7-1 Hydrogeological Background and Data

1. Hydrogeological Background and Data

7-1-1 Topography and geology

The project area is located in Orush Plain developed along the watershed of the Dor River System and Mangai River System. The plain was developed from a rift valley created by a fault movement in the Hazara Mountains. The catchment areas of the two river systems are about 73.52 km2 for the Dor and 14.02 km2 for the Mangai, 14.02 km2, totaling 87.54 km2, of which a flat landform of Orush Plain accounts for 25.91 km2. The divide of the two river systems runs from the south of Mirpur to the north of Dera Wandah, dividing Orush into two parts of north and south.

Orush plain is composed of the eastern terraced fans with its top in the northeast stretching towards Karakurram Highway and the western terrace of a smaller size consisting of several fans rising in the western mountainous area. The Dor and the Mangai rise in this plain, cutting down the Pleistocene terrace into gorges of 5 to 20 m in depth, the former running towards the southwest and the latter towards the northwest.

Hills and mountainous areas surrounding Abottabad are formed of Carboniferous to Triassic dolomite, Cretaceous limestone and schist and shale ranging from Precambrian to Ordovician Period. While the hills on the west side are composed of schist and shale, the mountainous areas from the northeast to southeast are predominantly formed of dolomite and limestone. Orush plain is overlain by Pleistocene deposits ranging from 20 to 200 m in thickness consisting of clay, sand and sand/gravel, with belts of alluvial sediments lining the water channels of streams.

7-1-2 Geology

The geological structure of the project area consists of clay, sand and sand/gravel, although its west side terrace and the central area of the plain show a slight difference. Fig. 1 shows the typical geological cross sections of the area, A-A', B-B' and C-C', the locations of which are indicated in a plan in Fig. 2.

Based upon this analysis, the regional geology features three-layer structure as follows:

a) 1st Layer

The first layer is predominantly clay and silt, partly with interbeds of gravel. While it is 30 to 40 m thick in the west side terrace, it increase the thickness in the central area of the plain to 70 to 80 m near Nawansher, where gravel interbeds in the west side is almost replaced by clay and silt.

b) 2nd Layer

The 2nd layer mainly consists of gravel. In the west side terrace, this feature is typically shown in its northern part such as Banda Dilazak and Dobathar, while it occurs as interbeds of gravel and clay in places such as Jhangi and Derawanda. In the plain, gravel becomes conspicuous with its thickness increasing from 30 to 40 m in Sheikhul Bandi and Nawansher. In Banda Phugwarian, it gets thicker than 50 m. In Mirpur, the northenmost area of the project site, this layer is 30 m thick, according to the well log at No. 2 tubewell (T/W2).

c) 3rd Layer

This is the underlying bedrock in the project site, represented by shale in the west side terrace and dolomite and limestone in the east side lowland around Sheikhul Bandi.

7-1-3 Aquifers and Hydraulic Conductivity

Aquifers in the project area are identified as the first and the second layers - sand and sand/gravel - classified in the previous section 1-2. In the west side terrace the main aquifer is interbeds of sand/gravel alternately occurring with interbeds of clay, while in the plain area gravel overlying the bedrock develops a horizontally extending broad aquifer. The water bearing capacity of this layer as an aquifer is much better in the plain area than in the west side terrace, where limited distribution of gravel is likely to result in limited groundwater occurrence.

The following table shows the values of hydraulic conductivity analyzed by the pumping test results at 5 wells as an indicator to represent water bearing capacity of aquifers:

Table 1 Hydraulic conductivity of aquifers

	Test well	Hydraulic conductivity (cm/sec)
1	Derawanda No. 4	1.43×10^{-3}
2	Jhangi No. 3	1.65×10^{-3}
3	Banda Phugwarian No. 3	1.94×10^{-4}
4	Banda Ghazan No. 2	1.1×10^{-4}
5	Mirpur No. 2	8.1×10^{-3}

Fig. 1 Indication Map of Geological Profile

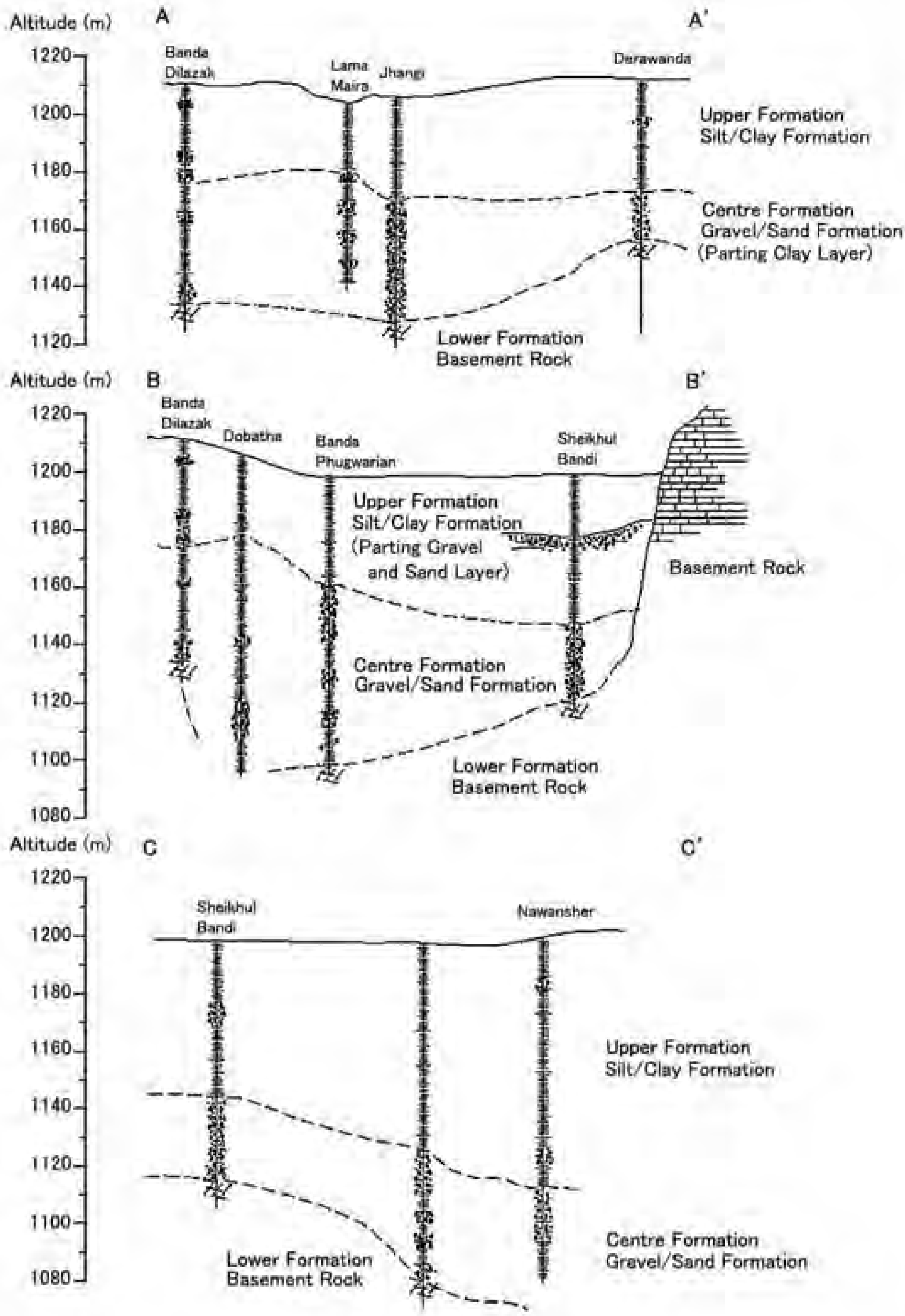

Fig 2 Geological Profile

The following diagram shows one example of a relation of hydraulic conductivity to aquifer capacity.

