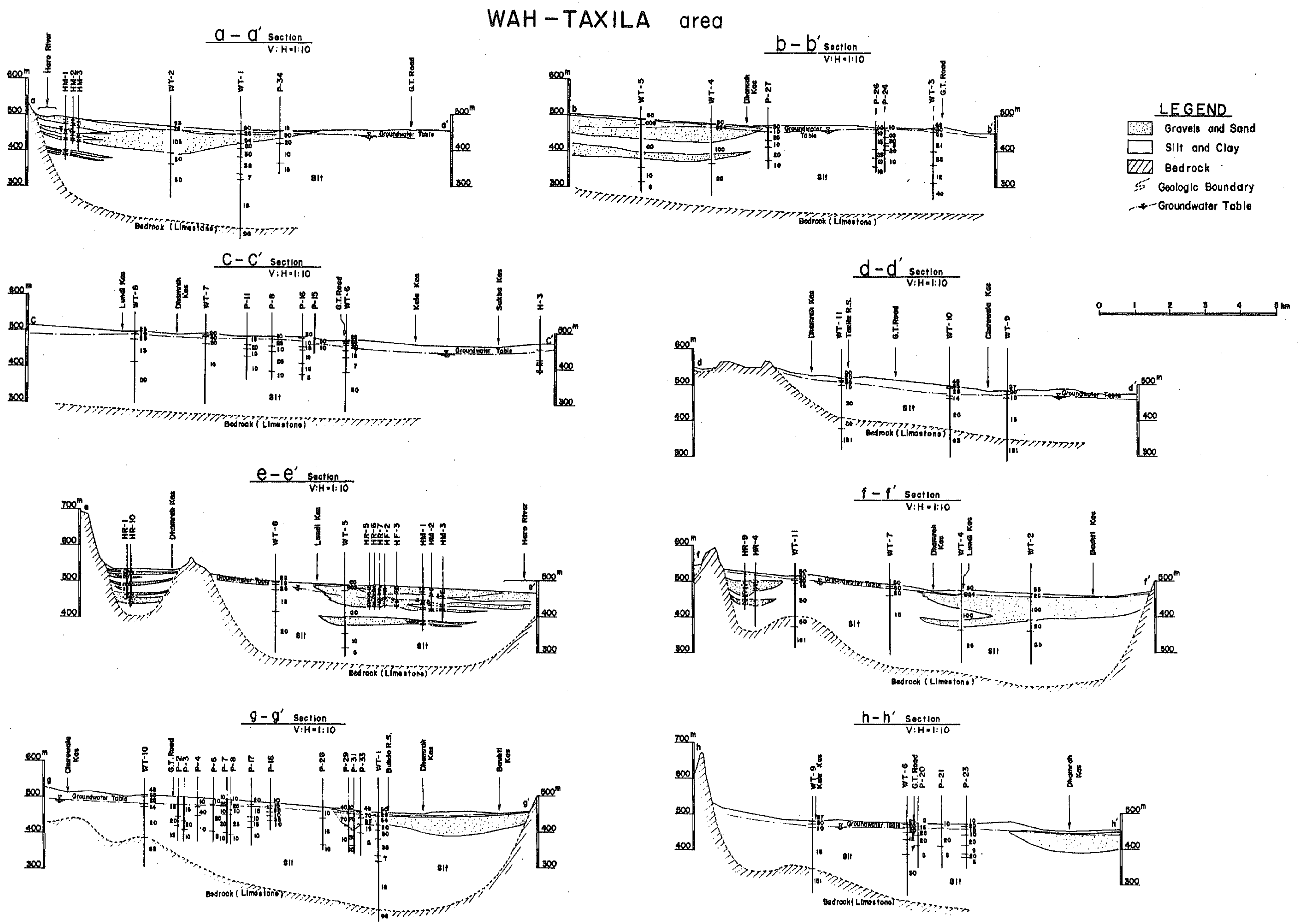


Figure B-2-22. The Geological Profile of Wah-Taxila Area

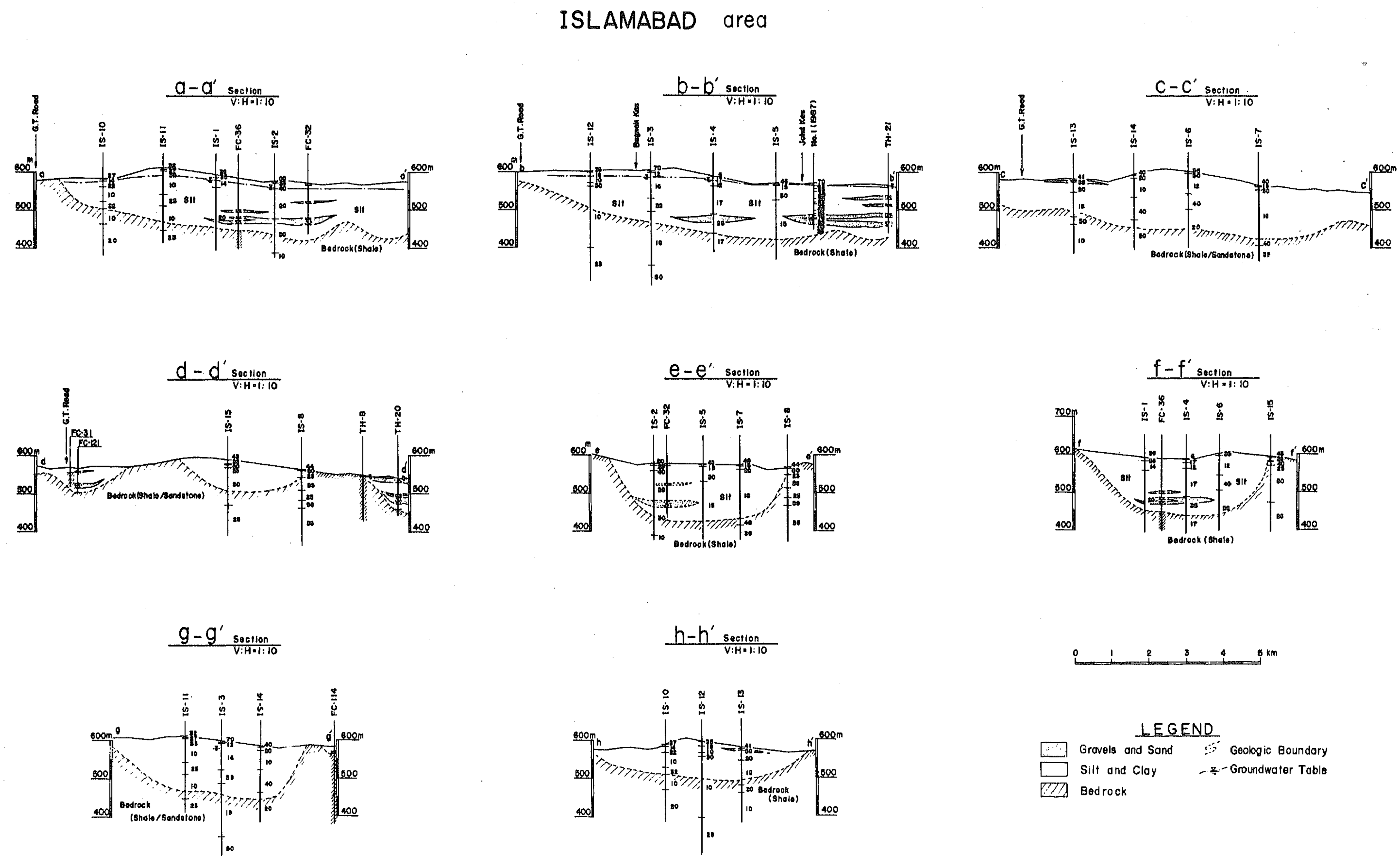


Figure B-2-23. The Geological Profile of Islamabad Area

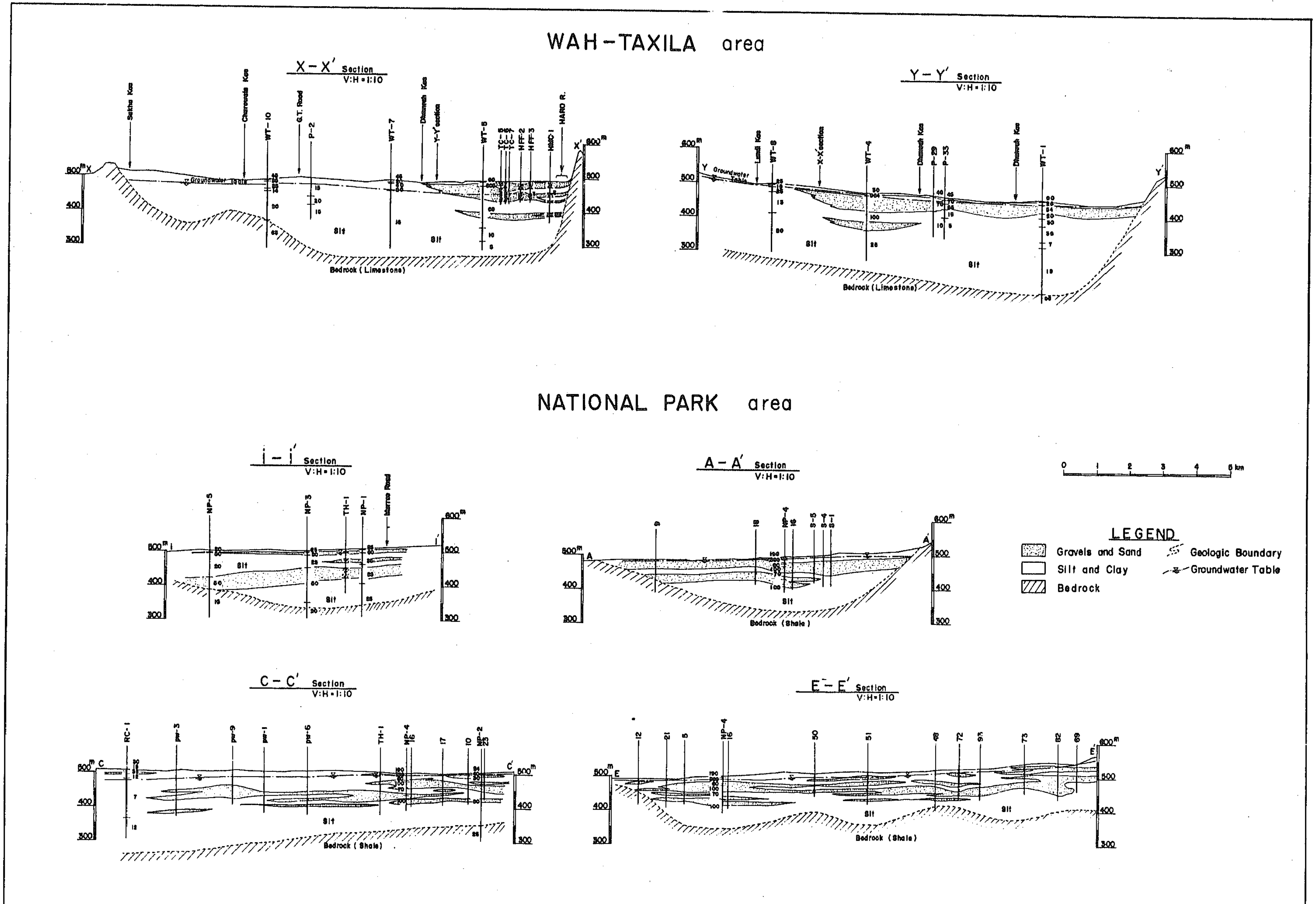


Figure B-2-24. The Geological Profile of National Park Area

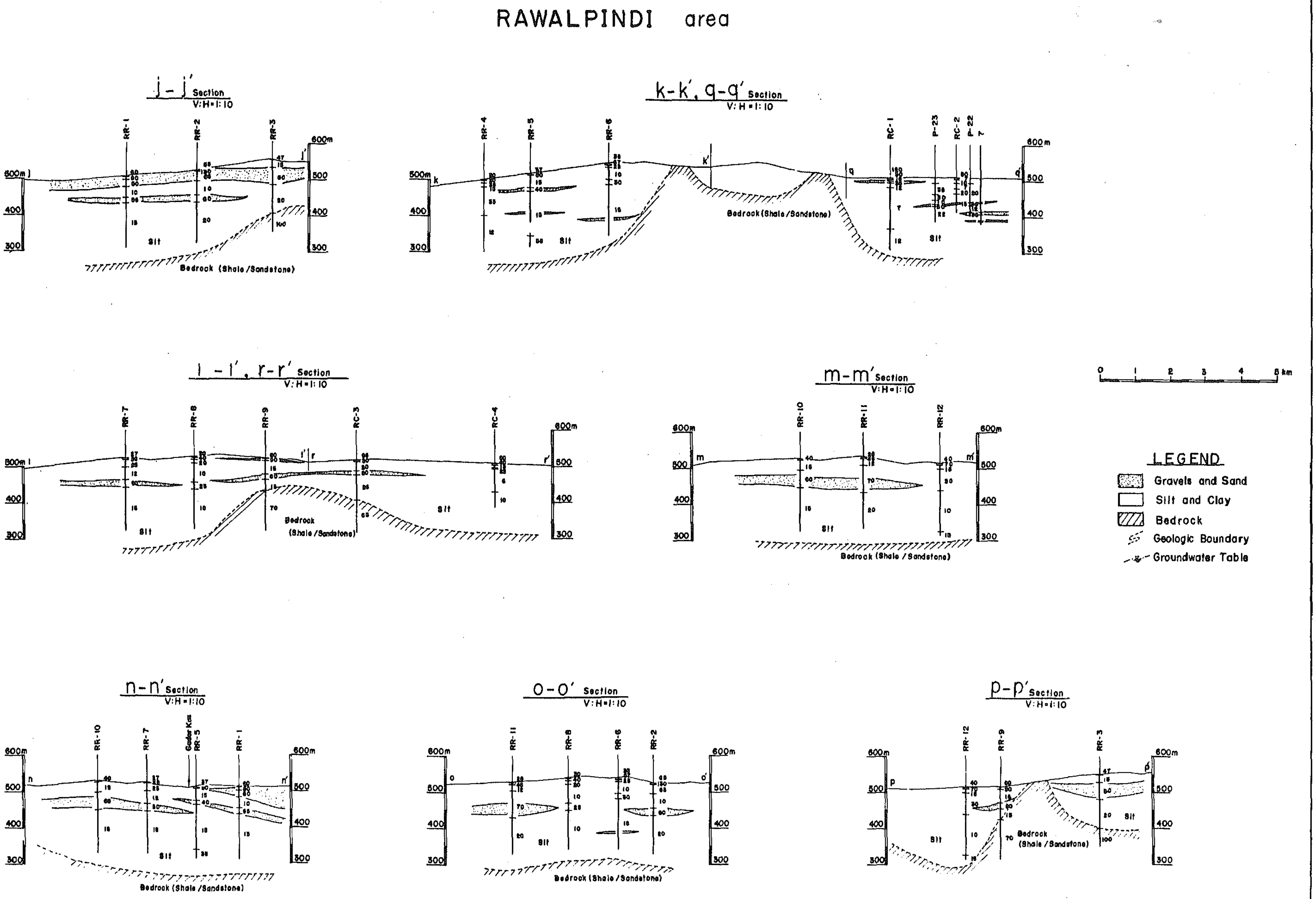


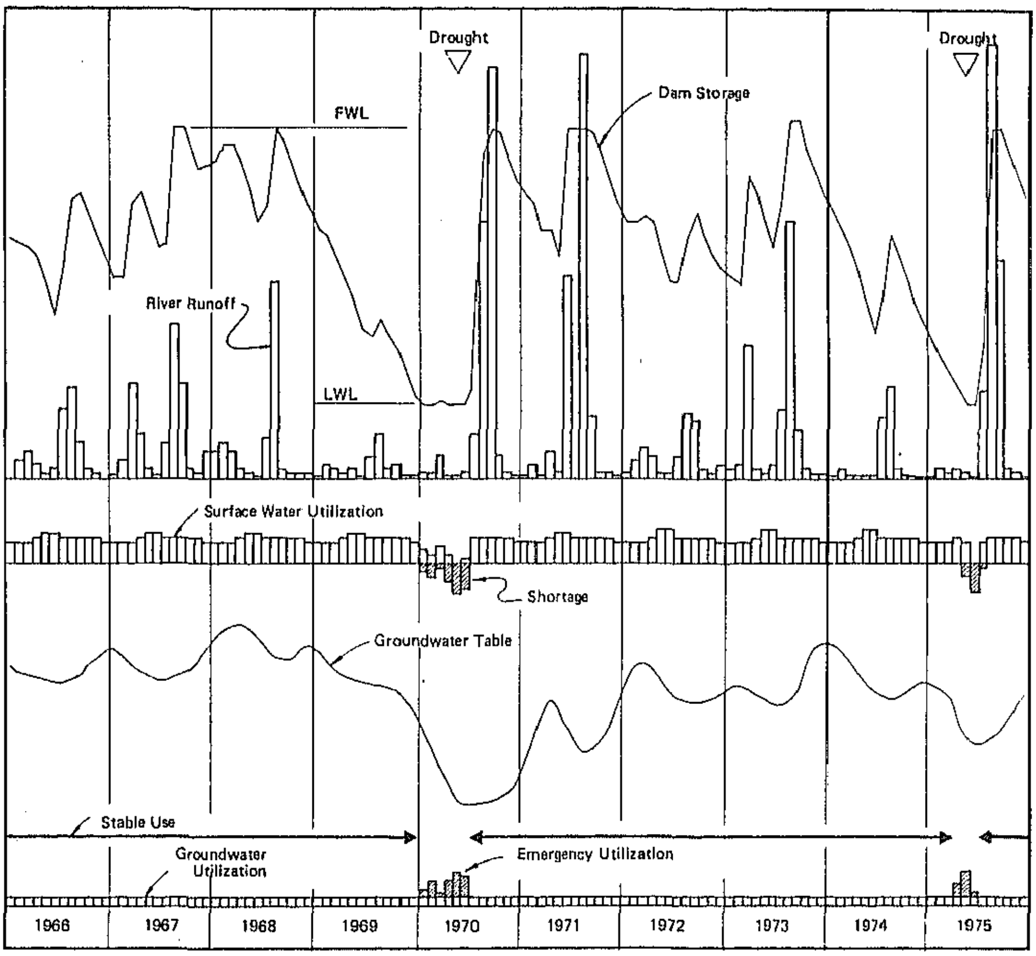
Figure B-2-25. The Geological Profile of Rawalpindi Area

B.2.4. Potentials for Groundwater Development

There are two conceptions for the groundwater development scheme. One is to use the groundwater under stable conditions over a years time. The other is to use only in the drought year.

For stable utilization, the discharge to be used in a year should be restricted to an amount within the annual amount recharged to the groundwater basins. Otherwise many detrimental effects including ground subsidence will arise.

For emergency utilization in the drought year, discharge may be permitted to exceed the annual recharge amount. The amount of utilization can be recharged in several years after the drought year. The schematic drawing indicating the concepts of the stable use and emergency use is shown below.



(1) Rainfall Infiltration

