4. RAINFALL ANALYSIS

4.1 DATA PROCESSING

4.1.1 ANNUAL RAINFALL

Fourteen out of thirty rainfall observation stations, listed in Table-2.1 (1) "List of Collected Rainfall Data", were selected for the purpose of analysis because of the availability of rainfall data on them for the last 31 years i.e. from 1951/52 to 1981/82.

These fourteen stations are listed in Table-4.1, which tabulates the annual rainfall and the maximum annual daily rainfall by each station.

(1) Relation Between Annual Rainfall and Altitude

Fig.-4.1 is an isohyetal map based on the mean annual rainfall of the fourteen rainfall observation stations mentioned above. Fig.-4.2 shows the relation between the mean annual rainfall and the altitude as a semi logarithmic graph.

The following observations can be made according to Fig.-4.1 and 4.2.

(i) The isohyets of the mean annual rainfall and the contour lines are almost parallel i.e. when the altitude increases, the rainfall also increases.

(ii) The mean annual rainfall increase almost in proportion to the altitude above 200 m.

(2) Fluctuation of Annual Rainfall

Fig.-4.3 shows the fluctuation of annual rainfall for two stations given below.

Table-4.10)List of Maximum Anual Daily Rainfall & Annual Rainfall

No.	Station	Year / El.(m)		51/52	52/53	53/54	54/55	55/56	56/57	57/58	58/59	59/60	60/61	61/62	62/63	63/64	64/65	65/66	66/67
1.	BESUK SAT	795	RA	2,484	3,968	3,863	4,932	3,840	4,543	3,716	3,627	4,573	2,761	2,512	2,870	2,705	3,069	3,254	3,943
			RM	90	200	105	324	135	258	138	127	162	105	75	101	135	150	137	133
2.	PASRU JAMBE	481		2,108	3,619	2,634	4,463	3,308	3,940	3,223	3,149	3,882	2,287	3,305	2,777	2,558	2,925	2,577	2,554
				77	137	115	200	110	254	193	115	144	100	150	138	132	178	110	98
3.	BEDO (SUMBER DUREN)	510		1,931	2,705	2,431	3,596	3,262	3,730	2,626	2,556	2,918	1,782	2,364	1,987	2,052	2,109	2,036	2,365
				65	92	85	160	140	276	116	93	120	95	119	100	75	69	100	89
4.	KERTOSARI	345		1,884	2,850	1,882	3,258	3,158	3,240	2,613	2,527	2,523	1,516	1,838	1,767	2,084	2,281	1,726	2,427
				75	95	90	124	145	211	115	138	129	62	103	112	162	170	72	97
8.	PASIRIAN	155			1,862	1,484	2,220	2,275	2,100	1,604	2,026	1,664	982	1,638	1,833	1,644	2,125	1,475	1,642
					58	45	203	100	146	125	129	66	70	101	113	144	114	96	107
9.	CANDIPURO	322		2,076	2,585	2,102	3,519	3,434	3,574	3,169	2,420	3,177	1,721	1,812	2,425	2,061	2,932	2,036	2,561
				100	69	130	211	143	206	225	107	145	79	62	138	131	182	64	110
10.	GUNUNG SAWUR	682		2,072	3,684	3,732	4,925	3,810	4,246	3,631	3,731	4,291	2,890	2,784	2,710	2,996	3,172	2,487	1,968
				98	128	218	195	144	365	225	105	210	101	108	126	106	119	92	90
11.	CURAH KOBO'AN	734			3,627	2,830	3,950	3,133	4,335	3,179	3,361	3,533	2,130	2,522	3,173	3,416	3,221	2,757	3,072
					163	95	150	125	360	230	130	120	126	101	55	90	180	92	186
16.	SENDURO	435				2,722	4,767	4,090	4,158	2,699	2,749				1,993	1,883	1,551	2,733	2,565
						111	132	183	324	75	83				81	92	69	96	84
17.	DOWUHAN LOR	97		1,547	1,939	1,841	2,117	1,964	1,801	1,637	1,530	1,635	1,117	1,389	1,606	1,471	1,511	1,341	1,383
				66	163	103	90	95	134	128	65	81	90	91	82	83	96	90	79
19.	GUCIALIT	600		2,356	3,456	2,741	2,952	3,500	4,719	2,200	2,[illegible]72	2,492	1,785	3,027	2,785	2,810	2,495	2,917	2,550
				113	98	88	99	121	304	138	88	143	109	83	92	177	91	112	100
20.	MUNGGIR	600			2,811	3,121	4,797	3,276	4,176	3,195	2,377			3,679	2,210	1,955	2,855	2,474	3,059
					110	294	160	130	285	165	78			72	98	108	125	110	100
24.	SUKOSARI	93					2,130	1,831	1,794	1,057	1,963	1,629	1,086	1,231	1,519	1,077	1,667	1,307	1,756
							73	107	133	63	69	47	41	91	66	59	120	89	90
29.	LUMAJANG	50		1,792	2,034	1,760	2,288	2,114	2,051	1,654	2,127	1,992	1,441	1,404	1,915	1,234	1,647	1,788	1,284
				80	154	82	88	113	145	96	65	123	81	62	183	74	122	88	60

Table-4.1(2) List of Maximum Anual Daily Rainfall & Annual Rainfall

No.	Station	Year / El.(m)	67/68	68/69	69/70	70/71	71/72	72/73	73/74	74/75	75/76	76/77	77/78	78/79	79/80	80/81	81/82	$\bar{R}$
1.	BESUK SAT	795 RA	4,529	4,718	3,879	4,300	3,138	3,254	4,391	4,572	3,456	4,668	4,814	5,839	2,782	3,870	3,075	3,805
		795 RM	194	153	153	181	150	104	230	125	97	175	200	160	194	164	94	
2.	PASRU JAMBE	481	3,839	3,225	2,620	3,659	2,136	3,024	3,334	4,222	2,632	3,579	2,918	4,088	1,976	3,401	2,433	3,110
			175	120	125	185	100	175	200	193	88	147	202	125	90	140	92	
3.	BENDO (SUMBER DUREN)	510	3,837	3,535	2,910	3,109	2,683	3,287	3,988	4,183	2,367	3,619	3,314	3,992	2,232	3,670	2,860	2,904
			150	115	102	150	90	146	225	150	125	175	188	176	100	133	99	
4.	KERTOSARI	345	2,721	2,453	1,853	2,797	1,972	2,604	2,732	4,211	2,557	2,686	2,791	3,424	2,782	2,500	2,087	2,418
			130	112	112	98	70	114	94	250	103	134	196	127	194	133	66	
8.	PASIRIAN	155	2,205	2,068	1,191	1,925	2,156	2,206	1,969	2,189	1,762	1,839	2,490	2,737	1,381	2,395	1,917	1,900
			133	92	97	92	188	100	125	111	125	171	195	100	145	88	82	
9.	CANDIPURO	322	2,245	2,009	1,484	1,824	2,289	3,151	2,970	2,943	1,776	2,107	2,640	3,756	1,778	2,369	1,497	2,561
			150	86	134	96	137	152	101	145	85	200	155	120	133	152	81	
10.	GUNUNG SAWUR	682	4,583	3,571	3,105	3,581	2,793	3,530	3,385	4,582	2,616	3,456	3,810	4,712	2,433	3,698	2,596	3,406
			165	122	110	176	98	177	195	146	63	139	203	152	104	178	76	
11.	CURAH KOBO'AN	734	4,340	3,230	2,778	3,192	2,542	3,758	3,619	3,974	2,500	3,471	3,145	4,150	2,278	3,716	1,879	3,227
			204	115	128	167	87	165	210	208	95	325	105	390	175	225	72	
16.	SENDURO	435	3,095	2,736	2,306	2,957	1,878	2,209	2,478	3,188	2,469	3,015	3,104	5,057	2,852	4,152	2,664	2,931
			229	147	105	184	96	130	151	157	109	180	221	130	108	105	139	
17.	DOWUHAN LOR	97	1,948	1,750	496	764	1,967	2088	1,061	2,795	2,326	1,398	1,956	2,359	1,127	2,292	1,732	1,674
			97	135	84	87	97	111	50	174	101	85	114	87	61	91	77	
19.	GUCIALIT	600	4,091	3,346	2,265	3,807	2,161	2,794	2,491	3,656	2,586	2,096	3,161	3,528	1,986	1,606	2,161	2,806
			181	126	142	204	81	147	113	158	125	140	96	213	136	164	72	
20.	MUNGGIR	600	3,841	4,023	3,475	3,862	2,306	2,902	3,552	3,976	2,402	3,378	3,545	4,328	2,191	3,404	3,062	3,222
			156	135	107	190	65	108	210	190	66	167	195	125	136	153	168	
24.	SUKOSARI	93	1,284	1,766	1,401	2,292									1,193	1,566	1,460	1,511
			74	176	59	110									94	109	98	
29.	LUMAJANG	50	2,647	3,041	1,858	1,823	1,546	1,930	1,274	2,214	2,167	1,711	2,241	2,195	1,337	2,099	1,739	1,874
			118	127	126	146	62	116	45	162	141	70	183	82	101	103	85	

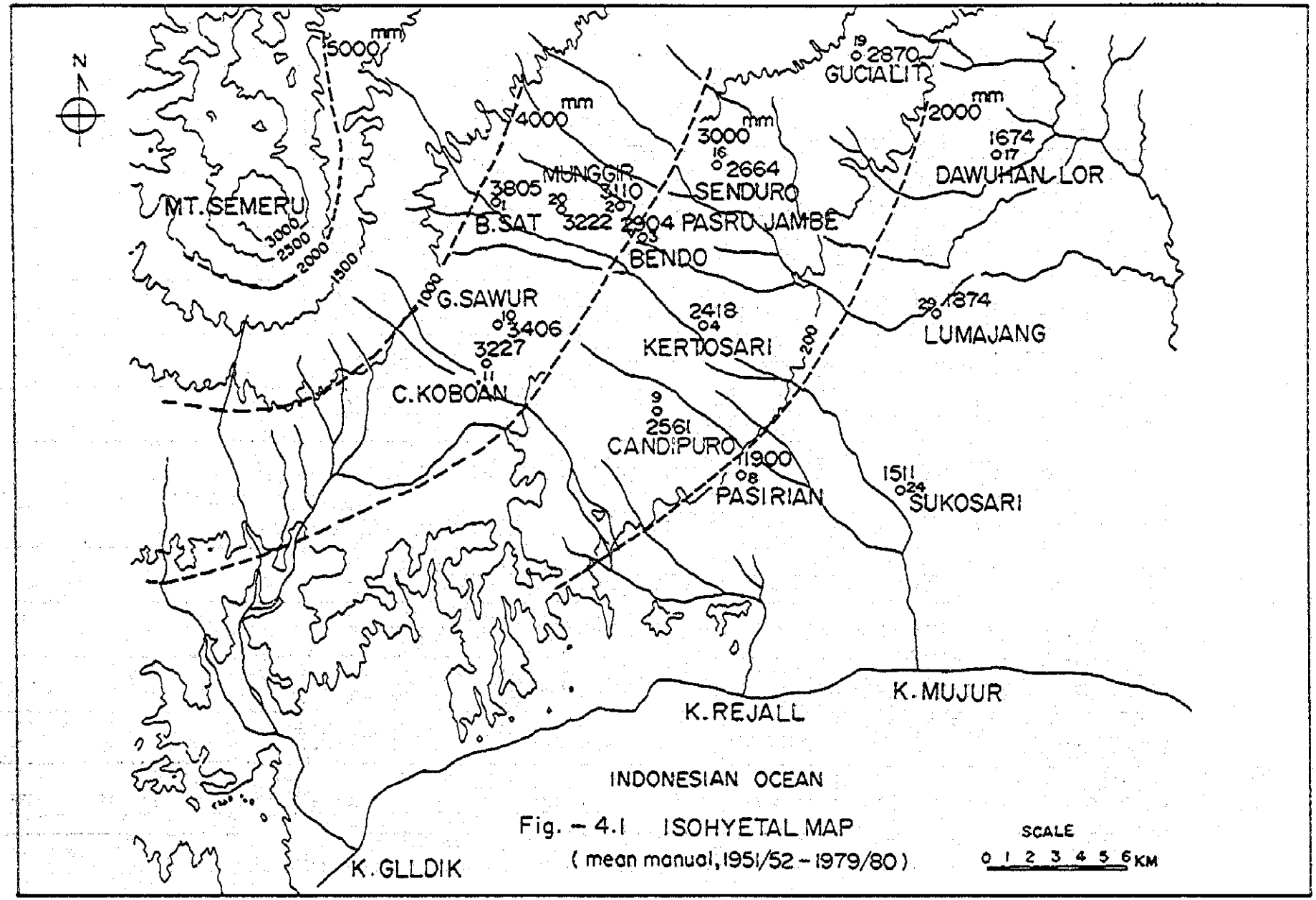


Fig. – 4.1 ISOHYETAL MAP
(mean manual, 1951/52 – 1979/80)

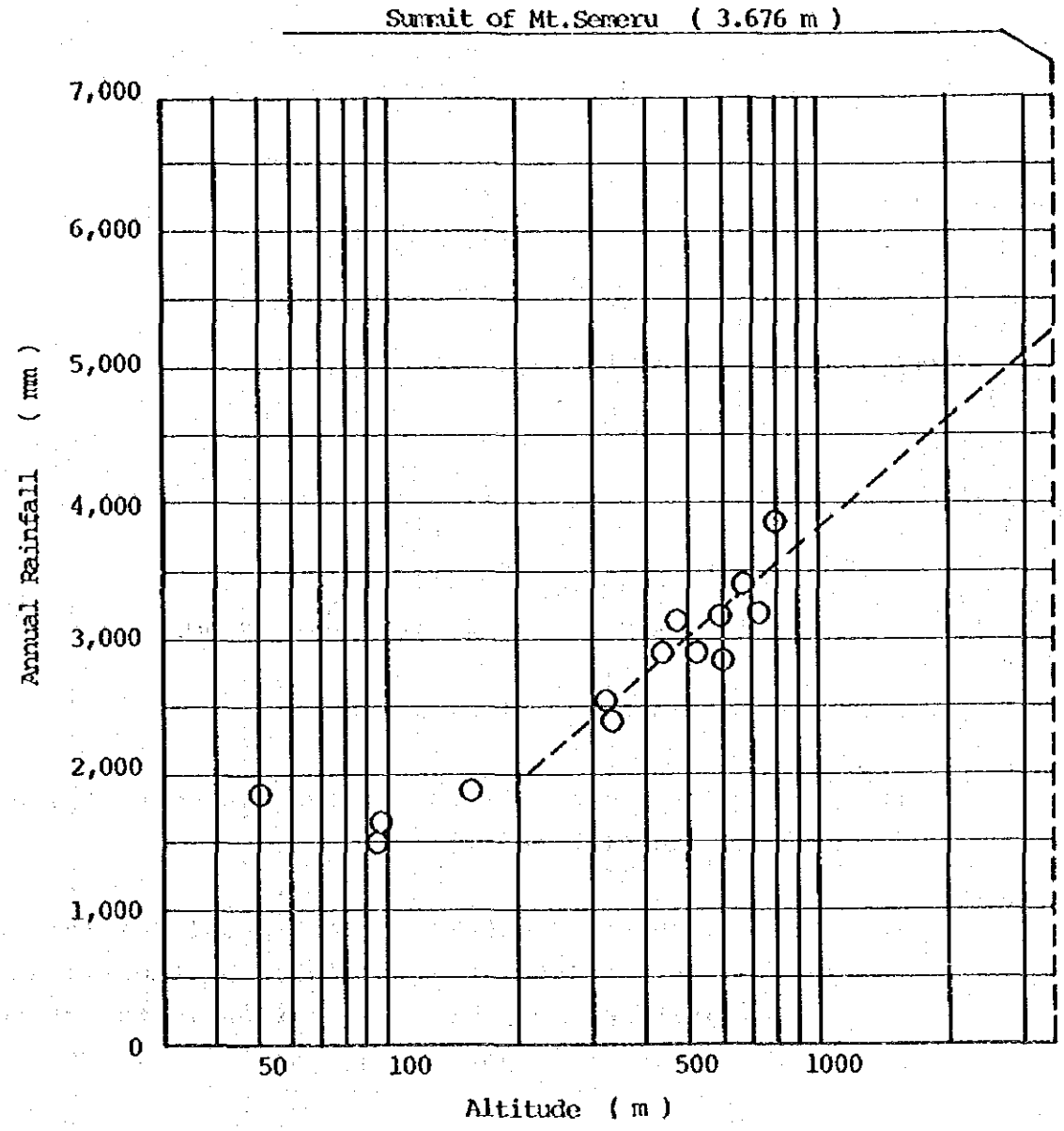


Fig.- 4.2 Relationship between Altitude and Annual Rainfall.

Rainfall Observation Station	Altitude(m)	Remakrs(s)
Lumajang	50	Representative Station in the plain area
Besuk Sat	795	Representative Station in the mountain area

(i) Lumajang : $\bar{R}$ = 1,870 mm
SD = 398 mm
C_f = 0.21

(ii) Besuk Sat: $\bar{R}$ = 3,800 mm
SD = 820 mm
C_f = 0.22

$\bar{R}$: Mean Annual Rainfall
SD: Standard Deviation
C_f: Fluctuation Coefficient (= SD/$\bar{R}$)

Fig.-4.3 indicates the following facts.

(i) A place of higher altitude shows a bigger fluctuation of annual rainfall.

(ii) The flucutuation coefficient of annual rainfall is constant regardless of altitude. In other words, the rainfall pattern of each station in the study area is uniform in any given year.

(3) Fluctuation of Monthly Rainfall

Fig.-4.4 shows the monthly rainfall pattern of two stations i.e, Lumajang and Besuk Sat.