(Hydraulic conductivity)

1.0 10^{-3} 10^{-7}

<table>
<tr><td>gravel</td><td>sand and sand/gravel</td><td colspan="3">fine sand, silt, and silt with sand</td><td>impervious rock</td></tr>
<tr><td colspan="3">Aquifer</td><td>Aquiclude</td><td colspan="2">Aquitard</td></tr>
</table>

Figure 3 Soil Classification, Aquifers and Hydraulic Conductivity

(Geohydrologic key point: Toshio Murashita)

According to this classification, the strata penetrated by Banda Ghazan tubewell falls into a category of an aquiclude, although the divide of the terms such as an aquifer and an aquiclude is relative in general.

2. Groundwater occurrence

7-2-1 Groundwater occurrence in the plain

Encircled with mountainous areas, Orush plain receives groundwater flow mainly from the following sources:

a) groundwater flow in the terrace rising in the west mountains
b) springs occurring in Mirpur in the north
c) springs occurring in Kakul in the east
d) groundwater flow occurring in limestone in the south

Groundwater moves into the central area of the plain with its levels varying from 1,190 to 1,210 m m.s.l, Springs in the east reportedly used to decrease the yield during the droughts, and groundwater from this source is likely to be subject to seasonal fluctuation. Part of the plain from Karakurram Highway, where the west side terrace falls into the plain, to the Cantonments in the east and south, forms an artesian flowing zone. The yields at flowing wells in the south of he plain range from 90 lit/min (5.4m3/h) in Naririan to 360 lit/min (21.6 m3/h) in Nawansher (T/W 7) . They occur in the 2nd layer overlain by thick beds of clay and silt.

The 2004 BD witnessed some drop of groundwater levels in the existing tubewells in comparison with the data at the time of their construction, although with reservation about the correctness of the initial data. During this study after 5 years, there were places in the west side terrace, (Derawanda and Jhangi) where the water level had tended to decline. As a result of the comparison of all the previous data and those in the present study, however, the water level as a whole has been relatively stable without any conspicuous change to date in the region, probably due to the total rate of groundwater consumption there which has so far been kept to a similar range.

7-2-2 Groundwater storage and movement

(1) Storage

Groundwater occurs and is stored in openings or pores of formations, which vary remarkably, depending on the types of materials and the geologic environments. Effective porosity is an index of how much groundwater can be stored in a saturated medium and is usually expressed as a percentage of the bulk volume of the material. The following table shows one example of the general trend of porosity and effective porosity of various types of soils of Pleistocene period.

Table 2 Porosity of Pleistocene layers

Formation		Porosity (%)	Effective porosity (%)
Pleistocene	Sand/gravel	30	15 ～20
	Sand	35～40	30
	Loam	50～70	20
	Clay/mud	50～70	5～10

In the case that the capacity of groundwater storage in this project site is estimated in accordance with Table 2, the result is as below.

Table 3 Capacity of Groundwater Storage

Site	Area (m2)	Average thickness of Aquifer(m)	Volume(m3)	Effective porosity(%)	Storage(m3)
Derawanda	1,500,000	7	10,500,000	0.15	1,575,000
Jhangi	8,300,000	12	99,600,000	0.15	14,940,000
Mirupur	5,700,000	15	85,500,000	0.15	12,825,000
Sheikhul Bandi	8,200,000	20	164,000,000	0.15	24,600,000
				Total	53,940,000

Note: Area of each project site is quoted from B/D report in 2004.

If the values in the table are assumed for aquifers in the whole project area, the capacity of the groundwater storage will be roughly estimated at about 54,000,000m3.

(2) Drainage

Groundwater is constantly moving through aquifers under the local hydraulic gradient. The volume of such drainage of groundwater from aquifers may be roughly estimated through the analysis of the regional groundwater level contour map, employing Darcy's formula as follows:

Q= K x A x *i*

in which Q= Volume , K= hydraulic conductivity, A=Aquifer section (aquifer width x thickness) and *i* = hydraulic gradient

To estimate a range of drainage in the plain, the following data are employed in this equation, as follows:

K= values obtained from the pumping test carried out under this study

Thickness of aquifers decided, based on the drilling data of existing tubewells

Width of aquifers (extent of aquifer distribution) decided through analysis of groundwater level contour map, and *i* decided through analysis of groundwater level contour map

Drainage into the plain occurs from all the four directions; a) from the west side terrace, b) from the north of the plain (Mirpur), c) from the spring area of the south and d) from the east. The flow from the east depends upon spring sources, although it is not clearly shown in the water level map. The calculation results are summarized in the following table

Table 4 Groundwater Flow in the Project Area

Source	Flow cross section	Hydraulic conductivity(K)	Aquifer width (L)	Aquifer thickness (b)	Hydraulic gradient (i)	Estimated drainage	
		m/d	m	m		m3/d	m3/y
West terrace	A - A'	1.42	5,000	10	40	1,775	647,875
North of plain	B - B'	7.0	2,640	15	120	2,310	843,150
South springs	C - C'	1.68	3,080	20	35	2,957	1,079,232
East springs*	Kakul	3.0	2.640	15	40	2.970	1,084,050
					Total	10,012	3,654,307

Remarks: (*) The factors for the calculation of drainage from the east springs were assumed ones, based on those in other sources.

As a result of this estimate, a daily volume of drainage in the project area is about 10,000 m3/d (yearly about 3,700,000 m3).