Rainfall infiltration to underground can be estimated based on the results of the hydrological analysis (tank model simulation) done in this study.

According to the hydrological analysis results, the infiltration rate of precipitation differs in the different surface geological condition as listed below.

	Infiltration rate (%)
i) Limestone Area	17.1
ii) Standstone and Shale area	11.6
iii) Alluvial Deposits Area	16.2

If the annual precipitation amount is given, the infiltration amount can be estimated using above figures. Thiesen polygons in Figure B-2-26 give precipitation data for the calculations.

The results of the calculations are shown in Table B-2-6 and B-2-7.

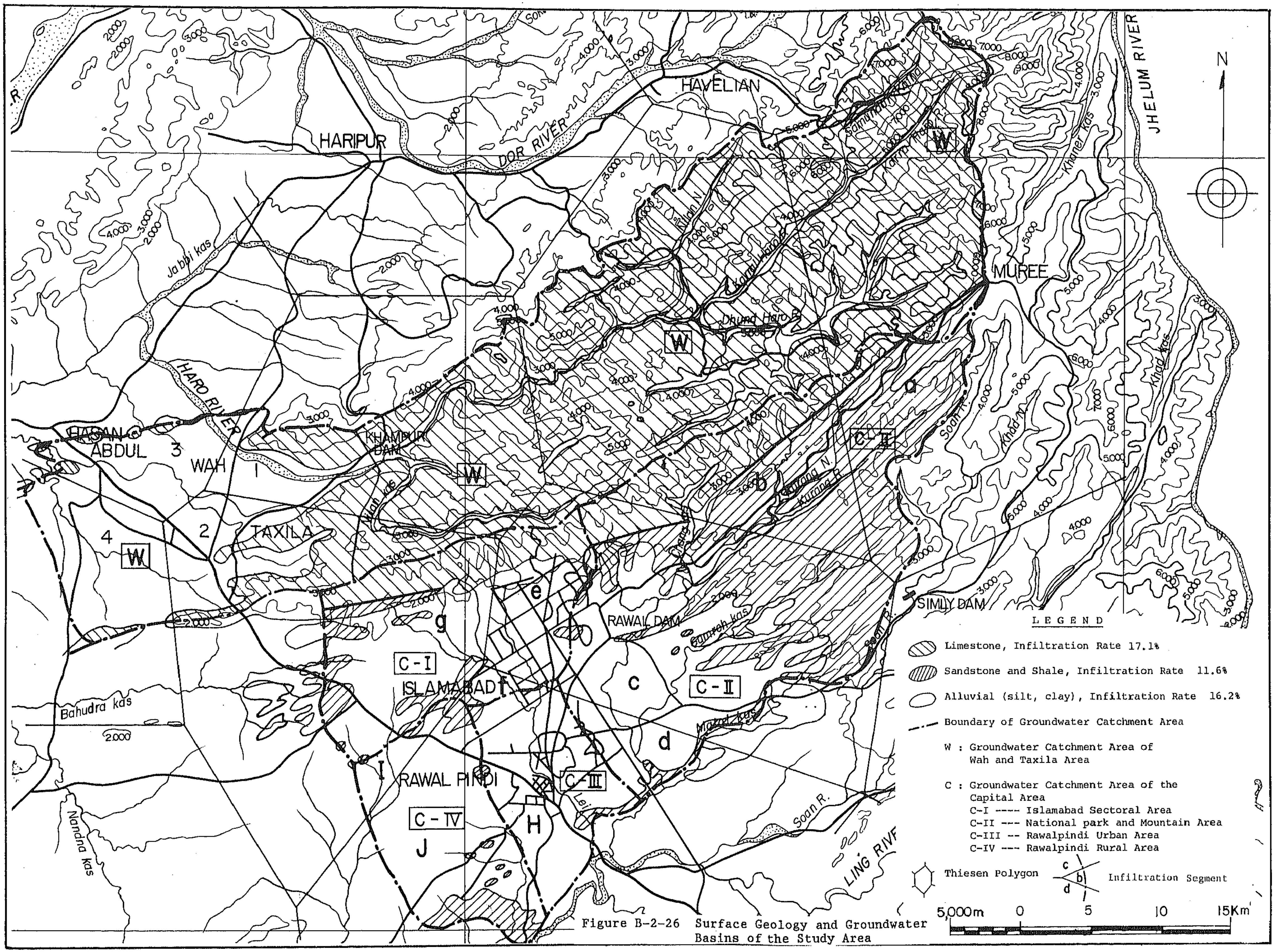


Figure B-2-26 Surface Geology and Groundwater Basins of the Study Area

Table B-2-6 Rainfall Infiltration of the Islamabad and Rawalpindi Catchment Area

Groundwater Basin	Segment	Annual Precipitation (m)		Limestone	Sandstone and Shale	Alluvial	Total
C - II	a	1.750	1) Area (km^2)	8	78	0	86km^2
			2) Infiltration (MCM/year)	2.4	15.8	0	18.2
	b	1.278	"	47	64	8	119
			"	10.3	9.5	1.7	21.5
	c	1.174	"	18	164	82	264
			"	3.6	22.3	15.6	41.5
	d	1.086	"	0	2	30	32
			"	0	0.3	5.3	5.6
						Sub Total	86.8MCM/year