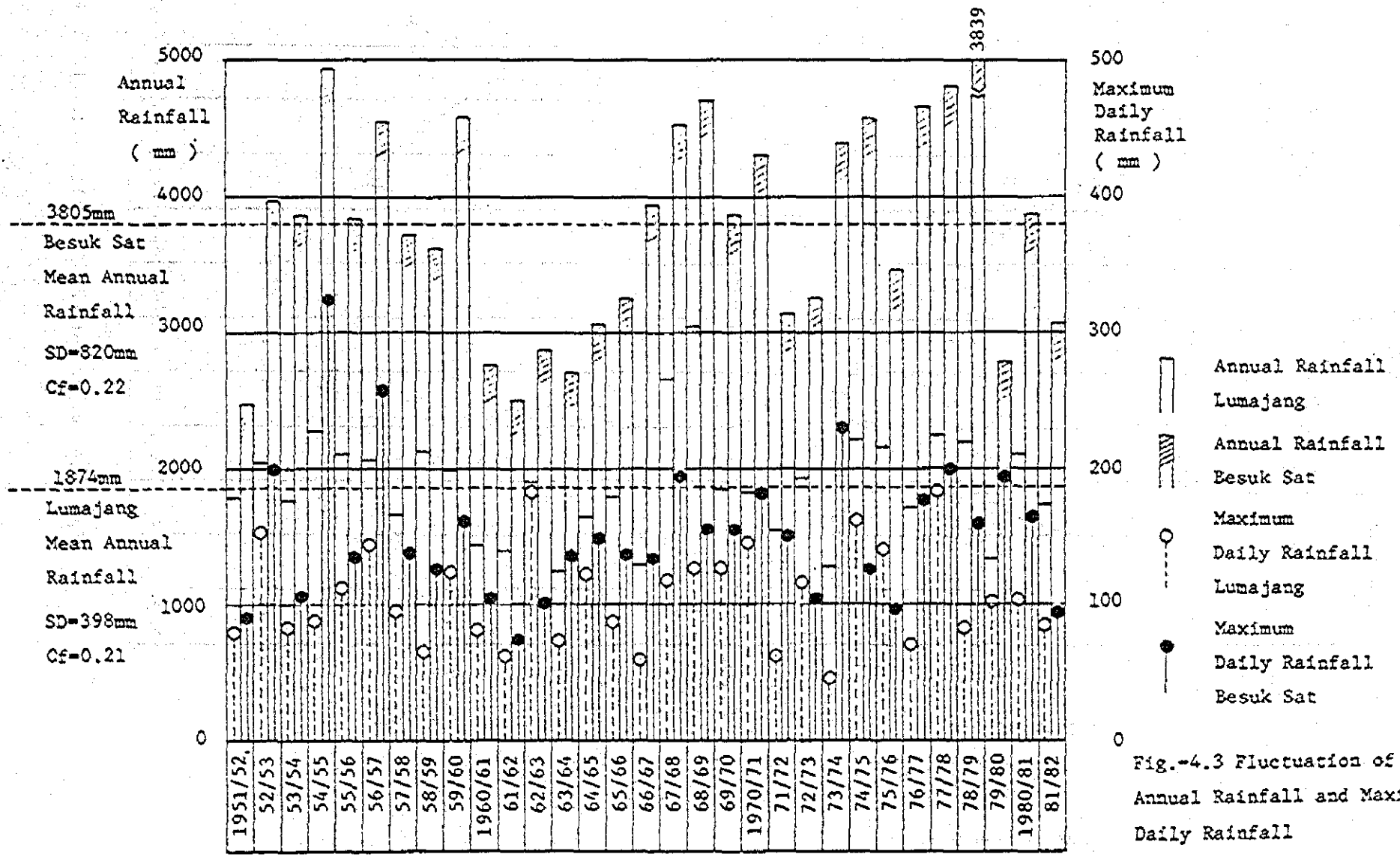


Fig.-4.3 Fluctuation of Annual Rainfall and Maximum Daily Rainfall

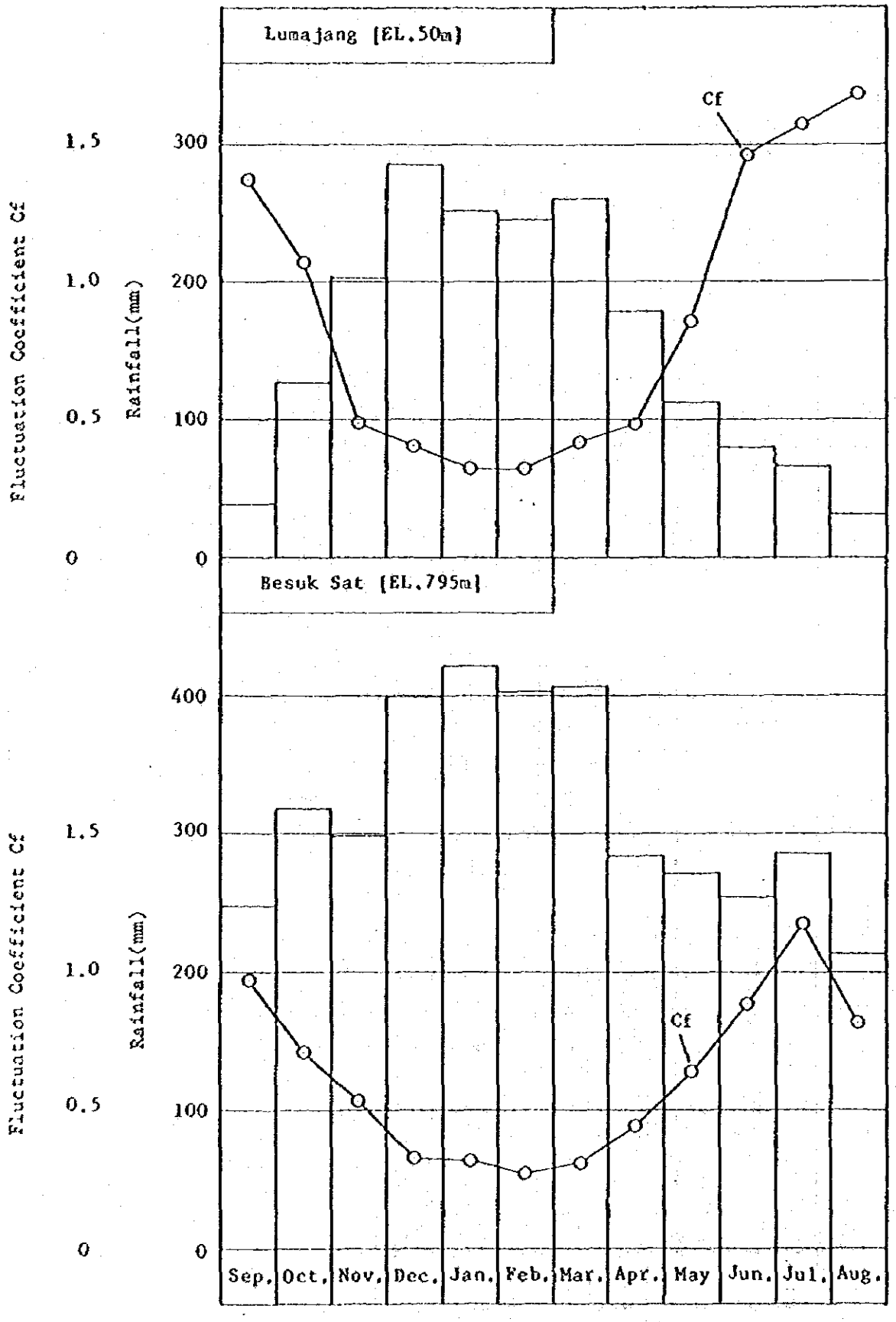


Fig. -4.4 Distribution of Monthly Rainfall

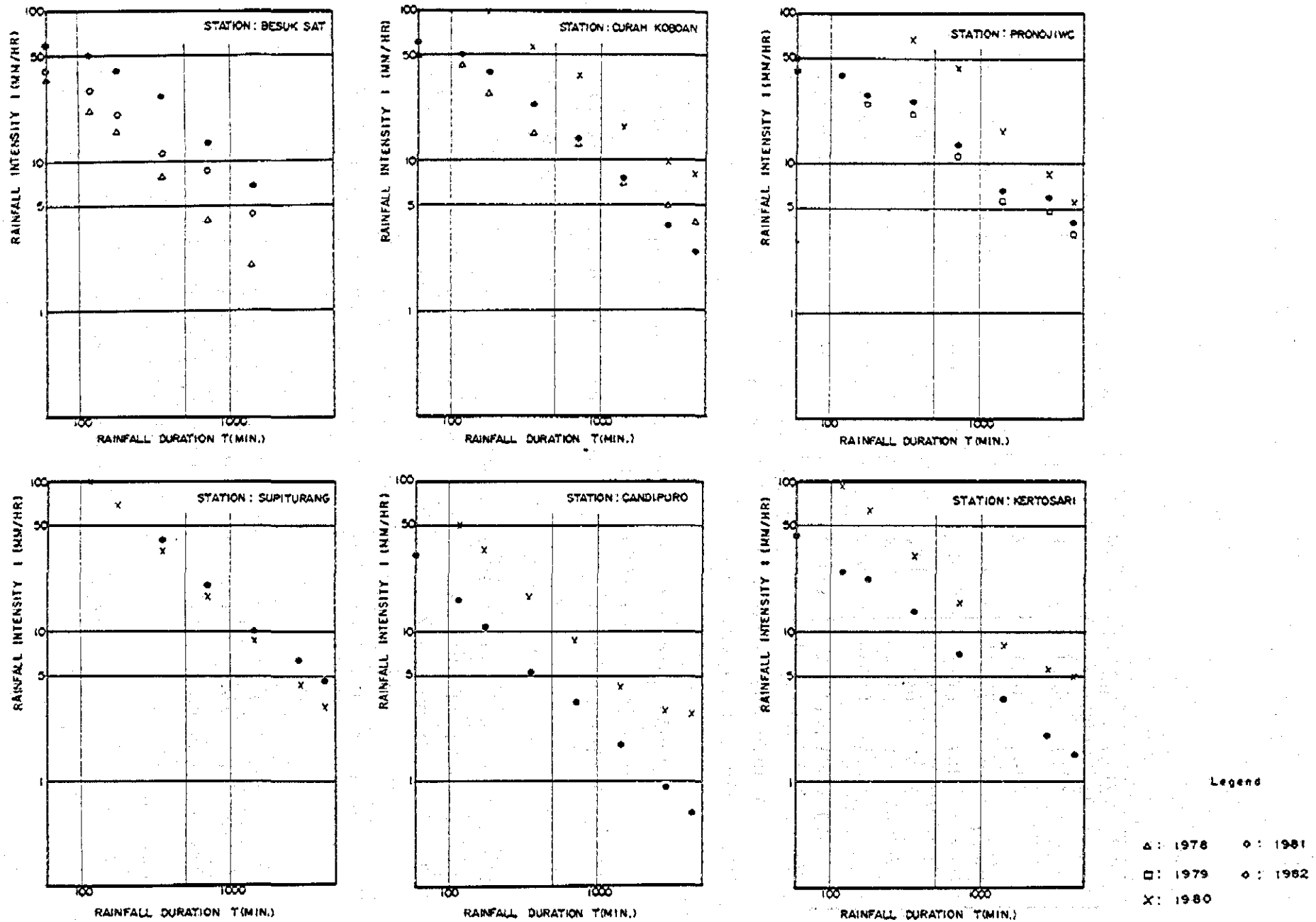


Fig.-4.5 Rainfall Intensity and Duration of Rainfall

The following observations were made.

(i) Monthly rainfall fluctuation is small and the rainfall is generally large in the mountain area. In other words, the distinction between dry and rainy seasons is not very clear as it rains all the year round.

(ii) In the plain area, the monthly rainfall fluctuation is large and, therefore, there is a clear distinction between the dry and rainy seasons. (From June to September expecially, the rainfall is small and the fluctuation coefficient is large at over 1.5.)

4.1.2 HOURLY RIANFALL

Six stations were selected for the purose of analysis from among the 15 stations listed in Table-2.1 (2) "List of Collected Rainfall Data (Automatic Type) and are shown in Table-4.2.

Table-4.2 Stations (Automatic Type) for Hourly Rainfall Analysis

Station No.	Name	EL. (m)	Available Data
34	Pronojiwo	600	1979 - 1982
36	Kertosari	345	1980 - 1982
37	Besuk Sat	775	1978 - 1982 (except 1980)
38	Curah Kobo'an	734	1978 - 1982
39	Candipuro	322	1979 - 1982
42	Supit Urang	675	1980 - 1982

Fig.-4.6 shows the relation between rainfall intensity and duration of rainfall in each year as a logarithmic graph.

As can be seen in Table-4.2, there are few hourly rainfall (automatic recording) observation stations and their period of data collection is short.

The debris flow which occured on May 14, 1981 was selected to understand the characteristics of hourly rainfall.

Fig.-4.6 shows the hourly rainfall on May 14, 1981 observed by six automatic rainfall recording stations in operation at that time. The daily rainfall at the same data, at all stations in the area, is shown in Fig.-4.7.

Based on these two figures, it can be said that the rainfall was concentrated for a few hours after 13:00 and that there were variations in the amount of local rainfall.

4.2 PROBABILITY ANALYSIS

4.2.1 SUMMARY

As Table-2.1 in Chapter 2 shows, there is little data for the hourly rainfall and as a result, it is difficult to conduct a probability analysis. For the daily rainfall, however, fourteen observation stations listed in Table-4.1 possess data for more than thirty years, which is enough for analytical purposes.

A probability calculation, therefore, is done by using the maximum annual daily rainfall data for 29 years (1951/52 - 1979/80) at these fourteen stations.

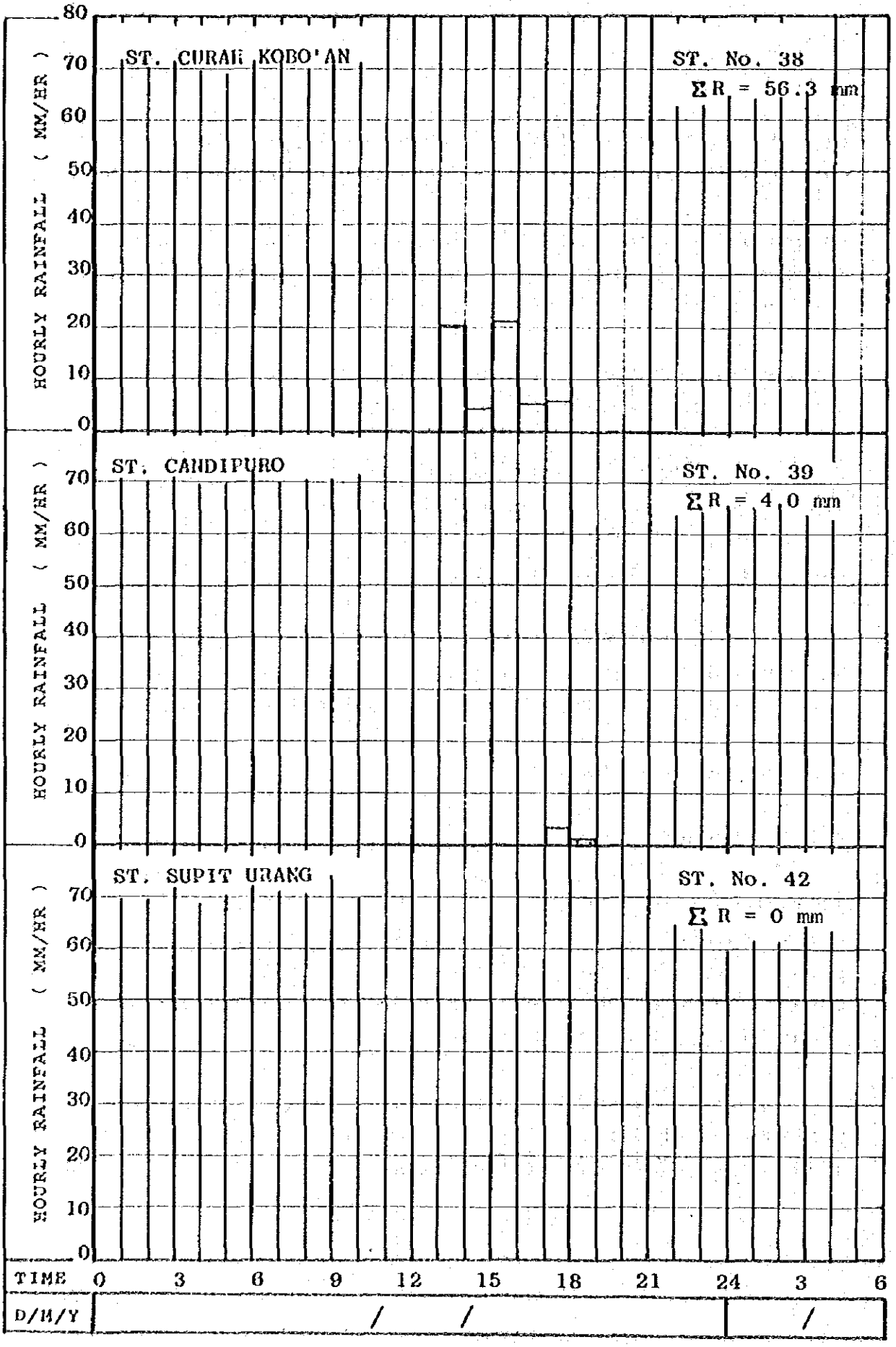


Fig.-4.6 (1) Rainfall on May 14, '81

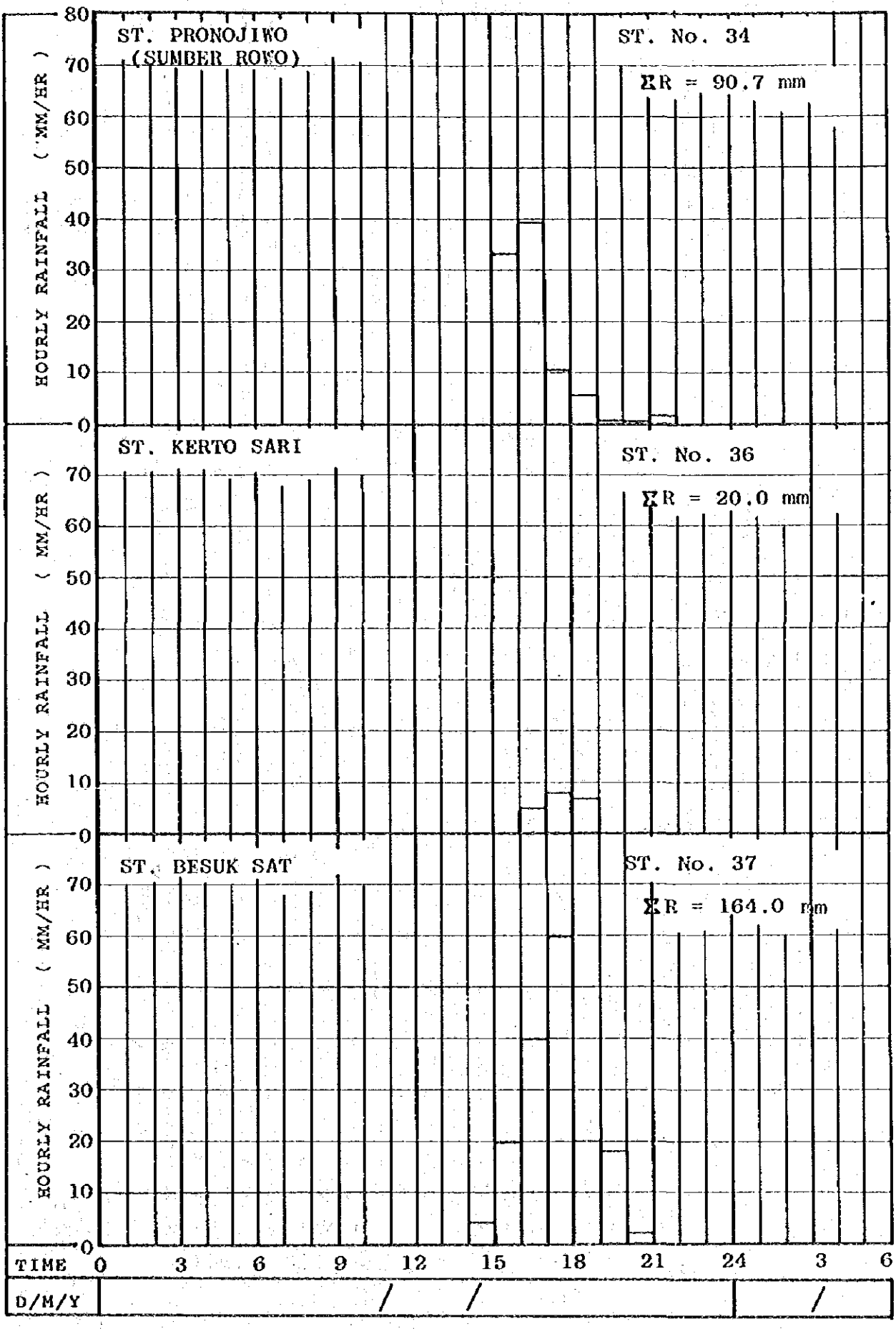
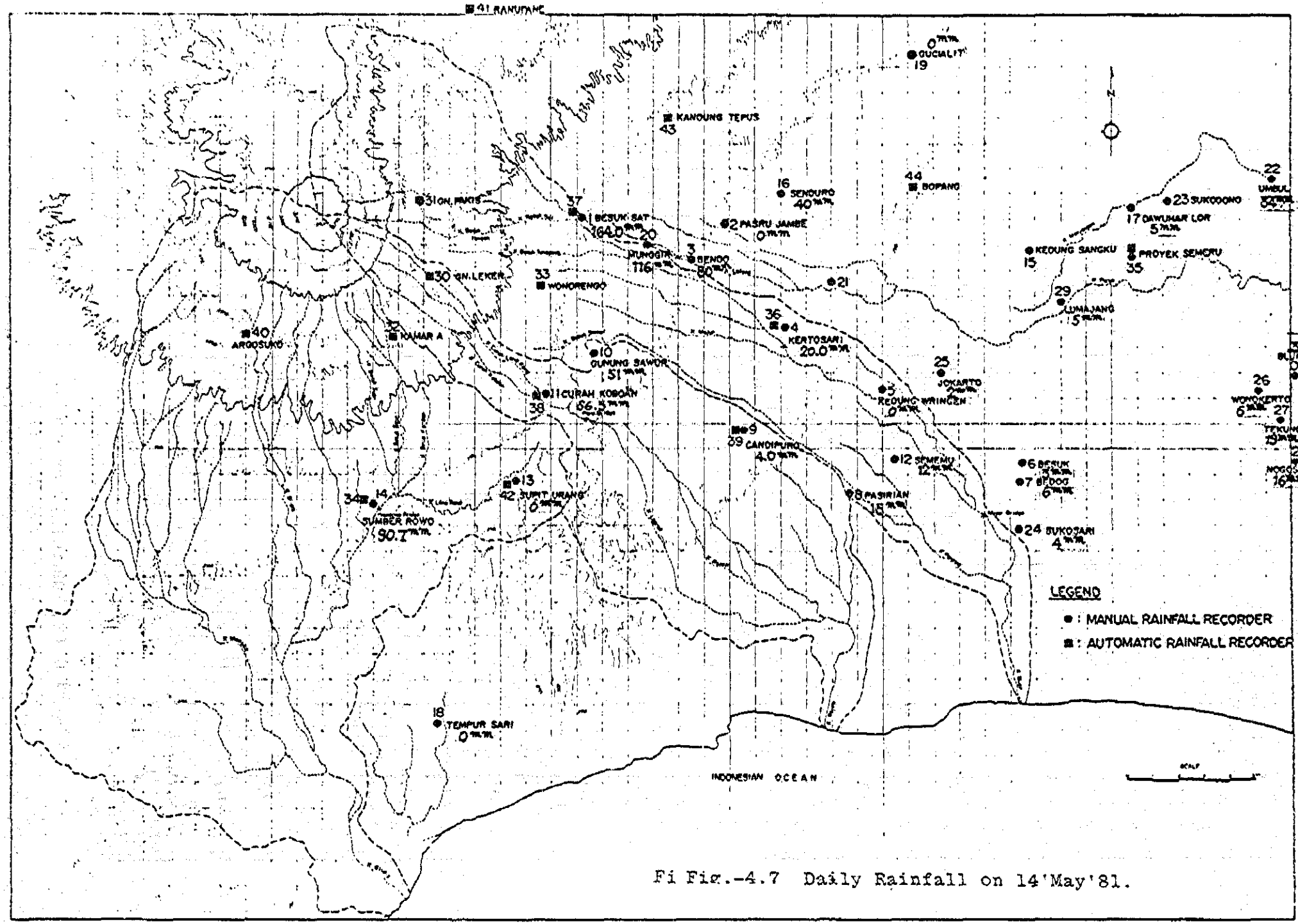


Fig.-4.6 (2) Rainfall on May 14, '81



Fi Fig.-4.7 Daily Rainfall on 14'May'81.