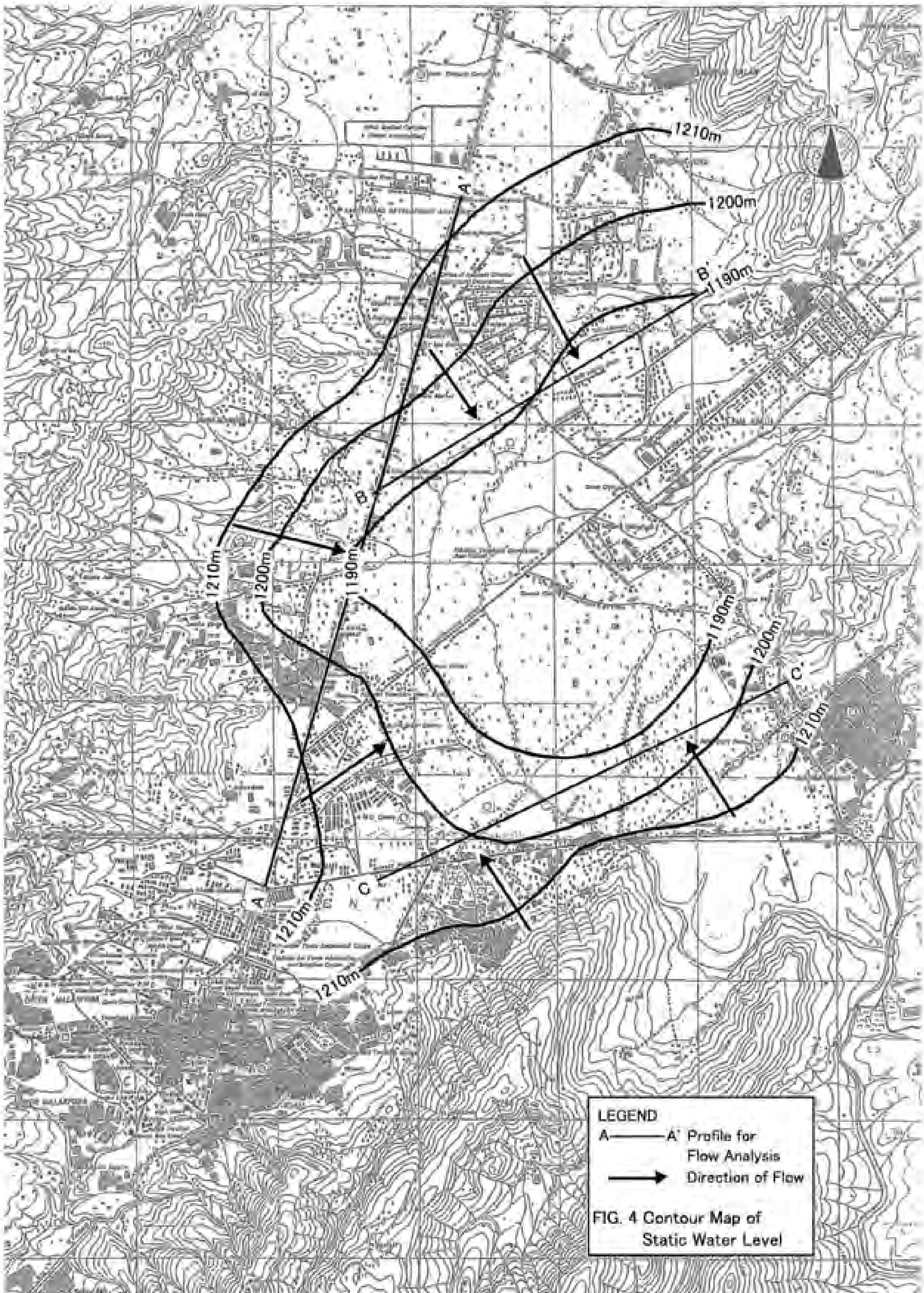

FIG. 4 Contour Map of Static Water Level

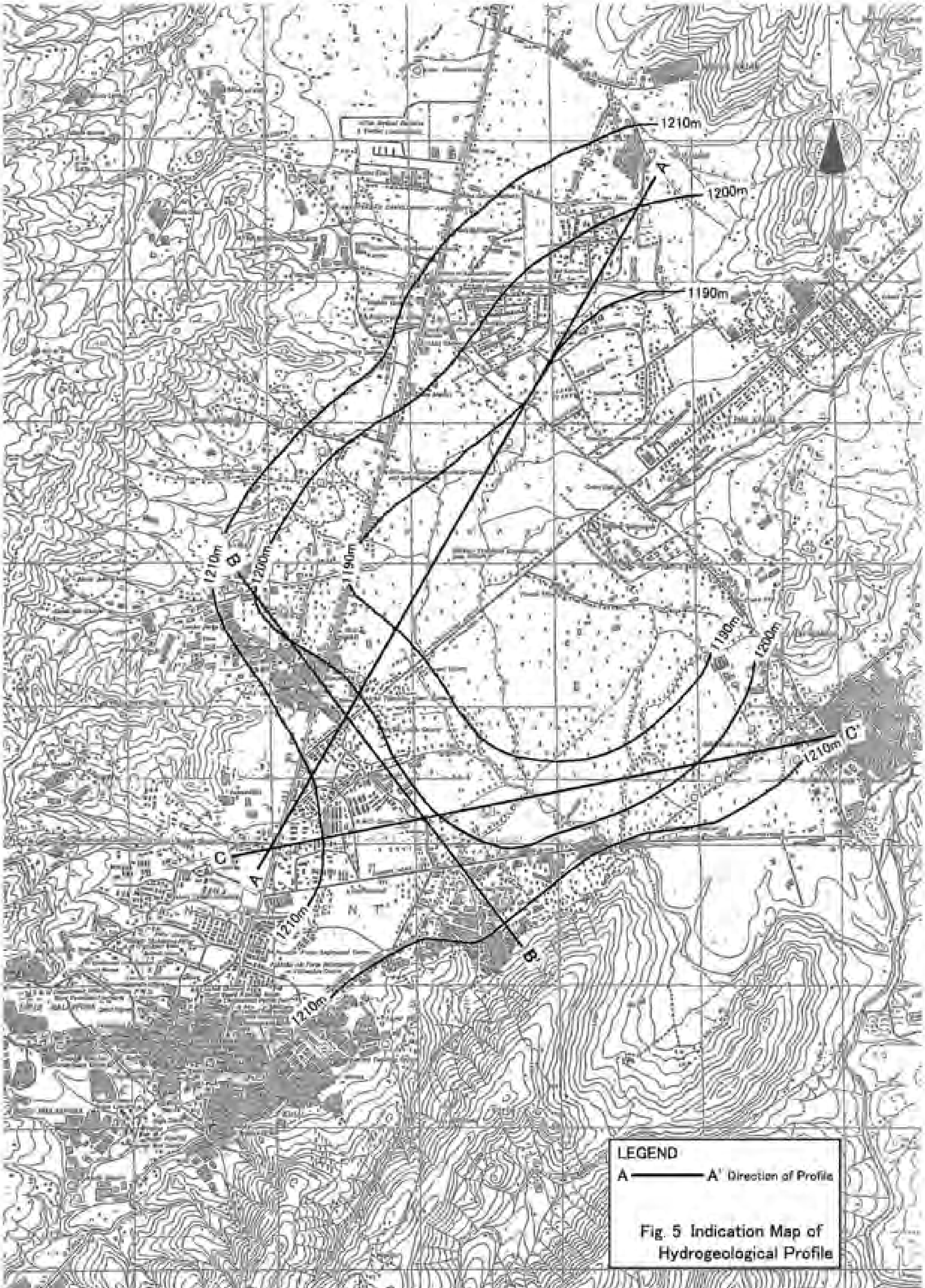

Fig. 5 Indication Map of Hydrogeological Profile

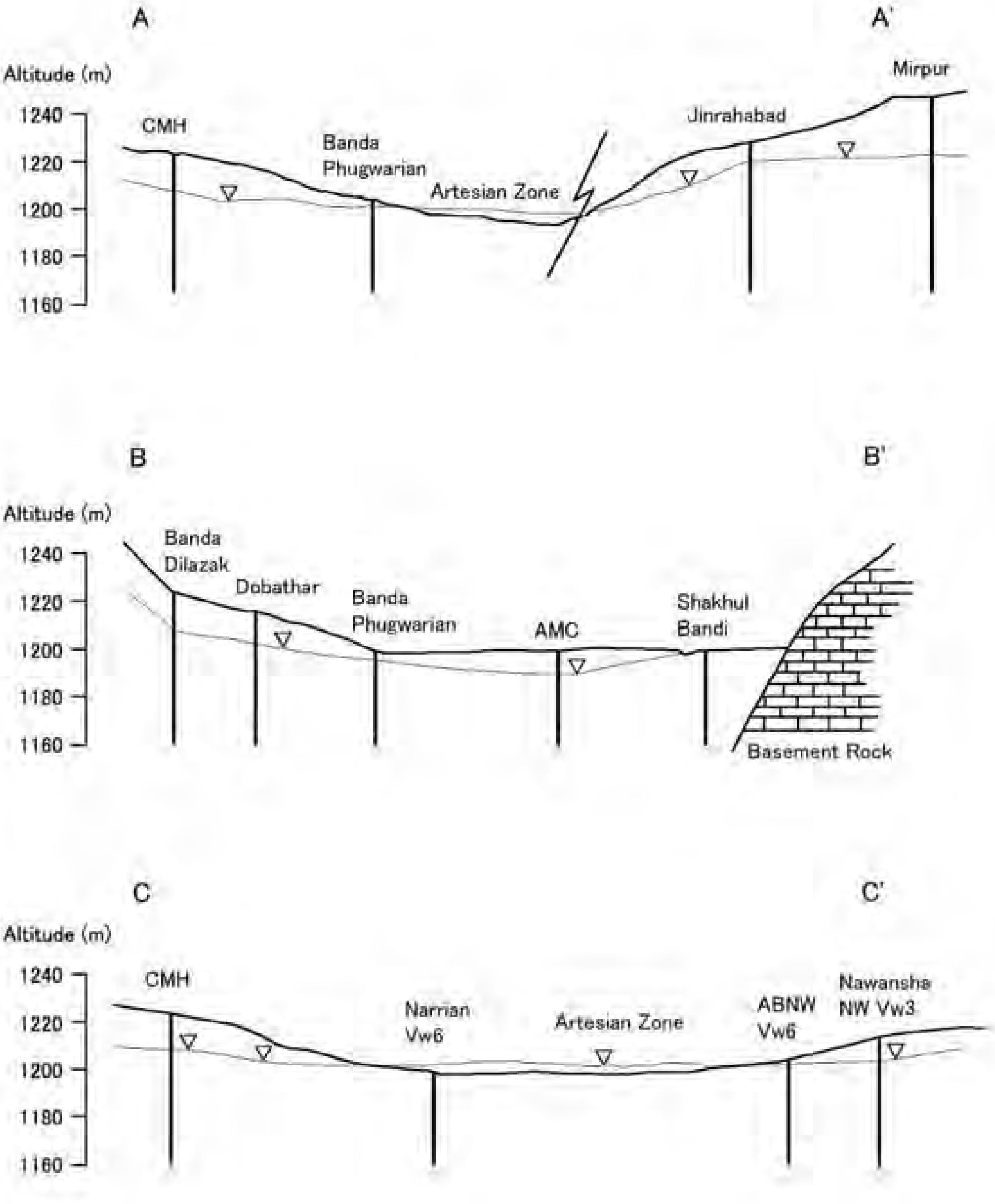

Fig. 6 Profile of Static Water Level

7-2-3　Criteria for Groundwater Development in the Project Area

In the project area groundwater including springs has so far been the sole water source, which is recharged by precipitation.　If an overall discharge of groundwater throughout the area is within the range of recharge, it could be one of criteria for ensuring sustainable groundwater development. For this purpose, the previous studies, 2004BD and the preliminary study in 2008 made efforts to estimate its range. This study proposes to reduce a natural drainage rate from aquifers estimated in the previous section from the recharge rate as a parameter for setting sustainable rate of groundwater development.　The estimation is summarized in the following table:

Table 5　Range of Sustainable Groundwater Development in the Project Area

2004BD	Estimated recharge	15,801,000 m3/y	①
Preliminary	Estimated recharge	13,145,600 m3/y	②
This study	Drainage rate	3,664,307 m3/y	③
Overall sustainable development rate		12,146,693 m3/y	①－③
		9,491,293 m3/y	②－③
Average index rate for sustainable development		10,818,993	m3/year
		29,641	m3/day
		343	litle/sec

The results of this estimation suggests the daily amount of groundwater withdrawal for sustainable development is about 30,000 m3/day.

During 2004BD, the total daily production of groundwater in the area was estimated at 26,000m3 (9,500,000 m3/year). Under the present study, there was no remarkable trend of water level fall witnessed in the area. Water levels in general appeared relatively stable, compared with the previous data.　This fact indicates the continuation of balanced discharge within the recharge since the year 2004 in the project area.

However, further progress of groundwater development in the area is likely to result in the deciline of discharge, accelerated fall of water level, environmental damages such as land subsidence, etc. The concerned areas include the west side terrace and Nawansher, where tubewells are congested without adequate spacing between them to minimize interference.

7-2-4　Drawdown Prediction

The following table summarizes the relation of distance and drawdown predicted around the existing test wells when they are continuously pumped at rates of respectively estimated safe yield. Fig. 7 to Fig. 11 show plots of the predicted curves, which indicates drawdown at locations at given distances from the pumping wells resulting from continuous pumping for one month, one year and five years respectively.