C - I	e	1.174	"	18	2	48	68
			"	3.6	0.3	9.1	13.0
	f	1.086	"	0	1	7	8
			"	0	0.1	1.2	1.3
	g	1.036	"	33	16	86	135
			"	5.8	1.9	14.4	22.1
						Sub Total	36.4MCM/year
C - III	h	1.086	"	0	7	89	96
			"	0	0.9	15.7	16.6
C - IV	i	1.036	"	0	3	14	17
			"	0	0.4	2.3	2.7
	j	1.086	"	0	16	101	117
			"	0	2.0	17.8	19.8
						Sub Total	22.5MCM/year
	Total	—	"	124	353	465	942 Km^2
			"	25.7	53.5	83.1	162.3MCM/year

Table B-2-7 Rainfall Infiltration of the Wah and Taxila Catchment Area

Segment	Annual Precipitation (m)		Limestone	Alluvial	Total
1	1.064	1) Area(Km^2)	21	32	53
		2) Infiltration (MCM/year)	3.8	5.5	9.3
2	1.036	"	33	55	88
		"	5.8	9.2	15.0
3	0.699	"	6	54	60
		"	0.7	6.1	6.8
4	0.759	"	6	92	98
		"	0.7	11.4	12.1
Upstream of Khapur Station, W	1.318	"	778	0	778
		"	175.3	0	175.3
Total	—	"	844	233	1,077
		"	186.3	32.2	218.5

(2) Potentials of Groundwater Development in Islamabad and Rawalpindi Area

(a) Stable Utilization

Based on the results of the hydrological analysis, the amount of infiltration into the catchment area of the three eastern groundwater basins reaches 140 MCM/year. Part of the infiltration will seep away into the bedrock and other basins. That which remains will recharge, or flow into these three groundwater basins as recharge.