4.2.2 METHOD OF CALCULATION

The Iwai method, which is the standard method for probability calculations in Japan, is used here.

(i) Basic Equations

$$\begin{cases} P(x) = 1 - F(x) = \frac{1}{\sqrt{2\pi}} \cdot \int_u^{\infty} e^{-u^2/2} du = \frac{1}{\sqrt{\pi}} \cdot \int_{\xi}^{\infty} e^{-u^2/2} d\xi \\ \mu = a' . \log \frac{x + b}{x_0 + b} \quad \text{or} \quad \xi = a . \log \frac{x + b}{x_0 + b} \\ \log(x + b) = \log(x_0 + b) + \frac{1}{a'} . u = \log(x_0 + b) + \frac{1}{a} . \xi \\ a,\ a' > 0,\ x_0 > -b,\ -b < x < \infty \end{cases}$$

....(Eq.-4.1)

Here, x: Probable hydrometric volume

μ and ξ: Conversed values of x and standard regular variables

$F(x)$: Non-exceeding probability of x

$P(x)$: Exceeding probability of x

x_0, a, a', b: Constants, $a' \cdot \sqrt{2} . a$, $\mu = \sqrt{2} \cdot \xi$

(ii) Estimation of b

For the hydrometric volume x, its first approximate value (x_g) is given as follows:

$$x_g : \log x_g = \frac{1}{N} \sum_{i=1}^{N} \log xi \quad (N = \text{Number of data available years})$$

....(Eq.-4.2)

Then, all values so attained are put in order from the highest to the lowest.

The value b_s is given by the equation shown below, based on the value x_s, which is the value of S' turn from the highest value, the x_l which is the value of S' turn from the lowest and x_g.

$$b_s = \frac{x_l x_s - x_g^2}{2x_g - (x_s + x_l)} \quad (l = N - s + 1) \qquad \text{...(Eq.-4.3)}$$

Assuming $m \doteqdot \frac{N}{10}$, b is given by b_s $(s = 1, 2, \ldots, m)$

$$b = \frac{1}{m} \sum_{s=1}^{m} b_s \qquad \text{....(Eq.-4.4)}$$

(iii) Estimate of x_0 and $\frac{1}{a'}$

$$\log (x_0 + b) = \frac{1}{N} \sum_{i=1}^{N} \log (x_i + b)$$

$$\frac{1}{a'} = \sqrt{V} = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} \{\log (x_i + b) = \log (x_0 + b)\}^2}$$

$$= \sqrt{\frac{1}{N-1} \Sigma \{\log (x_i + b)\}^2 - \frac{N}{N-1} \{\log (x_0 + b)\}^2} \qquad \text{...(Eq.-4.5)}$$

4.2.3 PROBABILITY RAINFALL

The result of the probability calculation by the Iwai method is given in the Supplements: "Computing Out-puts" and "Plot Diagrams".

Fig.-4.8 gives a plot diagram of the Besuk Sat observation station as an example.

The maximum annual daily rainfall for fourteen stations to main probability years are tabulated in Table-4.3.

4.2.4 CORRELATION BETWEEN PROBABILITY DAILY RAINFALL AND ALTITUDE

The probability daily rainfall and altitude of each observation station are plotted on the full logarithmic graphic paper and approximate values are estimated by the method of least squares.

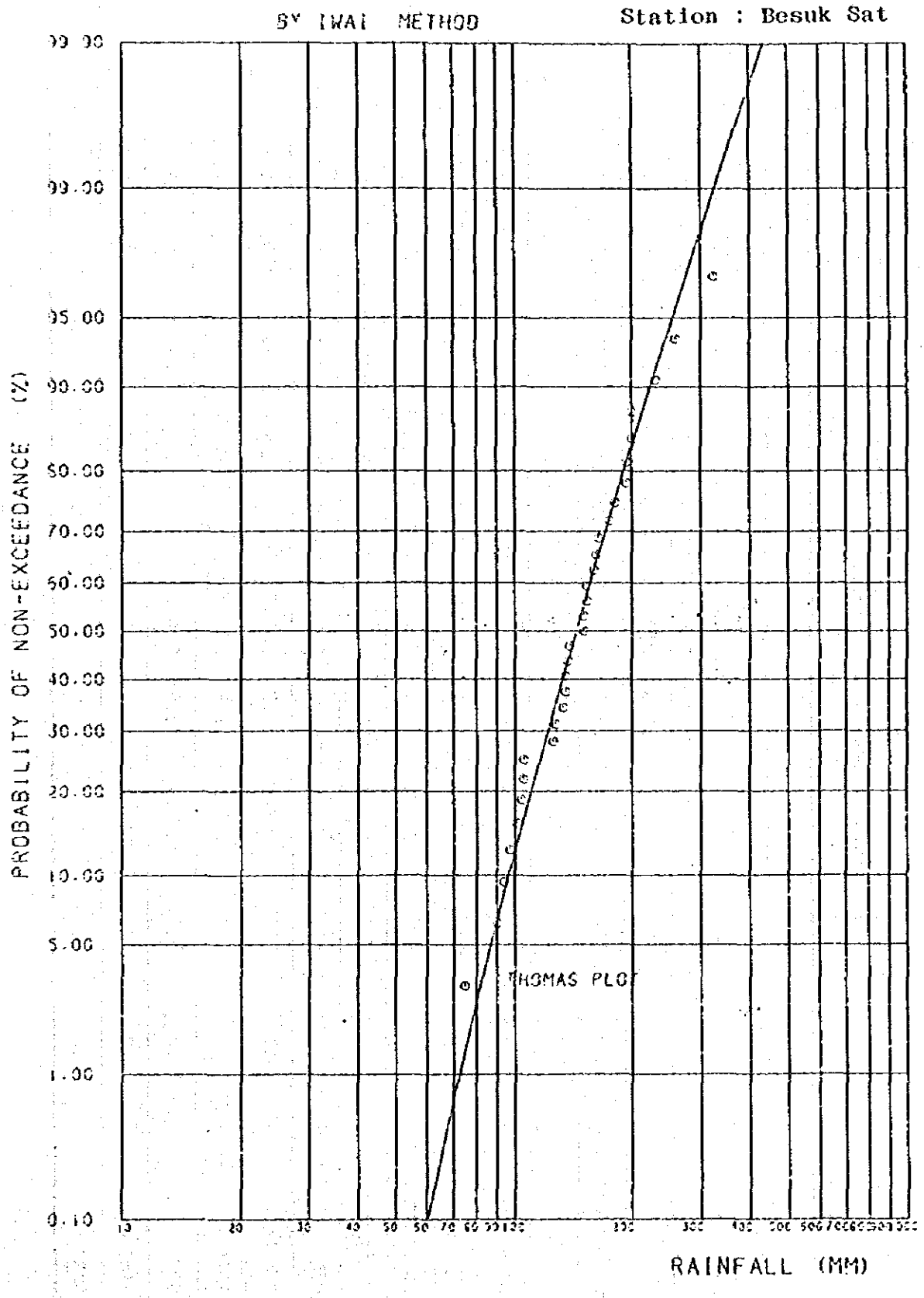


Fig.-4.8 Plot of Maximum Daily Rainfall

Table-4.3 Probable Daily Rainfall

R.O. Station	Station No.	El. (m)	Return Period (Year)							
			3	5	10	20	40	50	70	100
BESUK SAT	1	795	165.8	191.0	223.2	254.5	285.5	295.6	310.8	327.0
PASRUJAMBE	2	481	153.3	173.6	198.2	221.2	243.2	250.1	260.6	271.5
BENDO (SUMBERDUREN)	3	510	136.8	158.0	184.9	210.9	236.7	245.1	257.7	271.1
KERTOSARI	4	345	130.8	151.6	178.2	204.3	230.4	238.9	251.7	265.4
PASIRIAN	8	155	128.0	146.0	167.4	187.1	205.6	211.4	220.1	229.1
CANDIPURO	9	322	136.0	156.1	180.8	204.3	227.1	234.4	245.3	256.8
GUNUNG SAWUR	10	682	157.0	183.6	217.6	250.7	283.7	294.4	310.6	327.8
CURAH KOBO'AN	11	734	174.8	214.4	270.0	329.0	392.3	413.6	446.8	483.4
SENDURO	16	435	143.0	169.2	205.0	242.0	280.7	293.6	313.5	335.1
DAWUHAN LOR	17	97	103.8	116.3	131.5	145.8	159.6	164.0	170.6	177.5
GUCIALIT	19	600	140.5	159.8	183.8	206.0	227.4	234.2	244.4	255.1
MUNGGIR	20	600	157.9	182.9	214.5	245.1	275.4	285.2	299.9	315.6
LUMAJANG	29	50	119.9	136.7	156.9	175.4	192.9	198.4	206.6	215.2
SUKOSARI	24	93	95.9	111.1	129.3	147.3	164.3	169.7	177.9	186.5

Table-4.4 and Fig.-4.9 show the results of these estimation.

Table-4.4 Correlation between Probability Daily Rainfall and Altitude

Probability	Equation
1/3	$y = 52.602 \cdot x^{0.1657}$
1/5	$y = 58.479 \cdot x^{0.1723}$
1/10	$y = 61.094 \cdot x^{0.192}$
1/20	$y = 62.806 \cdot x^{0.210}$
1/40	$y = 66.834 \cdot x^{0.219}$
1/50	$y = 67.608 \cdot x^{0.2236}$
1/70	$y = 68.077 \cdot x^{0.231}$
1/100	$y = 68.391 \cdot x^{0.238}$

y = Probability Daily Rainfall Rday (mm)

x = Altitude El. (m)

4.3 CORRELATION ANALYSIS

The following correlations were examined by using the rainfall data of the eleven stations listed in Table-4.5.

(i) The correlation of daily rainfall (more than 50 mm/day) between these stations.

(ii) The correlation of annual rainfall between these stations.

Table-4.5 and Table-4.6 show the analysis results for the daily rainfall and the annual rainfall correlation respectively.

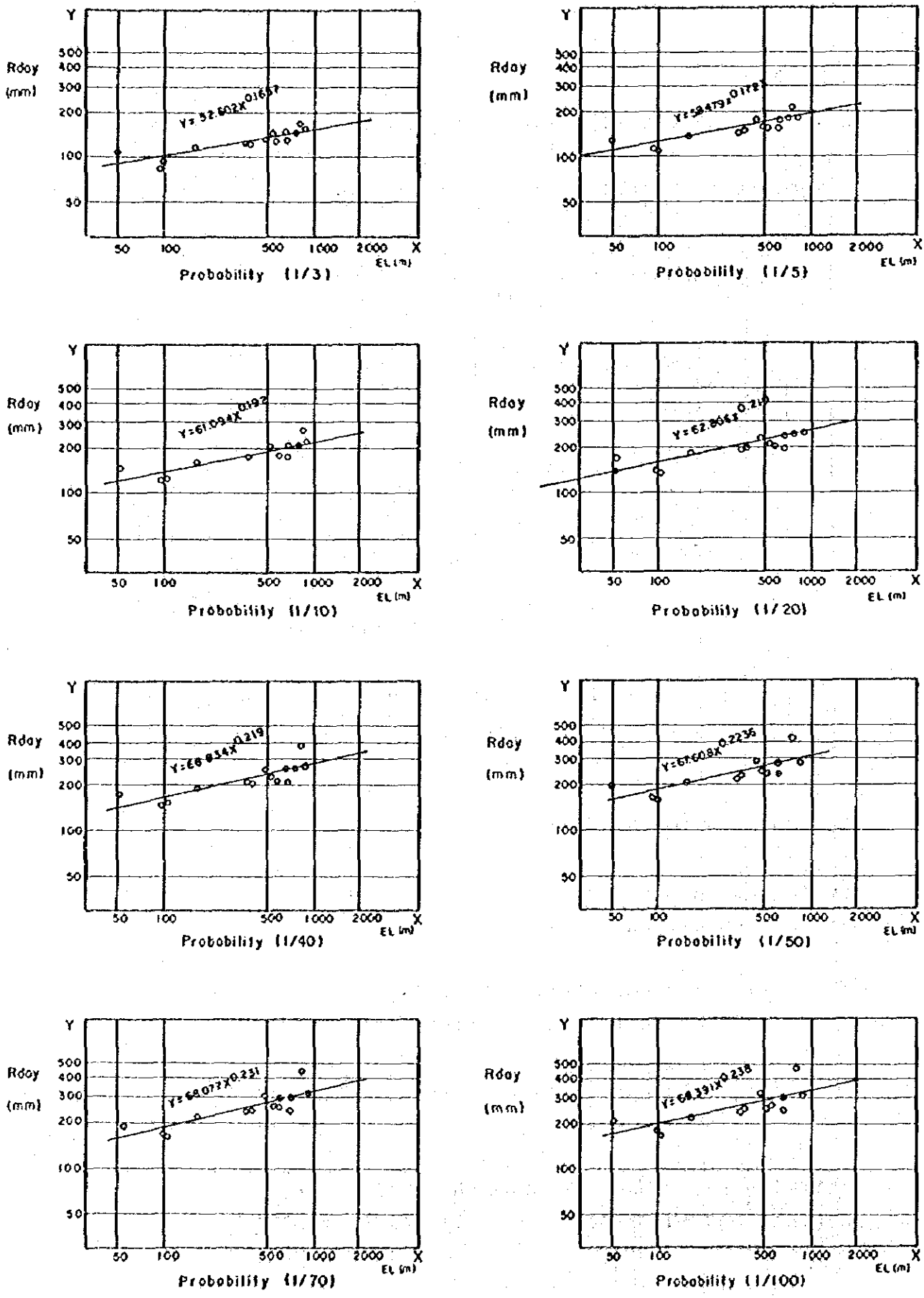


Fig-4.9 Relation between R_{day} (mm) and Elevation

Table-4.5 Correlation Analysis (Daily Rainfall > 50mm)

X \ Y	1 Besuk Sat 158	2 Kert Sari 160	3 Pasur Jambe 161	4 Sumber Duren 162	5 Curah Kobo'an 164A	6 Dawuhan Lor 183	7 Lum-Jang 185	8 Gunung Sawur 1888	9 Pasiri-an 189	10 Tempeh Kidul 190	11 Bulkon 224
Besuk Sat 158	(1) (2) (3) (4)	-0.36 40.99 0.033 (643)	0.168 40.09 0.161 (685)	0.281 30.05 0.275 (647)	0.230 36.98 0.269 (679)	0.467 48.69 0.364 (664)	0.388 49.74 0.344 (602)	0.090 53.72 0.037 (725)	-0.323 46.70 -0.285 (633)	-432 60.26 -0.367 (599)	-0.495 96.790 -0.874 (781)
Kerto Sari 160			0.152 56.75 0.160 (466)	0.032 58.255 0.035 (475)	0.008 66.84 0.010 (485)	0.473 60.42 0.419 (401)	-0.332 60.80 -0.341 (351)	0.001 65.50 0.001 (559)	-0.275 60.05 -0.284 (362)	-0.391 62.32 -0.392 (348)	-0.475 112.07 -1.042 (509)
Pasurjambe 161				0.363 34.83 0.367 (475)	0.074 54.03 0.091 (580)	-0.497 55.71 -0.420 (510)	-0.368 54.85 -0.361 (460)	0.130 52.86 0.142 (629)	-0.351 54.91 -0.336 (490)	-0.418 56.26 -0.387 (447)	-0.475 104.60 -0.938 (623)
Sumberduren 162					0.159 52.49 0.200 (543)	-0.551 58.90 -0.468 (485)	-0.432 59.65 -0.429 (435)	0.227 52.11 0.249 (584)	-0.391 58.95 -0.386 (458)	-0.445 59.52 -0.434 (420)	-0.502 106.44 -1.011 (598)
Curahkobo'an 164						-0.476 49.08 -0.326 (521)	-0.358 49.98 -0.274 (449)	0.443 43.11 0.387 (529)	-0.243 46.80 -0.193 (481)	-0.438 53.54 -0.329 (450)	-0.451 95.22 -0.737 (621)
Dawuhanlor 183							0.223 64.902 -0.267 (283)	-0.500 80.00 -0.642 (592)	-0.685 76.15 -0.693 (344)	-0.499 69.66 -0.562 (322)	-0.402 112.44 -1.036 (465)
Lumajang 185								-0.388 78.25 -0.441 (524)	0.760 70.16 -0.464 (282)	-0.362 65.65 -0.378 (284)	-0.444 117.54 -1.018 (415)
Gunungsawur 188									-0.292 49.28 -0.260 (548)	-0.455 53.98 -0.384 (533)	-0.478 97.73 -0.85 (699)
Pasirian 189										-0.299 65.59 -0.288 (282)	-0.363 109.95 -0.633 (445)
Tempehtengah 190											-0.333 106.97 -0.779 (427)
Blukon 224											

Notes: (1) = Correlation Coefficient
(2) = a (Y = a + b)
(3) = b
(4) = Number of Data

Table-4. 6 Correlation Analysis (Annual Rainfall)

X \ Y	1 Besuk Sat 158	2 Kert Sari 160	3 Pasur Jambe 161	4 Sumber Duren 162	5 Curah Kobo'an 164A	6 Dawuhan Lor 183	7 Lum-Jang 185	8 Gunung Sawur 188B	9 Pasiri-an 189	10 Tempeh Kidul 190	11 Bulkon 224
Besuk Sat 158	(1) (2) (3) (4)	0.720 538.51 0.519 23	0.807 609.33 0.648 24	0.843 64.19 0.733 27	0.743 780.04 0.628 24	0.318 913.62 0.193 27	0.608 975.31 0.229 14	0.770 956.61 0.765 26	0.628 629.53 0.316 26	0.773 1026.40 0.202 16	0.198 372.08 0.512 25
Kerto Sari 160	5 10.0km		0.833 609.33 0.872 30	0.274 579.40 0.939 23	0.735 1293.82 0.768 20	0.613 330.46 0.525 23	0.668 1026.63 0.316 11	0.750 728.80 1.058 22	0.694 763.13 0.443 22	0.285 1472.85 0.137 14	0.373 -1224.08 1.399 22
Pasurjambe 161	6.9	3.9		0.802 83.10 0.899 25	0.891 718.71 0.812 21	0.643 252.23 0.445 25	0.660 945.62 0.293 14	0.897 36.43 1.094 24	0.658 546.85 0.418 24	0.740 558.65 0.358 13	0.370 -1544.05 1.256 23
Sumberduren 162	5.3	4.6	2.9		0.824 990.78 0.754 24	0.389 891.02 0.264 29	0.462 1283.94 0.202 14	0.773 893.31 0.873 28	0.669 805.52 0.369 28	0.509 1013.92 0.269 17	0.222 407.94 0.659 27
Curahkobo'an 164	7.4	10.0	10.0	7.1		0.440 441.69 0.378 24	0.622 780.30 0.334 13	0.804 20.75 1.071 23	0.676 411.17 0.951 24	0.467 982.32 0.263 14	0.159 495.61 0.617 22
Dawuhanlor 183	22.1	14.7	15.4	17.7	24.3		0.836 829.01 0.602 14	0.458 2142.50 0.779 28	0.645 1041.73 0.508 28	0.354 1398.23 0.230 17	0.245 495.61 0.617 22
Lumajang 185	24.5	16.9	18.7	20.7	26.0	6.6		0.688 564.23 1.681 16	0.759 37.09 1.004 13	0.908 -423.07 1.092 8	0.440 -3587.20 1.248 27
Gunungsawur 188	7.6	7.9	9.9	5.0	2.1	22.4	26.4		0.801 932.01 0.281 27	0.418 1167.01 0.177 16	0.405 -1501.28 1.114 13
Pasirian 189	16.4	7.9	11.7	11.7	12.9	17.4	16.3	11.9		0.628 765.67 0.540 17	0.356 -314.02 1.398 26
Tempehtengah 190	22.4	12.5	16.0	17.0	21.0	12.5	9.0	19.3	8.6		0.393 -2164.03 2.657 17
Blukon 224	12.9	22.1	25.7	26.5	33.4	11.9	6.1	30.1	20.9	8.7	

Notes: (1) = Correlation Coefficient
(2) = a (Y = a + bx)
(3) = b
(4) = Number of Data
(5) = Distance between Stations

Conclusions given by these results are as follows:

(i) There is no daily rainfall (more than 50 mm/day) correlation between the stations; and

(ii) There is a relatively strong correlation in the annual rainfall data of these stations.