Table 6 Distance-Drawdown Relation

Area	① / ② (m)	Drawdown (s) m		
		30 days	One year	5 years
Banda Ghazan	10	55.3	82.1	99.1
	100	9.2	33.1	49.9
	500	0.0003	4.2	17
Jhangi	10	9.3	13.7	16.5
	100	1.7	5.7	8.5
	500	0.0002	0.86	3.06
Derawanda	10	15	20.2	23.5
	100	5.6	10.7	14
	500	0.5	4.2	7.4
Mirpur	10	2.3	2.9	3.3
	100	1.2	1.8	2.2
	500	0.4	1	1.4
Banda	10	16.3	22.9	27.3
Phugwarian	100	4.1	10.4	14.8
Q= 8 lit/sec	500	0.01	2.4	6.2

Remarks: ① = Time since pumping started

② = Distance from the pumping well

Among 5 wells, the one at Banda Ghazan in the west terrase is predicted to have drawdown of about 100m in 5 years after pumping started. In this area, drawdown tends to get high because of low hydraulic conductivity. However, since the analysis of time-distance-drawdown assumes no recharge (nonequilibrium equation), the drawdown in reality may not be so much as predicted due to likely recharge into this area.

At other 4 wells in the plain area, on the other hand, drawdown at locations from 500 m apart from the wells is limited to about 3 to 7 m in 5 years after pumping started. When there arises a need to install additional tubewells in the future in these areas, the spacing of 500 m between two tubewells appears at least necessary to avoid significant interference between them.

To ensure stable supply of groundwater, monitoring of discharge rates and water levels throughout the area is indispensable. It is recommended, therefore, that overall control and monitoring system of existing tubewells should be established to maintain sustainable groundwater development and usage in the area.

Table 7 Comparison with groundwater level (Static water level) (1)

Site		T/W No.	Altitude (m)	GWL * (GL- m)	
				2004B/D	2009
1	Derawanda	No. 1	1,224	7.8	7.32
		No. 2	1,224	6.9	13.44
		No. 3	1,224		
		No. 4	1,183		5.24
		No. 5	1,179		15
2	Jhangi	No. 1	1,211	9.6	
		No. 2	1,215		
		No. 3	1,212		7.68
3	Lama Maira	No. 1	1,212	0	
		No. 2	1,209	14.4	
4	Banda Phugwarian	No. 2A	1,198	15	
		No. 3	1,198		
		No. 4	1,196		1.72
5	Dobathar	No. 1	1,213	5.7	12.1
6	Banda Dilazak	No. 1	1,222	15	
		No. 2	1,213		
7	Banda Ghazan	No. 1	1,222	20.9	
		No. 2	1,219		19.99
8	Salhad	No. 1	1,180	9.6	8.58
		No. 2	1,190	11.4	
		No. 3	1,187		22.8
		No. 3 (Spring)	1,148		
9	Shekhul Bandi	No. 2	1,198		3.00
		No. 3	1,196	2.4	
		No. 4	1,197	3	0.41
10	Mirpur	No. 1	1,225	22.50	
		No. 2	1,242		30.93
11	Abbottabad TMA				
	Stoney Jhe	No. 1	1,209		
		No. 2	1,209	2.45	
		No. 3	1,209		
		No. 4	1,209		
	Narrian	No. 6	1,210	+6	+6
		No. 1			
		No. 2			
	Nawansher	No. 1			
		No. 3	1,208		
		No. 4	1,208	9.00	
		No. 5	1,206		
		No. 6	1,199		0.12
		No. 7	1,193	+3	
12	Nawansher	No. 1	1,215		
		No. 2	1,196		
		No. 3	1,212		
		No. 4	1,252		
13	Abbotabbado Hotel		1,188		0.25