It is impossible to estimate the amount recharged to the basins without information concerning the seepage into the bedrock and other basins. Long-term fluctuation data on the groundwater table can also give important suggestions for estimating the recharge amount to the basins. As such information is not yet available, an accurate estimation of the stable development amount is impossible.

Meanwhile, current measurements make it clear that about 30 MCM/year of groundwater is flowing into the Kurang river in the National Park groundwater basin. This effluent flow can be regarded as surplus water overflowing from this groundwater basin and an abstraction of the effluent amount will not affect other groundwater basin. Full exploitation of the effluent amount, however, will cause considerable decrease in the runoff of the Kurang river. Therefore the amount exploited will be restricted to 50% of the effluent amount. In this case, 15 MCM/year can be exploited in the National Park groundwater basin. Because the existence of thick and continuous high yield aquifers is groundwater can be effectively developed.

The groundwater basin in the Rawalpindi rural area is separated from other groundwater basins and has no groundwater inflow from them. Groundwater has hardly been exploited in this basin. The infiltration amount from the precipitation in the catchment area is assumed to be around 22 MCM/year, based on hydrological analysis.

Because the infiltration mainly takes place on the surface of the groundwater basin, a large part of the infiltration is considered to be flowing in the groundwater basin with little seepage to the bedrock and other basins. For these reasons, the total recharge amount can be fully exploited.

On the other hand, the strata in this basin are assumed to be abundant in finer materials, making it impossible to successfully exploit any more than 50% of the total recharge amount. 50% of the annual recharge amount in the Rawalpindi Rural area is some 11 MCM/year.

As mentioned above, groundwater of 26 MCM/year might be developed at the least in the capital area including the Rawalpindi rural area. But the actual potential for groundwater development should be assessed based on further studies. Such studies would include the measurement of long-term groundwater table fluctuations and so on.

(b) Emergency Utilization

The groundwater basins in the capital area have enormous capacities and the reserved groundwater is up to 3 billion tons total.

Dropping the entire groundwater table by 10 m, 140 MCM of water could be gained, assuming that the effective porosity of the deposits is 10%.

Therefore, it is the conclusion of this report that sufficient water resources have been preserved in the capital area against a severe drought year.

For emergency groundwater utilization, a total scheme combining the groundwater and surface water should be employed.

(2) Potentials of Groundwater Development in Wah and Taxila Area

(a) Stable Utilization

According to the hydrological analysis the amount for the entire catchment area which infiltrates to the subsurface is assumed to be around 210 MCM/year and a large amount of the infiltration flows into the groundwater basin as recharge. Hydrological analysis suggests that the effluent flow to the rivers was 160 MCM/year during the period from 1961 to 1965. This means that some 80% of the annual amount of groundwater recharged was flowing out to the other basins in the form of surface runoff. It can be that this phenomenon is due to the special hydrogeological structure that the groundwater is dammed up by the upervious ridges.

The assumed present groundwater balance is shown next and it takes into account well discharges form the Khanpur dam reservoir.

Rainfall Infiltration in Catchment Area (MCM/year)	Recharge from Khanpur Dam (MCM/year)	Discharge by Tubewells (MCM/year)	Effluent through Spring (MCM/year)	Leakage and Outflow (MCM/year)
210	20	21	160	49

As shown in above, the amount of effluent groundwater is 160 MCM/year and this figure is though to be almost coincident with the maximum value of groundwater development potential.

Because the surface runoff and the groundwater flow are closely related, groundwater abstraction of large quantities by tubewells will immediately cause the runoff in the rivers to decrease.

Accordingly, there are two methods by which to develop groundwater in this area. One would be to exploit the groundwater in the groundwater basin as groundwater. The second would be to develop the surface water in the northern part of the groundwater basin which had its origin in the groundwater.

When a groundwater development scheme is established in this area it should take account of O/M cost, the conditions of the beneficiaries, water quality and so on.

(b) Emergency Utilization

The amount of groundwater reserved in the Wah and Taxila groundwater basin is estimated to be around 3 billion tons. If the entire groundwater table in the basin is dropped 10 m by discarding, the water discharged is calculated to be around 140 MCM on the assumption that the effective porosity is 10%.

If the discharging area is set 5 km apart from the springs in order to prevent them from being effected by the drawdown, about 10 MCM may be exploited with a 10 m drawdown.

As mentioned above, it is the consideration of this report that there are enough water resources available in this area to meet the drought year. For emergency groundwater utilization the total water resources development plan recommended in the capital area should be considered for this area too.

B.2.5. Further Investigation

The groundwater investigations performed in this study only delineate an outline of the hydrogeological conditions of the study area. It has not been made clear in this study that even the present groundwater abstraction amount is optimum or not because of the lack of data. For the reasons mentioned above, further studies should proceed for more accurate estimation of the area's groundwater development potential based on more detiled and reliable data. Such data would include long-term hydrographs of the groundwater tables.

The groundwater investigations performed in this study only delineate an outline of the hydrogeological conditions of the study area. Further studies should proceed for more accurate estimation of the area's groundwater development potential based on more detailed and reliable data. Such data would include long-term hydrographs of the groundwater tables.

With proceeding of the studies, the totalized water resources development schemes can be established for the rational water controls on both of groundwater and surface water.

The Landsat imagery techniques is the one of the effective method for groundwater investigation. Nevertheless it is judged that the landsat data is unsufficient in this study because the Landsat imagery techniques contribute for the groundwater investigation in the vast and undeveloped area such as desert and would not be so helpful to the high developed areas such as the study area where many and detailed data can be available. As for the detailed discussions for the effectiveness of the landsat imagery data, refer to the supplement B-1 attached at the end of APPENDIX B.

Other investigation for which further study is necessary is listed below:

(a) Investigations for the Aquifer

1. Simultaneous well observation covering the entire study area (twice a year, using the existing wells).

2. Study of the aquifer with drilling surveys and geo-electric soundings.

3. Study of permeability and storage coefficient of the aquifers with aquifer tests.

4. Chemical analysis of groundwater.

(b) Investigation for the Groundwater Flow

1. Long-term observation of groundwater table (observation wells and existing wells)

2. Observation of precipitation.

3. Current measurement of the rivers.

4. Precise measurement of discharge amount of groundwater.

5. Assumption of recharge amount of groundwater.

6. Study of groundwater balance.

(c) Planning of the Groundwater Utilization

1. Prospect of groundwater balance of the each groundwater basin.

2. Consideration of the possibility of urgent groundwater utilization for the each groundwater basin.

3. Comparison and examination of the measures for water shortage of the rivers.

4. Planning of groundwater utilization.

B.3. Geology of Planned Facility Sites

B.3.1. Geology of Damsite

Six damsites have been selected as proposed damsites for this study. The topographical and geological features of the selected damsites are described in following. Their locations are shown in Figure B-3-1. Their geological cross sections are shown in Figure B-3-2.

(1) Damsite D-1

a. Topography

The Dor river abruptly narrows just upstream of damsite D-1, forming a gorge. The width of the gorge is about 20 m and steep bluffs around 10 m in height are distributed on both flanks. The terrace spreads out widely on both flanks.

b. Geology

The geology of damsite D-1 is comprised of upper unconsolidated terrace deposits and lower consolidated terrace deposits. Although bedrock mountains are distributed on both flanks, they are far away from the Dor river.