Fig.-4.10 examines the relation of a correlation coefficient of annual rainfall to the distance between stations. There is a tendency that a correlation coefficient is in reverse relation to the distance.

4.4 CHARACTERISTICS OF RAINFALL

Characteristics of rainfall in the study area are described below based on study results reported 4.1 through 4.3.

(i) Correlation exists between the annual rainfall and the altitude. The higher the altitude is, the larger the rainfall is; 2,000 mm at EL. 200m, 3,000 mm at EL. 500 m and 4,000 m at EL. 1,000 m.

(ii) In the Mt. Semeru mountain range, a distinction between a rainy and a dry season is not so clear that there is much rain through out the year.

(iii) In the plain area to the south of study area, a distinction between a rainy and a dry season is so clear that it rains little for four months from June to September.

(iv) Duration of rain is generally short and concentrates in few hours after one o'clock in the afternoon.

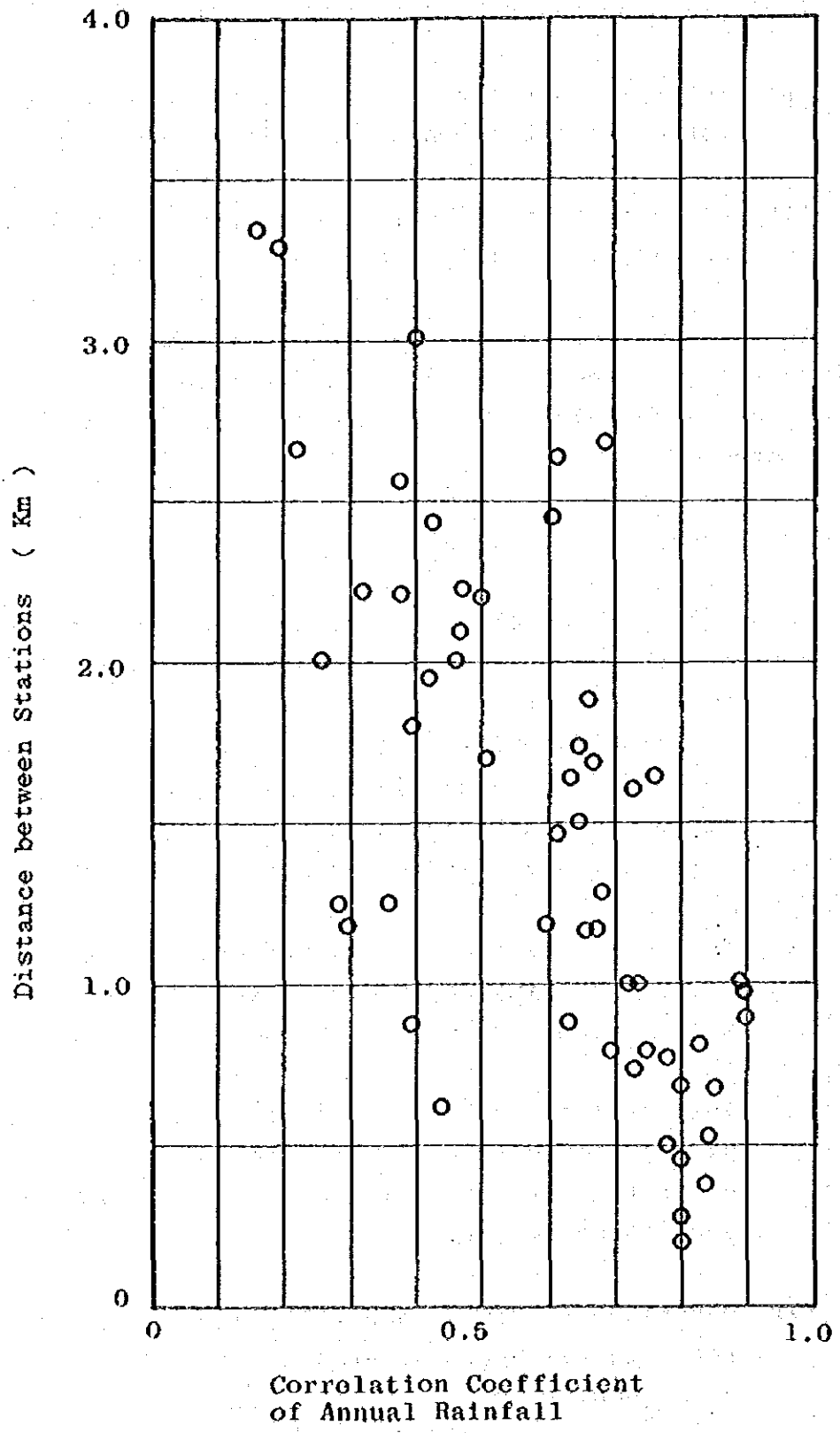


Fig.-4.10 Distance between Stations and Correlation Coefficient of Annual Rainfall

(v) Regional as well as time variations of rain can be arrested.

5. FLOOD STUDY

Flood runoff is defined as a process in which much rainfall in the catchment area will be changed, over a period of time, being to flow due to gravity. Suppose rainfall (or hyetograph) is regarded as the input, then the discharge (or hydrograph) can be considered as the output from a system called a catchment area. Catching this output at designated reference points with the help of a suitable runoff model, is the main target of this study, in order to establish a volcanic debris control plan or to accomplish a feasibility study.

5.1 FLOOD RUNOFF MODEL

5.1.1 SELECTION OF THE MODEL

(1) Preconditions for Selection of the Model

The followings were considered carefully when selecting the flood run-off model to be applied to this study.

① Usefulness of the outcome from the model.

② Dominant factor in flood runoff process.

③ Existence of enough data to calibrate a model.

④ Characteristics of the catchment area.

(2) Select Model

As the flood runoff model is to be calibrated with limited data, the Kinematic Wave Method was selected considering the characteristics of flood and catchment area.

5.1.2 DESCRIPTION OF THE MODEL

(1) Division of the Study Area

For the purpose of flood study, the study area is divided, into three hydrological units; namely: Kali Mujur basin (Unit-M); Kali Rejali basin (Unit-R) and Kali Glidik basin (Unit-G), as shown in Fig.-5.1. Each unit is composed of several blocks in accordance with the river channel systems, as shown in Fig.-5.2.

Discharge reference points of each unit are shown as follows. These points are located at the confluences of the main rivers or at significant points in view of flood and sediment control planning.

Unit -M: K. Mujur Basin

- Confluence point of K. Besuk Tompe and K. Besuk Sat (A = 56.4 km^2)
- Confluence point of K. Besuk Sat and K. Besuk Tungen (A = 68.3 km^2)
- Confluence point of K. Besuk Tungen and K. Mujur (A = 89.7 km^2)
- Mujur Bridge (A = 125.7 km^2)
- Confluence point of K. Mujur and K. Pancing (A = 164.7 km^2)
- River Mouth (A = 170.6 km^2)

Unit-R: K. Rejali Basin

- Confluence point of K. Curah Lengkong and K. Besuk Kobo'an (A = 22.9 km^2)
- K. Leprak Check Dam No. 1 (A = 27.6 km^2), 500 m downstream from Perok Bridge
- Confluence point of K. Legoyo and K. Rejali (A = 123.9 km^2)
- River mouth (A = 131.8 km^2)

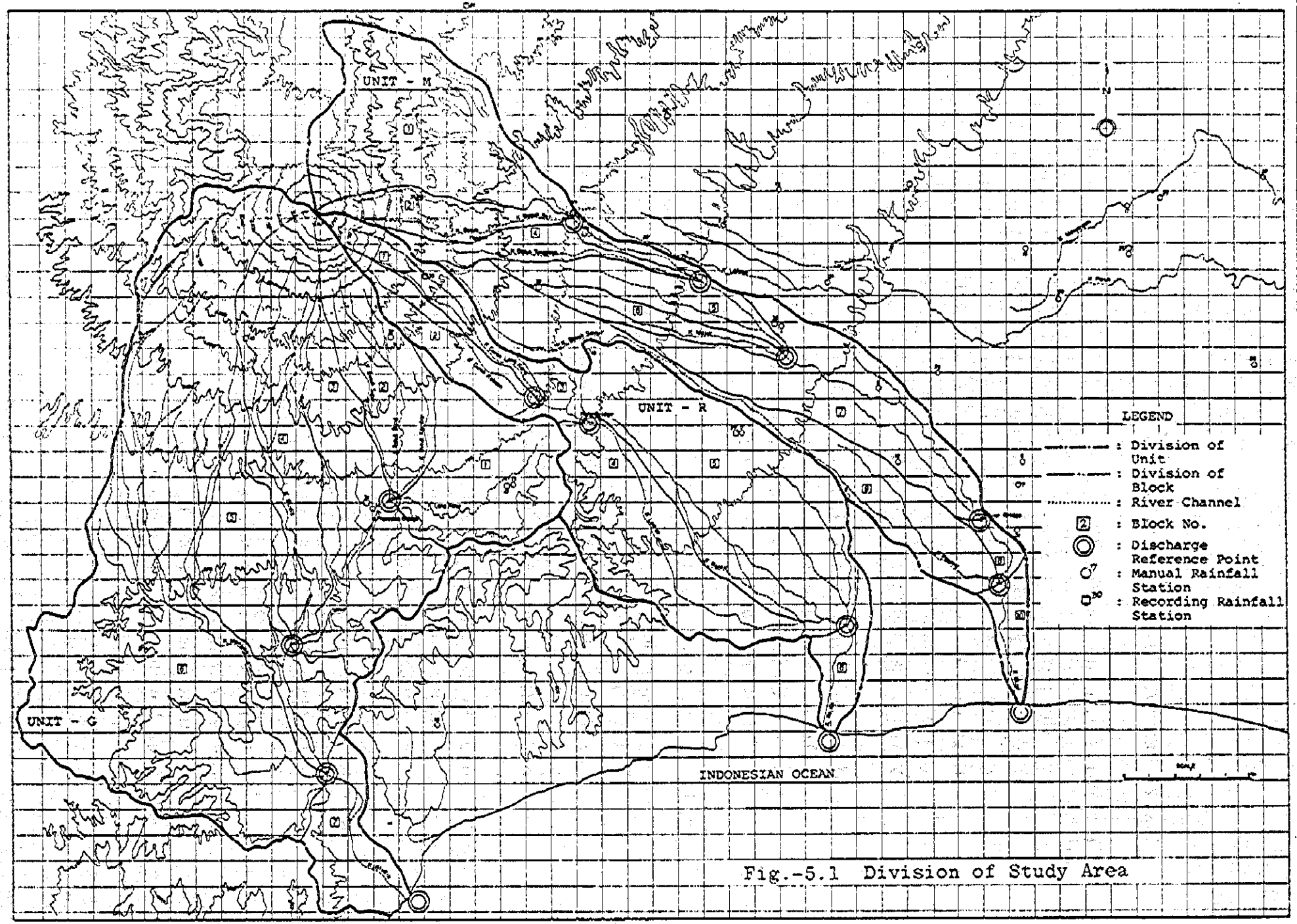


Fig.-5.1 Division of Study Area

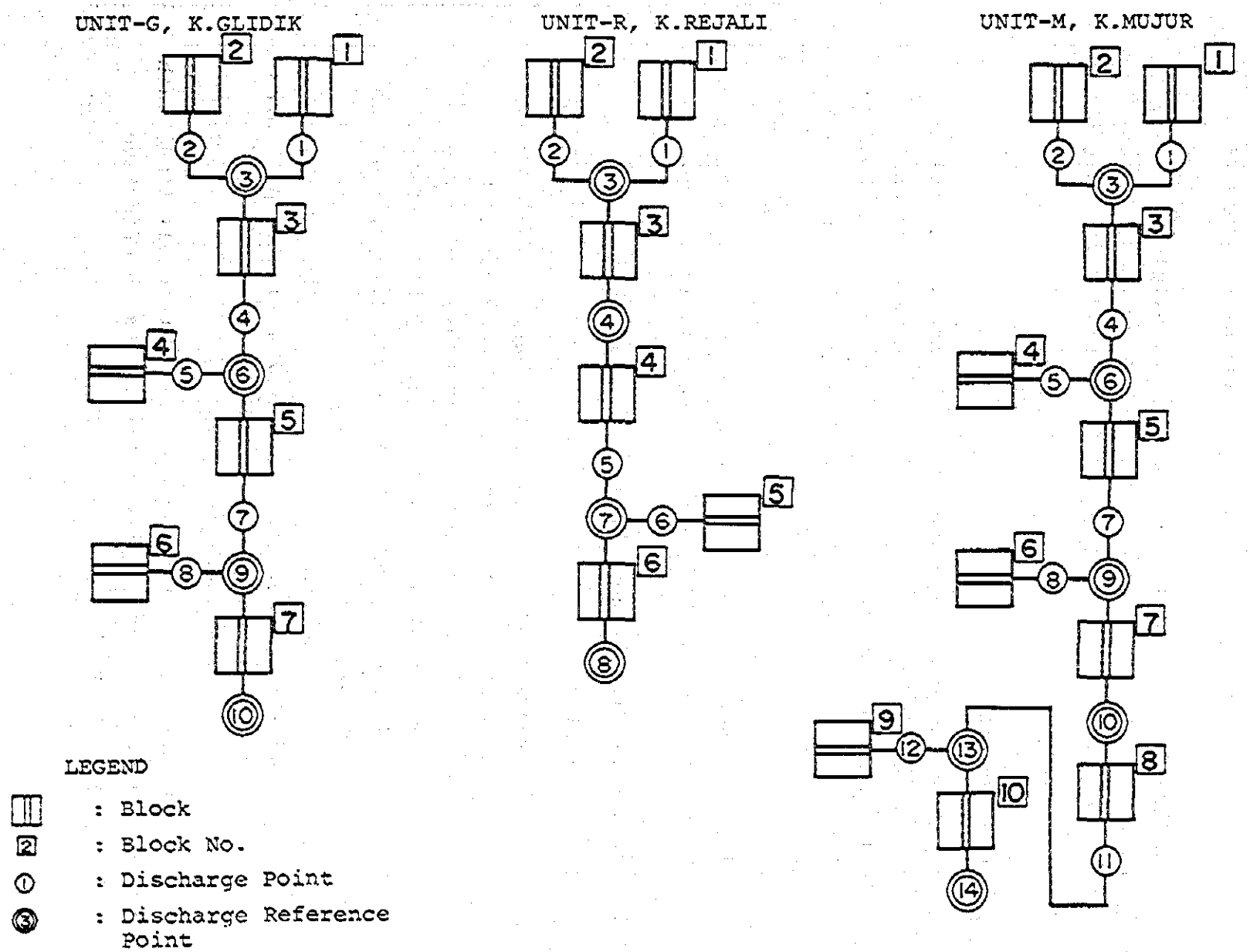


Fig.-5.2 Units and Blocks for Flood Runoff Model

Unit-G: K. Glidik

- Confluence point of K. Besuk Bang and K. Lengkong (A = 54.3 km^2)
- Confluence point of K. Lengkong and K. Glidik (A = 129.4 km^2)
- Confluence point of K. Monjng and K. Glidik (A = 310.0 km^2)
- River mouth (A = 326.3 km^2)

(3) Input Rainfall System

For flood computation, hyetographic data is essential. The hyetographic mean rainfall of each block or unit is calculated by applying the Thiessen Method with the data of the rainfall stations distributed in or near the study area.

Fig.-3.1 shows a Thiessen polygon of the study area, and the Thiessen coefficient is compliled in Table-5.1.

(4) Outline of Flood Runoff Model

(a) Characteristics of the Model

The model adopts the specific characteristic curve method, showing the flow movement by using the formula for continuity and movement, for discharge computation by setting up several parameters established through such data as geomorphology, land use and channel condition.

In addition, the slope and channel flow is presented as Kinematic waves.

Further, to depict the process of rainfall loss, both by time and space, the model adopts an effective rainfall system.

Table-5.1 List of Thiessen Coefficient

BASIN	BLOCK & Discharge Reference Point	AREA(km²)	Rainfall Observation Station																				
			3	5	7	8	10	12	18	20	24	30	31	32	33	34	36	37	38	39	40	41	42
			162	185	190B	189	185B		167A			I	II	III	IV	V	VI	VII	VIII	X	XI	XII	XIII
K. MUJUR	1	45.²											0.64					0.10				0.26	
	2	11.³										0.06	0.71		0.03			0.20					
	③	56.⁵										0.01	0.65		0.01			0.12				0.21	
	3	3.⁶	0.30							0.23								0.47					
	④	59.⁸	0.02							0.01		0.01	0.61		0.01			0.14				0.20	
	4	8.⁹	0.11							0.09		0.26	0.02		0.26			0.26					
	⑥	68.³	0.03							0.02		0.04	0.55		0.04			0.15				0.17	
	5	13.⁹	0.30							0.22					0.23		0.22	0.03					
	⑦	82.¹	0.07							0.06		0.04	0.45		0.07		0.04	0.13				0.14	
	6	7.³	0.23				0.40			0.03					0.21		0.13						
	⑨	89.¹	0.09				0.03			0.05		0.03	0.42		0.08		0.04	0.12				0.14	
	7	36.⁶	0.01	0.30	0.04		0.04	0.22			0.02						0.25			0.12			
	⑩	125.³	0.07	0.08	0.01		0.04	0.06		0.04	0.01	0.02	0.30		0.06		0.10	0.09		0.03		0.09	
	8	2.⁸									1.00												
	⑪	128.³	0.06	0.08	0.01		0.04	0.06		0.04	0.03	0.02	0.30		0.06		0.10	0.08		0.03		0.09	
	9	36.²		0.01		0.18	0.13	0.17			0.15	0.04			0.20					0.12			
	⑬	164.⁷	0.05	0.06	0.01	0.04	0.06	0.08		0.03	0.05	0.03	0.23		0.09		0.08	0.07		0.05		0.07	
	10	5.⁹									1.00												
	⑭	170.⁸	0.05	0.06	0.01	0.04	0.05	0.08		0.03	0.09	0.03	0.23		0.08		0.07	0.06		0.05		0.07	
K. REJALI	1	10.¹										0.59	0.16		0.07				0.18				
	2	12.⁶										0.31		0.39					0.30				
	③	22.⁴										0.44	0.07	0.21	0.03				0.25				
	3	4.⁷					0.13												0.87				
	④	27.⁶					0.02					0.36	0.06	0.18	0.03				0.35				
	4	36.⁶				0.16													0.12	0.36			0.36
	⑤	63.⁸				0.09	0.01					0.16	0.03	0.08	0.01				0.22	0.20			0.20
	5	60.³				0.39	0.15												0.01	0.45			
	⑦	123.⁹				0.23	0.08					0.08	0.01	0.04	0.01				0.12	0.32			0.11
	6	7.⁹				1.00																	
	⑧	131.⁸				0.28	0.07					0.08	0.01	0.04	0.01				0.11	0.30			0.10
K. GLIDIC	1	30.⁶												0.06		0.11			0.16				0.67
	2	23.⁹										0.02	0.04	0.69		0.23							0.02
	③	54.³										0.01	0.02	0.34		0.16			0.09				0.38
	3	39.⁹							0.10					0.09		0.72					0.08		0.01
	④	93.⁹							0.04			0.01	0.01	0.24		0.39			0.05		0.03		0.23
	4	36.¹										0.01	0.02	0.01		0.41					0.55		
	⑥	129.⁵							0.03			0.01	0.01	0.17		0.40			0.04		0.18		0.16
	5	33.²							0.32			0.10				0.58							
	⑦	162.⁹							0.09			0.02	0.01	0.14		0.44			0.03		0.14		0.13
	6	147.⁴							0.33				0.01			0.28					0.38		
	⑨	310.⁶							0.20			0.01	0.01	0.07		0.36			0.02		0.26		0.07
	7	16.³							1.00														
	⑩	326.³							0.24			0.01	0.01	0.07		0.34			0.02		0.25		0.06

(b) Composition of the Model

Each block is composed of the following systems.

① S1: Slope System

The amount of effective rainfall, rainfall loss and surface run-off at the slope are sought. This system is composed of the following two subsystems.

- S11: Effective Rainfall System
  Rainfall is divided into run-off and rainfall loss.

- S12: Slope Surface Flow System
  The run-off amount at the sloping surface downstream end of each block is calculated by using:
  . Effective rainfall, as defined in S11.
  . The specific characteristic curve method that uses the Kinematic wave method, based on the manning equation and the continuity formula.

② S2: Channel System

The movement of the channel water input from the upper reaches and the sloping surfaces is calculated by the specific characteristic curve method, as for the slope surface flow system and the out flow from the lower reaches is thus gained.