*GWL: Groundwater level

Table 7 Comparison with groundwater level (Static water level) (2)

Site	T/w No.	Altitude (m)	GWL* (GL- m)	
			2004B/D	2009
Stony Jheel(1)	1			
Stony Jheel(2)	2	1222	2.45	
Stony Jheel(3)	3			
CMH	4	1221	10.82	16.83
FFCMT Ground	5		9.14	
Golf Course	6		6.1	
AMC Centre(1)	7	1196	10.13	
AMC Centre(2)	8	1196		
AMC Centre(3)	9		0	
B.Center	10		5.63	
Narrian(1)	3		Artes	
Narrian(2)	4		+6	
Narrian(3)	5		+6	
Narrian(4)	6		+6	
Narrian(5)	7		+6	
Narrian(6)	8	1210	+6	
Gvmt College	9		19.81	
Jinah Bagh(1)	10			
Jinah Bagh(2)	11			
Jinnahabad(1)	3		6.1	
Jinnahabad(2)	4	1222	12.2	
Jinnahabad(3)	5	1222	3.26	
Womens'&Ch.Hosp.	1	1227	32.97	
Magistrates Office	2	1225		18.24
Gvmt.Hosp.(1)	3	1221	18.46	22.2
Gvmt.Hosp.(2)	4			
Gvmt.Deg.College	5	1219	19.8	
Pol.Off.Col	1	1232	30.5	
Civil Off	2	1208		
Potato.Res	3	1208	15.8	
Ayub MC(1)	4		15.2	
Ayub MC(2)	5			
Ayub MC(3)	6			
Ayub MC(4)	7		15.8	
Womens'T.S.	8	1219		
Polytechnic	9	1217		
Comm.College	10	1218	7.92	