The unconsolidated terrace deposits are composed of unconsolidated silt, sand and gravel about 30 m thick. They are generally loose and it is supposed that their permeability is 10^{-2} to 10^{-3} cm/sec in magnitude.

The consolidated terrace deposits are composed of almost the same components as the unconsolidated. The

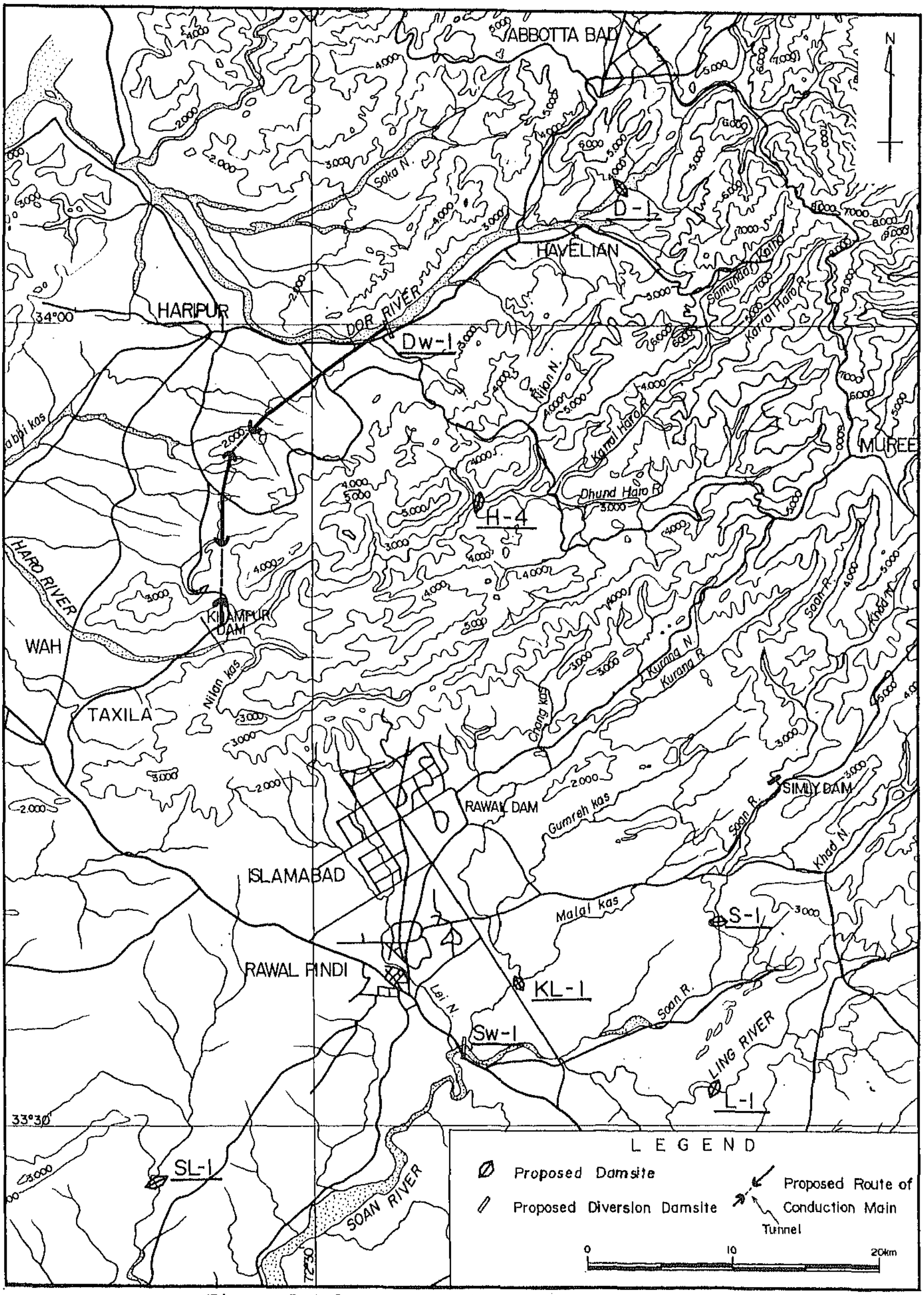
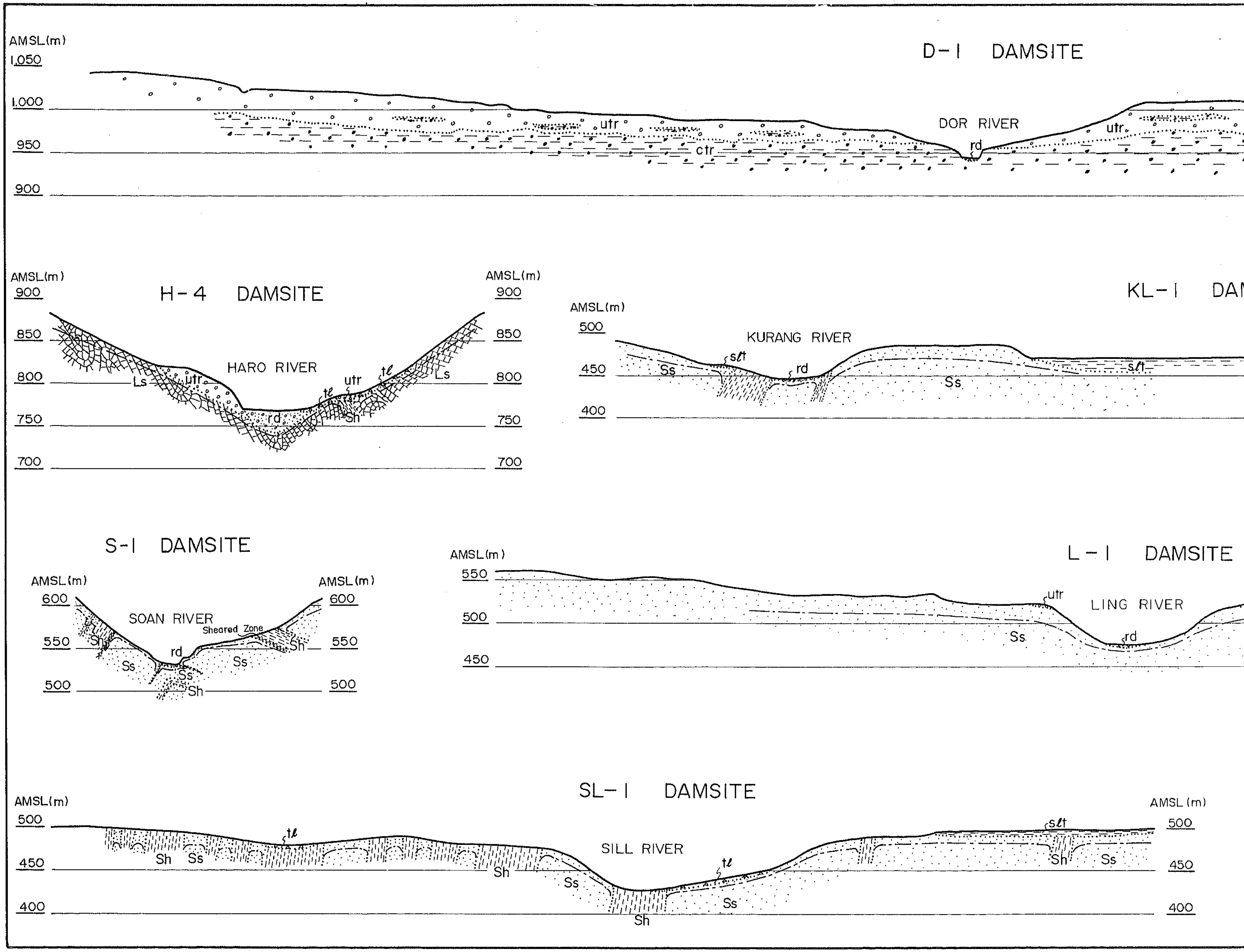


Figure B-3-1 Location Map of Planned Facilities



D-I DAMSITE
AMSL(m)
1,050
1,000
950
900
DOR RIVER
utr
ctr
rd
H-4 DAMSITE
AMSL(m)
900
850
800
750
700
HARO RIVER
Ls
utr
rd
tl
Sh
KL-I DA
AMSL(m)
500
450
400
KURANG RIVER
slt
rd
Ss
S-I DAMSITE
AMSL(m)
600
550
500
SOAN RIVER
Sheared Zone
Sh
Ss
rd
L-I DAMSITE
AMSL(m)
550
500
450
LING RIVER
utr
rd
Ss
SL-I DAMSITE
AMSL(m)
500
450
400
SILL RIVER
tl
slt
Sh
Ss

