(4) "Banjir" Floods

The Indonesian term "Banjir" means floods caused by a torrential tropical rainfall. This term is similar to the Japanese "Dosharyu" (sediment/sandy flow) and "Kozui" (flood). The flood is mostly water and flows downwards with tractive force. Deposits are mainly sand with small and medium sized gravel. They are thin and show a clear bedding structure.

Banjir floods have no rushing energy, but the volume of water causes destruction to cultivated areas.

1.4 Nature of Lahar Deposit

The sediment deposit characteristics as determined by surveys conducted in 1977 and 1978, mainly in K. Krasak and K. Bebeng, are summarized below and in Table 3 and Figs. 3 ∿ 5.

(1) Specific gravity (2.75-2.80) does not differ between upstream and downstream areas; however, it is rather high in comparison with Japanese riverbed materials, probably due to the higher iron content.

(2) Porosity: 25-30%

(3) Angle of internal friction: 10-33°

The results of laboratory tests cover a wide range. This is probably due to the methods of sampling and testing loose materials and also to the difference in grading, moisture ratio and degree of compaction of each sample.

(4) Grain size distribution did not show vertical change for the 1969 lahar deposits, but the silt (<0.074mm) and gravel (>2.0mm) content was higher. The present riverbed deposits are characterized by a low silt content. The sandpockets inspected in K. Krasak and K. Woro had a sand content of over 85% with fairly uniform grain size.
Samples were taken during 1977/8 and 1978/9 from the deposits listed below:

(1977/1978)

No. I-1	Riverbed deposits
I-2	Banjir deposits of 1976
II-1	Riverbed deposits
II-2	Banjir deposits of 1976
II-3	Lahar deposits of 1969
III-1	Riverbed deposits
III-2	Banjir deposits of 1976
III-3	Lahar deposits of 1969
IV-1	Riverbed deposits
IV-2	Banjir deposits of 1976
IV-3	Lahar deposits of 1969
V-1	Banjir deposits of 1976
V-2	Banjir deposits of 1976

(1978/1979)

No. I-1	Banjir deposits of 1976
I-2	Lahar deposits of 1969
I-3	"
I-4	"
II-1	Riverbed deposits
III-1	"
III-2	"

Table 1 Stratigraphy of G. Merapi

Group Name	Formation Name	Geological Component	
Recent Merapi Volcanic Products	Recent pyroclastic materials		Volcanic ash, lapilli, block, volcanic bomb.
	Lahar deposit of 1969	L_3	Volcanic ash, sand, block, etc.
	Lahar deposit of 1961 ∿ 1962	L_2	"
	Lahar deposit of 1930	L_1	"
	Dome and lava flow		Andesitic lava flow, flow ages are identified
Unconsolidated deposits	Alluvial deposit	Al	Sand, gravel, clay
	Terrace deposit		Gravel, sand, etc.
	Alluvial fan deposit	Fl	"
Young Merapi volcanic products	Fan like deposit	Fu	Gravel, sand, etc.
	Pyroclastic deposit	YMp	Volcanic breccia, ash, etc.
	Lavas	YMl	Hypersthene-augite andesitic lava
Old Merapi volcanic products	Loam	L_o	Pumice bearing loam
	Pyroclastics	OM_p	Volcanic breccia, tuff breccia, tuff etc.
	Lavas	OMl	Olivine brearing hypersthene augite basalt and andesite
Base Rocks	Bemmelen formation	Tb	Andesitic lava and breccia
	Semilir formation	Ts	Tuff breccia, tuff, clay stone

Table 2 History of Volcanic Activity of G. Merapi

Period of activity	Date of eruption and/or nuée ardente	Duration in years	Period of dormancy	Remarks
1806-07		1		
		2	1807-09	
09-10		1		
		1	10-11	
11-12		1		
		6	12-19	
19-23	Jul. 23-31, '22	4		Lahar to K. Pabelan, K. Blongkeng in 1822
		8	23-31	
31-38		7		
		1	38-39	Lahar to K. Blongkeng in 1937. Accumulated on valleys 3 km long, 60 m wide and 25 m thick
39-40		1		
		5	40-45	
45-49	Nov. 16-18, '45	4		
		5	49-54	
54-56	Aug. 29, '54 Oct. Nov. Dec. '55	2		
		5	56-61	
61-67	Apr. '61, May 23, '63	6		
		4	67-71	Lahar down to the national road of K. Blongkeng
71-72	Apr. 24, '71, Sep. 24, '71	1		
		4	72-76	
76-77	Aug. 76 ∿ Jun. 77	1		
		4	77-82	
82-85	Dec. '83 Nov. 12, '85	3		
		1	85-86	
86-89	Mar. 31, May 3, '86 Feb. 19, Mar. 19, '88, 27-29, '89	3		
		1	89-90	
90-91		1		
		1	91-92	
92-94		2		
		4	94-98	
98-99		1		
		1	99-1900	

Period of activity	Date of eruption and/or nuée ardente	Duration in years		Period of dormancy	Remarks
67-69	Sep. 23, Oct. 7 ∿ 8, '67, Jan. 7 ∿ 9, '69	2	6	61-67	Lahar to K. Blongkeng and K. Krasak
			3	69-72	" "
72-76		4			Lahar to K. Blongkeng and K. Batang

Fig. 1 Direction of Lava Flow in Recent Years

Direction / Year of Eruption	North	Northwest	West	Southwest
1930			x	
1931			x	
1934			x	
1942		x		
1943				x
1953	x			
1954	x			
1955				
1956		x		
1957			x	
1958			x	
1961				x
1969				x

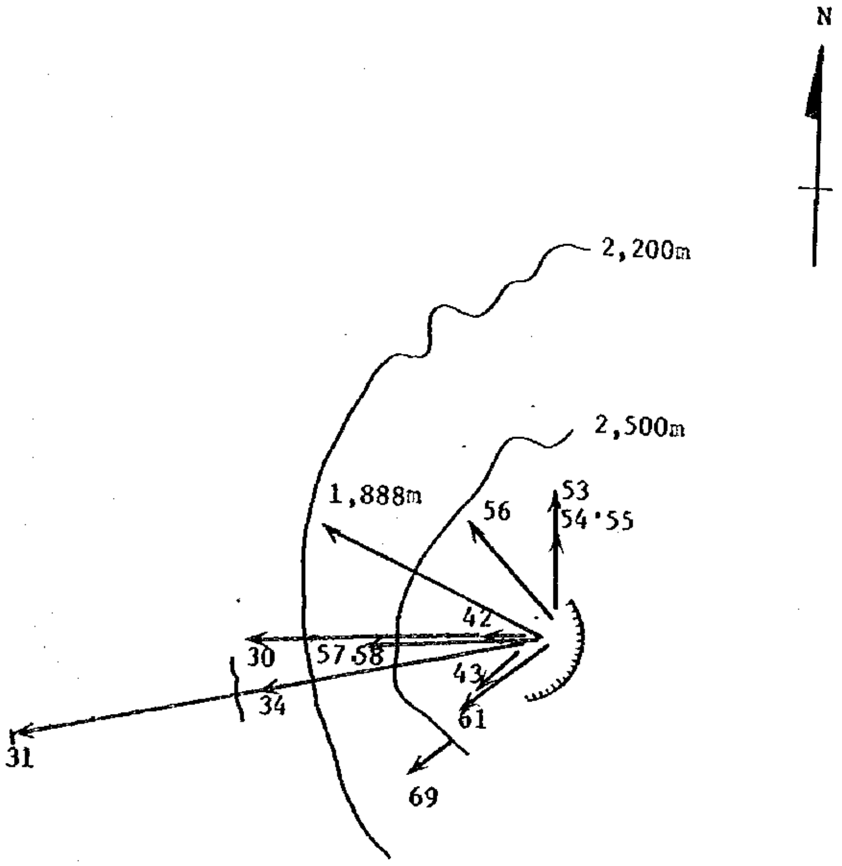
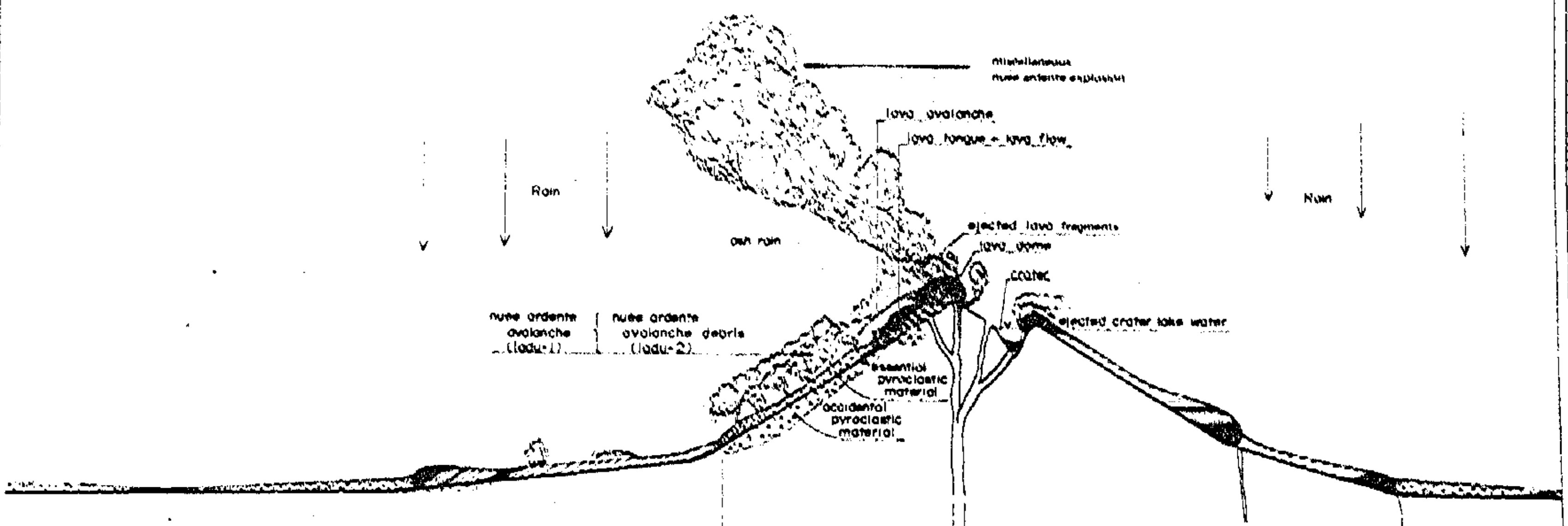
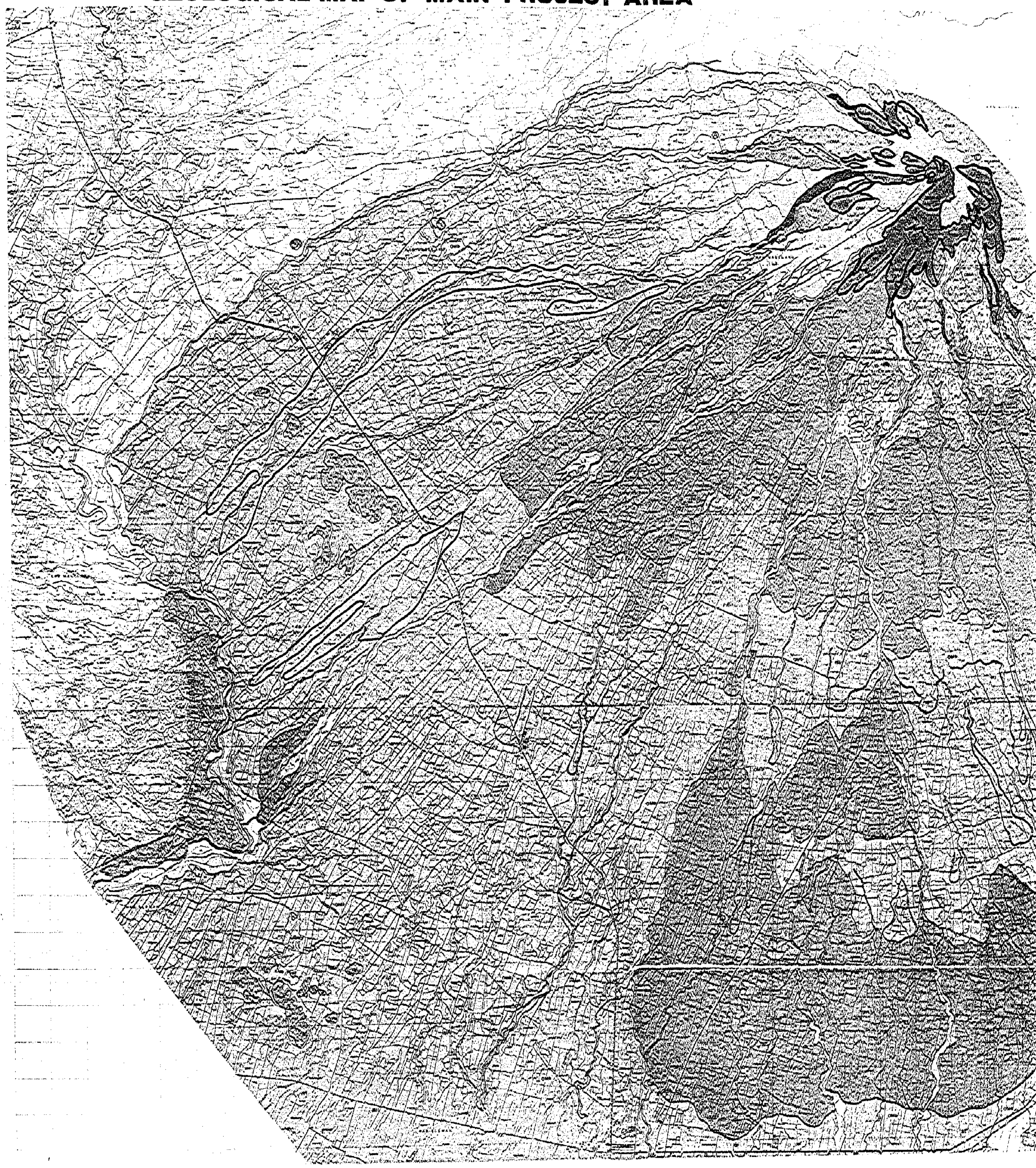


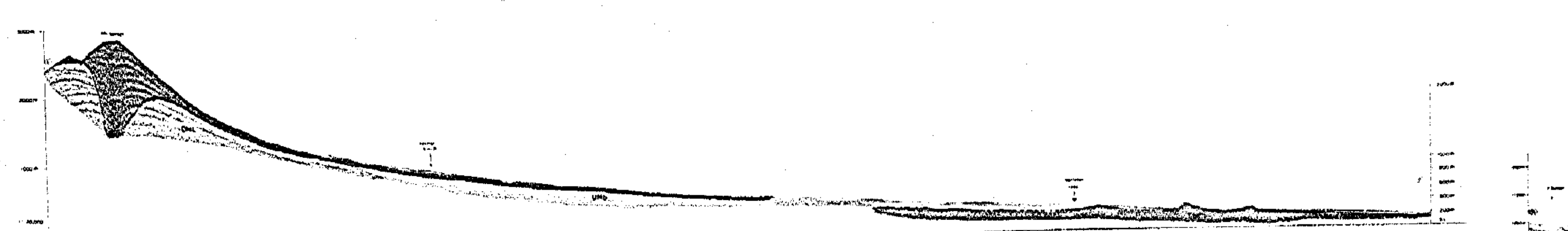
Fig. 2 Schematic of Volcanic States



VOLCANIC STATE	Banjir (Kozuiryu · Dosharyu)	Rain Lahar (Dosharyu · Dosekiryu)	Nuee Ardente Avalanche (Kasairyu or Pyroclastic flow)	Eruption Lahar: Primary Lahar (Kazandeiryu, Dosekiryu)	Secondary Lahar (Dosekiryu, Deiryu)	Banjir (Dosharyu)
Weather Condition	Wet	Wet	Dry	Dry + Crater Water	Wet	
Type of Transportation	Individual Objects Flow (including bed load and suspended load)	Massive Flow	Debris Flow or Pyro-Volcanic Flow	Hot Lahar Flow	Secondary Lahar flow	