*GWL: Groundwater level

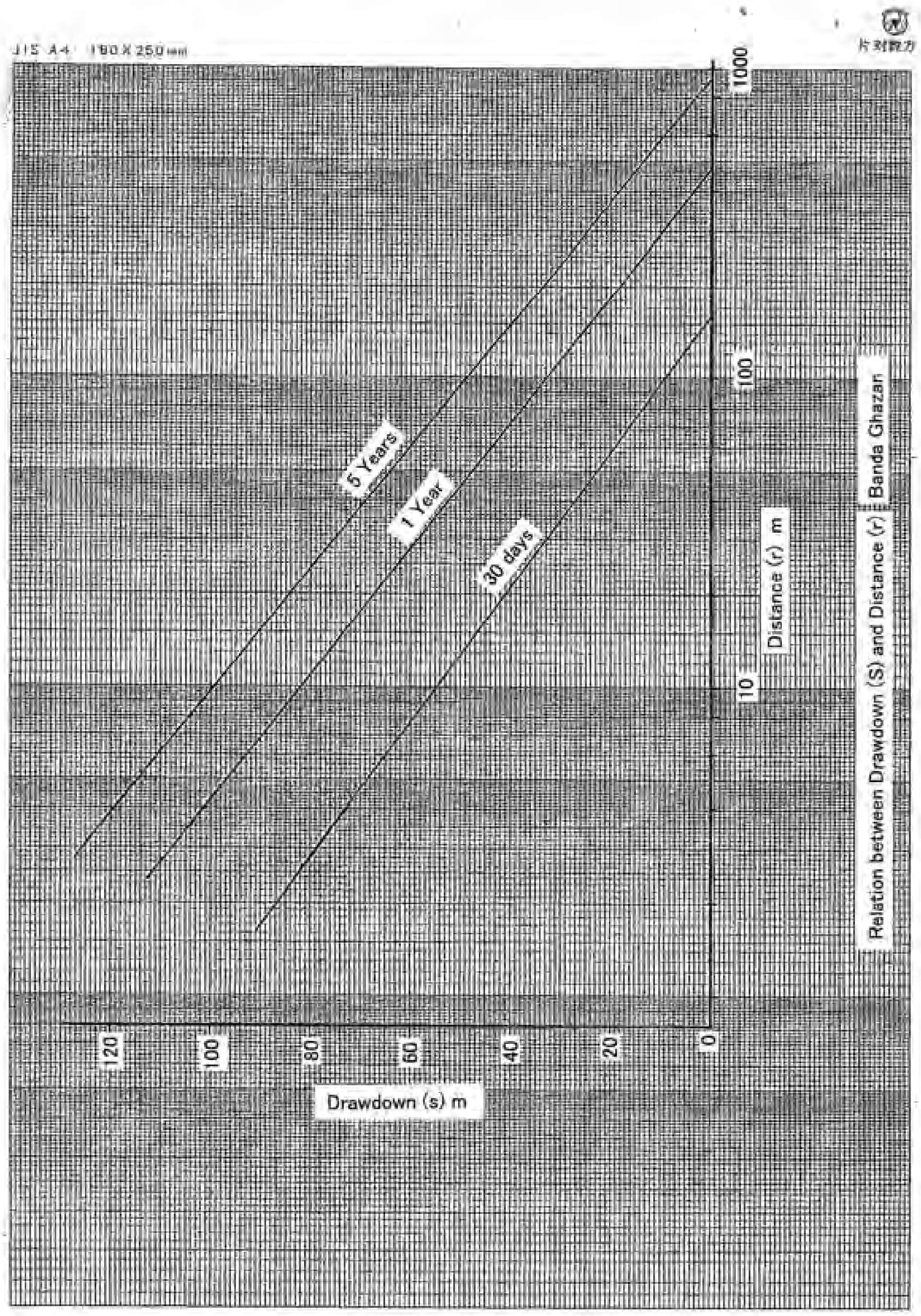

Fig 7 Relation between Drawdown (s) and Distance (r) in Banda Gahzan

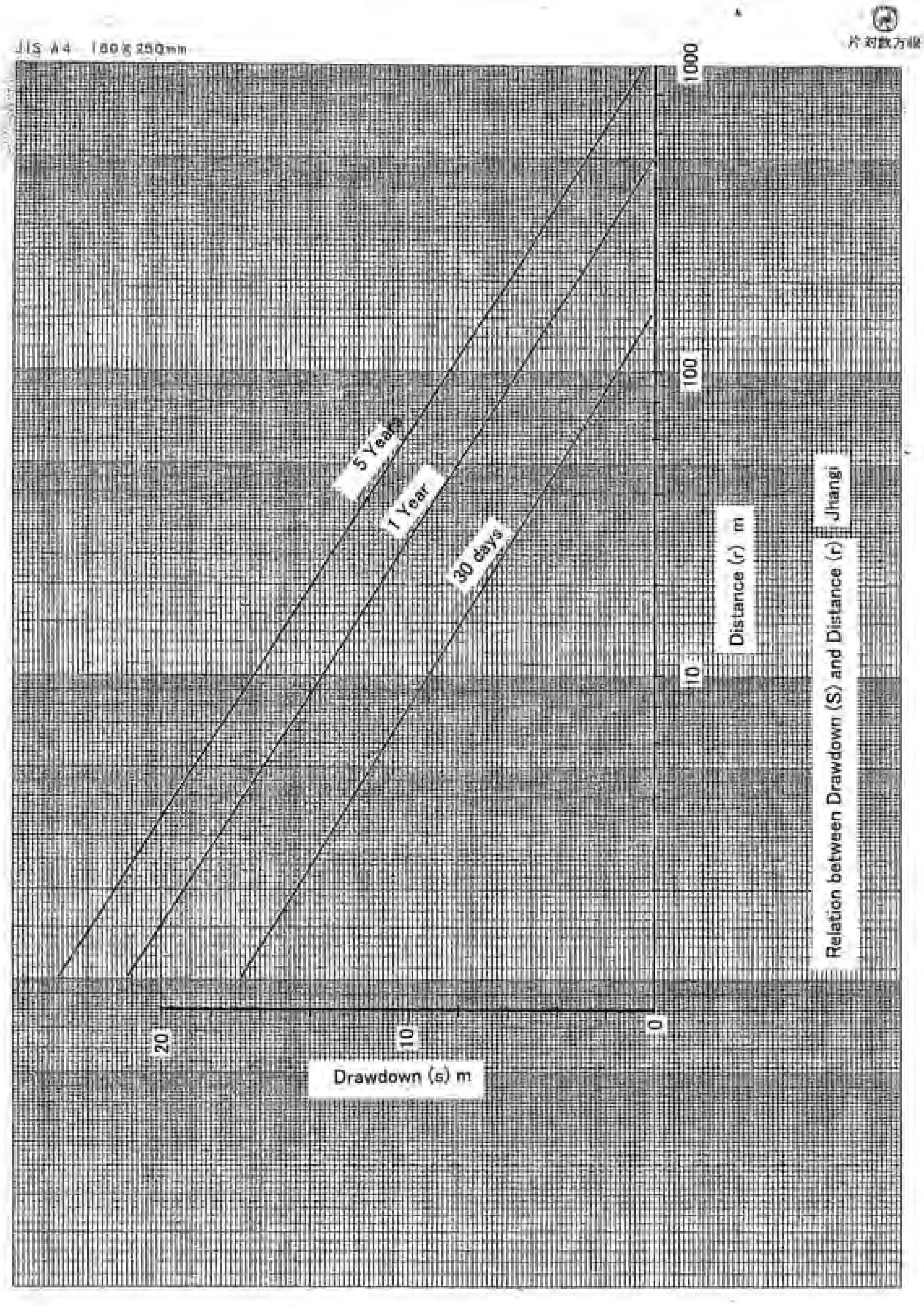

Fig 8 Relation between Drawdown (s) and Distance (r) in Jhangi

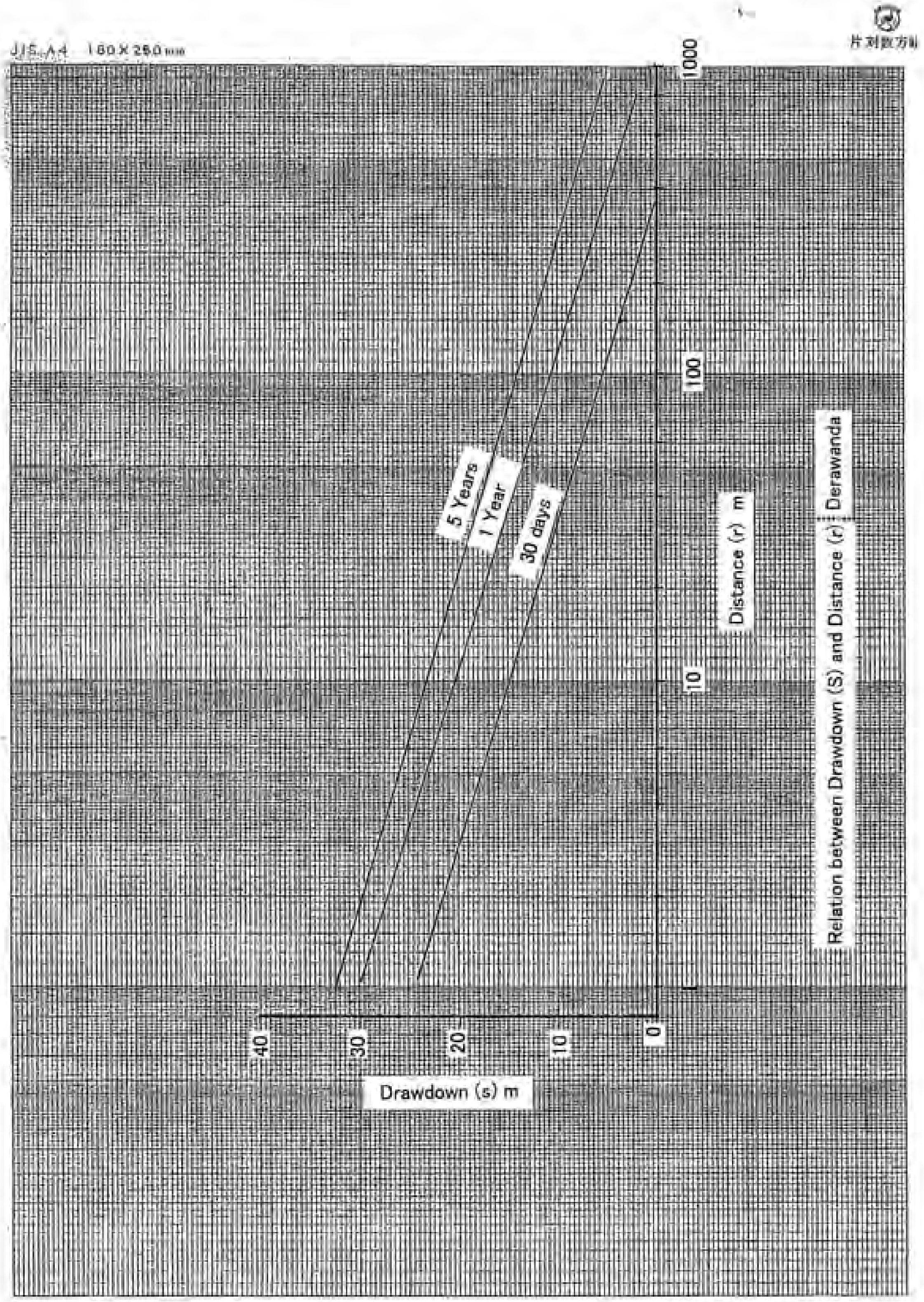