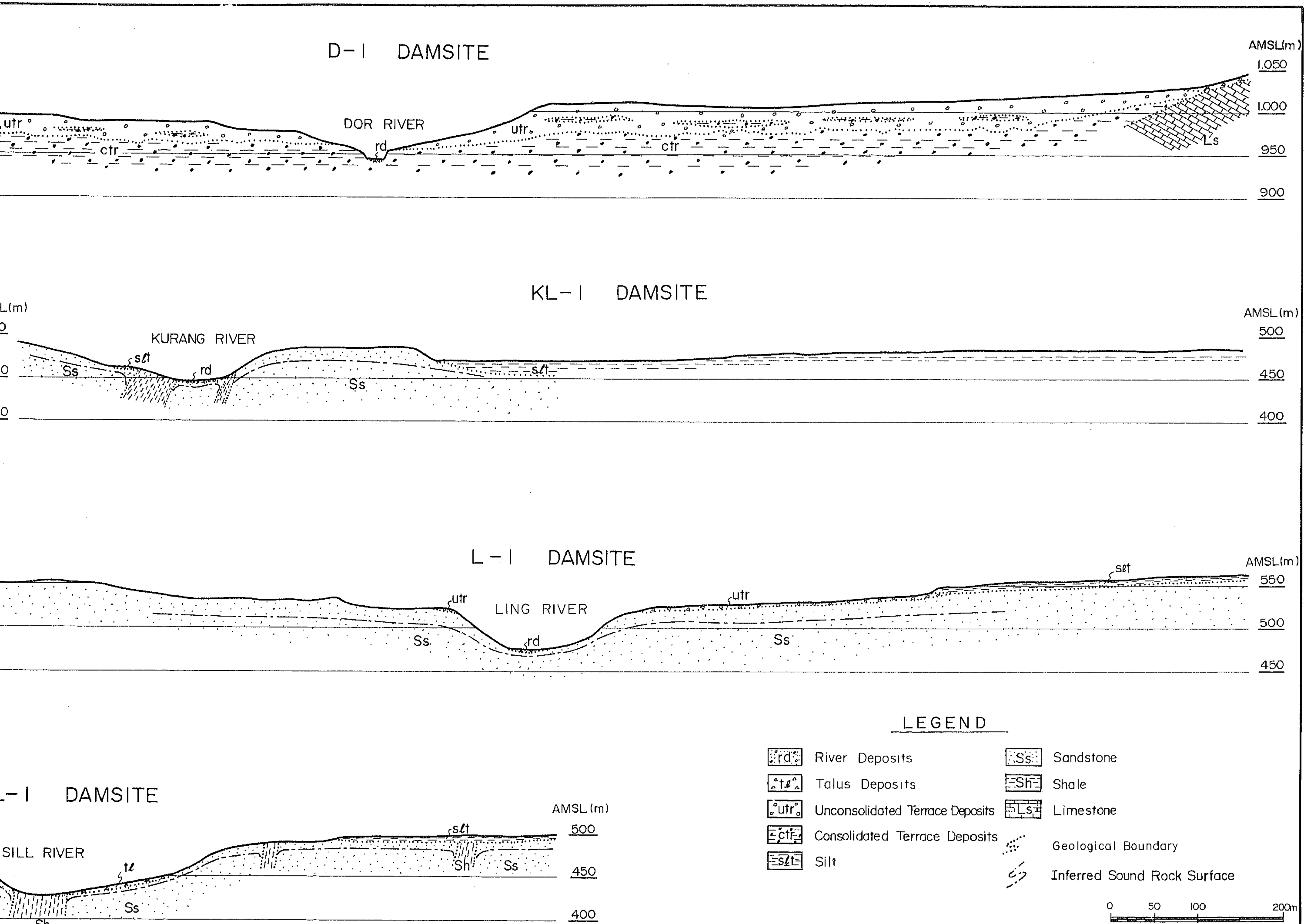


Figure B-3-2 Geological Sections of Proposed Damsites

consolidated terrace deposits are highly cemented with $CaCO_3$ deposition. They are generally overlain with unconsolidated deposits. The consolidated terrace deposits seem too strong to be bedrock. Their permeability is assumed to be considerably lower than that of the unconsolidated.

However, the boundary between consolidated and unconsolidated deposits is ambiguous and many of the consolidated layers are intercalated in the unconsolidated terrace deposits and vice versa.

(2) Damsite H-4

a. Topography

Damsite H-4 is situated in the upper reaches of the Haro river, flowing through the mountains. Damsite H-4 is surrounded by very steep, high mountains.

The river width at damsite H-4 is 70 m and steep slopes of 30° to 40° inclinations appear up and down both flanks.

A terrace of 100 m in width is located on the left bank at a height of 50 from the riverbed.

b. Geology

The bedrock in this damsite is composed of limestone. The limestone is highly folded but no large scaled faults have been detected. Highly sheared shale is vertically distributed on the lower part of the right bank. Its thickness is 10 to 15 m. The limestone outcrops are not fresh and have many cavities. The permeability of the bedrock is therefore supposed to be very high.

The terrace deposits on the left bank are composed of compact sand and gravel layers of an assumed thickness of 20 to 30 m.

River deposits of loose sand and gravel have accumulated thickly along the course of the river. Their thickness reaches up to 30 m.

(3) Damsite KL-1

a. Topography

Damsite KL-1 is situated about 500 m downstream of the confluence of the Kurang river and Malal Ksss. As shown in Figure B-1-1, the area is a weathered bed rock plain spread with gentle rolling hills.

The width of the river is about 60 m. Kurang river cuts through the plain with a depth of around 40 m. A steep, 30° inclination slope has been formed on the right bank and a relatively gentle, 15° inclination slope is found up and down the left bank.

As the weathered bedrock plain has been highly dissected, both flanks are not even and many valleys have been cut perpendicular to the course of the river.

b. Geology

The bedrock of damsite KL-1 is composed of an alternation of sandstone and shale of Rawalpindi group. The bedrock is highly weathered and sheared having turned into very weak and crumbly rocks. The shale layers are especially highly sheared and show fault-like features composed of very weak red clay. Such highly sheared shale layers are widely distributed on the left bank slope.

The strike of the strate is parallel to the course of the river and dips to the left bank side to the south with an inclination of around 70°.

The river deposits are very thin and assumed to be less than 5 m in thickness. The silt layer overlays the bedrock in the northern park from the damsite (right bank side) and its thickness is assumed to be over 10m.

(4) Damsite S-1

a. Topography

As damsite S-1 is situated upstream on the Soan river, flowing across a mountain ridge in a weathered bedrock plain, the topography of the damsite is very narrow and steep.

The width of the river is about 20 m. The left bank slope is very steep and its inclination is about 40°. On the right bank a valley cuts into the slope from downstream to upstream, and a small terrace is located at a relative height of 10 m from the riverbed.

b. Geology

The geology of damsite S-1 comprises Rawalpindi group sandstone and shale. The sandstone is very hard and compact in the riverbed, but weathered and turning into crumbly rock on the slopes. A thick shale layer is intercalated in the mid to high elevations of both flanks. It is weak and highly sheared in parts.

Because an anticline runs along the course of the river, the dip of the layers differ on the right and left banks and they incline toward the mountain side.

The river deposits are very thin and assumed to be less than 3 m.

(5) Damsite L-1

a. Topography

Damsite L-1 is situated on the Ling river, running on the ridge and trough area as shown in Figure B-1-1.
The ridge and trough area is a rolling plain area with many bedrock ridges and troughs running in a ENE-WSW direction.

The Ling river cuts the plain deeply and bluffs of 40 m in height are formed on both flanks. The width of the river is about 30 m.

Because many valleys have dissected the plain perpendicular to the course of the river, many small and thin ridges protrude to the river.

b. Geology

The bedrock of damsite L-1 is composed of an alternation of sandstone and shale of Siwalik group. It is highly sheared and weathered and has turned into very crumbly sandstone and very weak shale showing fault-like features.

The single stratum thickness is about 5 to 30 m. The strike of the layers trends to the NNE-SSW direction, almost perpendicular to the course of the river. They incline towards upstream with a steep inclination of 80° to 90°.

An overburden comprised of gravel and silt layers thinly overlays the bedrock on the right bank plain. Its maximum thickness is assumed around 10 m. The thickness of river deposits is assumed to be less than 3 m.