GEOLOGICAL MAP OF MAIN PROJECT AREA





PROJECT AREA

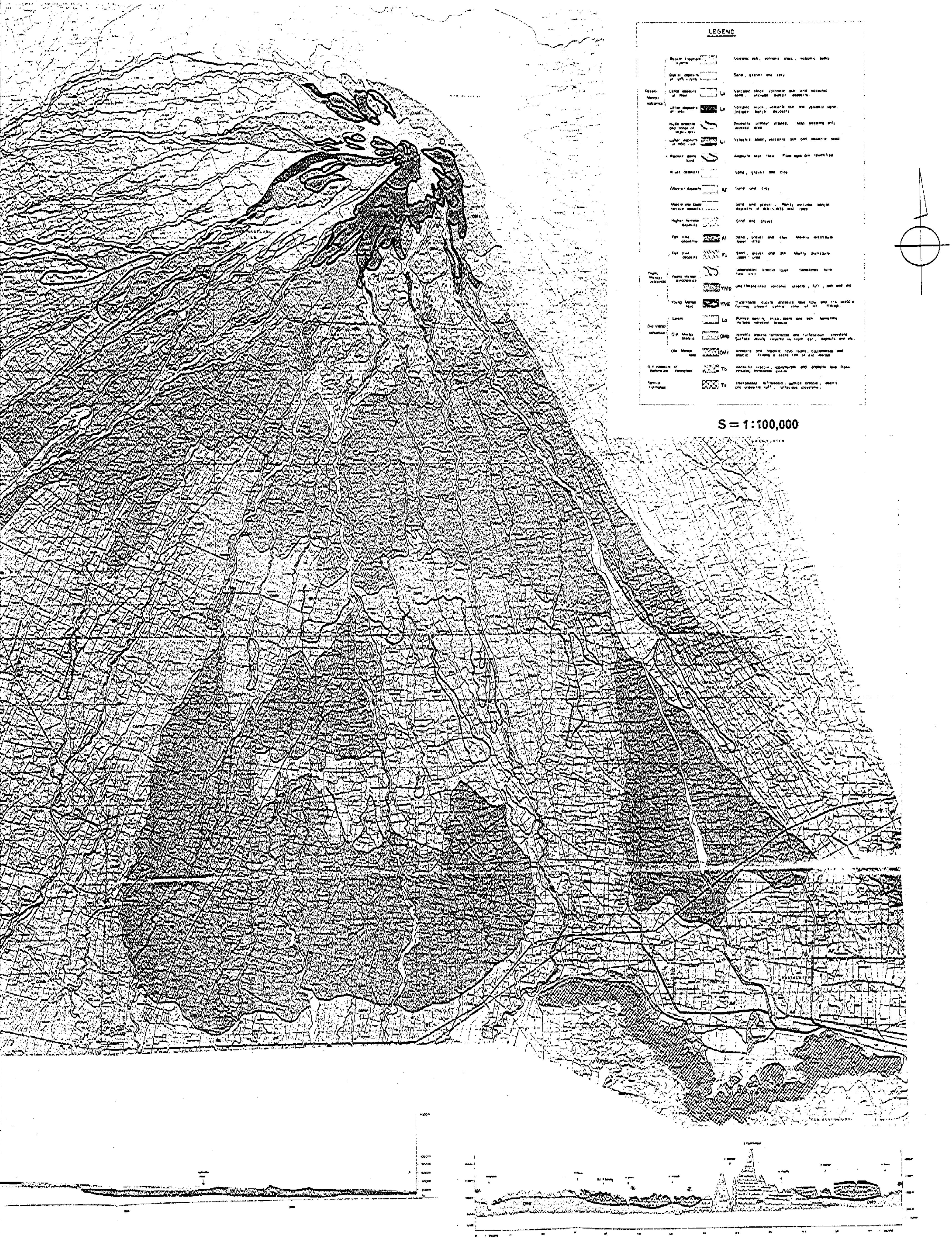


Fig. 3 Map Location of Test Pits

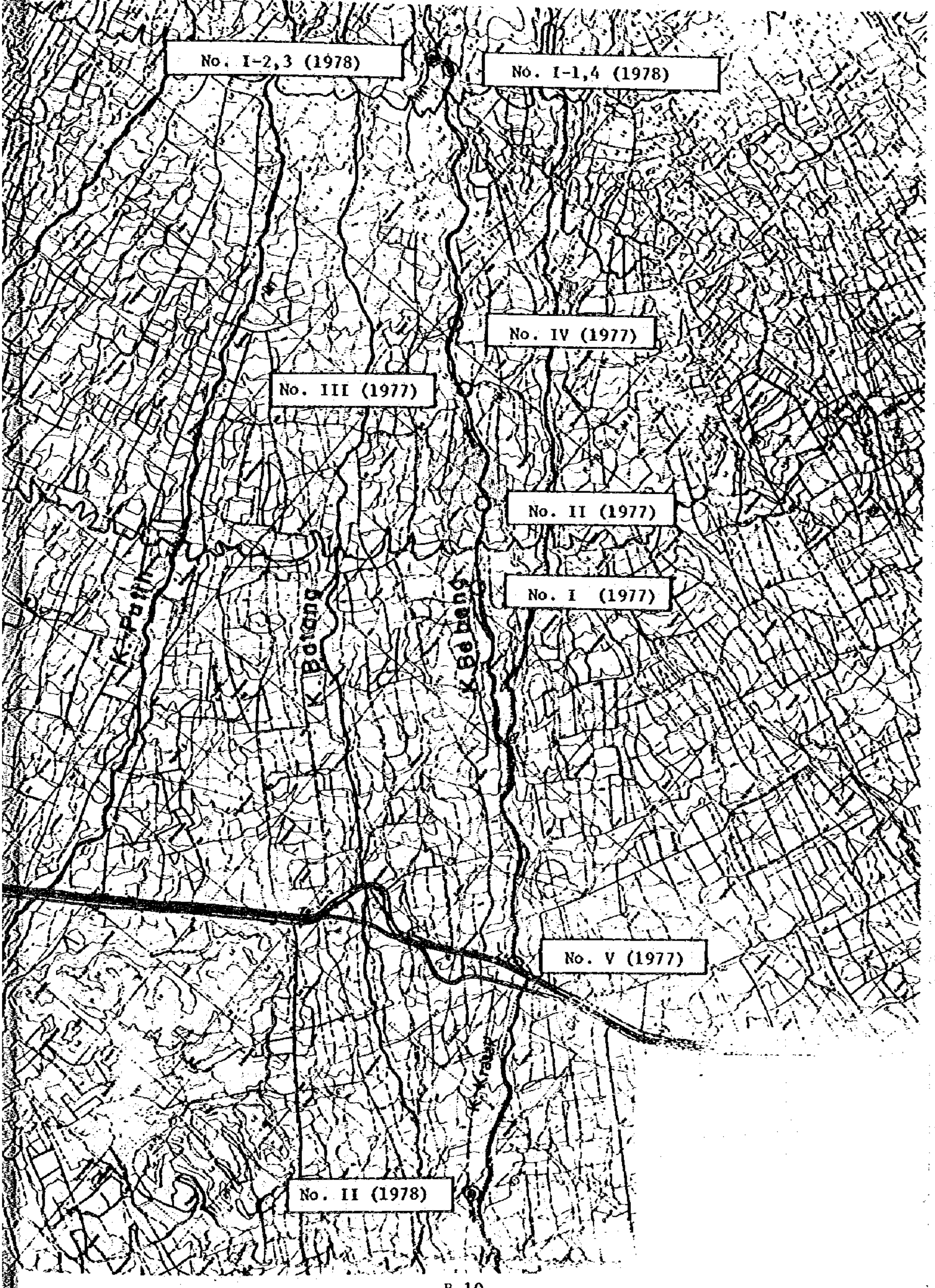


Table 3 Results of Soil Tests (1978)

Location and Sample No.			K. Bebeng				K. Krasak	K. Woro	
			I-1	I-2	I-3	I-4	II-1	III-1 Sand pocket upper stream	III-2 Sand pocket downstream
Grain size	Gravel (> 2.00 mm)	(%)	37.3	38.8	45.0	64.9	10.3	3.6	11.4
	Sand (0.074 ~ 2.00 mm)	(%)	58.4	54.0	48.2	32.5	88.7	93.3	84.0
	Silt and clay (< 0.074 mm)	(%)	4.1	7.0	6.9	2.3	1.0	3.1	4.7
Water content w		(%)	3.93	7.62	4.71	5.01	8.01	2.60	3.29
Specific gravity Gs			2,642 (2,839)	2,781 (2,771)	2,797 (2,759)	2,797	2,736	2,900	2,783
Compaction test	Moisture content w	(%)	11.95	12.92	13.06	14.37	16.34	12.59	12.59
	Bulk density γt	(t/m^3)	2,195	2.24	2.25	2,258	2.10	2,234	2,223
	Dry density γt	(t/m^3)	1,955	1.98	1.99	1,974	1.80	1.77	1.77
	Void ratio e		0.35	0.41	0.40	0.42	0.52	0.64	0.57
Direct shear	Compact Condition	ϕ	35°00'	57°23'	55°37'	52°25'	37°27'	45°57'	47°07'
		C	0.38	0.16	0.06	0.00	0.25	0.09	0.15
	Loose Condition	ϕ	27°	24°	10°	10°	20°	33°	15°
		C	0	0	0	0	0	0	0
Sampling total weight	w (kg)		1569.5	979.6	767.9	1031.8	4,976	3,994	3,485
Cubic volume	$V_s = W/2.8$	($1,000 cm^3$)	560.5	350.0	274.3	368.5	1.78	1.43	1.24
Capacity	V	($1,000 cm^3$)	793.6	473.0	366.0	511.0	2.90	1.89	1.51
Porosity	$n_a = \frac{V - V_s}{V} \times 100$	(%)	29.4	26.0	25.1	27.9	38.6 *	24.3 *	17.9 *

( ) of specific gravity are the data of Japanese Laboratory.

* data not reliable due to small size of sample.

Fig. 4 Grainsize Accumulation Curves (1977)