Fig 9 Relation between Drawdown (s) and Distance (r) in Derawanda

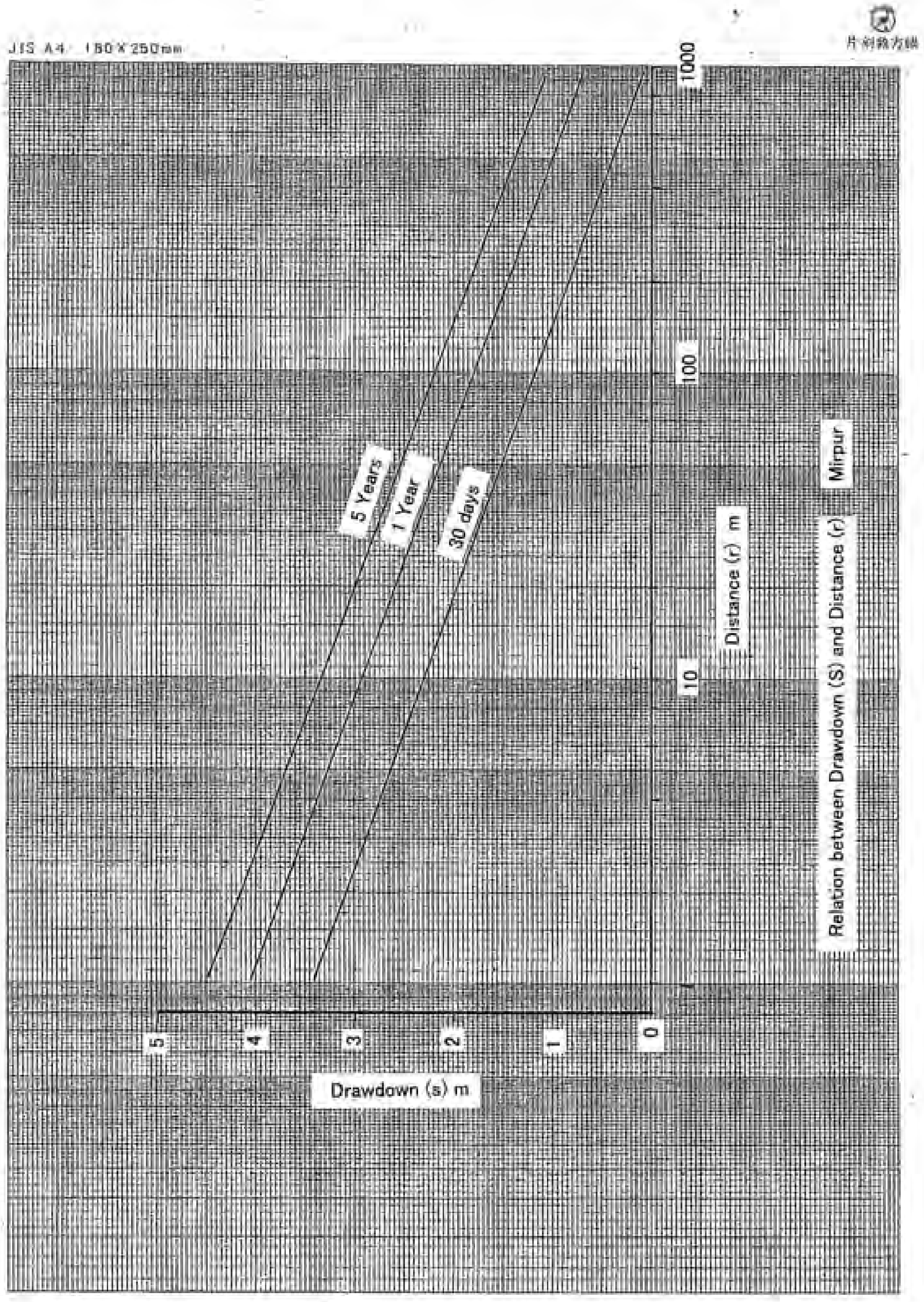

Fig 10 Relation between Drawdown (s) and Distance (r) in Mirpur

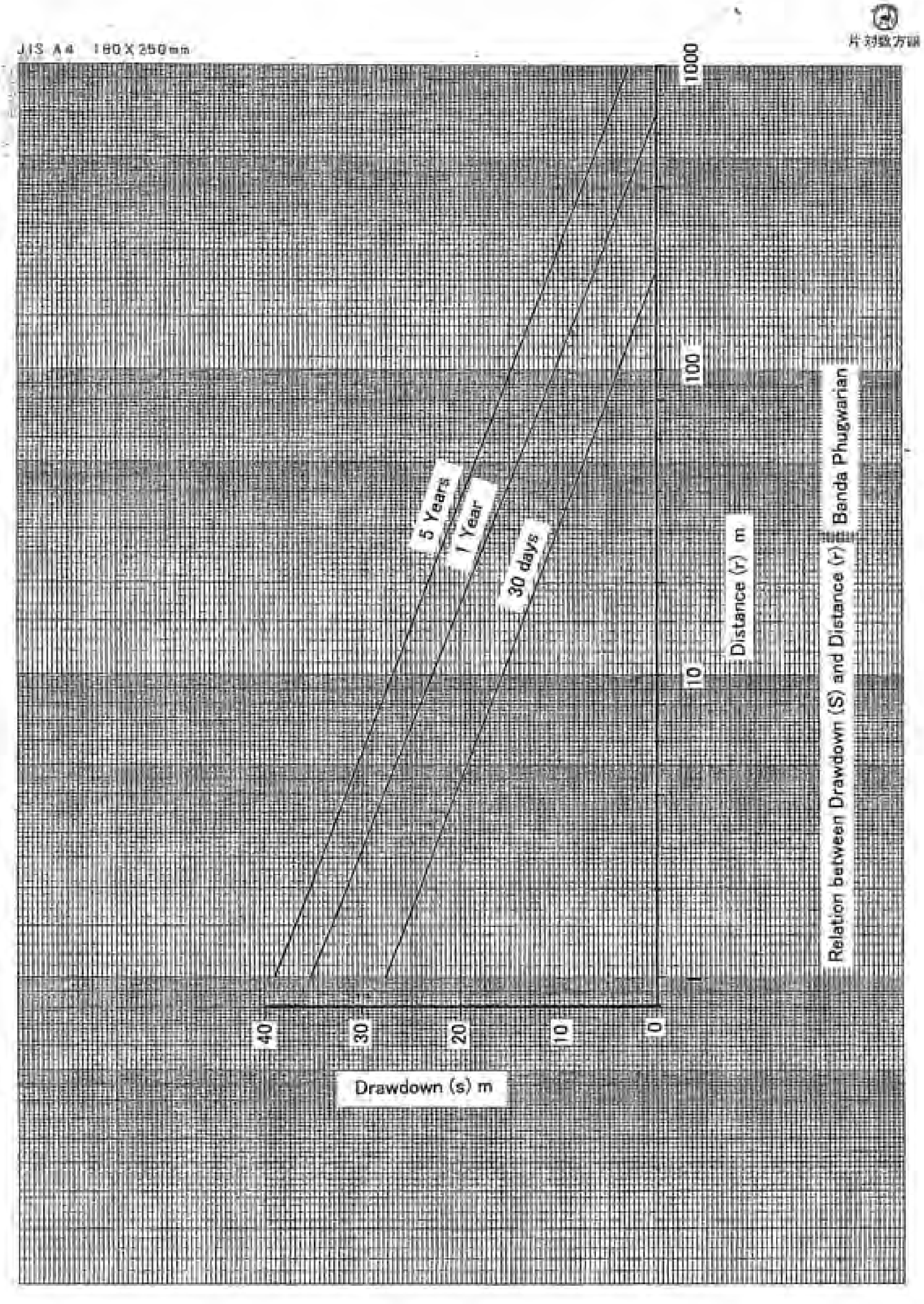

Fig 11 Relation between Drawdown (s) and Distance (r) in Banda Phugwarian