(6) Damsite SL-1

a. Topography

Damsite SL-1 is situated in the middle course of the Sil river which flows across the mountain area, as shown in Figure B-1-1. However, as the mountains are low in relief, the topography in the vicinity of the damsite can be categorized as a ridge and trough area rather than a mountain area.

On the left bank ridges and troughs composed of bedrock run in an ENE-SWS direction with widths of around 1 km and they do not extend to the right bank.

An expansive dissected plain is found on the right bank and very small bedrock ridges are sporadically distributed.

The Sil river cuts across the plain at a depth of around 50 m, forming very steep bluffs on both flanks.

Because many small valleys are to be found in the vicinity of the damsite, the ridges on both flanks are very thin and small.

b. Geology

The bedrock of damsite SL-1 is composed of alternation of sandstone and shale of Siwalik group. Like that of damsite L-1 it is highly sheared and weathered.

A stratum thickness is 3 m to 10 m. The strike of the layers tends to be in an ENE-WSW direction almost perpendicular to the course of the river. They dip toward the downstream with an inclination of 70° to 90°.

An overburden of silt and gravels covers the right bank plain with a maximum thickness of 10 m. The thickness of river deposits is assumed to be less than 3 m.

B.3.2. Geology of Diversion Damsite

Two diversion dams have been planned for the Dor River and Soan River. Their locations are shown in Figure. B-3-1.

(1) Diversion Damsite Dw-1

Diversion damsite Dw-1 is situated in the middle course of the Dor River. The width of the river is around 160 m at the site. Recent low terraces spread out widely on its left flank. Up and down of the right bank are steep cliffs composed of compacted sand and gravel layers.

The size of gravels in the riverbed range from cobble to pebble size with some boulders. The sorting of these deposits is so fair that their permeability might be lower and their bearing capacity high if it were not for 1 m to 2 m of lower material on the surface.

(2) Diversion Damsite Sw-1

The proposed diversion damsite is situated at the point where the Soan river meanders in a large, wide "S" shape. The Soan river joints with the Kurang River on the right bank just upstream of the site and with Kas Dovac on the left bank downstream.

There is a hilly area of a bout 40 m in relative height from the riverbed on both flanks. This area consists of silt, sand and gravels.

Highly consolidated gravel layers (known as "Lei Conglomerate") are recognized at the floor of the right bank.

The river deposits are loose materials, 5 to 10% cobbles (ø10 to 15 cm, maximum diameter 15 cm), 60% pebbles (ø3 - 8 cm) and sand without silt. The permeability of the river deposits is assumed to be high.

On the foot of the right bank there is a recent terrace whose relative height is 3 to 5 m from the river floor and whose width is around 200 m. The terrace deposits are also comprised of the same loose gravels and sand as the river deposits.

B.3.3. Geology of Proposed Tunnel Route

A conduction route is planned from diversion damsite Dw-1 on the Dor river to the Khanpur dam on the Haro river. Two tunnels are scheduled along this route, as shown in Figure B-3-1. The schematic geological profiles of the scheduled tunnel routes (A-B and C-D) are shown in Figure B-3-3.

(1) A-B Section

The geology of the A-B section is composed mainly of black, hard and compact limestone with occasionally intercalated sandstone and shale. Among them, the shale layers are highly sheared and fractured. Shale layer outcrops can be recognized mainly near the middle of the route.

(2) C-D Section

The C-D section is composed of an alternation of sandstone and shale. Sandstone is particularly rich. Although it is in general hard and compact, some sheared shale layers might be intercalated in it. A single stratum is 10 to 30 cm thick. The strata incline toward the south with a steep 80° to 90° inclination.

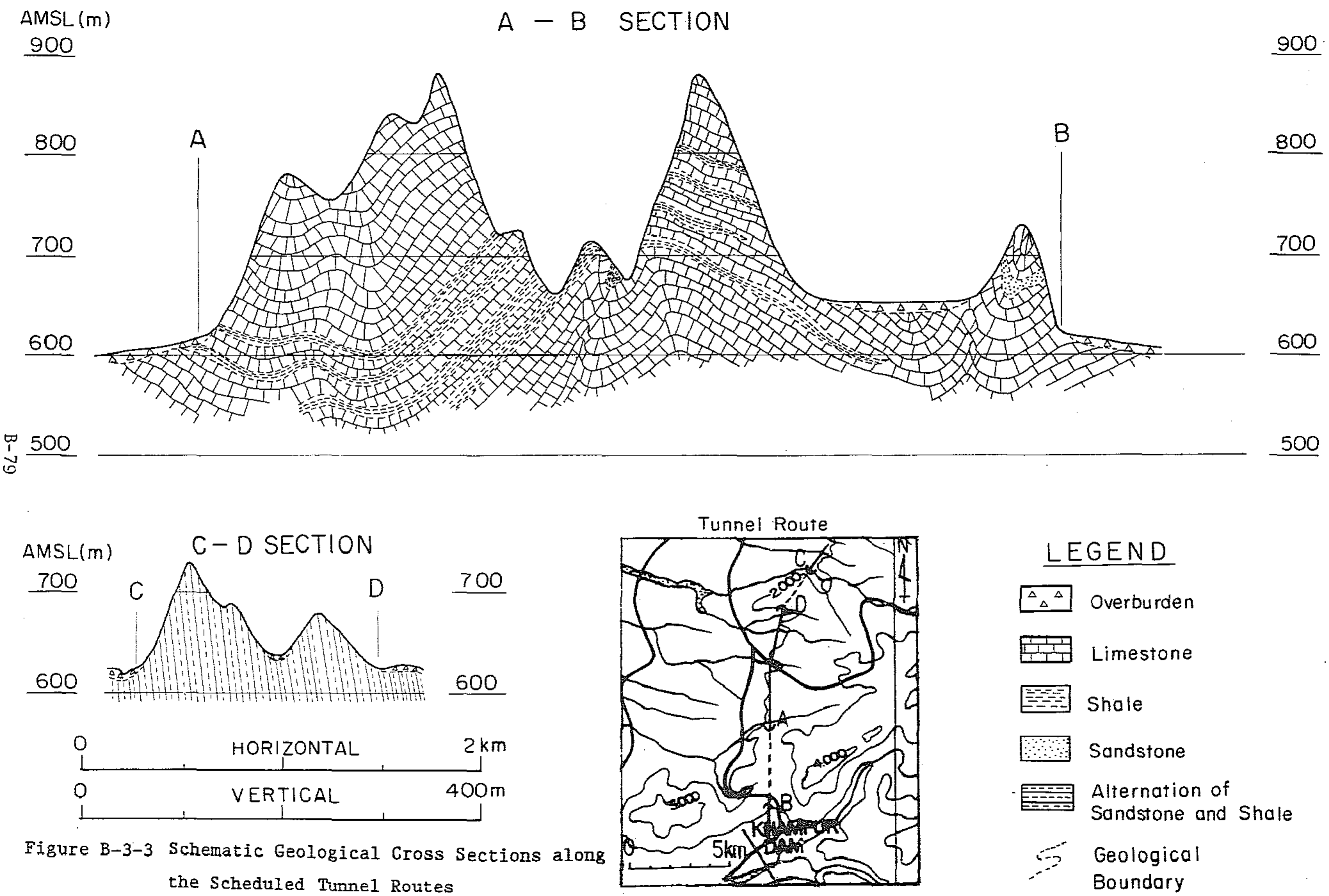


Figure B-3-3 Schematic Geological Cross Sections along the Scheduled Tunnel Routes

B.4. Soil Mechanics and Construction Materials

The filed reconnaissance for construction materials are carried out in the each proposed damsites.

The results of the survey are summarized in Table B-4-1.

B.4.1. Concrete Aggregate

At the D-1, H-4 and S-1 damsites, materials suitable for concrete aggregate are available in the vicinity of the damsites. On the other hand, at the L-1, KL-1 and SL-1 damsites materials for concrete aggregate must be obtained from a distance of 4 to 12 km.

The main materials suitable for concrete aggregate are both fresh and sound rock materials, such as limestone and sandstone. The river gravels distributed on the river bed of the D-1 and H-4 damsites are also expected to be available for the said materials.

B.4.2. Embankment Materials

For the embankment materials, impervious materials, semi-pervious materials and pervious materials with suitable quality are prospected around the proposed damsites.

(1) Impervious Materials

There are two promising sources for impervious materials, one of which is silty clay to be available from terrace deposits and the other is from alluvial deposits.