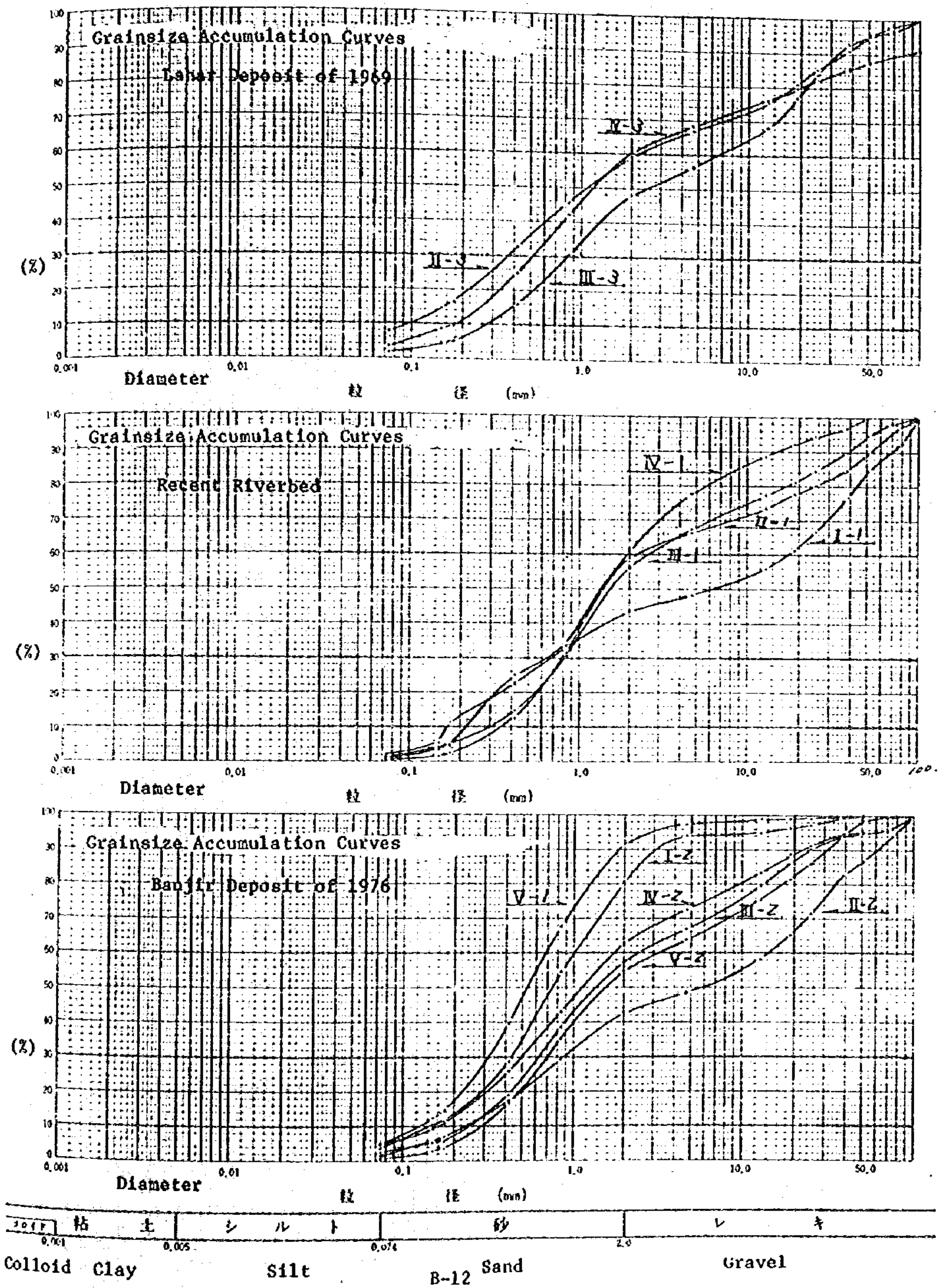
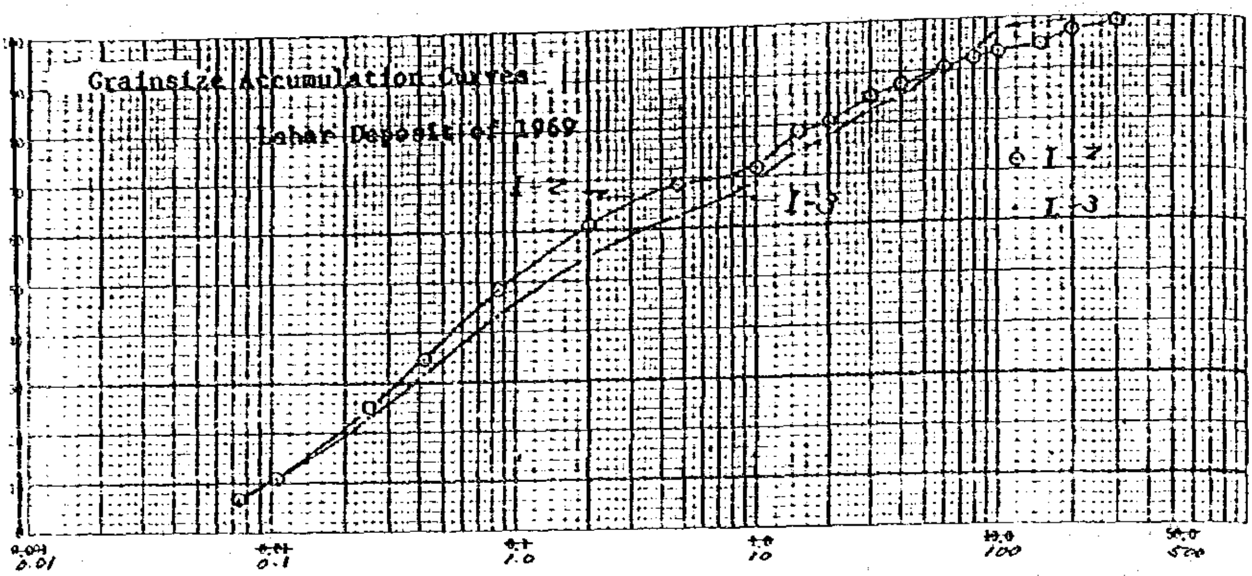
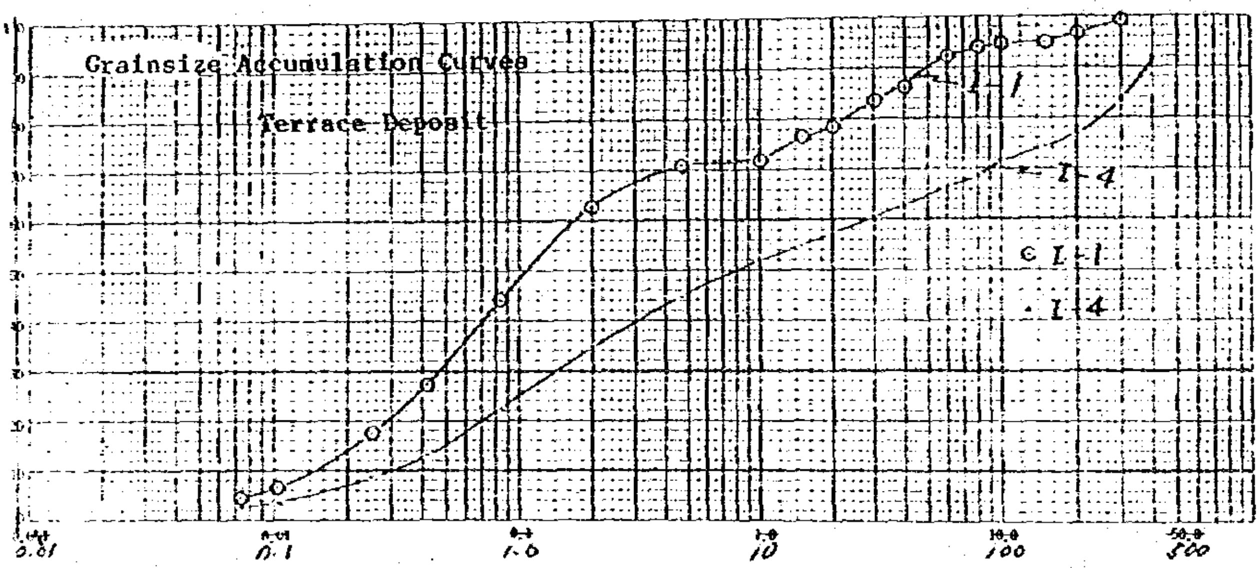
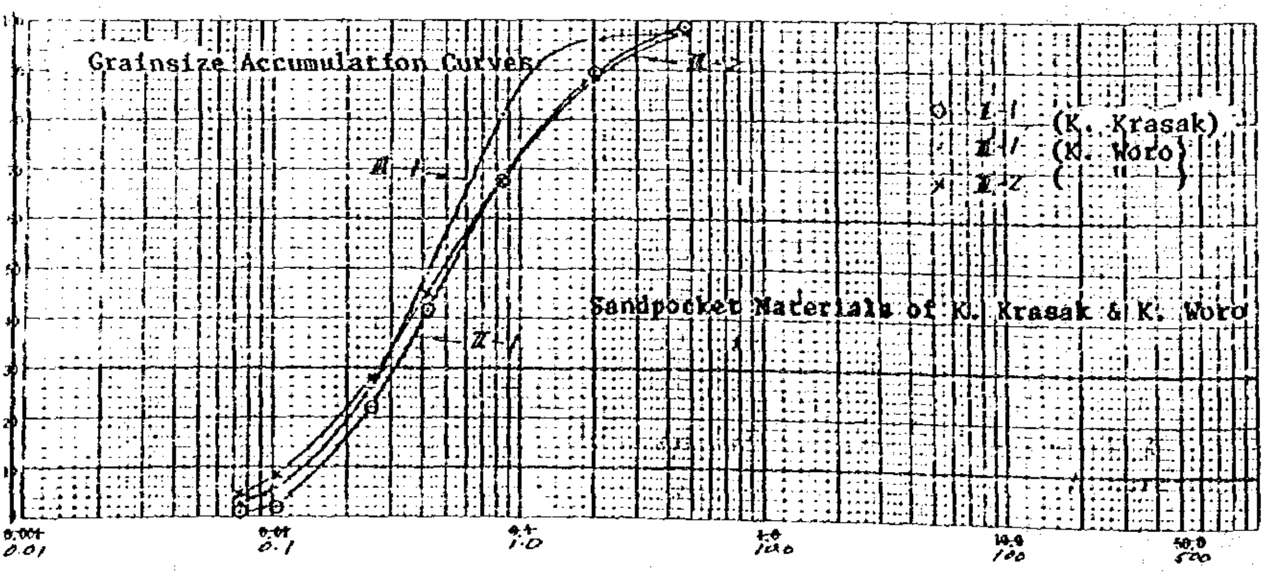


Fig. 5 Grainsize Accumulation Curves (1978)







2. AMOUNTS OF SEDIMENT PRODUCT AND DISCHARGE

In order to protect and stabilize the foothill zone, it is necessary to reduce and control the amount of sediment produced and discharged from the rivers of G. Merapi. To determine the amount of sediment in the study area ("the sediment balance"), the total amount of sediment produced during the period (1969 - 1977) and amount of existing unstable deposits along river channels have been calculated using various methods such as field investigation, airphoto-interpretation, aerial photographic survey and review of previous statistical data.

2.1 Sediment Area Terminology and Characteristics

2.1.1 Sediment Area Terminology

Disasters in the foothill zone of G. Merapi are mainly caused by sediment transported by the rivers and flooding in the middle slope area. The sources of sediment are the volcanic eruptions and the continuous erosion of unstable deposits along the river channels. Since the middle slopes of G. Merapi cover a wide area, the area has been divided by rivers (the unit of sediment transport) and then classified into 3 types depending on the amount of sediment present. A description of the sediment characteristics and rivers included in each type of area follows. (see Map of Fig. 6)

(1) In Type-I areas the amount of sediment present is greatest since the areas experienced Lahar/Banjir flooding many times in the last ten years and since about 95% of the sediment discharged from 1969 to 1977 was produced by lateral and downward erosion of the river channels. K. Krasak (including K. Bebeng), K. Batang and K. Putih are the main rivers of Type-I areas.

(2) In Type-II areas the amount of sediment present is very considerably less since the areas only experienced a few Lahar/Banjir floods in recent years and since sediment discharge comes mainly from unstable river terrace deposits, K. Woro and K. Gendol are the main rivers of Type-II areas.

(3) In Type-III areas the amount of sediment present is smallest or about 30-50% of the sediment in Type-II areas. K. Kuning, K. Boyong and K. Pabelan (including K. Senowo and K. Trising) are the main rivers of Type-III areas.

2.1.2 Characteristics of Sediment Production

(1) G. Merapi eruptions produce a large quantity of pyroclastic products such as lava, blocks, breccias and ashes.

(2) The longitudinal slope of the riverbeds around G. Merapi are generally controlled by the old Merapi volcanic products which distribute in some places along riverbeds and form a kind of base level of erosion. The deepening of river channel makes it harder to exceed this level, but the lateral advance of erosion is an influencial product source.

(3) Because each river channel is formed by loose pyroclastic materials, production of sediment by erosion is almost unlimitted. This causes also U-shaped valley.

(4) Riverbed forming materials are rich in volcanic ash, silt and clay materials, so even big boulders can easily be trasnported to the downstream area.

(5) The present active sediment producing section in the Type-I area is the section from 3 to 12km from the top of mountain and in Type-II and III areas it from 3 to 8km.

2.1.3 Characteristics of Sediment Discharge

(1) Amounts of sediment discharged in this area are related to the volcanic activity. Unstable volcanic debris supplied by eruptions easily cause large-scale Lahar and erosion of existing materials.

(2) After Nuée Ardente and/or large-scale lahar in the upper stream area, piracy of a river channel sometimes occurs. In this case, a small river is developed to a large one by rapid large-scale erosion.

(3) Lahar has the same form of transportation as the Japanese so-called "Dosekiryu" and owing to its massive nature to flow straight down, it causes large-scale excavation along undercut slopes of river channels and also flooding.

(4) Banjir has the same form of transportation as the Japanese so-called "Dosharyu" and flows along old river channels at flood time.

2.2 For Type - I Area

2.2.1 The amount of sediment product and discharge for the period (1969 ∿ 1970)

The large-scale nuée ardente eruptions of 1969 supplied debris in large quantities in the uppermost area. Some part of this debris flowed down as far as the downstream area in the form of large-scale hot lahar. One branch of hot lahar flowed down through K. Bebeng to K. Krasak, and another branch flowed down K. Blongkeng and then changed its direction to K. Putih due to the damming of the K. Blongkeng at Jurangjero.

1) Sediment balance at K. Krasak

The balance of sediment products and discharge at K. Krasak are summarized as follows and are itemized in Table 10 and Fig. 11.

Amounts of sediment produced (erosion) $11,804 \times 10^3 (m^3)$
Amounts of sediment deposited $5,425 \times 10^3 (m^3)$
Amounts of sediment discharged to K. Progo $6,379 \times 10^3 (m^3)$

The bases of estimation are summarized as follows:

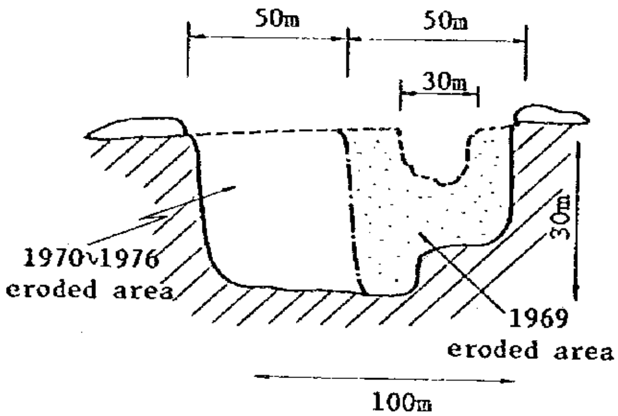
(1) Amounts of debris distributed at the alluvial fan area of upper stream, which were derived from the crater and the uppermost area by eruption, were calculated from their area of distribution and their depth. The distribution was checked by photo interpretation and the depth was estimated by field inspection using a map on a scale of 1:5,000.

(2) According to the questionnaire, most of the debris deposit distributed along the middle stream of K. Bebeng, typically observed at Kaligesik, which overflowed in 1969.

(3) In accordance with the questionnaire and the field inspection, cross sectional profiles of K. Bebeng before 1969 and just after erosion by lahar at the upper and middle streams were reproduced as shown in next figure. Based on the the estimation, the lahar of 1969 eroded about 40% of present cross sectional area in the upper stream and 60% in the middle stream.

K. Bebeng upper stream
(from 3-7km)

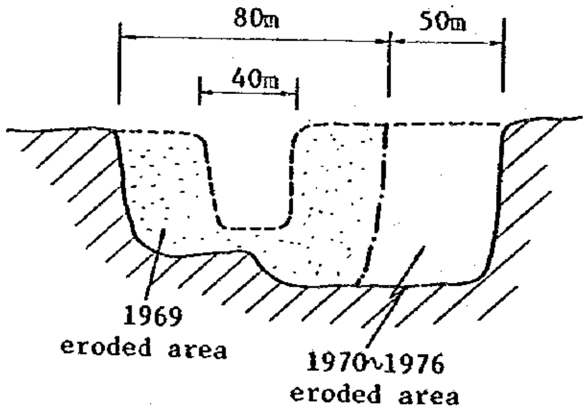
From 3 - 7km



About 40% of recent cross sectional area was eroded by 1969 Lahar

K. Bebeng middle stream
(from 7-12km)

From 7 - 12km

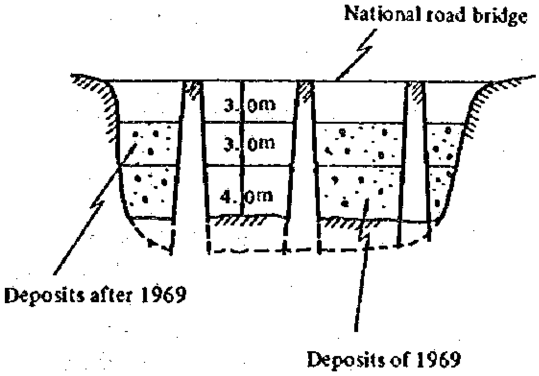


About 60% of recent cross sectional area was eroded by 1969 Lahar

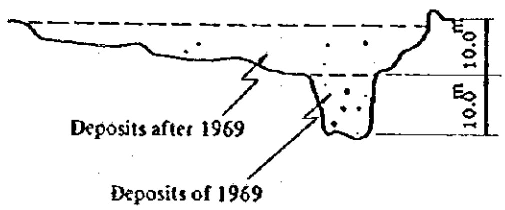
(4) At the downstream area of K. Krasak, the longitudinal profiles were surveyed by the Indonesian team immediately after the lahar of 1969. Cross sectional profiles before 1969 determined by questionnaire were reproduced as shown in next figure. The amounts of sediment estimated by these profiles are shown in Table 10.

[K. Krasak]

Typical profile of cross sectional area



Typical profile of cross sectional area



2) Sediment balance at K. Putih

The balance of sediment product and discharge at K. Putih are summarized below by the same method as for the K. Krasak, and itemized in Table 11 and Fig. 17.

Amounts of sediments produced	$6,060 \times 10^3 (m^3)$
Amounts of sediments deposited	$5,052 \times 10^3 (m^3)$
Amounts of sediments discharged to K. Progo	$1,008 \times 10^3 (m^3)$

(1) Amounts of debris at the alluvial fan of the upper stream area from the eruption of 1969 were calculated by field inspection and photo interpretation.

(2) The main part of lahar (including a part of the nuée ardente) deposited along K. Blongkeng and dammed it up near Jurangjero.

(3) Lahar/Banjir flowed down along K. Putih due to the damming of K. Blongkeng, and overflowed several times along the undercut slopes of the middle stream, and flooded a wide area near the national road.

(4) Lahar deposits of 1969 are well preserved as terrace along the middle and lower part of K. Putih, because no large scaled lahar flowed down after 1969.

3) Summary of Type-I Sediment Products 1969 - 1976

Based on the relation between produced and deposited amounts of volcanic materials at each distance (km) from the top of G. Merapi as shown in Fig. 7, we may conclude that;

(1) The amounts directly produced by eruption and derived from uppermost parts (within 3 kms from the top) are comparatively smaller than the amounts produced by continuous erosion of the river channel.