Pumping Test

Step Drawdown Test

Constant Discharge Test・Recovery Test

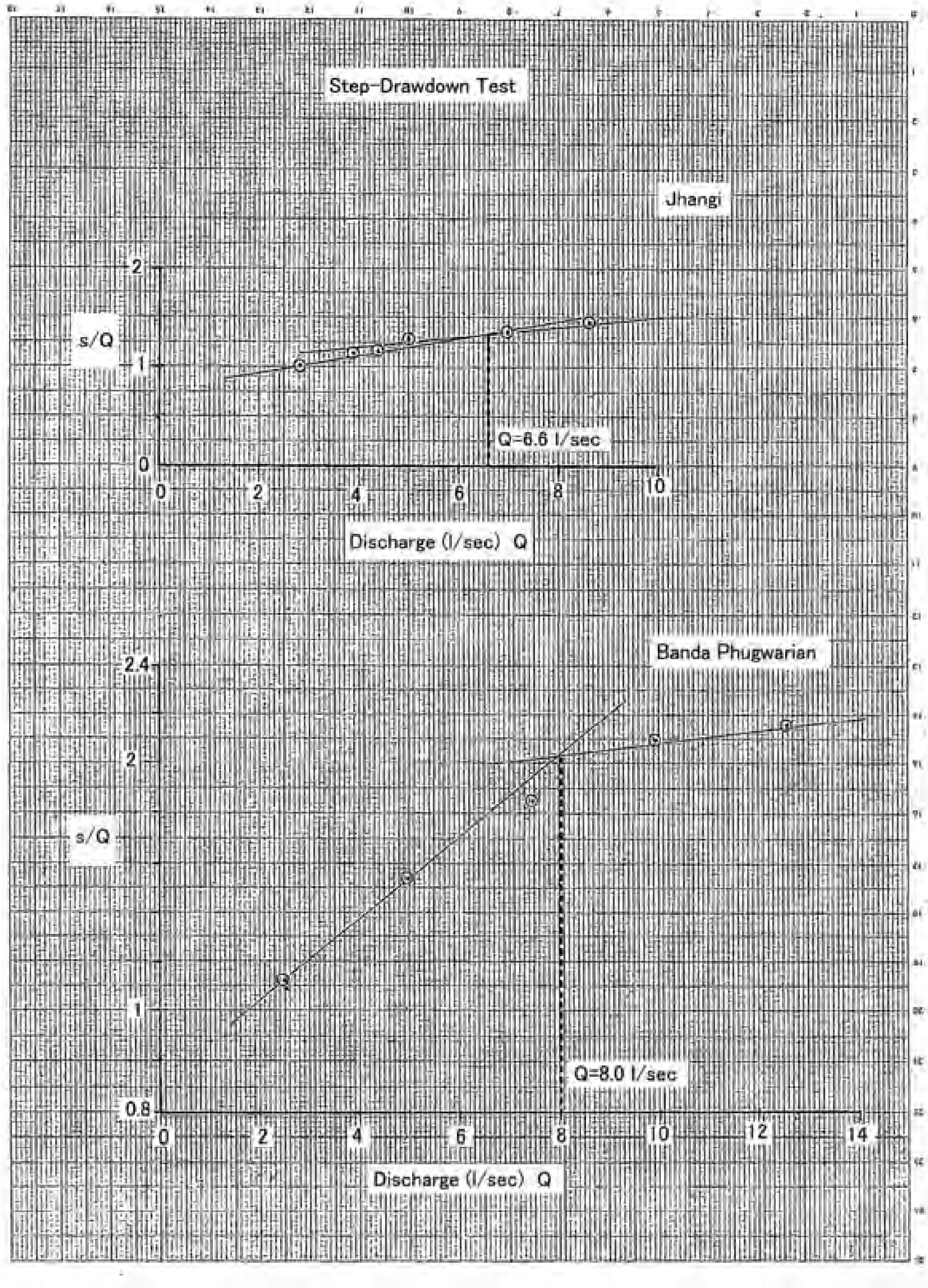

Fig 13 Step drawdown test in Jhangi and Banda Phugwarian

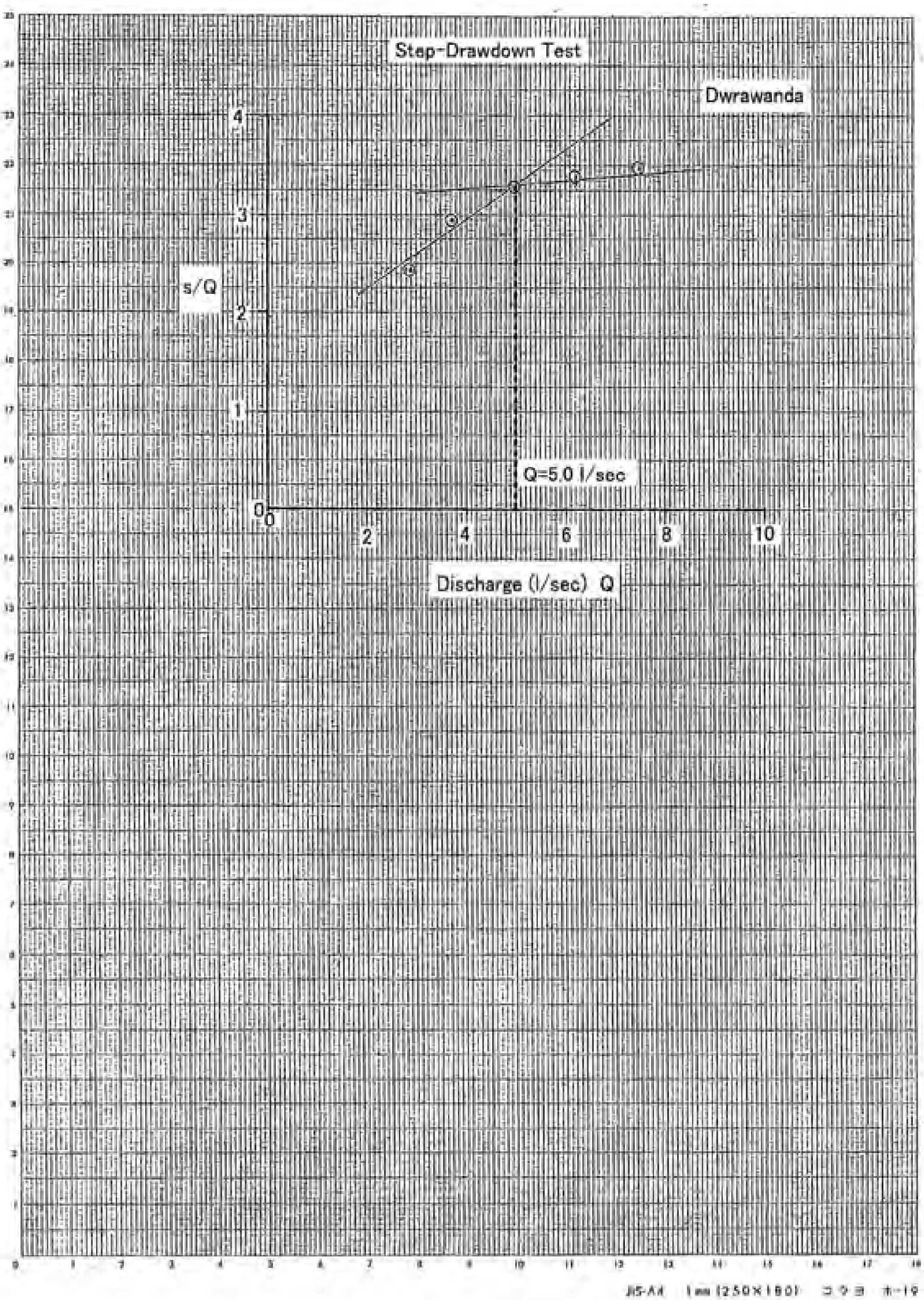

Fig 13 Step drawdown test in Derawanda