(c) Composition of Computer Program

The computer program is composed as follows.

Sub-program - 1:	Computation of the mean hourly rainfall amount of each discharge area.
Sub-program - 2:	Computation of effective rainfall at each block slope.
Main-program :	Computation of runoff amount at each discharge reference point.

The variables and parameters used in the above computer program are shown in Table-5.2.

(4) Effective Rainfall System

Effective rainfall is sought by the following formula, as a function of accumulating rainfall amount.

$$R_{e(i)} = R_{(i)} - R_{loss(i)}$$

$$R_{(i)} = R_{(i)} - R_{(i-1)}$$

$$R_{loss(i)} = R_{loss(i)} - R_{loss(i-1)}$$

$$R_{loss(i)} = R_{(i)} - (R_{(i)})$$

Table-5.2 Variables and Parameters for Flood Runoff Model

Variable or Parameter	Sign	Unit	Description
	(Subroutin-1 : Mean Hourly Rainfall)		
Input Variable	ri	mm/h	Hourly Rainfall
Parameters	Ct	-	Thiessen Coefficient
	Lsl	m	Left Slope Length
	Lsr	m	Right Slope Length
	Lc	m	Channel Length
Output Variable	r	mm/h	Mean Hourly Rainfall
	(Subroutin-2 : Effective Rainfall)		
Input Variable	r	mm/h	Mean Hourly Rainfall
Parameters	Rsa	mm	Saturated Rainfall
	Rlsa	mm	Saturated Loss Rainfall
Output Variable	re	mm/h	Effective Rainfall
	(Mainroutin : Discharge)		
	- Slope Surface Flow -		
Input Variable	re	mm/h	Effective Rainfall
Parameters	Ksl	-	Left Slope Constant
	Psl	-	Left Slope Constant
	Ksr	-	Right Slope Constant
	Psr	-	Right Slope Constant
	Lsl	m	Left Slope Length
	Lsr	m	Right Slope Length
Oupput Variable	qs	m3/s.m	Slope Discharge /m
	- Channel Surface Flow -		
Input Variable	Qc	m3/s	Channel Discharge
	qs	m3/s.m	Slope Discharge /m
Parameters	kc	-	Channel Constant
	Pc	-	Channel Constant
	Lc	m	Channel Length
Output Variable	Qc	m3/s	Channel Discharge

where,

$R_{e(i)}$: Effective rainfall at time i
$R_{(i)}$: Rainfall at time i
$R_{loss(i)}$: Rainfall loss at time i
$R_{(i)}$: Total rainfall until time i
$R_{loss(i)}$: Total rainfall loss until time i

α : Const. ($= \frac{1}{(R_{sa})^{\beta-1}}$)

β : Const. ($= \frac{R_{sa}}{R_{sa} - R_{esa}}$)

R_{sa} : Saturated rainfall amount
R_{esa} : Saturated loss rainfall amount

Fig.-5.3 shows an example of total rainfall loss usually employed in Japan.

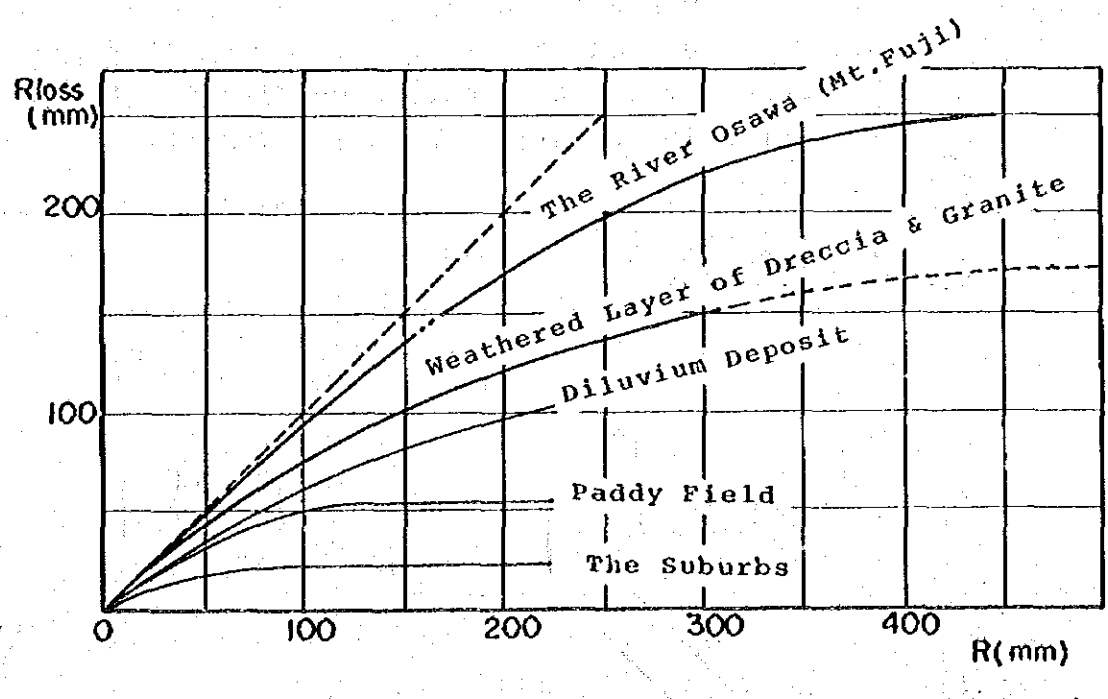


Fig.-5.3 Correlation between Total Rainfall (Σ R) and Total Rainfall loss (Σ Rloss)

(5) Slope Surface Flow System

This system examines hydrologically the downflow phenomenon of rainwater over the sloping surface of a partitioned river basin (partitioned in blocks), employing the current movement equation and the continuity formula. Here, the input will be the above-mentioned effective rainfall, and the run-off amount at the downstream end of the slopes will be obtained as output.

The formula of continuity and movement of the current, when the rainwater flowing down the sloping surfaces is assumed to be transmitted in the form of a Kinematic wave, can be expressed as follows: (See Fig.-5.4)

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = \alpha r e \qquad \text{(Eq.-5.1)}$$

$$h = K_s \cdot q^{Ps} \qquad \text{(Eq.-5.2)}$$

where,

h	:	Water depth (m)
q	:	Slope discharge per unit slope width (m^3/sec.m)
α	:	Constant of unit conversion ($1/3.6 \times 10^{-6}$)
r_e	:	Effective rainfall intensity (mm/h)
t	:	Time (sec)
x	:	Distance (m)
K_s, P_s	:	Constant

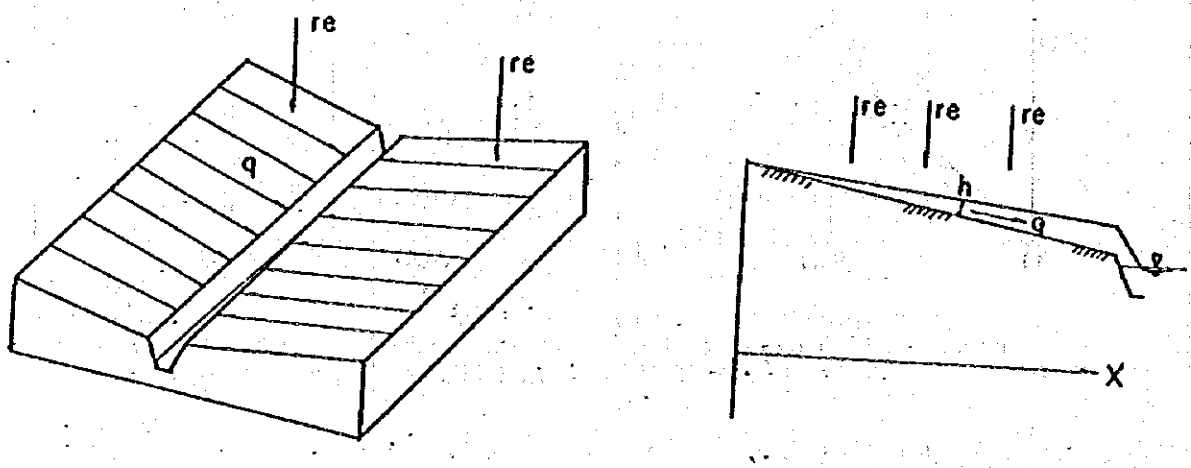


Fig.-5.4 Slope Flow System

When Manning's law is applied to the slope flow:

$$V_s = 1/N \cdot h^{2/3} \cdot i^{1/2} \qquad \text{(Eq.-5.3)}$$

$$q = h \cdot v \qquad \text{(Eq.-5.4)}$$

where,

V_s: Mean velocity of slope surface flow (m/sec)
N : Equivalent roughness ($m^{-1/3}$. sec)
h : Water depth (m)
i : Gradient of slope (non-dimension)

Using Eq.-(5.3) and (5.4), the Eq. (5.2) can rewritten as follows.

$$q = 1/n \cdot h^{5/3} \cdot i^{1/2} \qquad \text{(Eq.-5.5)}$$

$$h = (\frac{N}{i})^{3/5} \cdot q^{3/5} = K_s \cdot q^{P_s} \qquad \text{(Eq.-5.7)}$$

$$K_s = (\frac{N}{i})^{0.6}, \; P_s = 0.6 \qquad \text{(Eq.-5.7)}$$

The flow over the sloping surfaces can be obtained through the specific characteristic curve method with Eq.-(5.1) and (5.2).

(6) Channel Flow System

The water flowing through the channels can be expressed by the following formula of continuity and movement. (See Fig.-5.5)

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \qquad \text{(Eq.-5.8)}$$

$$A = K_c \cdot Q^{P_c} \qquad \text{(Eq.5.9)}$$

where,

A : Discharge area (m^2)
Q : Channel discharge (m^3/sec)
q : Slope discharge per unit channel length (m^3/sec.m)
t : Time (sec)
x : Distance (m)
K_c, P_c: Channel constant

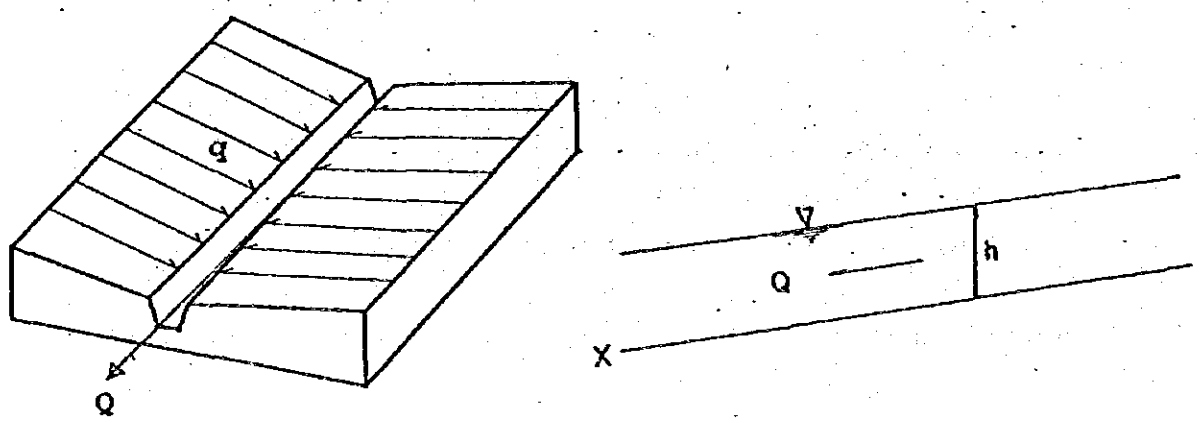


Fig.-5.5 Channel Flow System

When Manning's law is applied to channel flow:

$$V_c = \frac{1}{n} \cdot R^{2/3} \cdot I^{1/2} \qquad \text{(Eq.-5.10)}$$

$$Q = A \cdot V \qquad \text{(Eq.-5.11)}$$

where,

V_c: Mean velocity of channel flow
n: Roughness ($m^{-1/3}$/sec)
R: Hydraulic radius (m)
I: Gradient of channel (non-dimension)

K_c and P_c of the formula (5.9) are determined by the graph method, using the Eq.-(5.10), (5.11) and the survey data of channel.
The flow in the channels is sought by utilizing the specific characteristic curve method with Eq.-(5.8) and (5.9).

5.1.3 CALIBRATION OF THE MODEL

(1) Target of the Model Calibration

Judgement of the degree to which the simulated flood matches the observed flood has been based chiefly on the following items:

① Shape of hydrograph

② Runoff volume

③ Peak discharge

(2) Data Used

(a) K. Mujur Basin Model

As there were not enough floods to calibrate the model of the K. Mujur Basin, no profitable calibration was made regarding the K. Mujur Flood Runoff Model.

(b) K. Rejali Basin Model

Table-5.3 shows the main observed floods (exceeding peak discharge 100 m^3/s) and the availability of rainfall data. From this flood data, the following two floods were used for the model calibration due to the availability of rainfall data.

- Flood in 17/Mar./1983
  (Peak discharge: 135 m^3/s)

- Flood in 19/Mar./1983
  (Peak discharge: 176 m^3/s)

(c) K. Glidik Basin Model

Table-5.4 shows the main observed floods (exceeding peak discharge 200 m^3/s) and the availability of rainfall data. From this flood data, the following three floods were used for the model calibration due to the availability of rainfall data.

- Flood in 19/Apr./1983
  (Peak discharge: 244 m^3/s)

- Flood in 28/Apr./1983
  (Peak discharge: 222 m^3/s)

- Flood in 6/May/1983
  (Peak discharge: 421 m^3/s)

Table-5.3 Main Observed Floods in K. Rejali

RAINFALL STATIONS & THIESSEN COEFFICIENT

DATA (in 1983)	PEAK DISCHARGE (m^3/s) RP - 4 K. LEPRAK NO.1 CHECK DAM	10 G. SAWUR	30 G. LEKER	31 G. PAKIS	32 KAMAR A	33 WONORENGGO	38(11) CURAH KOBO'AN
		0.02	0.36	0.06	0.18	0.03	0.35
17/MAR	135.5	○	×	×	○	○	○
19/MAR	175.9	○	×	×	○	○	○
20/MAR	191.5	○	×	×	○	×	○
1/MAY	422.0	○	×	×	×	○	○
26/MAY	289.0	○	×	×	×	○	○

DATA AVAILABLE ○ : YES × : NO

Table-5.4 Main Observed Floods in K. Glidik

RAINFALL STATIONS & THIESSEN COEFFICIENT

DATA (in 1983)	PEAK DISCHARGE (m^3/s) RP - 3 PLANNED PRONOJIWO DAM	30 G. LEKEL	31 G. PAKIS	32 KAMAR A	34(14) PRONOJIWO	38(11) C. KOBO'AN	42(13) S. URANG
		0.01	0.02	0.34	0.16	0.09	0.38
26/FEB	720.5	×	×	○	○	×	○
3/MAR	468.4	×	×	○	○	×	○
13/MAR	436.0	×	×	○	○	○	○
19/MAR	436.0	×	×	○	○	○	○
20/MAR	517.0	×	×	○	○	○	○
29/MAR	232.6	×	×	×	○	○	○
19/APR	243.7	×	○	○	○	○	○
28/APR	221.6	×	○	○	○	○	○
1/MAY	2,956.8	×	×	×	○	○	○
3/MAY	221.6	×	○	×	○	○	○
6/MAY	421.0	×	○	○	○	○	○
7/MAY	532.0	×	×	○	○	○	○
13/MAY	243.7	×	×	○	○	○	○
25/MAY	998.2	×	×	×	○	○	○
27/MAY	243.7	×	×	×	○	○	○

DATA AVAILABLE ○ : YES × : NO

(3) Verification of Results

The parameters that were finally adopted are indicated in Table-5.5.

Fig.-5.6 and 5.7 show the simulated discharges compared with the observed discharges.

Summary of the verification is as follows:

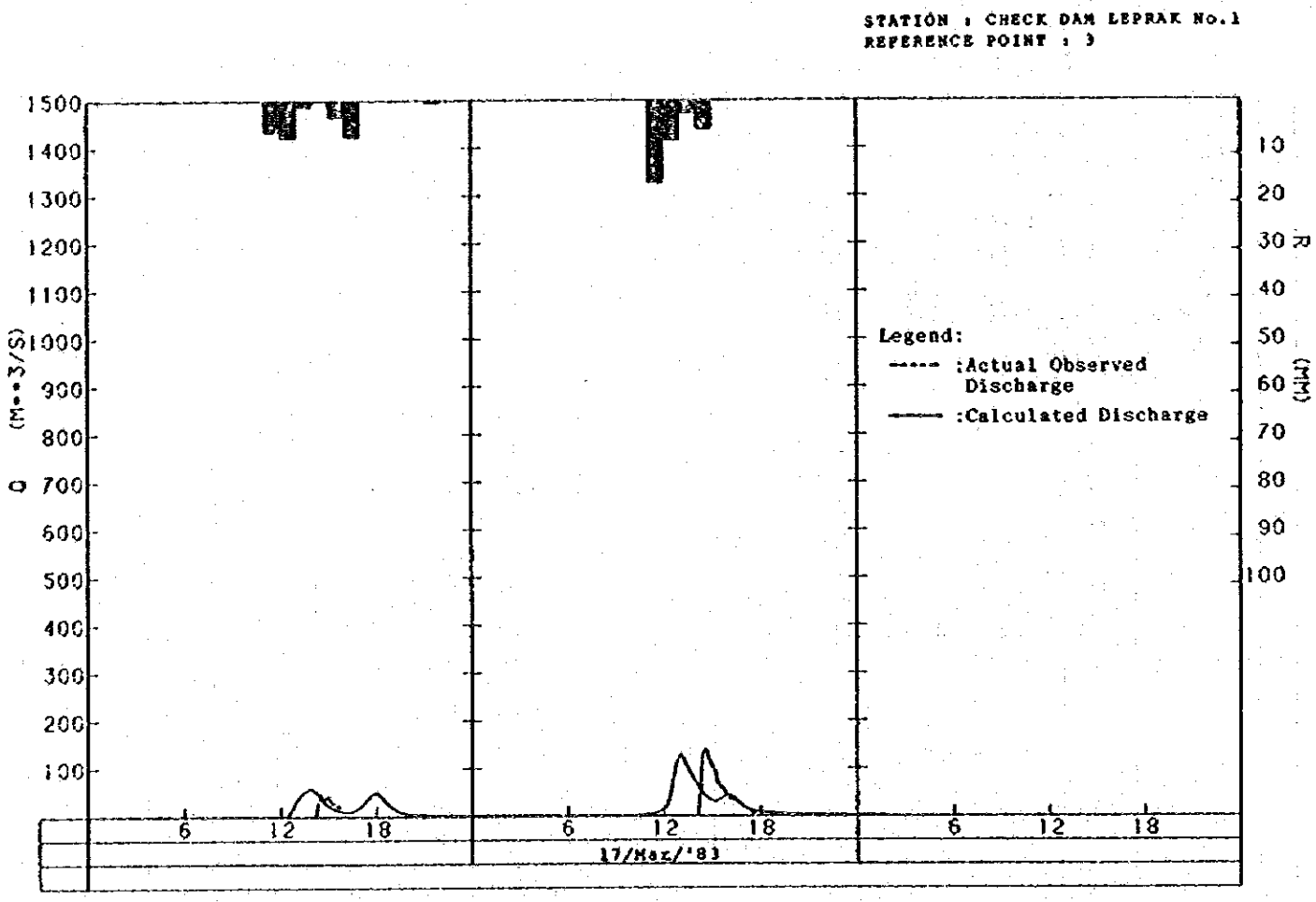
① A flood wave pattern peculiar to steep slopes with an outstanding run-off phemonemon is expressed relatively well.

② A small discrepancy in the time between the simulated and the observed hydrographs is believed to be caused by a difference in accuracy of the time pieces employed in the instrument for rainfall measurement and the one used for observation.

③ The simulated and observed hydrographs for the flood of K. Glidik of May 6, as shown in Fig.-5.7, do not coincide. While it has never been confirmed, the said flood is thought to have been sediment discharge. Since the flood was laden with sediment, the apparent discharge swelled greatly. It is not surprising, therefore, to find that the simulated hydrograph based on water only would not coincide with the hydrographs based on observation. It is also plausible that accurate measurement of the average rainfall in the basin could not have been obtained since out of the three rainfall observation stations located, one each in G. LEKER, G. PAKIS and KAMA A, the station at G. LEKER, failed to take measurement.