(2) Along K. Krasak, the section 12 kms from the top may be called the producing section. A large amount of deposit can be seen at the section between 13 km and 15 km from the top. Along K. Putih, the section 9 km from the top forms its producing section.

(3) In the upper stream area of K. Putih, unstable debris is distributed in large quantities.

2.2.2 The Amount of Sediment Product and Discharge for the Period 1976 ∿ 1978

The calculation sediment balance for the above period was based on measurement riverbed variation using comparative aerial survey airphotographs taken in 1976, 1977, and 1978, and by additional field inspection in the upper stream area. During this period, a medium-scale Banjir occurred in 1976 causing floods and the deposition of about 1,180 x $10^3(m^3)$ at the downstream area of K. Krasak and about 26 x $10^3(m^3)$ at the middle stream area of K. Putih. The aerial survey airphotographs of 1978 were used only along K. Krasak and K. Bebeng because their variation were more pronounced than other rivers. The findings are summarized in Table 4.

Table 4 Riverbed Variation by Aerial Survey

unit: $\times 10^3 (m^3)$

Period	River	Estimated Amounts of Sediment by Field Inspection		Aerial Survey of Calculation of Riverbed Variation		Amounts of Discharge to K. Progo
1976 ~ 1977	K. Bebeng	upper stream above 7km point	-1,797	7km-15km	69	(Discharge to K. Krasak) 1,728
	K. Krasak (main channel)	flood deposit near 20km point	+1,180	5km-22km	420	
	K. Krasak (whole area)		-617		489	128
	K. Putih	upper stream above 7km point	-124	7km-23km	-5	103
		flood deposit near point 11km	+26			
	K. Batang	upper stream above 7km point	0	7km-23km	-64	64
	K. Blongkeng	upper stream above 7km point	0	7km-24km	-52	52
1977 ~ 1978	K. Bebeng	upper stream above 6km point	-586	3km-15km	-383	(Discharge to K. Krasak) 969
	K. Krasak (main channel)			7km-27km	411	
	K. Krasak (whole area)		-586		28	558

On basis of the foregoing, a summary of the characteristics of the sediment balance in Type-I area for the period 1976 ∿ 1978 is as follows:

(1) The amount of sediment discharged from each river excluding K. Krasak ranged from 50 to 100 x 10^3m^3. It is estimated that these amounts are constantly discharged every year, assuming that no large change happens in upper stream areas.

(2) The amounts of discharge from K. Krasak to K. Progo during the period for 1976 ∿ 1977 was apparently as small as 128 x 10^3m^3, but the amounts including flood depositing in the lower stream area reached more than 1,000 x 10^3m^3.

(3) The amounts of discharge from K. Krasak during the period 1977 ∿ 1978 also reached 558 x 10^3m^3.
This data is more recent than data for the other rivers of G. Merapi.

2.2.3 The Amount of Sediment Product and Discharge for the Cumulative Period 1969 ∿ 1977

Sediment balance for the cumulative period is summarized in Table 5 and Figs. 9 and 10.

Table 5 Sediment Balance for the Cumulative Period

unit: x 10^3m^3

River	Period	Volume of Sediment Product from uppermost area	Volume of Sediment Products derived from Erosion	Volume of Alluvial fan and Flooding Deposit	Volume of Deposits in Middle and Down-Stream Area	Amounts of Sediment Discharged to K. Progo
K. Krasak	1969 ∿1970	1,235	10,569	2,449	2,976	6,379
	∿1976	0	10,713	0	7,254	3,459
	∿1977	0	1,992	0	1,864	128
K. Putih	1969 ∿1970	2,480	3,580	2,480	2,572	1,008
	∿1976	0	1,457	0	558	899
	∿1977	0	129	0	26	103

The annual amount of sediment discharge to K. Progo from K. Batang and K. Blongkeng may be similar to that in 1976 ∿ 1977, because K. Batang changed and had almost no sediment product since 1961; K. Blongkeng also changed and has had almost no sediment since 1969.

Therefore, the amount of sediment discharge of these two rivers for the period 1969 ∿ 1977 was estimated as follows.

K. Batang   64 x 9 years = 576 x $10^3(m^3)$
K. Blongkeng 52 x 9 years = 468 x $10^3(m^3)$

The total amount of sediment discharge to K. Progo from the Type-I area is summarized as 13,020 x $10^3(m^3)$

(1) The total amount of sediment discharged for the above nine(9) years to K. Progo from the Type-I area is estimated as 13 x $10^6 m^3$.

(2) The amount of sediment discharged from K. Krasak occupies about 77% and K. Putih about 15% of the total amount from the Type-I area. This means these two rivers made up 92% of the total for the Type-I area.

(3) As shown in the curve of annual change of K. Krasak in Fig. 10 a large-scale discharge occurred just after the eruption of 1969; after that, discharge decreased and became more stable.

In the cases of upper stream of K. Krasak main and K. Lamat, however, the river characteristics are similar to those in Types II and III. The amounts of sediment produced and discharged were estimated by using the same calculation method as in Types II and III, and showed in Tables 6 ∿ 9 of section 2.3.

Fig. 6 Map of River Type Areas

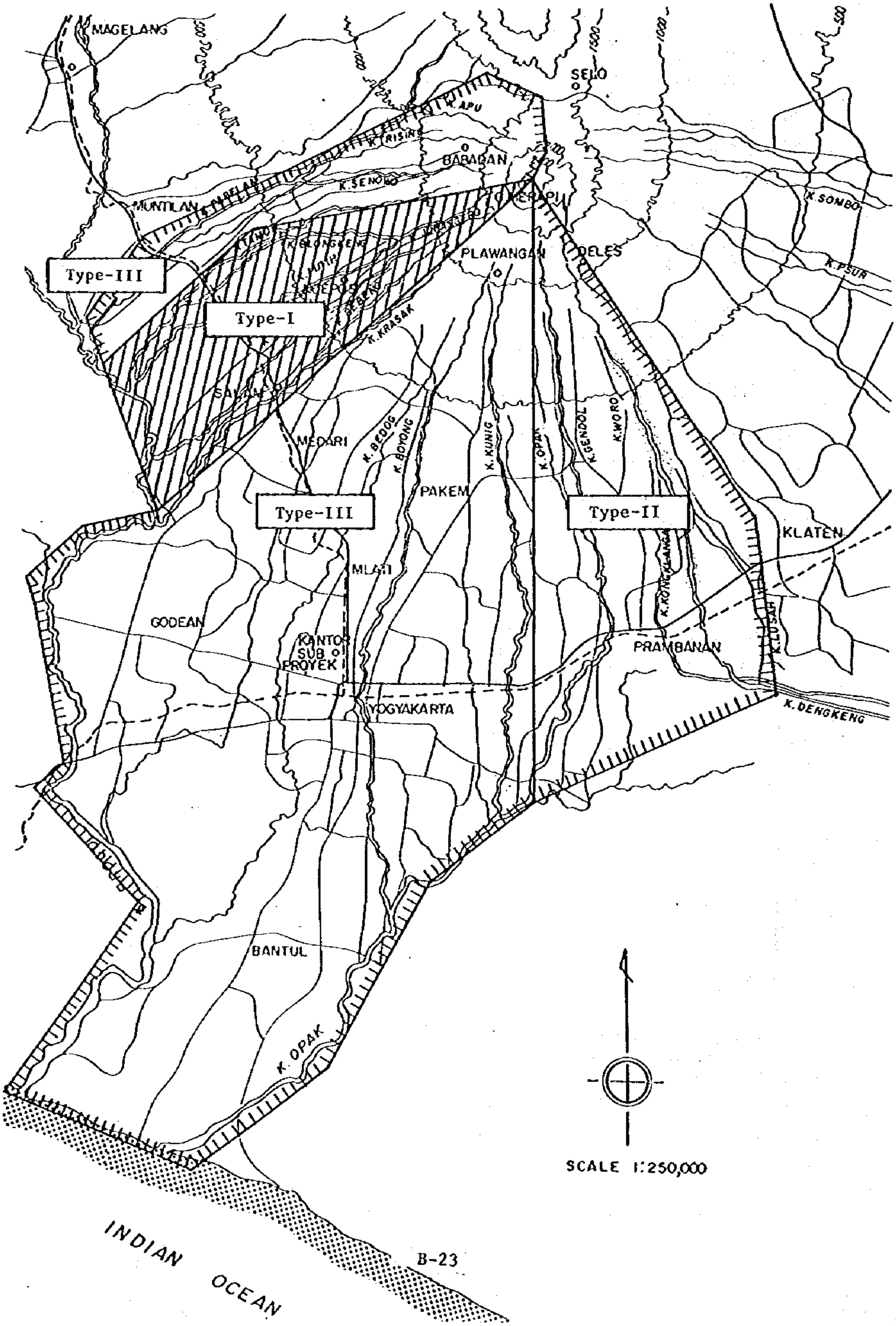


Fig. 7 The Amount of Sediment Producted and Deposit Per km (from 1969 to 1970)

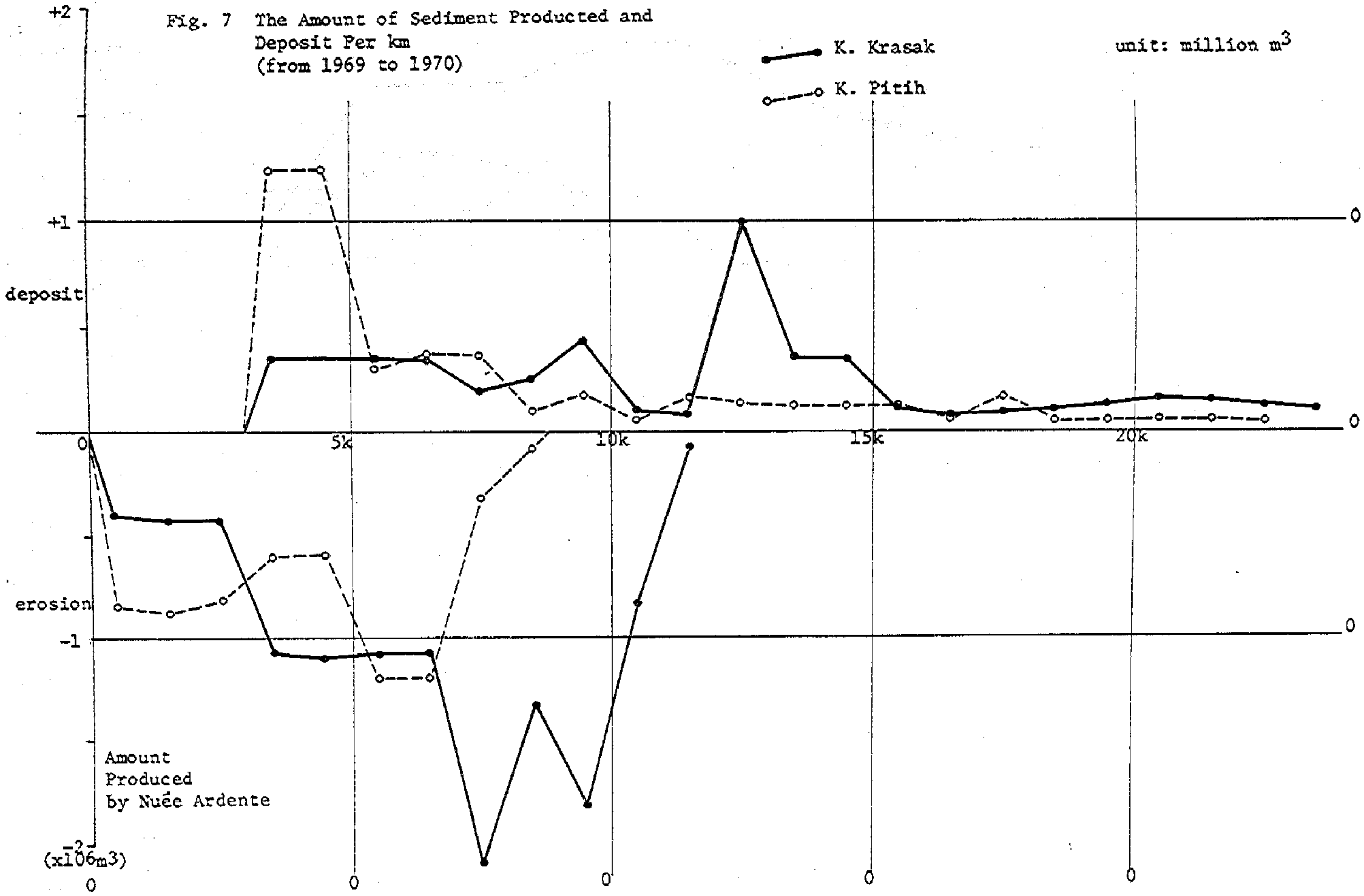


Fig. 8 Sectional Sediment Changes in K. Krasak (from 1976 to 1978)
(K. Krasak + K. Bebeng 1976 ~ '78)

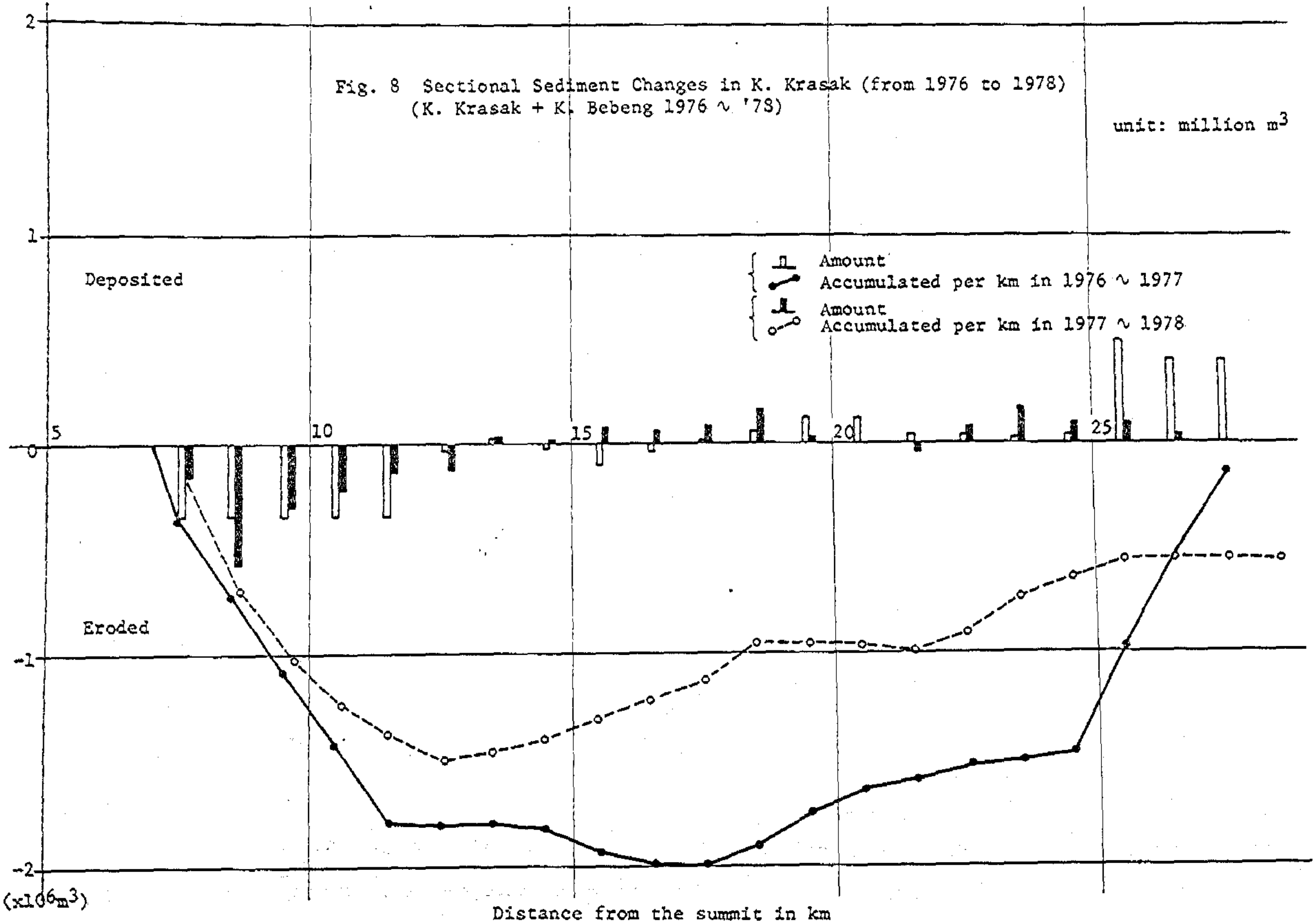


Fig. 9 The Amount of Sediment Producted and Deposit Per km (from 1969 to 1977)