Terrace deposits are distributed along the river banks of D-1 and H-4 damsites, and they are irregular mixtures of silty clay layers and gravel layers. Among them the silty clay layer can be judged to be utilized for the impervious embankment materials.

(2) Pervious Materials

The sources of best quality for pervious materials are same as those of concrete mentioned above.

The rock materials obtained from the excavation of spillways should be utilized from a economical point of view. Because the materials expected to be obtained at L-1, KL-1 and SL-1 damsites are so highly weathered, that the considerations in dam zoning must be needed for the utilization of such matérials.

(3) Semi-pervious Materials

As for the semi-pervious materials, sands and gravels and comparatively fine rock materials at quarry sites would be applied.

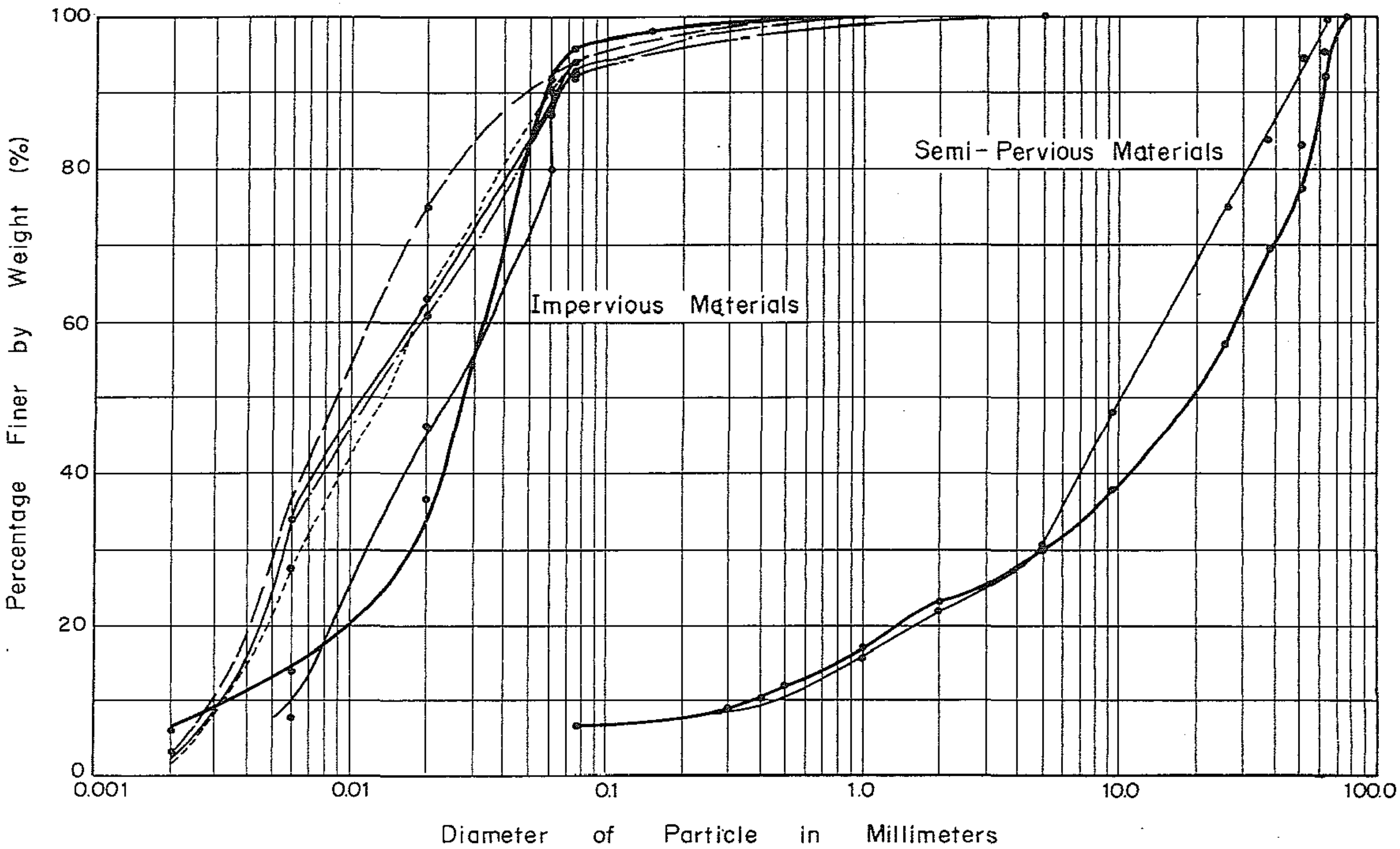


Figure B-4-1 Gradings of Embankment Materials

Table B-4-1 Construction Materials for the Proposed Damsites

Dam	Impervious Materials		Pervious Materials		Concrete Aggregate	
	Materials	Location	Materials	Location	Materials	Location
D-1	Terrace Deposits	Damsite	Limestone	Damsite	Limestone	Damsite
			River Deposits	Damsite	River Deposits	Damsite
H-4	Terrace Deposits	Near Battal, tributary of Dhund Haro (12Km)	Limestone	Damsite	Limestone	Damsite
			River Deposits	Damsite	River Deposits	Damsite
S-1	Alluvial Deposits	Damsite	Sandstone (Fresh)	Damsite	Sandstone (Fresh)	Damsite
L-1	Alluvial Deposits	Damsite	Sandstone (Moderate)	Damsite	Sandstone (Moderate)	Damsite
			Sandstone (Fresh)	South-Wast of S-1 (12Km)	Sandstone (Fresh)	South-West of S-1 (12Km)
KL-1	Alluvial Deposits	Damsite	Sandstone (Moderate)	Damsite	Sandstone (Moderate)	Damsite
			Sandstone (Fresh)	Near Rawal Lake (12Km)	Sandstone (Fresh)	Near Rawal Lake (12Km)
SL-1	Alluvial Deposits	Damsite	Sandstone (Moderate)	Damsite	Sandstone (Moderate)	Damsite
			Sandstone (Fresh)	North of SL-1 (4Km)	Sandstone (Fresh)	North of SL-1 (4Km)

SUPPLEMENT B-1.

Effectiveness of Landsat (Satellite) Imagery Data

Supplement B-1. Effectiveness of Landsat (Satellite) Imagery Data

A. Outline of Landsat Imagery Techniques

Landsat imagery data comprises of several bands of different rays in wave length taken from Satellites. Some of them are visible rays and remains are not visible (infrared rays). Objects on the earth have specific reflective characteristics to rays of specific wave length. For example water (H_2O) shows high reflection to infrared rays. Furthermore, various informations on the earth can be obtained by combining of the bands. Such procedures are called "Remote Sensing Techniques" and have been highly developed for this decade in accordance with the rapid progress of the computer technology.

One scene of the Landsat data covers 180 km by 170 km and the scene is consist of digital dots of 80 m by 80 m in size.

B. Application to the Ground Water Investigations

For the ground water investigations, the remote sensing of the Landsat data can provide the informations for the Pleliminary Study of the following items on the ground surface.

- Soil moistures:
  If the ground water is shallower, the soil moisture may increase.
- Vegetations:
  Some kind of vegetation may grow in the area of shallow ground water.
- Rock Outcrops:
  The rock outcrops may give important informations in order to grasp the scale of the groundwater basins.
- Lithology and geological structure:
  For detection of the permeable strata and structures such as sandstone, limestone and faults and their continuities.

- Surface Water

  River conditions, Ponds and lakes distributions, standing water and etc.

The remote sensing of the Landsat imagery data can greatly contribute to the groundwater investigation in the very vast area in which few informations can be available such as a desert.

C. Application to the Study.

As mentioned above, the Landsat data is effective to the ground water investigations in general.

Nevertheless, it is judged that the Landsat data is insufficient for the study. The reasons are described below;

1) Many and detailed informations have been collected all over the study area. The collected data, which are the inventories of some 200 tubewells, detailed 1:50,000 geological maps, around 100 lithological logs of tubewells, detailed geo-electric sounding by the study team, 1:40,000 aerial photos and so on, are much more precise and much greater than those of the Landsat.

2) Landsat data is too large scaled to apply it to the study. (one scene of landsat data is 180 km by 170 km. On the other hand, the area of the ground water investigation in this study is mere 30 km and 40 km.)

3) The information Landsat data is restricted to the earth surface. The necessary informations in this stage, however, should be concerned to subsurface conditions.

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