Table-5.5 Fixed Parameters for Flood Runoff Model

BASIN	Block and Discharge Reference Point		Area (ha)	Slope: Length (m)	Slope: Gradient (%)	Slope: Equiv. Roughness	Ps	Ks	R_{sa} (mm)	R_{lsa} (mm)	Channel: Length (m)	Channel: Gradient (%)	Channel: Roughness n	Pc	Kc	Remarks
K. MUJUR	1	L	29.1	6,770	21.67	0.098	0.6	0.39	450	250	4,300	6.28	0.040	0.76	0.41	
		R	16.1	3,140	26.31	0.093	0.6	0.36	450	250						
	2	L	2.7	230	369.8	0.096	0.6	0.33	450	250	12,000	189.2	0.040	0.76	0.27	
		R	8.5	710	350.0	0.087	0.6	0.32	450	250						
	③		56.4													SUB RP-1
	3	L	1.5	260	130.9	0.100	0.6	0.46	450	250	5,700	47.4	0.040	0.71	0.68	
		R	1.5	260	75.7	0.100	0.6	0.54	450	250						
	④		59.4													
	4	L	6.6	630	128.1	0.090	0.6	0.44	450	250	10,500	80.0	0.040	0.70	0.39	SUB RP-2
		R	2.3	220	141.2	0.091	0.6	0.43	450	250						
	⑥		68.3													
	5	L	1.3	270	26.5	0.200	0.6	1.13	125	55	4,900	25.5	0.040	0.70	0.78	
		R	12.6	2,570	54.8	0.099	0.6	0.60	212	84						
	⑦		82.2													
	6	L	4.5	510	55.6	0.161	0.6	0.80	131	56	8,800	41.5	0.040	0.70	0.66	
		R	3.0	340	59.0	0.165	0.6	0.79	135	58						
	⑨		89.7													
	7	L	12.1	1,100	29.0	0.176	0.6	1.02	124	54	11,000	23.2	0.040	0.71	0.80	
		R	23.9	2,170	32.7	0.169	0.6	0.96	142	61						
	⑩		125.7													
	8	L	1.2	390	6.3	0.146	0.6	1.44	179	74	3,100	13.6	0.040	0.75	0.70	
		R	1.6	520	15.0	0.050	0.6	0.43	364	137						
	⑪		128.5													
	9	L	26.4	1,160	66.5	0.131	0.6	0.67	207	99	22,800	33.4	0.040	0.71	0.70	
		R	9.8	430	67.8	0.056	0.6	0.40	374	179						
	⑬		164.7													R.P.
	10	L	4.2	820	4.8	0.065	0.6	0.96	450	233	5,100	7.4	0.035	0.81	0.81	
		R	1.7	330	10.3	0.036	0.6	0.54	450	184						
	⑭		170.6													
K. REJALI	1	L	5.0	470	151.4	0.096	0.6	0.43	450	250	10,700	165.9	0.040	0.76	0.28	
		R	5.1	480	350.5	0.096	0.6	0.34	450	250						
	2	L	4.1	470	276.1	0.100	0.6	0.37	450	250	8,700	146.6	0.040	0.76	0.30	
		R	8.1	1,000	203.7	0.075	0.6	0.34	450	233						
	③		22.9													
	3	L	3.4	1,620	160.9	0.066	0.6	0.34	288	205	2,100	102.4	0.040	0.71	0.52	
		R	1.3	620	269.4	0.077	0.6	0.32	297	139						
	④		27.6													SUB RP
	4	L	10.3	750	36.8	0.148	0.6	0.86	184	83	13,800	30.8	0.040	0.85	0.48	
		R	25.1	1,860	170.5	0.101	0.6	0.43	375	194						
	⑤		63.6													
	5	L	52.7	4,050	71.4	0.138	0.6	0.73	285	81	13,000	29.2	0.040	0.78	0.62	
		R	7.6	580	50.7	0.103	0.6	0.53	231	93						
	⑦		123.9													R.P.
	6	L	5.3	1,180	10.9	0.140	0.6	1.19	186	72	4,500	13.3	0.035	0.74	0.78	
		R	2.6	580	136.9	0.117	0.6	0.50	313	158						
	⑧		131.8													
K. GLIDIC	1	L	13.1	1,620	141.7	0.102	0.6	0.46	303	104	9,200	8.7	0.040	0.76	0.74	
		R	17.3	1,880	63.0	0.137	0.6	0.70	223	112						
	2	L	12.6	1,330	115.5	0.085	0.6	0.44	450	250	9,500	121.1	0.040	0.74	0.31	
		R	11.3	1,190	312.4	0.093	0.6	0.34	450	248						
	③		54.3													SUB RP-2
	3	L	17.3	2,160	213.1	0.063	0.6	0.30	431	184	8,000	58.1	0.040	0.73	0.43	
		R	21.7	2,710	122.6	0.063	0.6	0.96	412	199						
	④		93.3													
	4	L	20.2	1,260	213.1	0.092	0.6	0.38	441	244	16,000	119.7	0.040	0.72	0.33	
		R	15.9	990	122.6	0.089	0.6	0.44	443	238						
	⑥		129.4													SUB RP-1
	5	L	8.5	1,470	294.2	0.095	0.6	0.36	339	144	5,800	22.4	0.035	0.73	0.72	
		R	24.7	4,260	222.0	0.047	0.6	0.25	400	153						
	⑦		162.6													
	6	L	54.8	2,130	144.8	0.077	0.6	0.38	414	198	25,700	48.4	0.040	0.84	0.84	
		R	92.6	3,600	79.5	0.077	0.6	0.46	414	198						
	⑨		310.0													R.P.
	7	L	5.2	740	76.7	0.074	0.6	0.45	392	207	7,000	7.9	0.035	1.19	1.19	
		R	11.1	1,590	235.5	0.096	0.6	0.38	450	250						
	⑩		326.3													



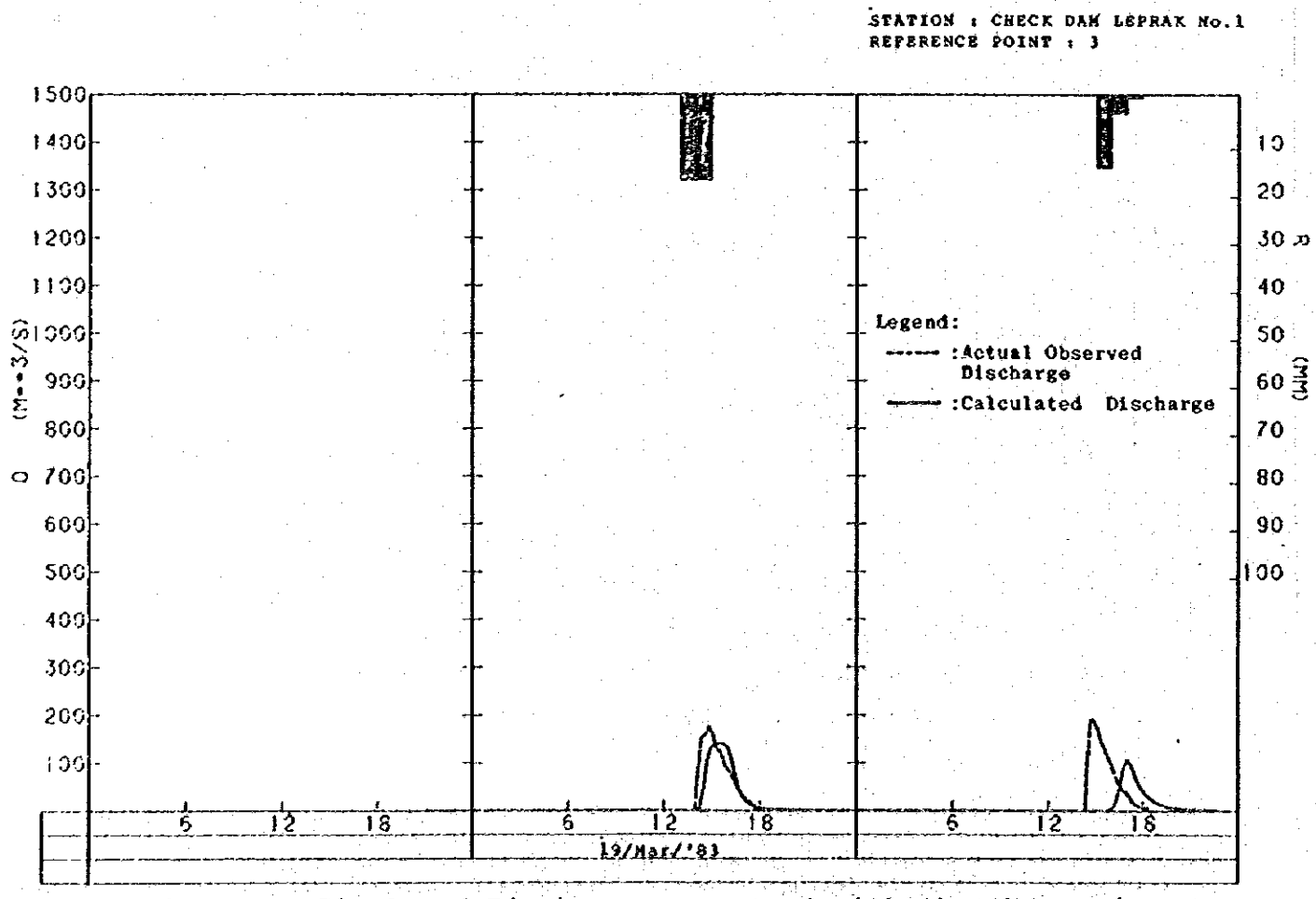
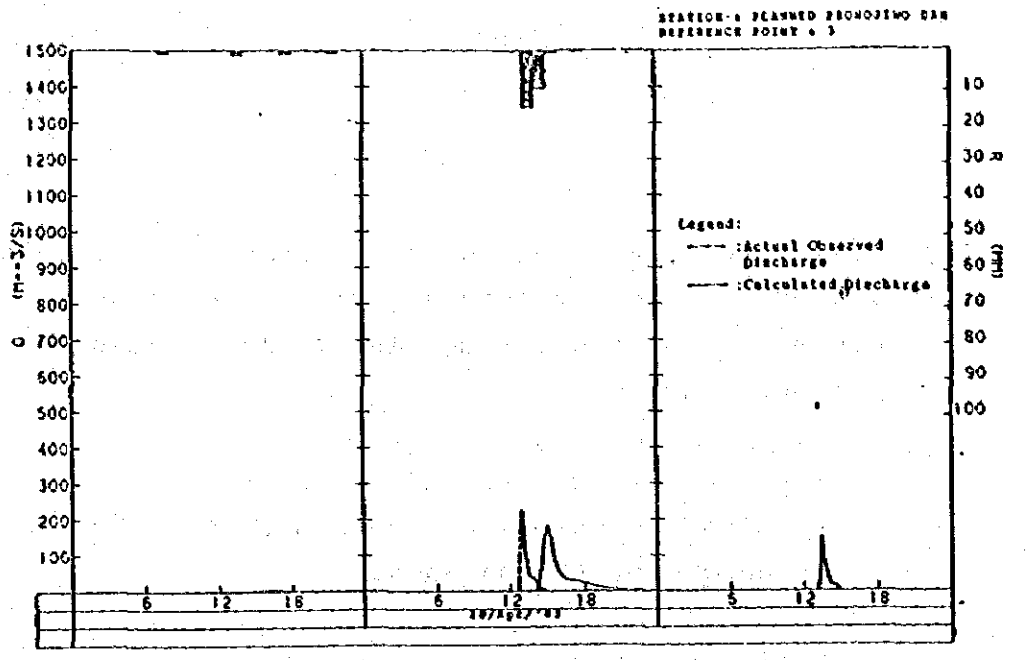
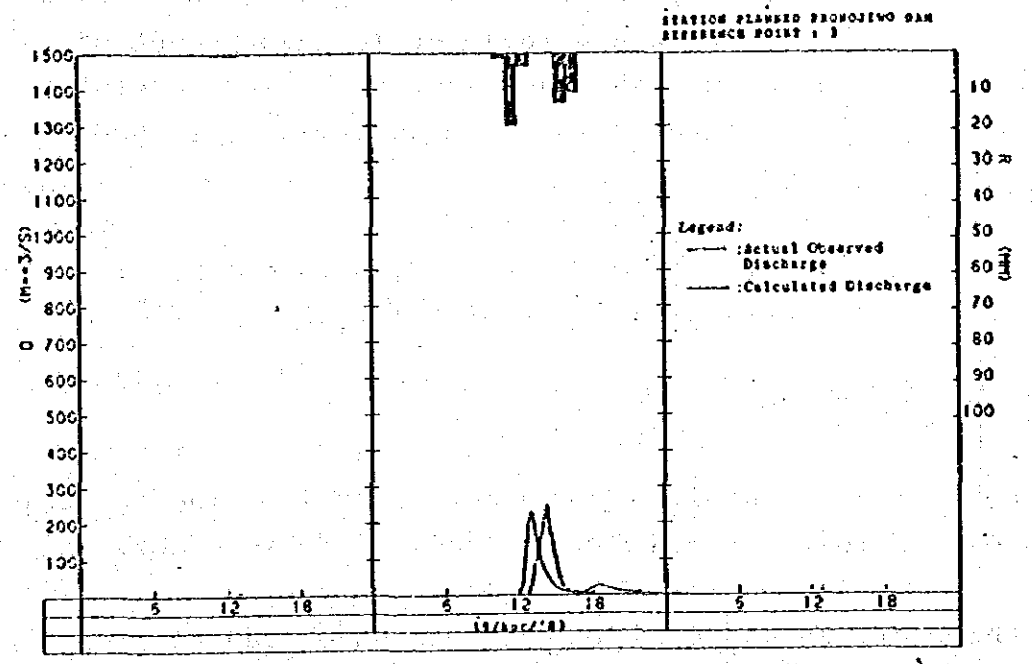


Fig.-5.6 Simulated Discharges compared with the Observed Discharges in K. Rejali





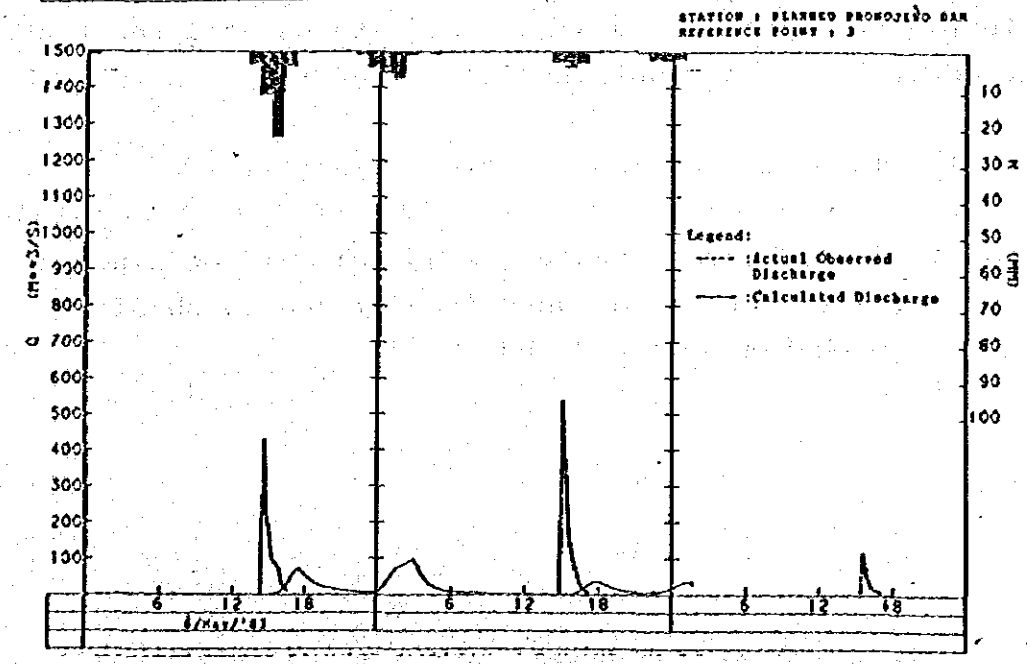


Fig.-5.7 Simulated Discharges compared with the Observed Discharges in K. Glidik

(4) Taking the preceding considerations into account, improvement in the accuracy of a flood run-off model could be attained through the implementation of the following actions.

- Improve the accuracy of flood measurement through raising the existing standard of the observation technique of technicians.

- Minimize, if not eliminate, the disfunction of timepieces and failures in measurement of rainfall data through loser inspection and careful maintenance of rainfall measurement instruments on a regular basis.

- Verify the parameters of a runoff model through increase in a set of rainfall runoff data at flood.

5.2 DESIGN FLOOD

We can obtain an arbitrary hydrograph by inputing an arbitrary hydrograph to the flood run-off model described above.

As there are no observed hydrographs which can be properly evaluated, the probable design floods to be used for the sediment control plan are obtained as follows:

(1) To make a probable design rainfall;

(2) To input a probable design rainfall obtained above (1) to the flood run-off model and to obtain a probable design flood.

5.2.1 DESIGN RAINFALL

(1) Rainfall Intensity Curve

Judging from Fig.-4.5, rainfall intensity curve can be expressed by the following Sharman Type formula.

$$I = a \cdot t^{b} \qquad \text{(Eq.-5. 12)}$$

Where, I: Rainfall Intensity (mm/h)
t: Rainfall duration
a, b: Constant

A list of constant b (gradient of curve) of each station, which is calculated by the least squares method, is shown in Table-5.6.

Table-5.6 List of Constant b

Station		EL. (m)	b	Remarks
BESUK SAT	1	775	-0.821	1978 - 1982
KERTOSARI	4	345	-0.872	1980 - 1982
CURAH KOBO'AN	11	734	-0.780	1978 - 1982
CANDIPURO	9	322	-0.887	1979 - 1982
SUPITURANG	13	675	-0.827	1979 - 1982
PRONOJIWO	34	600	-0.717	1979 - 1982

As can be seen from Table-5.6, the rainfall intensity curve for each station is approximated by the following equation.

$$I = a.t^{-0.85} \qquad \text{(Eq.-5.13)}$$

(2) Probable Design Rainfall

The probable rainfall intensity curve for each station can be obtained by substituting the probable daily rainfall (shown in Table-4.3) into Eq.5.13.

Using the curve obtained above, the probable design rainfall, or probable design hydrograph is established in the manner shown in Fig.-5.8.

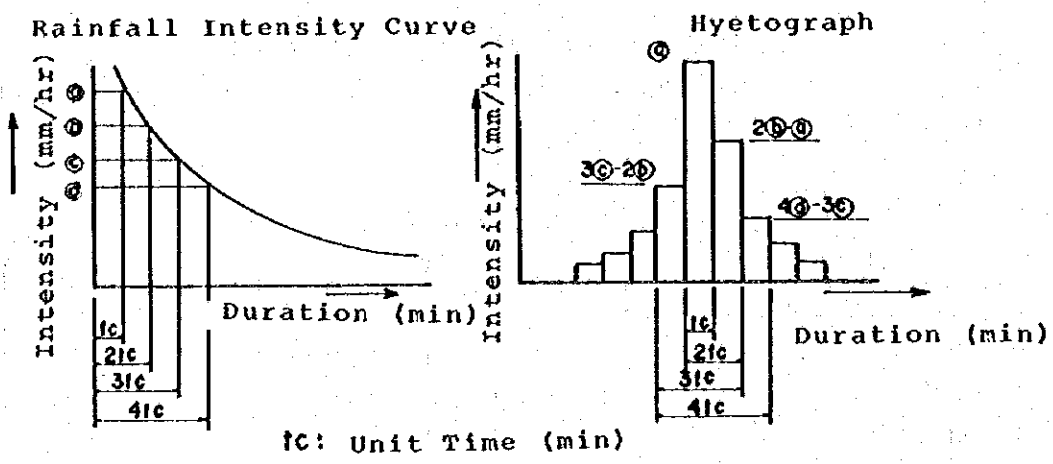


Fig.-5.8 Preparation of Hydrograph

The probable design rainfall for each unit basin is indicated in Fig.-5.9, 5.10 and 5.11.