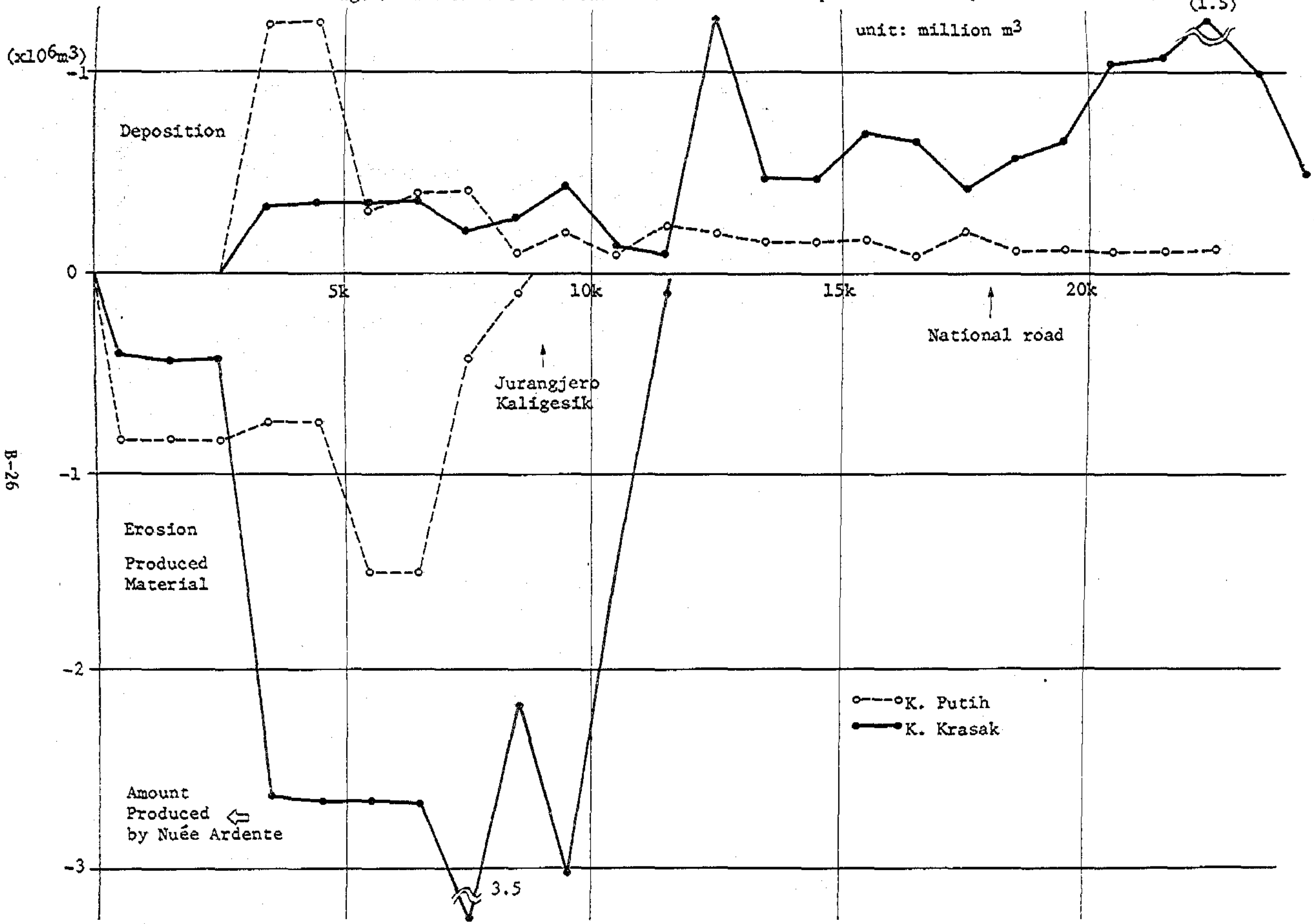
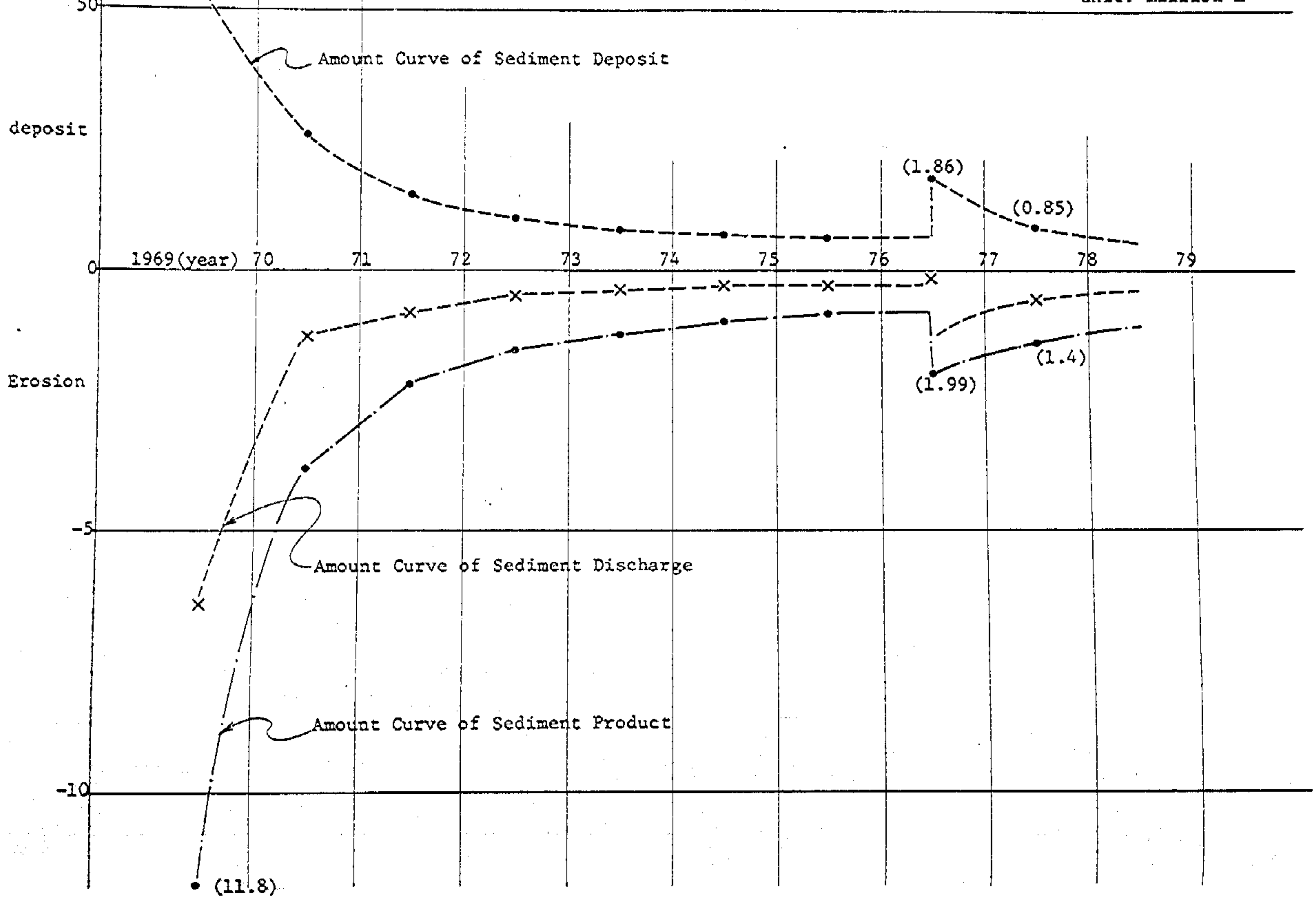


Fig. 10 Tendency of Annual Produced and Deposited Volumes in K. Krasak

unit: million m3



2.3 For Type-II and Type-III Areas

2.3.1 Present Amount of Unstable Materials

Among the kinds of unstable materials presently found in Type-II and Type-III areas are new volcanic ash, debris, talus, and alluvial fan deposits on the mountainside, terrace deposits and present riverbed deposits. These unstable materials constitute source of future sediment discharge.

Although the banks of the rivers in the middle and upper slope areas consist of unconsolidated and semi-consolidated loose volcanic ash strata and gravel strata. Type II and III area rivers have almost stabilized and there is very small possibility for rapid erosion of volcanic materials in them during the project life, therefore these river materials are not considered as unstable materials for the present purpose.

The method of calculation used was to interpret the surface distribution of various kinds of deposits on the basis of aerial photographs and then to check the thickness of these deposits in subsequent field surveys. The depth of present riverbed deposits has been estimated as 2m (the average change in the level of riverbeds as measured in Type-I areas). The size of present unstable deposits is presented in Table 6 and summarized in Table 8.

2.3.2 Amount of Possible Sediment Discharge

Except for K. Krasak, it is estimated that the amount of sediment discharge for tributaries in Type-II and Type-III areas is several thousands or tens of thousands of cubic meters a year: i.e., similar to the amount from tributaries in Type-I areas. In the case of K. Woro and K. Gendol (Type-II), however, there were major occurrence of lahar and banjir flows around 1930 and 1969, causing the formation of terraces in the upper slope area and large-scale flooding and sedimentation in the middle and lower slope areas.* In all areas, it is necessary first to calculate the possible amount of sediment discharge (sediment product) in terms of large-scale flooding for the purposes of disaster prevention planning. Next, it will be necessary to calculate that part of the existing unstable deposit that can be expected to flow out at the time of major flooding. The amount possible sediment discharge for each tributary is presented in Table 9 and summarized in Table 7.

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* Generally speaking, the occurance of flooding and sedimentation in K. Kuning, K. Boyong and K. Pabelang (Type-III) was very significantly less.

Table 6 Summary of Present Unstable Deposits in Type II and Type III Areas

Type	Name of river	Distance from the summit (Km)	Recent Riverbed deposits (x10³m³)	Lower Terrace deposits (x10³m³)	Middle and upper terrace deposits (x10³m³)	Other unstable deposits (x10³m³)	Total volume (x10³m³)
Type - II	K. Woro	0 ~ 12	1,198	(343) 424	(1,875) 2,316	(1,900) 2,347	6,285
Type - II	Sandpocket of K. Woro	12 ~ 17	1,375	4,500	–	–	5,875
Type - II	K. Gendol	0 ~ 19	874	(1,468) 1,813	(837) 1,034	(2,125) 2,624	6,345
Type - III	K. Kuning	0 ~ 18	830	(1,183) 1,461	(238) 294	(648) 800	3,385
Type - III	K. Boyong	0 ~ 17	755	(519) 641	(484) 598	(128) 158	2,152
Type - III	K. Senowo (A)	0 ~ 12	610	(324) 399	(685) 846	(366) 452	2,307
Type - III	K. Trising (B)	0 ~ 19	1,112	(1,817) 2,243	(212) 262	(186) 230	3,847
Type - III	K. Pabelan (C)	0 ~ 13	300	(303) 373	(114) 141	(278) 343	1,157
Type - III	A + B + C	0 @ 19	2,022	(2,444) 3,015	(1,011) 1,249	(830) 1,025	7,311
Type - I	K. Krasak	0 ~ 12	1,353	(564) 697	–	–	2,050
Type - I	K. Lamat	0 ~ 12	510	(23) 29	–	–	539

( ) means volume before loosened bulk factor of soil = 1,235

Table 7 Summary of Possible Sediment Discharge Volume in Type II and Type III Areas

Type	Name of river	Area of basin (Km²)	Distance from the summit (km)	Recent riverbed deposits (x10³m³)	Lower terrace deposits (x10³m³)	Middle and upper terrace deposits (x10³m³)	Other unstable deposits (x10³m³)	Volume of sediment products (x10³m³)	Specific probable Volume (x10³m³/Km²)
Type - II	K. Woro	7.1	0 ~ 10	637	(343) 424	(1,500) 1,853	(1,057) 1,305	4,219	594
Type - II	K. Gendol	10.5	~ 13	400	(390) 482	(670) 827	(1,173) 1,449	3,158	301
Type - III	K. Kuning	9.6	~ 13	320	(720) 889	(190) 235	(324) 400	1,844	192
Type - III	K. Boyong	10.3	~ 13	445	(349) 431	(332) 410	(114) 141	1,437	140
Type - III	K. Senowo (A)	8.8	~ 12	510	(323) 399	(548) 677	(223) 275	1,861	211
Type - III	K. Trising (B)	12.4	~ 12	400	(483) 597	(170) 210	(123) 152	1,359	110
Type - III	K. Pabelan (C)	52.0	~ 13	300	(303) 373	(92) 113	(169) 204	990	19
Type - III	A + B + C	73.2	~ 13	1,210	(1,109) 1,369	(810) 1,000	(515) 631	4,210	58
Type - I	K. Krasak	13.6	~ 12	1,353	(564) 697	–	–	2,050	151
Type - I	K. Lamat	14.2	~ 12	430	(23) 29	–	–	459	32

( ) means volume before loosened bulk factor of soil = 1,235

Table 8 Unstable Materials Data from Type-II,III Area by Tributary and Distance from Summit

Name of River	Distance from the Sumit (km)	Recent riverbed deposits A (m^3)	Lower terrace deposits B (m^3)	Middle and higher terrace deposits C (m^3)	Other unstable deposits D (m^3)	Total unstable materials (m^3)	Loosened Volume A+(B+C+D) x1.235 (m^3)	Accumulation (Loosened condition) (m^3)
K. Woro	0 ~ 3				1,312,500 562,500	1,875,000	2,316,000	
	~ 4	10,000		100,000	25,000	135,000	164,000	2,480,000
	~ 5	20,000		441,000		461,000	565,000	3,045,000
	~ 6	40,000		750,000		790,000	966,000	4,011,000
	~ 7	40,000	144,000	422,000		606,000	739,000	4,750,000
	~ 8	367,000	45,000	100,000		185,000	546,000	5,296,000
	~ 9	60,000	86,000	62,500		208,500	244,000	5,540,000
	~ 10	100,000	67,500			167,500	184,000	5,724,000
	~ 11	281,000				281,000	281,000	6,005,000
	~ 12	280,000				280,000	280,000	6,285,000
	Total	1,198,000	342,500	1,875,000	1,190,000	4,989,000	6,285,000	
	12 ~ 17	1,375,000	4,500,000			5,875,000	5,875,000	5,875,000
K. Gendol	0 ~ 5	20,000			562,500 1,562,500	2,145,000	2,644,000	
	~ 6	40,000	58,000			98,000	112,000	2,756,000
	~ 7	60,000	19,000	387,500		466,500	562,000	3,318,000
	~ 8	60,000	52,500	244,000		356,500	426,000	3,744,000
	~ 9	60,000	41,000	62,500		163,500	188,000	3,932,000
	~ 10	10,000	28,000	75,000		113,000	137,000	4,069,000
	~ 11	40,000	86,000	68,500		194,500	231,000	4,300,000
	~ 12	60,000	45,000			105,000	116,000	4,416,000
	~ 13	60,000	60,000			120,000	134,000	4,550,000
	~ 14	50,000	64,000			114,000	129,000	4,679,000
	~ 19	414,000	1,014,000			1,428,000	1,666,000	6,345,000
	Total	874,000	1,467,500	837,500	2,215,000	5,304,000	6,345,000	
K. Kuning	0 ~ 5		71,000		648,500	719,500	889,000	
	~ 6	20,000	41,000	62,500		123,500	148,000	1,037,000
	~ 7	20,000	64,000			84,000	99,000	1,136,000
	~ 8	10,000	52,500			62,500	75,000	1,211,000
	~ 9	80,000	39,500	125,000		244,500	283,000	1,494,000
	~ 10	100,000	47,000	50,000		197,000	220,000	1,714,000
	~ 11	100,000	15,000			115,000	119,000	1,833,000
	~ 12	100,000	124,000			224,000	253,000	2,086,000
	~ 13	100,000	266,000			366,000	428,000	2,514,000
	~ 18	300,000	463,000			763,000	871,000	3,385,000
	Total	830,000	1,183,000	237,500	648,500	2,899,000	3,385,000	
K. Boyong	0 ~ 5				127,500	127,500	157,000	
	~ 6	5,000	11,000	56,000		72,000	88,000	245,000
	~ 7	10,000	62,000	306,000		378,000	464,000	709,000
	~ 8	40,000	56,000			96,000	109,000	818,000
	~ 9	100,000	62,000			162,000	177,000	995,000
	~ 10	80,000	112,500	53,000		245,500	284,000	1,279,000
	~ 11	100,000	5,500			105,500	107,000	1,386,000
	~ 12	100,000	15,000			115,000	119,000	1,505,000
	~ 13	80,000	24,500			104,500	111,000	1,616,000
	~ 17	240,000	170,500	69,000		479,500	536,000	2,152,000
	Total	755,000	519,000	484,000	127,500	1,885,500	2,152,000	
K. Senowo	0 ~ 4	10,000	26,000	372,000	366,000	774,000	954,000	
	~ 5	40,000	47,000	150,000		237,000	283,000	1,237,000
	~ 6	40,000	120,000			160,000	188,000	1,425,000
	~ 7	60,000	24,500	162,500		247,000	291,000	1,716,000
	~ 8	80,000	5,000			85,000	86,000	1,802,000
	~ 9	100,000	43,000			143,000	153,000	1,955,000
	~ 10	100,000				100,000	100,000	2,055,000
	~ 11	100,000				100,000	100,000	2,155,000
	~ 12	80,000	58,000			138,000	152,000	2,307,000
	Total	610,000	323,500	684,500	366,000	1,984,000	2,307,000	
K. Trising	0 ~ 4	10,000	43,000		186,000	239,000	293,000	
	~ 5	20,000	80,500	65,500		166,000	200,000	493,000
	~ 6	20,000	69,500	90,500		180,000	218,000	711,000
	~ 7	40,000	45,000	56,000		141,000	165,000	876,000
	~ 8	80,000	43,000			123,000	133,000	1,009,000
	~ 9	80,000	47,000			127,000	138,000	1,147,000
	~ 10	80,000	26,000			106,000	112,000	1,259,000
	~ 11	100,000	47,000			147,000	158,000	1,417,000
	~ 12	40,000	82,500			122,500	142,000	1,559,000
	~ 13	125,000	245,500			370,500	428,000	1,987,000
	~ 14	100,000	234,500			334,500	390,000	2,377,000
	~ 15	112,500	326,000			438,500	515,000	2,892,000
	~ 19	304,000	527,000			831,000	955,000	3,847,000
	Total	1,111,500	1,816,500	212,000	186,000	3,326,000	3,847,000	

Table 8 Unstable Materials Data from Types-II and III Areas by Tributary and Distance from Summit

Name of River	Distance from the Sumit (Km)	Recent riverbed deposits A (m^3)	Lower terrace deposits B (m^3)	Middle and higher terrace deposits C (m^3)	Other unstable deposits D (m^3)	Total unstable materials (m^3)	Loosened Volume A+(B+C+D) x1.235 (m^3)	Accumulation (Loosened condition) (m^3)
K. Pabelan	0 ~ 4	20,000	43,000	20,000	278,000	361,000	440,000	
	~ 5	30,000	13,000	10,000		53,000	58,000	498,000
	~ 6	30,000	15,000	9,000		54,000	59,000	557,000
	~ 7	30,000	9,000	7,000		46,000	50,000	607,000
	~ 8	50,000	14,000			64,000	67,000	674,000
	~ 9	60,000	46,000			106,000	117,000	791,000
	~ 10	40,000	64,000	31,000		135,000	158,000	949,000
	~ 11	20,000	61,000	37,000		118,000	141,000	1,090,000
	~ 12	20,000	23,000			43,000	48,000	1,138,000
	~ 13		15,000			15,000	19,000	1,157,000
	Total	300,000	303,000	114,000	278,000	995,000	1,157,000	
K. Krasak	Main Channel							
	7 ~ 8	110,000	32,000			142,000	150,000	
	~ 9	163,000	46,000			209,000	220,000	370,000
	~ 10	199,000	114,000			313,000	340,000	710,000
	~ 12	225,000	304,000			529,000	600,000	1,310,000
	Sub total	697,000	496,000			1,193,000	1,310,000	
	Tributary I							
	7 ~ 7.6 (1)	84,000	–			84,000	84,000	
	" (2)	108,000	–			108,000	108,000	192,000
	7.6 ~ 8	73,000	6,000			79,000	80,000	272,000
	~ 9	178,000	50,000			228,000	240,000	512,000
	~ 9.4	120,000	–			120,000	120,000	632,000
	Sub total	563,000	56,000			619,000	632,000	
	Tributary II							
	9.4 ~ 9.7	48,000	–			48,000	48,000	
	~ 10	45,000	12,000			57,000	60,000	108,000
	Sub total	93,000	12,000			105,000	108,000	
	Total	1,353,000	564,000			1,917,000	2,050,000	
K. Lamat	4 ~ 5	30,000				30,000	30,000	
	~ 6	50,000				50,000	50,000	80,000
	~ 7	60,000	23,400			83,400	89,000	169,000
	~ 8	40,000				40,000	40,000	209,000
	~ 9	60,000				60,000	60,000	269,000
	~ 10	100,000				100,000	100,000	369,000
	~ 11	50,000				50,000	50,000	419,000
	~ 12	40,000				40,000	40,000	459,000
	~ 20	80,000				80,000	80,000	539,000
	Total	510,000	23,400			533,400	539,000	

Table 9 Possible Sediment Discharge Data from Types-II and III Area by Tributary and Distance from Summit (1)

Name of River	Area of basin (Km²)	Distance from the summit (Km)	Recent riverbed deposits (x10³m³)	Lower terrace deposits (x10³m³)		Middle and higher terrace deposits (x10³m³)		Other unstable deposits (x10³m³)		Volume of sediment products (x10³m³)		Specific probable Volume (x10³m³/Km²)
				Stable	Loose	Stable	Loose	Stable	Loose	Stable	Loose	
K. Woro		0 ~ 3						656 281	810 347	937	1,157	
		~ 4	10			80	99	20	24	110	133	
		~ 5	20			353	436	10	12	383	468	
		~ 6	40			600	741	20	25	660	806	
		~ 7	40	144	178	337	416	20	25	541	659	
		~ 8	367	45	56	80	99	30	37	522	559	
		~ 9	60	86	106	50	62	20	25	216	253	
		~ 10	100	68	84					168	184	
	7.1	Total	637	343	424	1,500	1,853	1,057	1,305	3,537	4,219	594
K. Gendol		0 ~ 5	20					1,063	1,313	1,083	1,333	
		~ 6	40	58	72			30	37	128	149	
		~ 7	60	19	23	310	383	40	49	429	515	
		~ 8	60	53	65	195	241	30	37	338	403	
		~ 9	60	41	51	50	62	10	12	161	185	
		~ 10	0	28	35	60	74			88	109	
		~ 11	40	86	106	55	68			180	214	
		~ 12	60	45	56					105	116	
		~ 13	60	60	74					120	134	
	10.5	Total	400	390	482	670	828	1,173	1,448	2,633	3,158	301
K. Kuning		0 ~ 5		71	88			324	400	395	488	
		~ 6	20	41	51	50	62			111	133	
		~ 7	20	64	79					84	99	
		~ 8	0	52	64					52	64	
		~ 9	40	40	49	100	124			180	213	
		~ 10	100	47	58	40	49			187	207	
		~ 11	100	15	18					115	118	
		~ 12	20	124	153					144	173	
		~ 13	20	266	329					286	349	
	9.6	Total	320	720	889	190	235	324	400	1,554	1,844	192
K. Boyong		0 ~ 5						64	79	64	79	
		~ 6	5	11	14	45	56			61	75	
		~ 7	10	62	77	245	302	20	25	337	414	
		~ 8	0	56	69			20	25	76	94	
		~ 9	100	62	77			10	12	172	189	
		~ 10	80	113	139	42	52			235	271	
		~ 11	100	6	7					106	107	
		~ 12	100	15	18					115	118	
		~ 13	60	24	30					84	90	
	10.3	Total	455	349	431	332	410	114	141	1,250	1,437	140
K. Senowo		0 ~ 4	10	26	32	298	368	183	226	517	636	
		~ 5	40	47	58	120	148	10	12	217	258	
		~ 6	40	120	148					160	188	
		~ 7	60	24	30	130	161	20	25	234	276	
		~ 8	80	5	6			10	12	95	98	
		~ 9	100	43	53					143	153	
		~ 10	0							0	0	
		~ 11	100							100	100	
		~ 12	80	58	72					138	152	
	8.8	Total	510	323	399	548	677	223	275	1,604	1,861	211
K. Trising		0 ~ 4	20	43	53			93	115	156	188	
		~ 5	40	80	99	52	64	10	12	183	215	
		~ 6	40	69	86	73	90	20	25	202	241	
		~ 7	40	45	56	45	56			130	152	
		~ 8	80	43	53					123	133	
		~ 9	80	47	58					127	138	
		~ 10	80	26	33					106	113	
		~ 11	20	47	58					67	78	
		~ 12	0	82	101					82	101	
	12.4	Total	400	483	597	170	210	123	152	1,176	1,359	110

Table 9 Possible Sediment Discharge Data from Types-II and III Areas by Tributary and Distance from Summit (2)

	Area of basin (Km^2)	Distance from the summit (Km)	Recent riverbed deposits ($x10^3m^3$)	Lower terrace deposits ($x10^3m^3$)		Middle and higher terrace deposits ($x10^3m^3$)		Other unstable deposits ($x10^3m^3$)		Volume of sediment products ($x10^3m^3$)		Specific probable Volume ($x10^3m^3/Km^2$)
				Stable	Loose	Stable	Loose	Stable	Loose	Stable	Loose	
K. Pabelan		0~4	20	43	53	16	19	139	172	218	264	
		~5	30	13	16	8	10	5	6	56	62	
		~6	30	15	18	7	9	10	12	62	69	
		~7	30	9	11	6	7	6	8	51	56	
		~8	50	14	17					64	67	
		~9	60	46	57			5	6	111	123	
		~10	40	64	79	25	31			129	150	
		~11	20	61	75	30	37			111	132	
		~12	20	23	28					43	48	
		~13		15	19					15	19	
	52.0	Total	300	303	373	92	113	165	204	860	990	19
K. Krasak		Main Canal										
		7~8	110	32	40					142	150	
		~9	163	46	57					209	220	
		~10	199	114	141					313	340	
		~12	225	304	375					529	600	
		Sub total	697	496	613					1,193	1,310	
		Tributary I										
		7~7.6 (1)	84							84	84	
		7~7.6 (2)	108							108	108	
		7.6~8	73	6	7					79	80	
		~9	178	50	62					228	240	
		~9.4	120							120	120	
		Sub total	563	56	69					619	632	
		Tributary II										
		9.4~9.7	48							48	48	
		~10	45	12	15					57	60	
		Sub total	93	12	15					105	108	
	13.6	Total	1,353	564	697					1,197	2,050	151
K. Lamat		4~5	30							30	30	
		~6	50							50	50	
		~7	60	23	29					83	89	
		~8	40							40	40	
		~9	60							60	60	
		~10	100							100	100	
		~11	50							50	50	
		~12	40							40	40	
		Total	430	23	29					453	459	

Table 10 Type-I Sediment Balance of K. Krasak and K. Bebeng, 1969 ∿ 1970

Distance from the summit (km)	Flood deposit D_1	Deposit in channel D_2	Total deposit $Dt=D_1+D_2$	Maximum volume of erosion E_1	Volume of former channel E_2	Total volume of erosion $Et=E_1-E_2$	Accumulated sediment discharge $V=\Sigma(Et-Dt)$
0 ∿ 3	-	-	-	(1,000) 1,235	-	1,235	1,235
7	(1,100) 1,359	-	1,359	(3,464) 4,278	-	4,278	4,154
8	(18) 22	166	188	(1,872) 2,312	(150) 185	2,127	6,093
9	(94) 116	151	267	(1,211) 1,496	(150) 185	1,311	7,173
10	(207) 256	176	432	(1,696) 2,095	(200) 247	1,848	8,553
11	(26) 32	80	112	(1,021) 1,261	371	890	9,331
12	(74) 91		91	(358) 442	(300) 371	71	9,311
13	(853) 1,053		1,053				8,258
K. Krasak confluence point						from K. Krasak	
15		737	737			44	7,565
National road							
17.6		221	221				7,344
20		300	300				7,044
24		629	629				6,415
K. Progo confluence point							
27		36	36				6,379
Total	(2,372) 2,929	2,496	5,425	(10,623) 13,119	1,359	11,804	6,379

Figure in ( ) means volume before loosening unit of volume = $10^3 m^3$

- o Items of volume in the sections between $0^{km} \sim 7^{km}$ (before loosening)
- o Volume of Sediment product from area ($334,000m^2$) x mean depth (3m)
- o The Upper-most area (0 ~ 3km) : $E_{1.1} = 1,000 \times 10^3 m^3$
- o Volume of Sediment products derived from gully erosion (3 ~ 7km):
  $E_{1.2} = 3,464 \times 10^3 m^3$ (after field survey)
- o Total volume of erosion:
  $Et = E_1 = 4,464 \times 10^3 m^3$
- o Volume of alluvial fan deposits between 3 ~ 7km
  $D_1 = Dt = 1,100 \times 10^3 m$ (after field survey and photo interpretation)