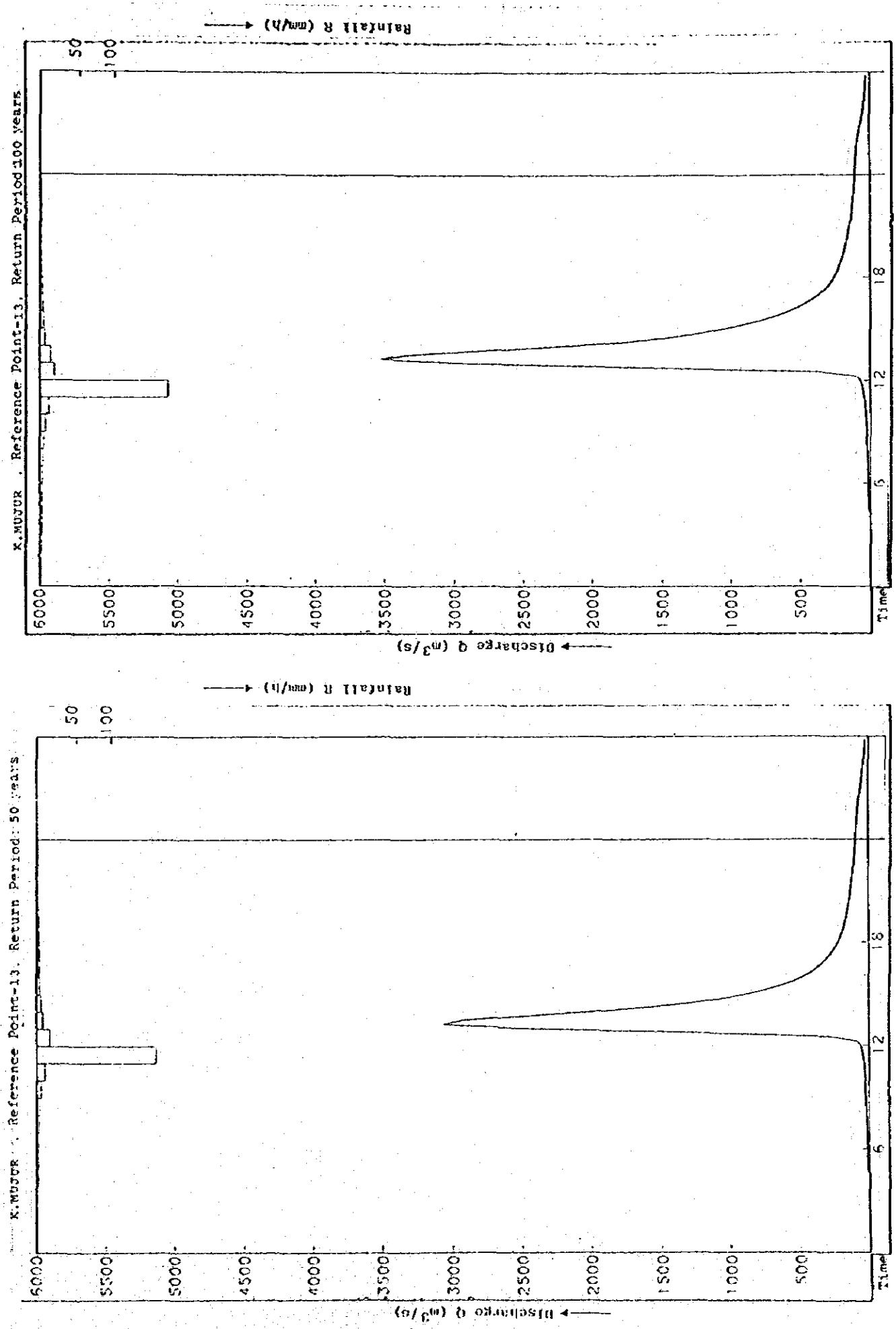
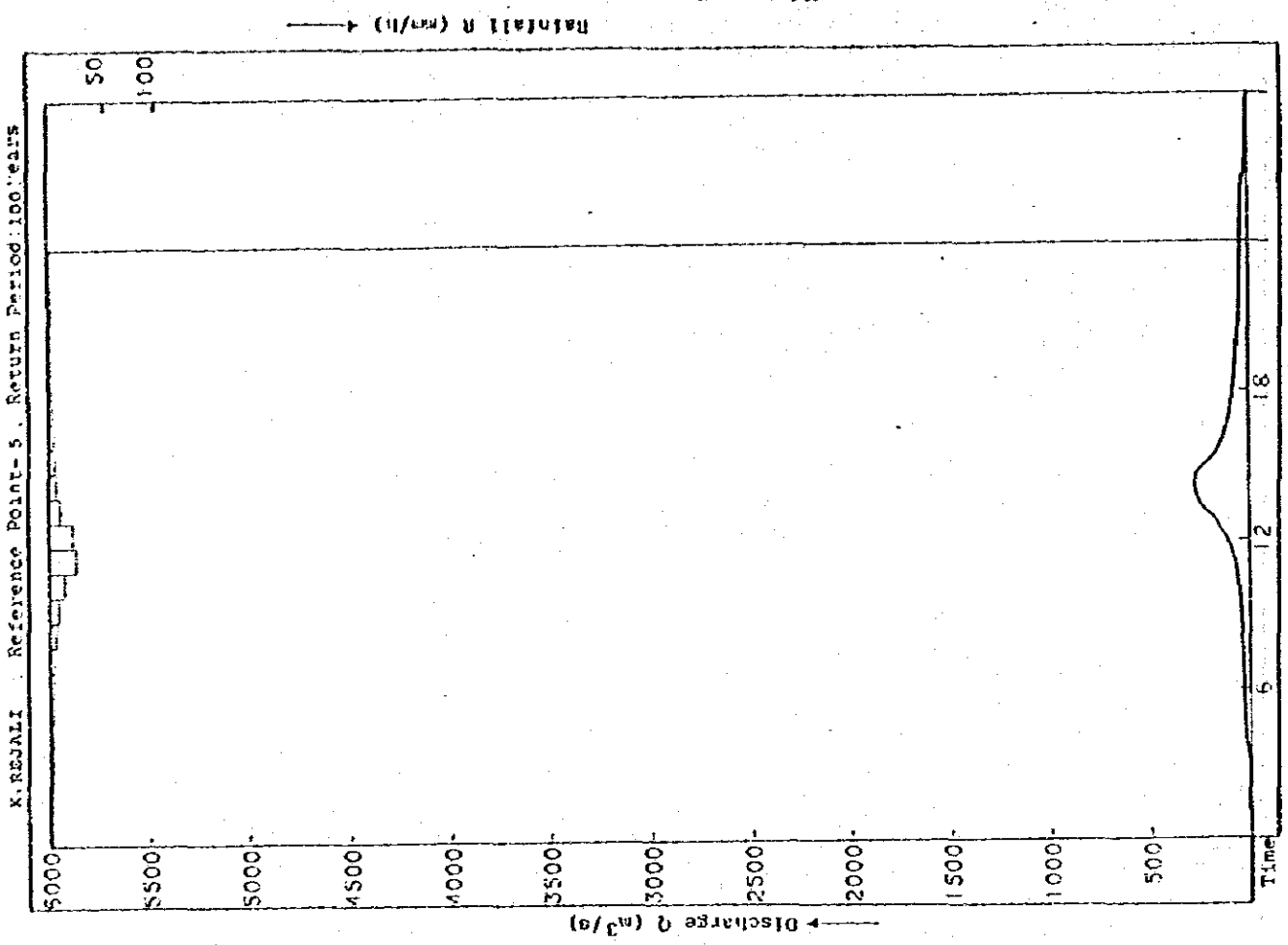


Fig.-5.9 Probable Design Floods in K.Mujur



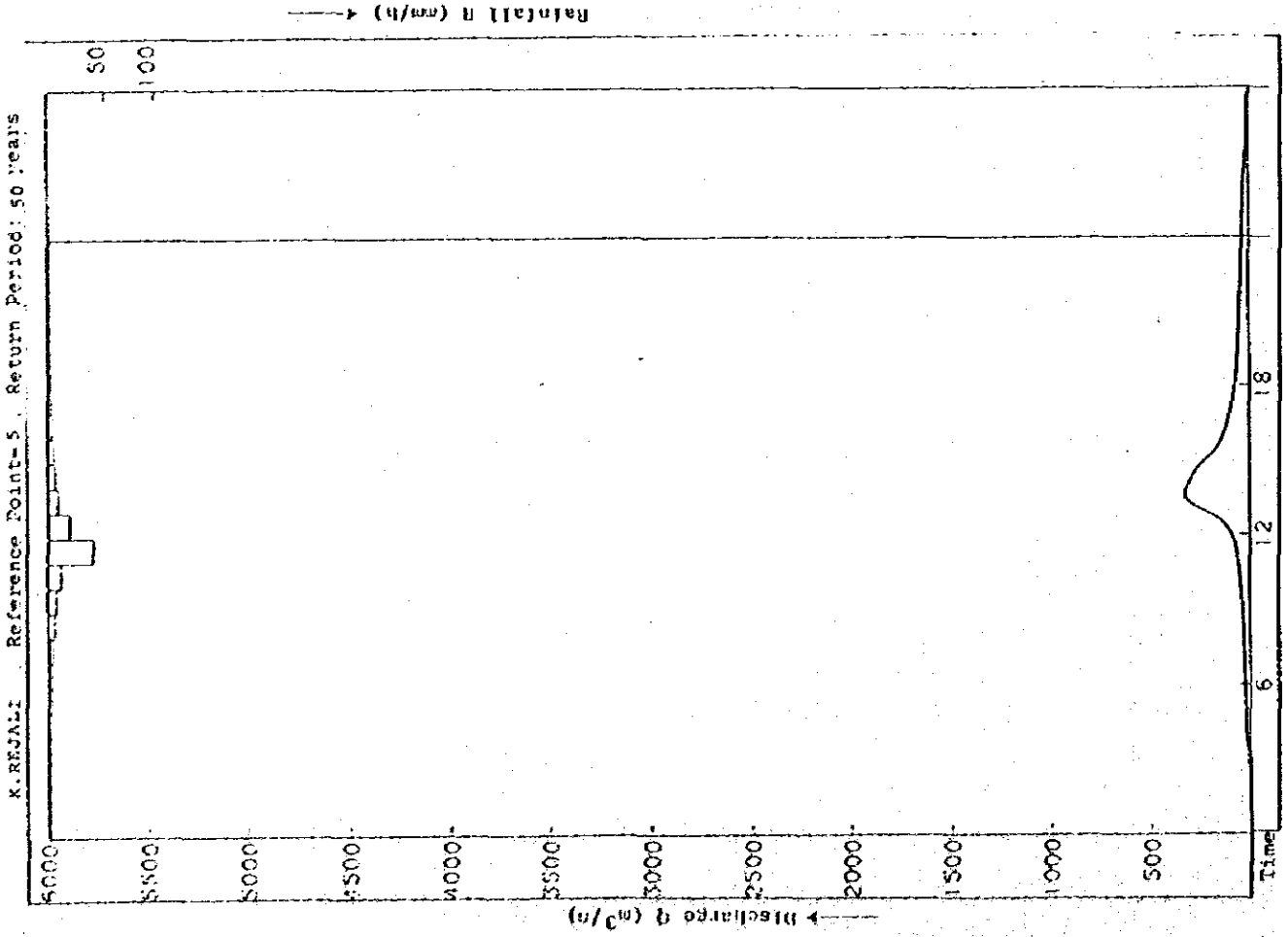
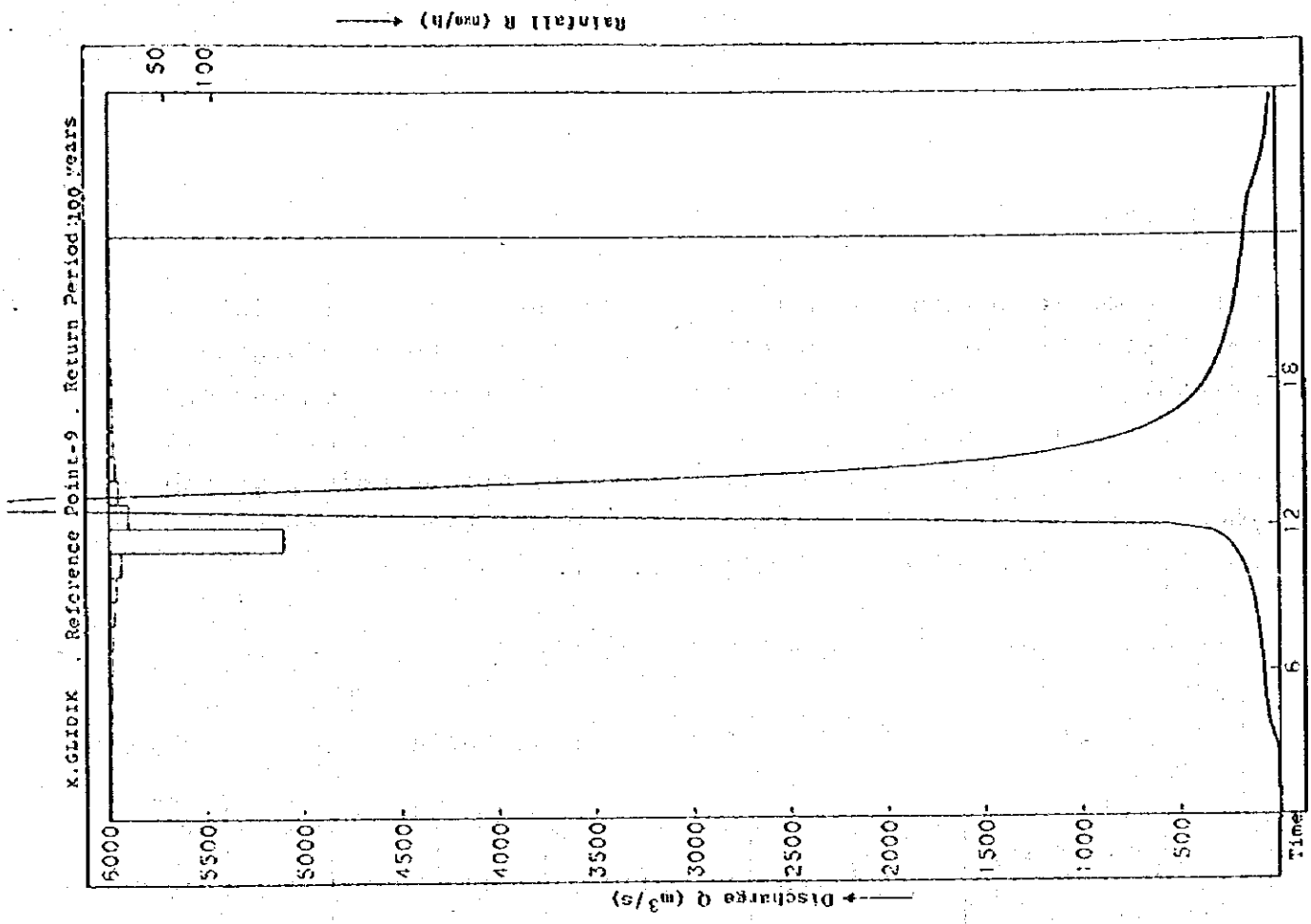


Fig.-5.10 Probable Design Floods in K.Rejali



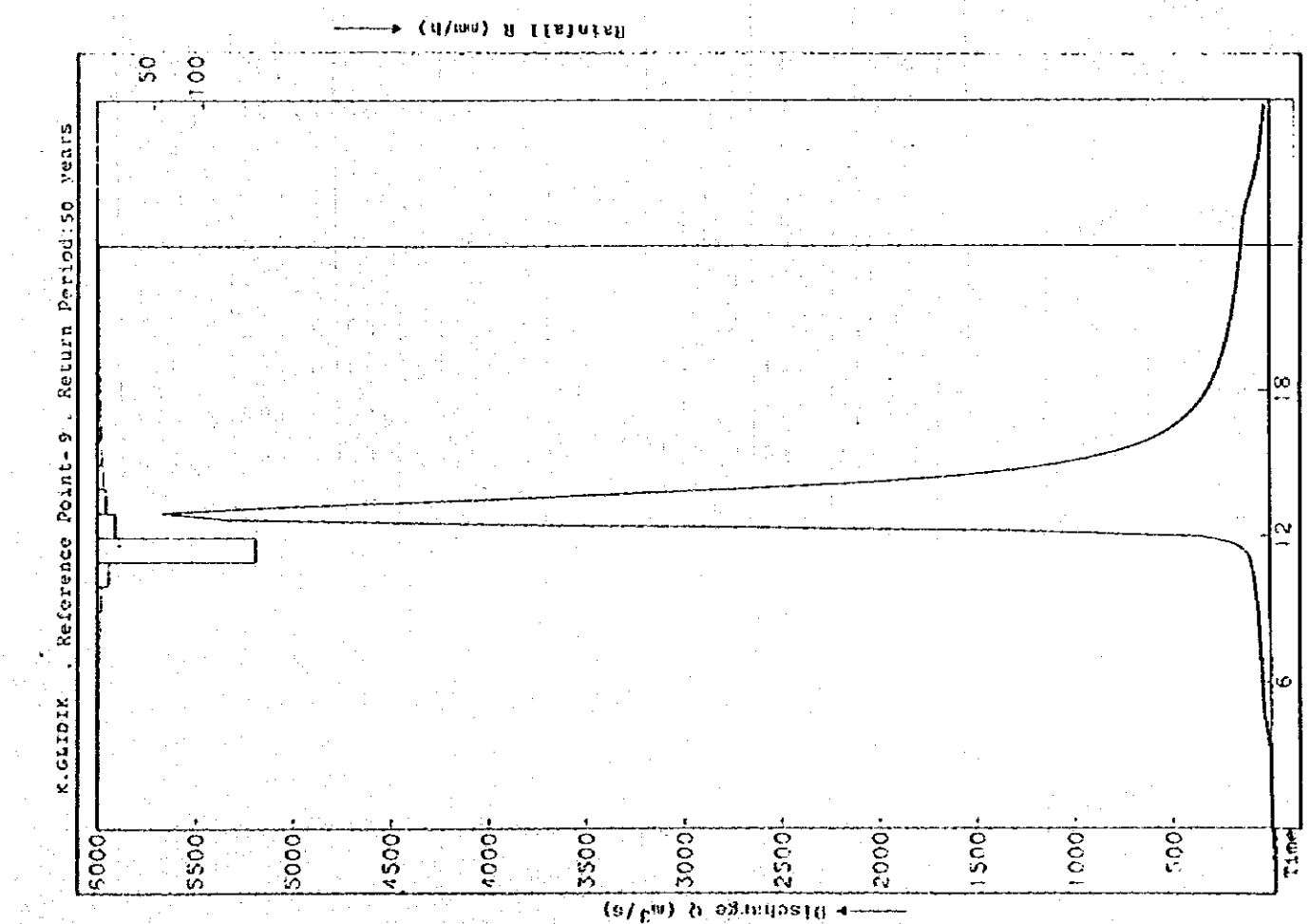


Fig.-5.11 Probable Design Floods in K.Glidik

5.2 DESIGN FLOOD

The probable design flood for each unit and reference point is simulated by the flood run-off model and the probable design flood. The probable design floods of return period of 50 and 100 years at the sabo reference point of each river system are shown in Fig.-5.9 to Fig.-5.11. Further, the principal probable design floods at the sabo reference and sub sabo reference points for each river system are in the supplement.

The peak discharge is tabulated in Tables-5.7, 5.8 and 5.9.

Table-5.7 Probable Peak Discharge for K. Mujur

(m^3/s)

Reference Point \ Probability (Year)	1/3	1/5	1/10	1/20	1/40	1/50	1/70	1/100
2	338	393	473	556	631	659	699	738
3	350	416	559	738	941	1,030	1,171	1,325
4	416	495	639	811	1,008	1,093	1,229	1,377
6	570	672	832	1,028	1,248	1,341	1,488	1,648
7	650	789	1,012	1,270	1,559	1,676	1,863	2,052
9	758	944	1,213	1,526	1,863	2,003	2,211	2,417
10	867	1,086	1,455	1,860	2,311	2,480	2,714	2,965
11	845	1,053	1,414	1,820	2,272	2,443	2,650	2,901
13	980	1,239	1,716	2,218	2,834	3,066	3,186	3,517
14	973	1,239	1,703	2,226	2,831	3,054	3,161	3,478

Table-5.8 Probable Peak Discharge for K. Rejali

(m^3/s)

Probability (Year) / Reference Point	1/3	1/5	1/10	1/20	1/40	1/50	1/70	1/100
1	303	356	433	515	591	620	660	714
2	375	443	539	638	739	778	835	902
3	678	800	972	1,151	1,330	1,397	1,495	1,616
4	809	964	1,175	1,393	1,608	1,672	1,802	1,943
5	910	1,143	1,486	1,855	2,251	2,385	2,603	2,815
7	1,119	1,438	1,893	2,387	2,924	2,982	3,405	3,697
8	1,140	1,449	1,883	2,352	2,882	2,949	3,386	3,698

Table-5.9 Probable Peak Discharge for K. Glidik

(m^3/s)

Probability (Year) / Reference Point	1/3	1/5	1/10	1/20	1/40	1/50	1/70	1/100
1	201	292	441	613	829	902	1,009	1,129
2	658	770	935	1,099	1,236	1,289	1,363	1,435
3	734	901	1,182	1,482	1,795	1,916	2,099	2,301
4	1,553	1,882	2,329	2,776	3,201	3,370	3,627	3,879
6	2,524	3,022	3,677	4,328	4,933	5,184	5,542	5,889
7	2,670	3,199	3,895	4,592	5,245	5,505	5,891	6,284
9	2,696	3,245	3,988	4,757	5,516	5,824	6,290	6,769
10	2,665	3,190	3,897	4,636	5,380	5,683	6,143	6,618

6. BASE FLOW STUDY

In the study area, the main rivers, K. Mujur, K. Rejali and K. Glidik have plentiful base flow which is discharged from the great natural reservoir of Mt. Semeru, and which does not dry up in the dry season. The river water is such widely used in relation to livelihood and also for irrigation and domestic use.

The object of the study discussed in this chapter is the comprehension of the characteristics of the base flow in the study area, with the help of a suitable base flow model in order to provide a useful information for the study on water conservation.