Table 11 Type-I Sediment Balance of K. Putih, 1969 ∿ 1970

Distance from the summit (km)	Flood deposit D_1	Deposit in channel D_2	Total deposit $Dt=D_1+D_2$	Maximum volume of erosion E_1	Volume of former channel E_2	Total volume of erosion $Et=E_1-E_2$	Accumulated sediment discharge $V=\Sigma(Et-Dt)$
0 ∿ 3	-	-	-	(2,010) 2,480	-	(2,010) 2,480	2,480
5	(2,010) 2,480	-	2,480	(605) 750	-	750	750
6	(176) 217	93	310	(2,097) 2,590	(1,124) 1,388	1,202	1,642
7	(260) 321	66	387	(2,134) 2,639	(1,157) 1,429	1,210	2,465
Jurangjero							
8	0	362	362	(610) 753	(339) 419	334	2,437
9	(13) 16	75	91	(1,104) 1,363	(1,036) 1,279	84	2,430
10	(120) 148	26	174	(271) 335	(271) 335	0	2,256
11	(43) 53	26	79	(243) 300	(243) 300	-	2,177
12	(101) 125	50	175				2,002
13	(81) 100	45	145				1,857
14	(78) 96	30	126				1,731
15	(63) 78	40	118				1,613
16	(75) 93	30	123				1,490
17	(29) 36	25	61				1,429
National road 18	(130) 161	10	171				1,258
Confluence point 23		250	250				1,008
Total	(3,177) 3,924	1,128	5,052	(9,077) 11,210	(4,169) 5,150	6,060	1,008

unit of volume = $10^3 m^3$

- o Items of volume in the sections between 0 ~ 5km (before loosening)
- o Volume of sediment product from the upper - most area (0 ~ 3km) $670{,}000m^2 \times 3m = 2{,}010 \times 10^3 m^3$
- o Volume of sediment products derived from gully erosion = $605 \times 10^3 m^3$
- o Total volume of erosion = $2{,}615 \times 10^3 m^3$
- o Volume of alluvial fan deposits = $2{,}008 \times 10^3 m^3$

Table 12 Type-I Sediment Balance of K. Krasak and K. Bebeng 1969 ∿ 1976

Distance from the summit (km)	Flood deposit D_1	Deposit channel D_2	Total deposit $Dt = D_1 + D_2$	Maximum volume of erosion E_1	Volume former channel E_2	Total volume of erosion $Et = E_1 - E_2$	Accumulated sediment discharge $V = \Sigma(Et - Dt)$
0 ∿ 7	(1,100) 1,359	-	1,359	(9,660) 11,930	-	11,930	10,571
∿ 8	(18) 22	166	188	(3,020) 3,730	(150) 185	3,545	13,927
∿ 9	(94) 116	151	267	(1,919) 2,370	(150) 185	2,185	15,846
∿10	(207) 256	176	432	(2,693) 3,326	(200) 247	3,079	18,493
∿11	(26) 32	80	112	(1,502) 1,855	(300) 371	1,484	19,865
∿12	(74) 91		91	(396) 489	(300) 371	118	19,892
∿13	(1,066) 1,317		1,317				18,575
K. Krasak confluence point ∿15		921	921			176	17,830
National road ∿17.6		1,574	1,574				16,256
∿20		1,392	1,392				14,864
∿24		4,575	4,575				10,289
K. Progo confluence point ∿27		451	451				9,838
Total	(2,585) 3,193	9,486	12,679	(19,130) 23,700	1,359	22,341	9,838

Figure in ( ) means volume before loosening

- o Items of volume in the sections between $0^{km} \sim 7^{km}$ (before loosening).
- o Volume of Sediment product from area ($334{,}000m^2$) x mean depth (3m)
- o The Upper - most area (0 ~ 3km) : $E_{1\text{-}1} = 1{,}000 \times 10^3 m^3$
- o Volume of Sediment products derived from gully erosion (3 ~ 7km) : $E_{1\text{-}2} = 8{,}660 \times 10^3 m^3$ (after field survey)
- o Total volume of erosion : $Et = E_1 = 9{,}660 \times 10^3 m$
- o Volume of alluvial fan deposits between 3 ~ 7km $D_1 = Dt = 1{,}100 \times 10^3 m$ (after field survey and photo interpretation)

Table 13 Type-1 Sediment Balance of K. Putih, 1969 ∿ 1976

Distance from the summit (km)	Flood deposit D_1	Deposit channel D_2	Total deposit $Dt = D_1 + D_2$	Maximum volume of erosion E_1	Volume former channel E_2	Total volume of erosion $Et = E_1 - E_2$	Accumulated sediment discharge $V = \Sigma(Et - Dt)$
* 0 ∿ 5	(2,008) 2,480	-	2,480	(3,222) 3,979		3,979	1,499
∿ 6	(176) 217	93	310	(2,341) 2,891	(1,124) 1,388	1,503	2,692
∿ 7	(260) 321	66	387	(2,381) 2,941	(1,157) 1,429	1,512	3,817
Jurangjero ∿ 8	0	402	402	(678) 837	(339) 419	418	3,833
∿ 9	(13) 16	85	101	(1,121) 1,384	(1,036) 1,279	105	3,837
∿10	(120) 148	40	188	(271) 335	(271) 335	0	3,649
∿11	(43) 53	40	93	(243) 300	(243) 300	0	3,556
∿12	(101) 125	100	225				3,331
∿13	(81) 100	90	190				3,141
∿14	(78) 96	60	156				2,985
∿15	(63) 78	80	158				2,827
∿16	(75) 93	60	153				2,674
∿17	(29) 36	50	86				2,588
National road ∿18	(130) 161	20	181				2,407
K. Progo confluence point ∿23		500	500				1,907
Total	(3,177) 3,924	1,686	5,610	(10,257) 12,667	(4,169) 5,150	7,517	1,907

* o Items of volume in the sections between 0 ~ 5km (before loosening)

o Volume of sediment product from the upper-most area (0 ~ 3km)
$670{,}000 m^2 \times 3m = 2{,}010 \times 10^3 m^3$

o Volume of sediment products derived from gully-erosion = $1{,}212 \times 10^3 m^3$

o Total volume of erosion = $3{,}222 \times 10^3 m^3$

o Volume of alluvial fan deposits = $2{,}008 \times 10^3 m^3$

Table 14 Type-I Sediment Balance of K. Krasak and K. Bebeng, 1969 ∿ 1977

Distance from the summit (km)	Flood deposit deposit D_1	Deposit in channel D_2	Total deposit $Dt = D_1+D_2$	Maximum volume of erosion E_1	Volume of former channel E_2	Total volume of erosion $Et=E_1-E_2$	Accumulated sediment discharge $V=\Sigma(Et-Dt)$
0 ∿ 7	1,359	-	1,359	13,727	-	13,727	12,368
∿ 8	22	166	188	3,743	185	3,558	15,738
∿ 9	116	160	276	2,370	185	2,185	17,647
∿10	256	176	432	3,355	247	3,107	20,322
∿11	32	80	112	1,961	371	1,590	21,800
∿12	91		91	524	371	153	21,862
∿13	1,317	14	1,331				20,531
K. Krasak confluence point							
∿15		1,226	1,226			214	19,519
National road							
∿17.6		1,721	1,721				17,798
∿20		1,478	1,478				16,320
∿24		5,903	5,903				10,417
K. Progo confluence point							
∿27		451	451				9,966
Total	3,193	11,375	14,568	25,680	1,359	24,534	9,966

unit of volume = x $10^3 m^3$

Table 15 Type-I Sediment Balance of K. Putih, 1969 ∿ 1977

Distance from the summit (km)	Flood deposit D_1	Deposit in channel D_2	Total deposit $Dt = D_1+D_2$	Maximum volume of erosion E_1	Volume of former channel E_2	Total volume of erosion $Et=E_1-E_2$	Accumulated sediment discharge $V=\Sigma(Et-Dt)$
0 ∿ 5	2,480		2,480	4,073		4,073	1,593
∿ 6	217	93	310	2,901	1,388	1,513	2,796
∿ 7	321	66	387	2,951	1,429	1,522	3,931
Jurangjero ∿ 8	0	402	402	847	419	428	3,957
∿ 9	16	85	101	1,391	1,279	112	3,968
∿10	148	44	192	335	335	0	3,776
∿11	53	40	93	300	300	0	3,683
∿12	125	126	251	11		11	3,443
∿13	100	97	197				3,246
∿14	96	66	162				3,084
∿15	78	82	160				2,924
∿16	93	60	153	6		6	2,777
∿17	36	50	86	12		12	2,703
National road							
∿18	161	23	184				2,519
K. Progo confluence point							
∿23		507	507				2,012
Total	3,924	1,741	5,665	12,827	5,150	7,677	2,012

unit of volume = x $10^3 m^3$

Table 16 Riverbed Variation Data by Aerial Photography, 1976 ~ 1978

Interval of Survey line	1976 ~ 1977										1977 ~ 1978			
	K. Krasak		K. Bebeng		K. Batang		K. Putih		K.Blongkeng		K. Krasak		K. Bebeng	
	Section change volume (m3)	Accumulation change volume (m3)	Section (m3)	Accumulation (m3)	Section (m3)	Accumulation (m3)	Section (m3)	Accumulation (m3)	Section (m3)	Accumulation (m3)	Section (m3)	Accumulation (m3)	Section (m3)	Accumulation (m3)
3 ~ 4													-414,800	-414,800
~ 5													-145,400	-560,200
~ 6	-11,300	-11,300											-77,500	-637,700
~ 7	-10,700	-22,000											-131,800	-769,500
~ 8	-8,300	-30,300	-12,700	-12,700	-3,000	3,000	4,700	4,700	-1,300	-1,300	700	700	-128,100	-897,600
~ 9	2,300	-28,000	8,900	-3,800	-1,100	-4,100	-11,400	-6,700	0	-1,300	-800	-100	52,400	-845,200
~ 10	-200	-28,200	-28,600	-32,400	1,800	-2,300	4,300	-2,400	8,600	7,300	-2,100	-2,200	31,000	-814,200
~ 11	5,000	-23,200	-106,100	-138,500	2,500	200	300	-2,100	-20,300	-13,000	-500	-2,700	92,500	-721,700
~ 12	1,400	-21,800	-34,700	-173,200	-1,500	-5,300	-11,400	-13,500	-14,000	-27,000	-3,200	-5,900	64,900	-656,800
~ 13	2,800	-19,000	14,100	-159,100	-3,200	-4,500	6,600	-6,900	7,300	-19,700	3,200	-2,700	93,100	-563,700
~ 14	5,600	-13,400	69,800	-89,300	-9,200	-15,700	5,800	-1,100	6,100	-13,600	3,500	800	176,400	-387,300
~ 15	-24,300	-37,700	158,500	69,200	-2,700	-16,400	2,200	1,100	8,600	-5,000	41,600	42,400	4,800	-382,500
~ 16	125,700	157,200			-2,400	-18,800	-6,000	-4,900	-3,300	-8,300	1,200	-338,900		
~ 17	47,800	205,000			-5,900	-24,700	-11,500	-16,400	1,200	-7,100	-34,700	-373,600		
~ 18	54,100	259,100			-14,600	-39,300	3,300	-13,100	-1,500	-8,600	80,000	-293,600		
~ 19	38,500	297,600			4,400	-43,200	-1,800	-14,900	-12,800	-21,400	171,200	-112,400		
~ 20	43,600	341,200			-10,400	-54,100	11,700	-3,200	-9,100	-30,500	90,300	-32,100		
~ 21	103,600	444,800			-4,700	-58,800	-4,300	-7,500	-7,000	-37,500	77,400	45,300		
~ 21.5	44,000	488,800												
~ 22					-3,800	-62,600	-800	-8,300	-6,700	-44,200	32,200	77,500		
~ 23					-900	-63,500	3,000	-5,300	-2,400	-46,600	9,200	86,700		
~ 24									-5,400	-52,000	-8,000	78,700		
~ 25											-43,500	35,200		
~ 26											-15,700	19,500		
~ 27											8,100	27,600		

- : erosion
+ : deposition

Fig. 11 The Balance of Sediment Product and Discharge Along K. Krasak (from Jan. '69 to Oct. '70)

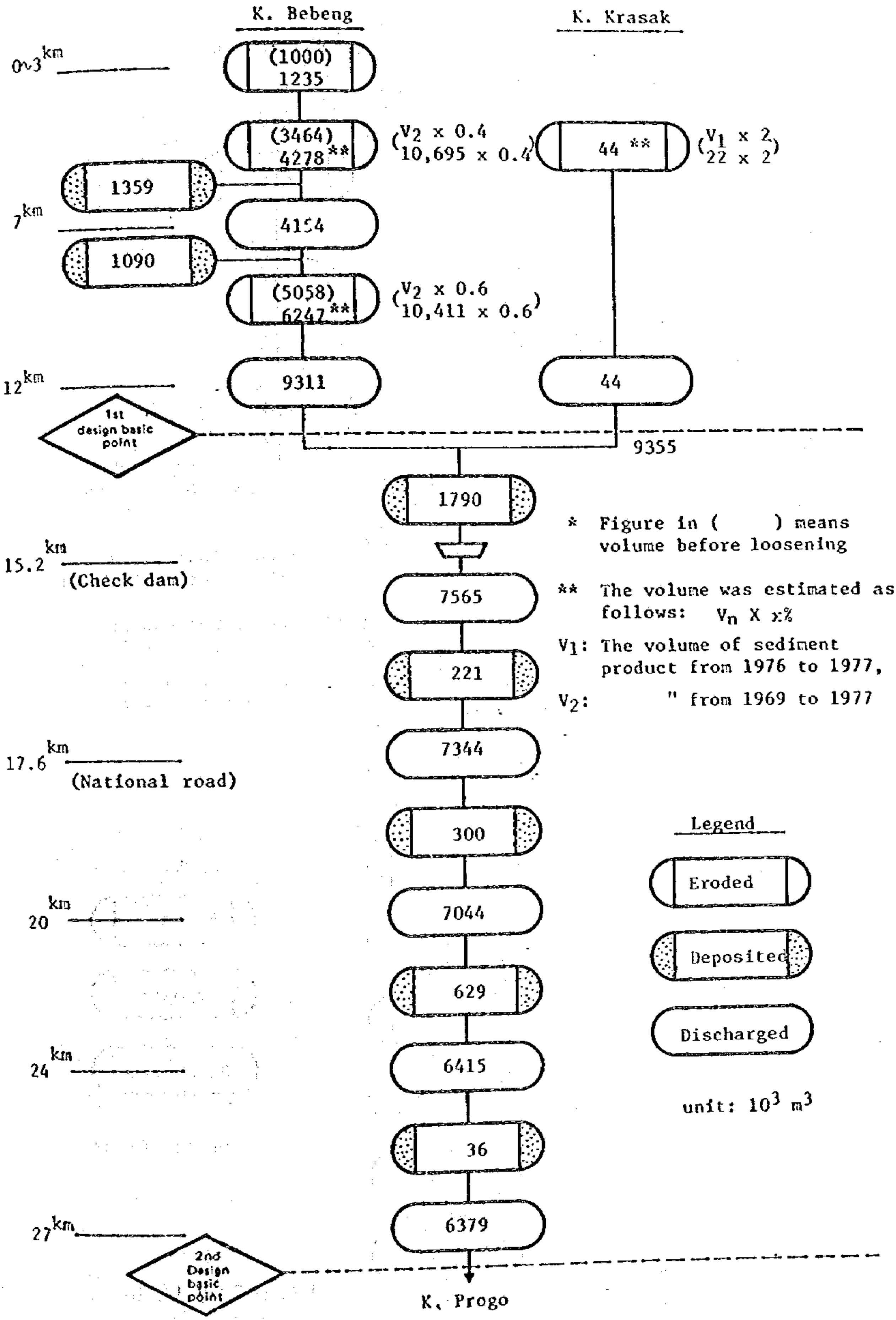


Fig. 12 The Balance of Sediment Product and Discharge Along K. Krasak (from Jan. '69 to Oct. '76)