6.1 BASE FLOW MODEL

6.1.1 SELECTION OF THE MODEL

(1) Preconditions for Selection of the Model

The following were considered carefully when selecting the base flow model.

① Usefulness of the outcome from the model.

② Dominant factor in the base flow run-off process.

③ Existence of enough data to caribrate a model.

④ Characteristics of the catchment area.

(2) Selected Base Flow Model

After consideration of the followings, the monthly stochastic base flow model, described in the next section, was chosen.

① Output most desired from the model is the long-term base flow distribution in order to understand the monthly or seasonal distribution and their fluctuation.

② As the daily fluctuation in base flow is small, due to the large capacity of the natural reservoir of the basin, the minimum unit of the base flow discharge can be considered as the monthly discharge.

③ There is not enough necessary data for a definite model, however, data on one year of observation and Monthly base flow discharge and rainfll records provide enough information for our study Model.

④ Such factors as evapotranspiration and the infiltration of rainfall which control the base flow are not investigated in the field.

6.1.2 DESCRIPTION OF THE MODEL

(1) Discharge Reference Point

The discharge reference point for each unit is as follows: (Refer to Fig.-5.12.)

① Unit M, K. Mujur

Rowojedang Intake
(Catchment area = 69.1 km^2)

② Unit R, K. Rejali

K. Leprak No.1 Check Dam
(Catchment area = 27.6 km^2)

③ Unit G, K. Glidik

Planned Pronojiwo Dam
(Catchment area = 54.3 km^2)

There is no intake upstream from these points, therefore, we can obtain a real amount of monthly base flow discharge from this model.

(2) Basic Equation

The basic equation to obtain a monthly mean base flow discharge (Q) is given below. (Refer to Fig.-5.13.)

$$Q = Ca \sum_{i=1}^{n} (Cm_{(i)} Rm_{(i)}) \qquad \text{(Eq.-6.1)}$$

Where,

Q: Monthly mean base flow discharge (m^3/s)
Rm(i): Monthly rainfall amount of i-month
Ca: Coefficient of area and discharge rate
Cm(i): Coefficient of i-month rainfall contribution
i: Past month from simulated month
n: Total contribution month
$\sum Cm(i) = 1.0$

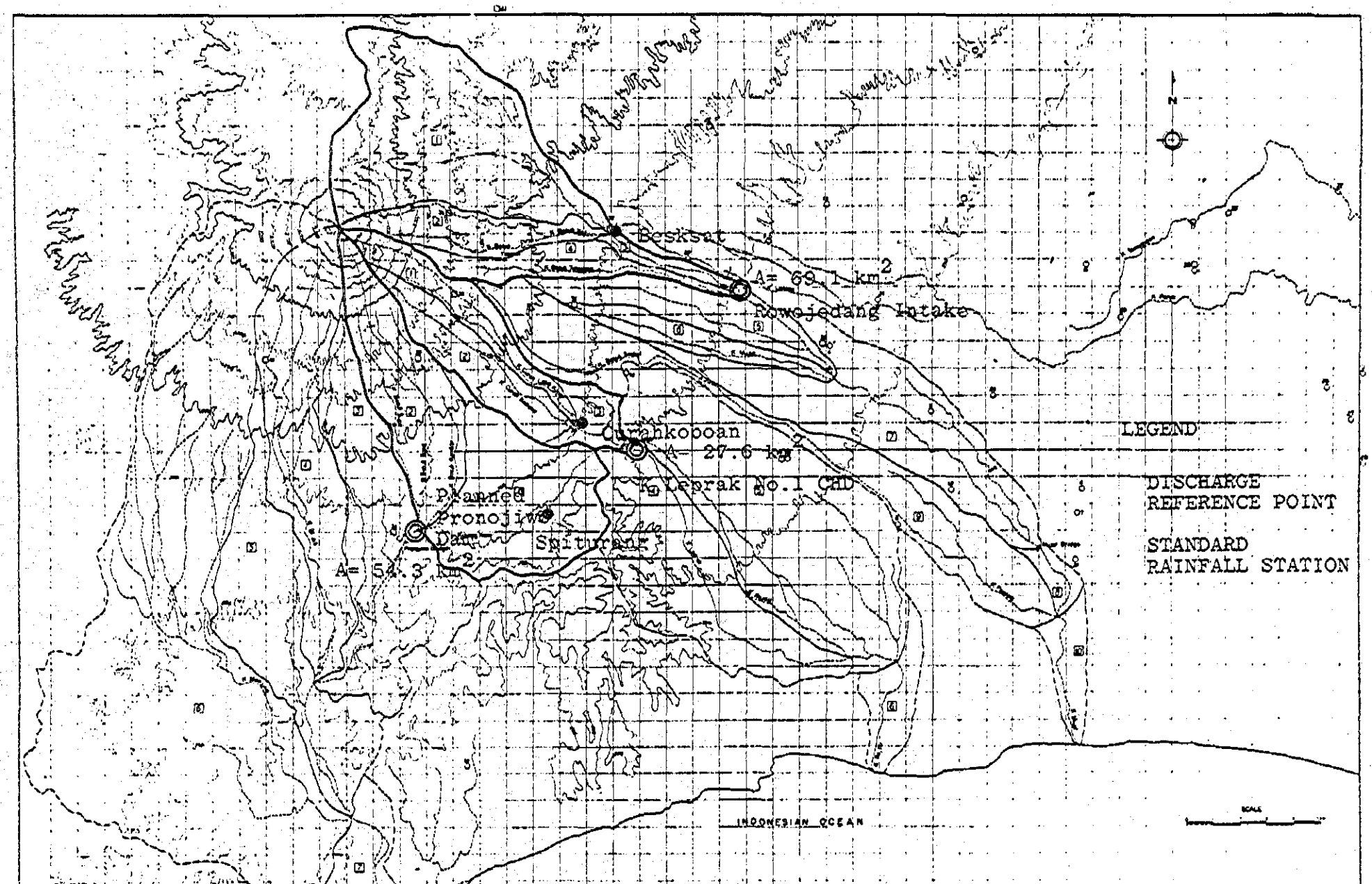


Fig.-5.12 Discharge Reference Points for Base Flow Model

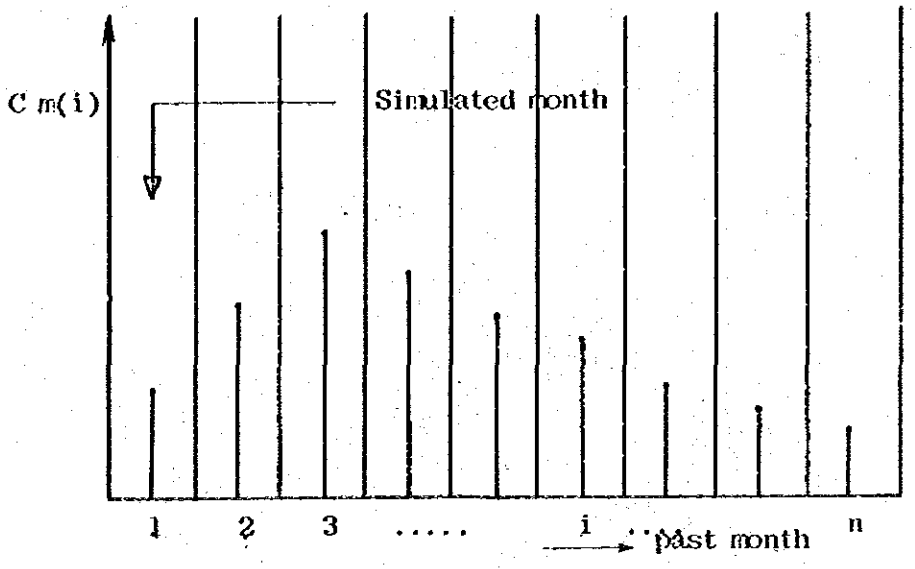


Fig.-5.13 Base Flow Model

The equation 6.1 means that the monthly mean discharge of an arbitrary month is composed of the past n-months monthly rainfall, however, the contribution rate of i-month rain- fall is restricted to Cm(i).

6.1.3 VERIFICATION OF THE MODEL

(1) Data Used

The data used for verification is as follows:

① Unit M, K. Mujur

- Monthly rainfall: Bosuk Sat
- Base flow : Rowojedang Intake

② Unit R, K. Rejali

- Monthly rainfall: Curah Kobo'an

- Base flow : K. Leprak No. 1 Check Dam

③ Unit G, K. Glidik

- Monthly rainfall: Supit Urang

- Base flow : Planned Pronojiwo Dam

The base flow data used was obtained through actual observation from Jul. to May of this year, and can be considered that there is no direct effect of flood.

(2) Results of Verification

The results of verification are shown in Fig.-5.14.

The fixed parameters are tabulated in Table-5.10.

Table-5.10 Parameters for Base Flow Model

Parameter	Unit	Unit M K. Mujur	Unit R K. Rejali	Unit G K. Glidik
Total Contribution Month n		12	12	12
Coefficient Ca		0.243	0.323	0.723
Coefficient Cm	Cm(1)	0.070	0.210	0.065
	Cm(2)	0.100	0.180	0.100
	Cm(3)	0.135	0.150	0.140
	Cm(4)	0.145	0.120	0.145
	Cm(5)	0.130	0.090	0.130
	Cm(6)	0.110	0.070	0.110
	Cm(7)	0.095	0.055	0.095
	Cm(8)	0.075	0.045	0.075
	Cm(9)	0.060	0.035	0.060
	Cm(10)	0.045	0.025	0.045
	Cm(11)	0.025	0.015	0.025
	Cm(12)	0.010	0.005	0.010

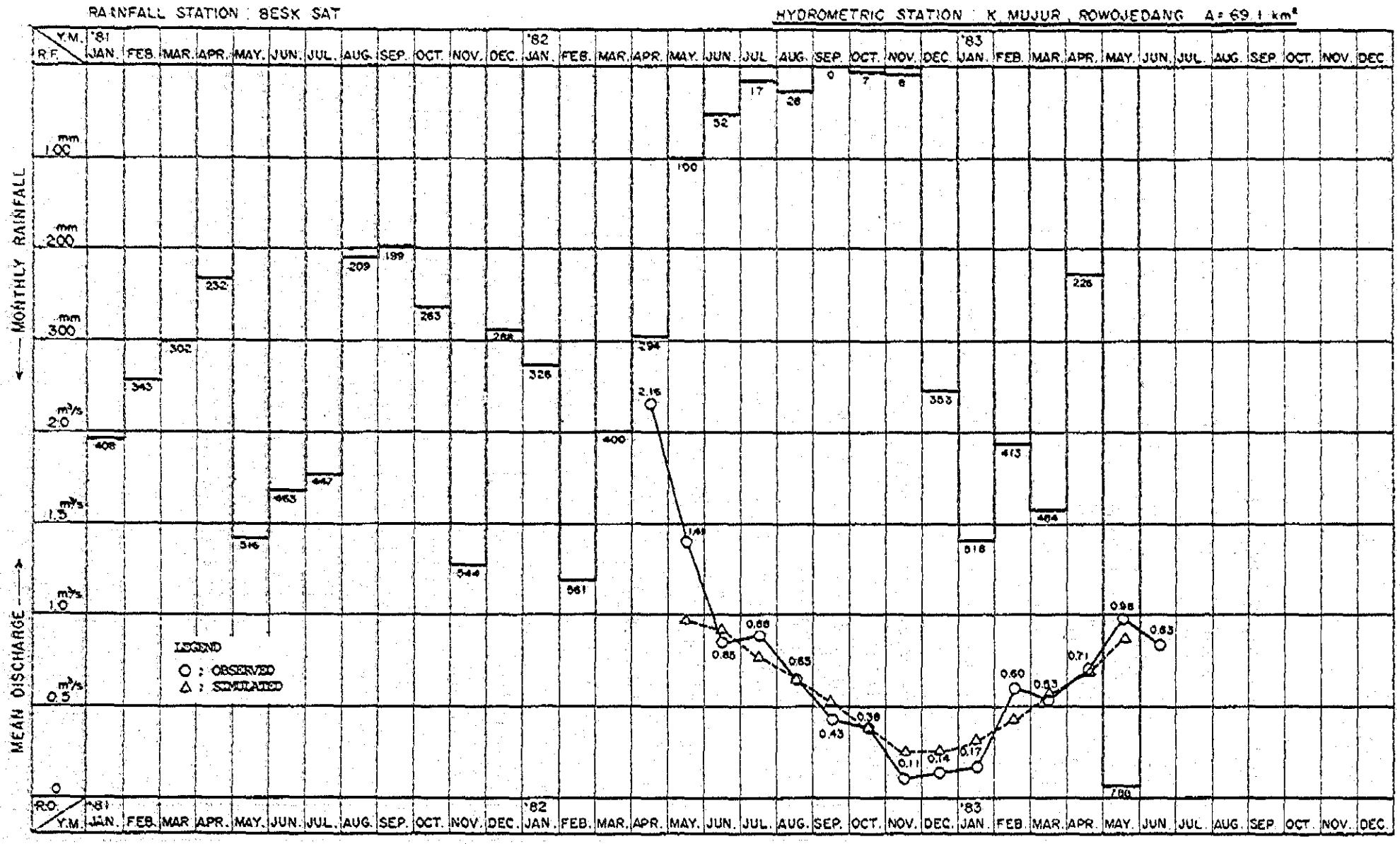


Fig - 5.14(1) Verification of Base Flow Model

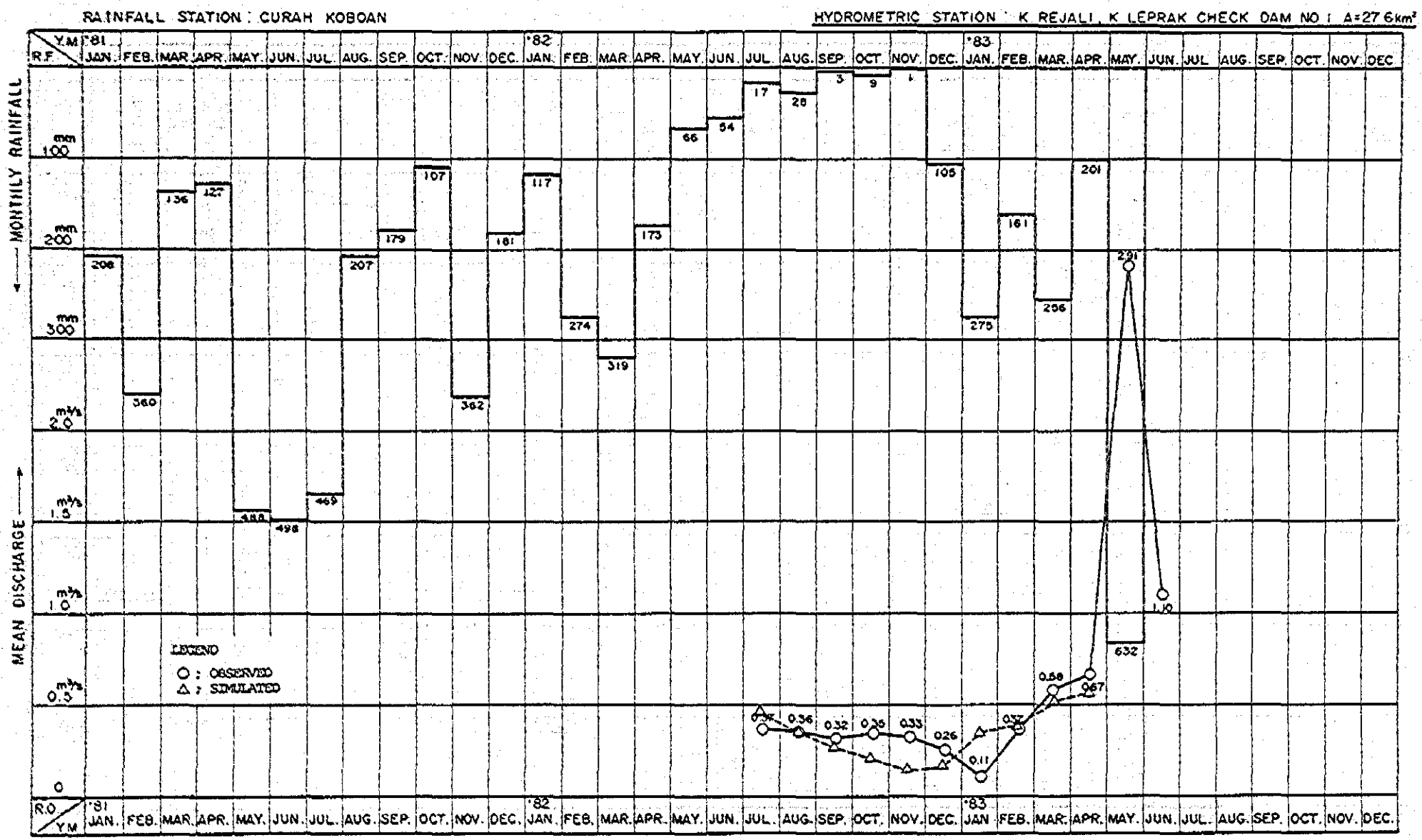


Fig - 5.14(2) Verification of Base Flow Model

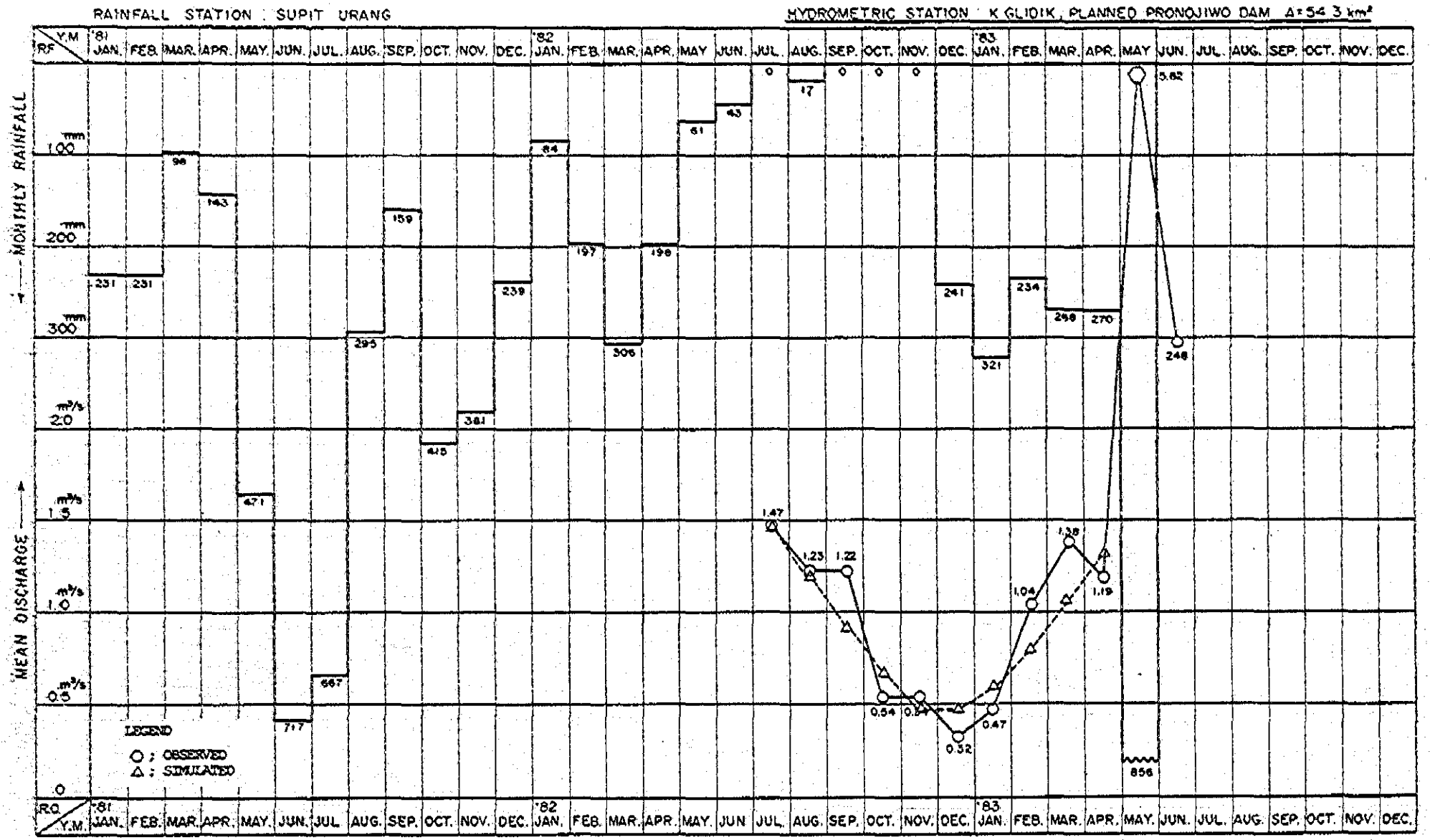


Fig - 5.14(3) Verification of Base Flow Model