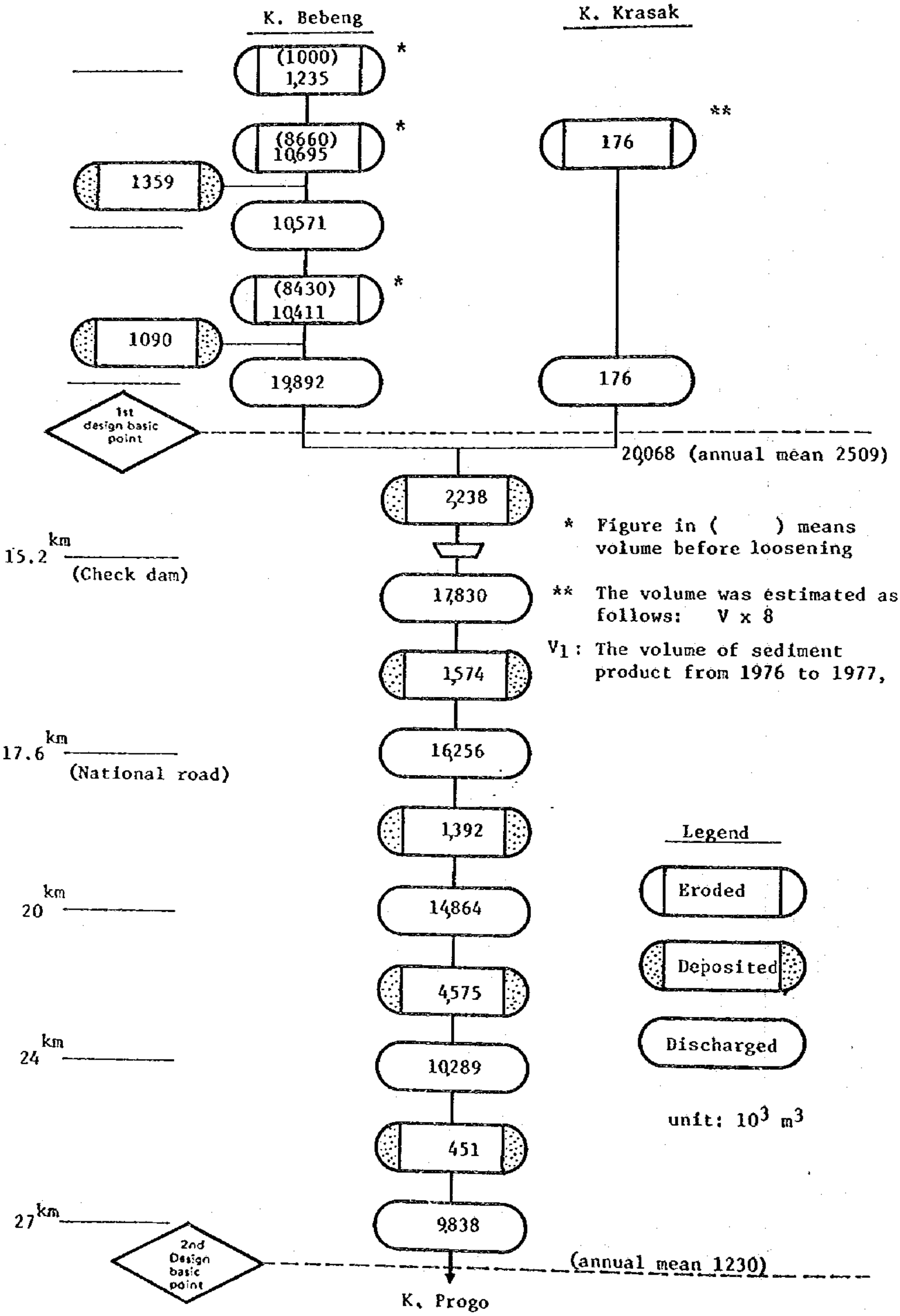


Fig. 13 The Mean Annual Sediment Product and Discharge Along K. Krasak (from Jan. '71 to Oct. '76)

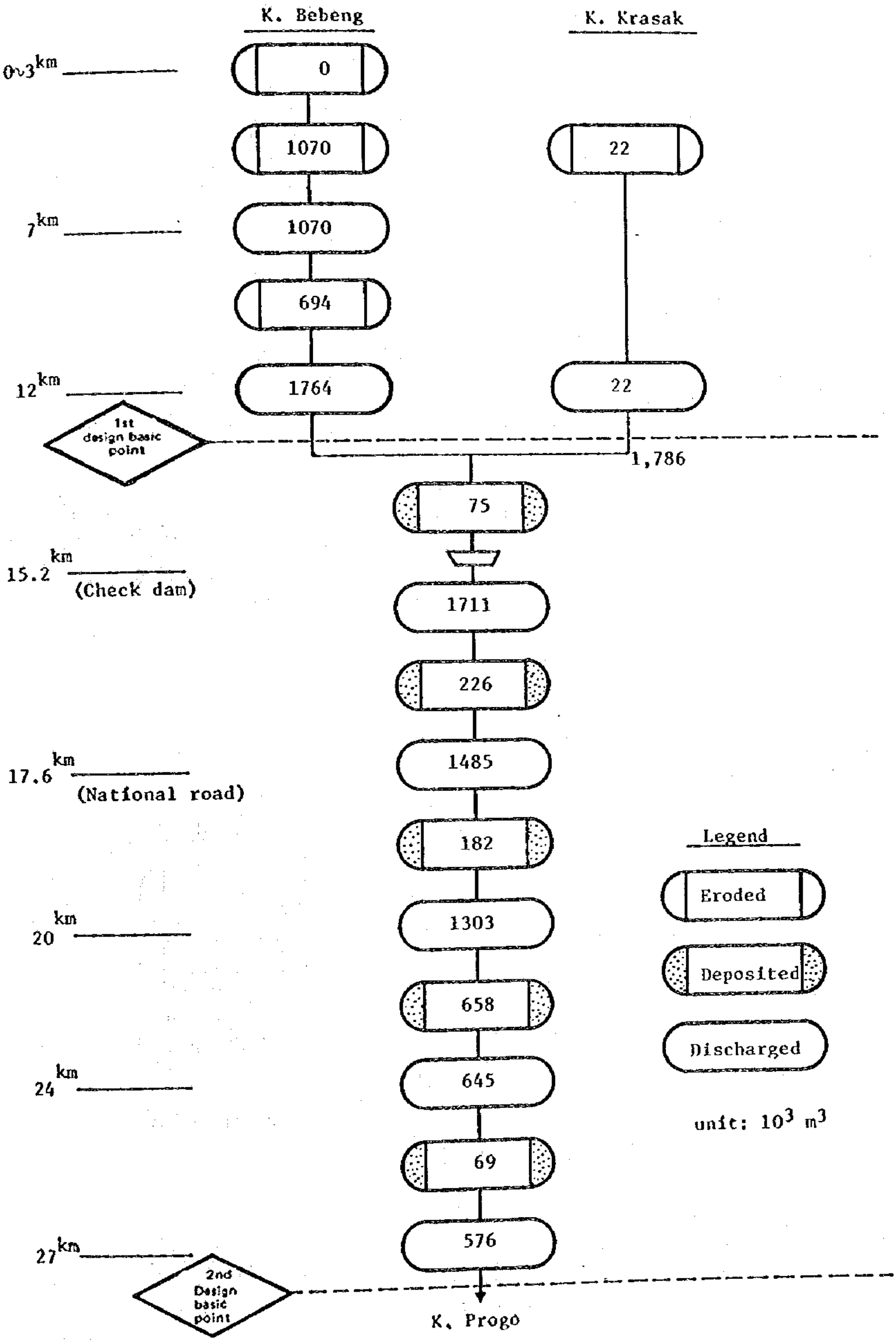


Fig. 14 The Balance of Sediment Product and Discharge Along K. Krasak (from Nov. '76 to Oct. '77)

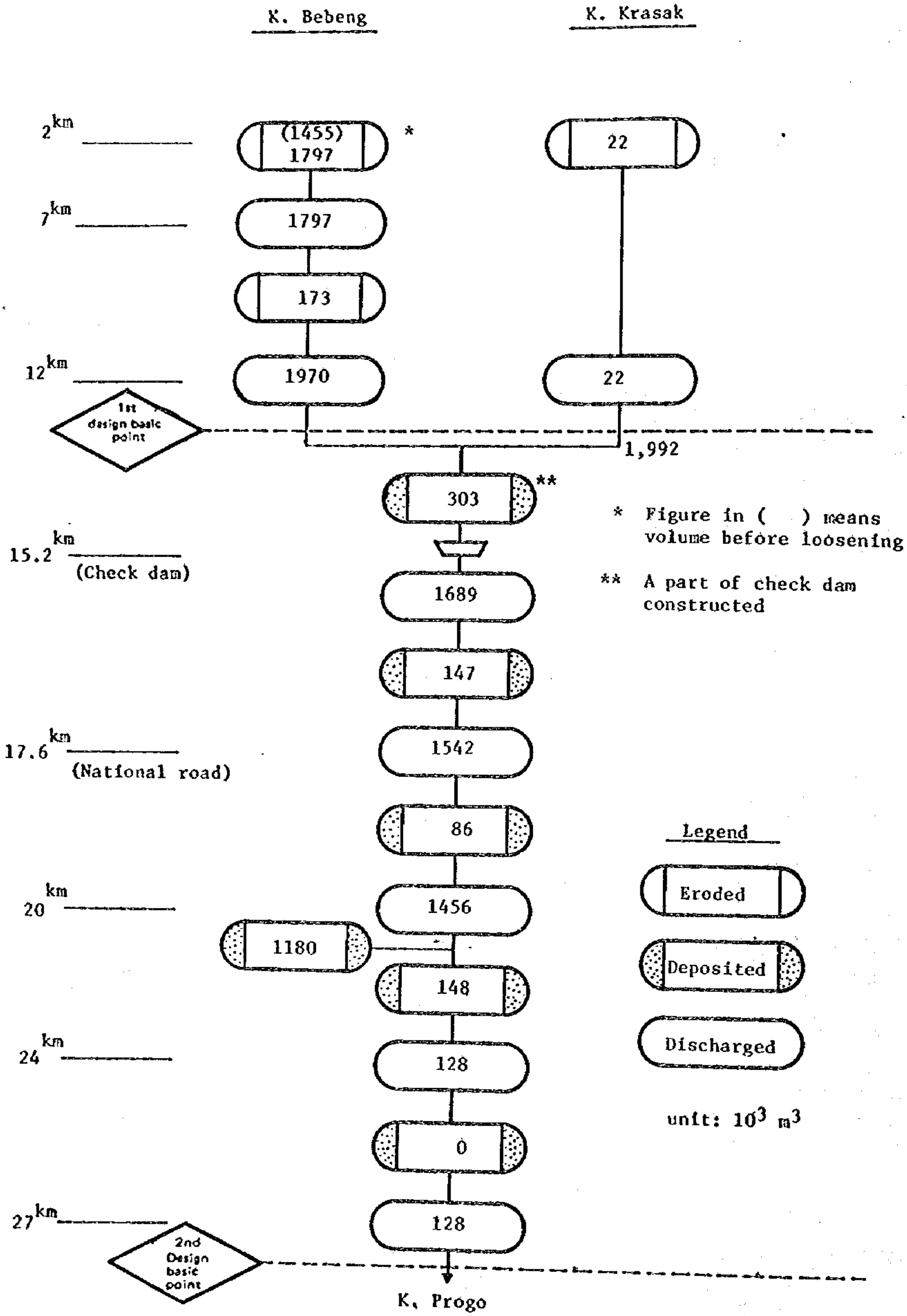
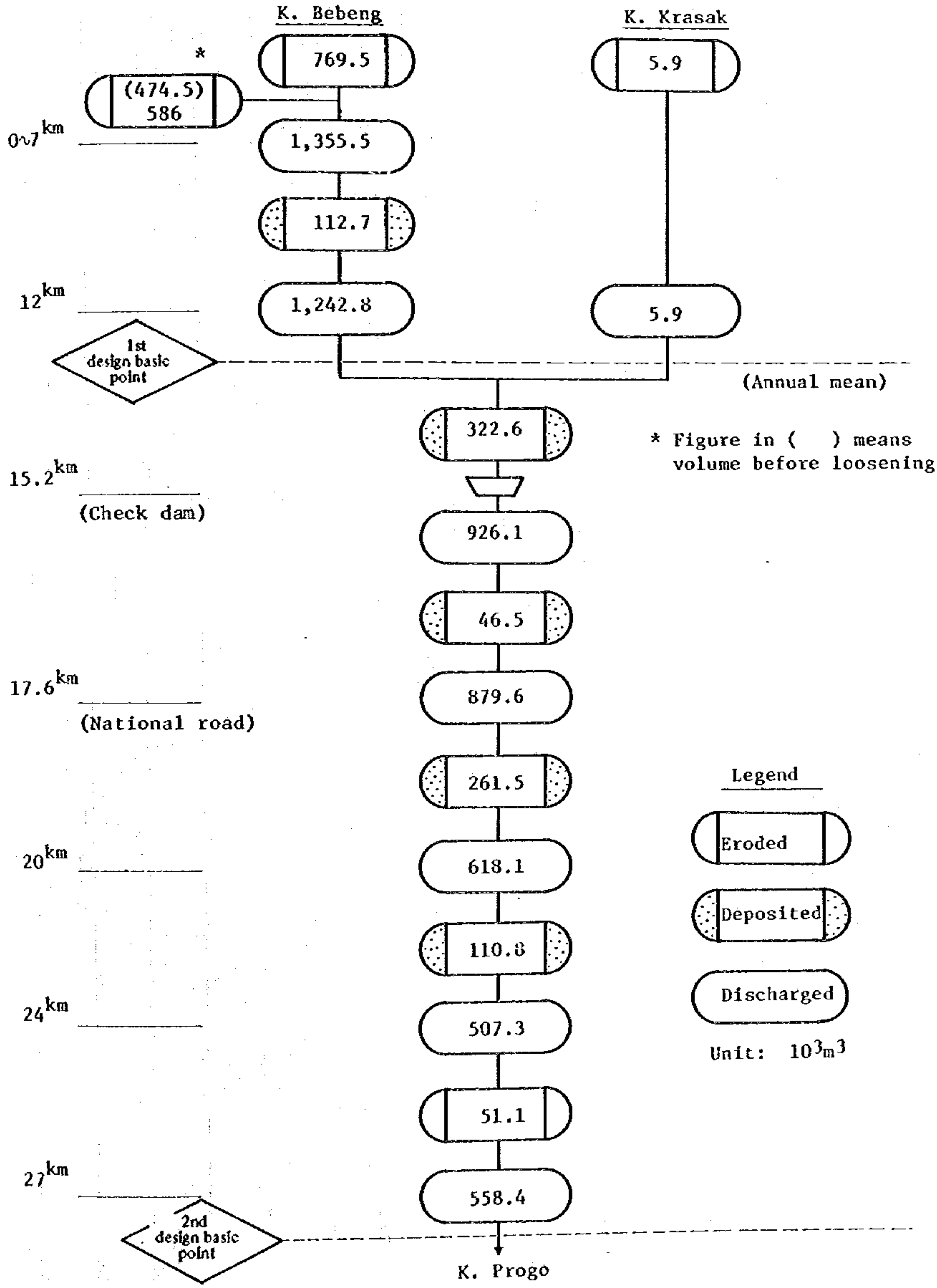


Fig. 15 The Balance of Sediment Product and Discharge Along K. Krasak (1977 ∿ 1978)



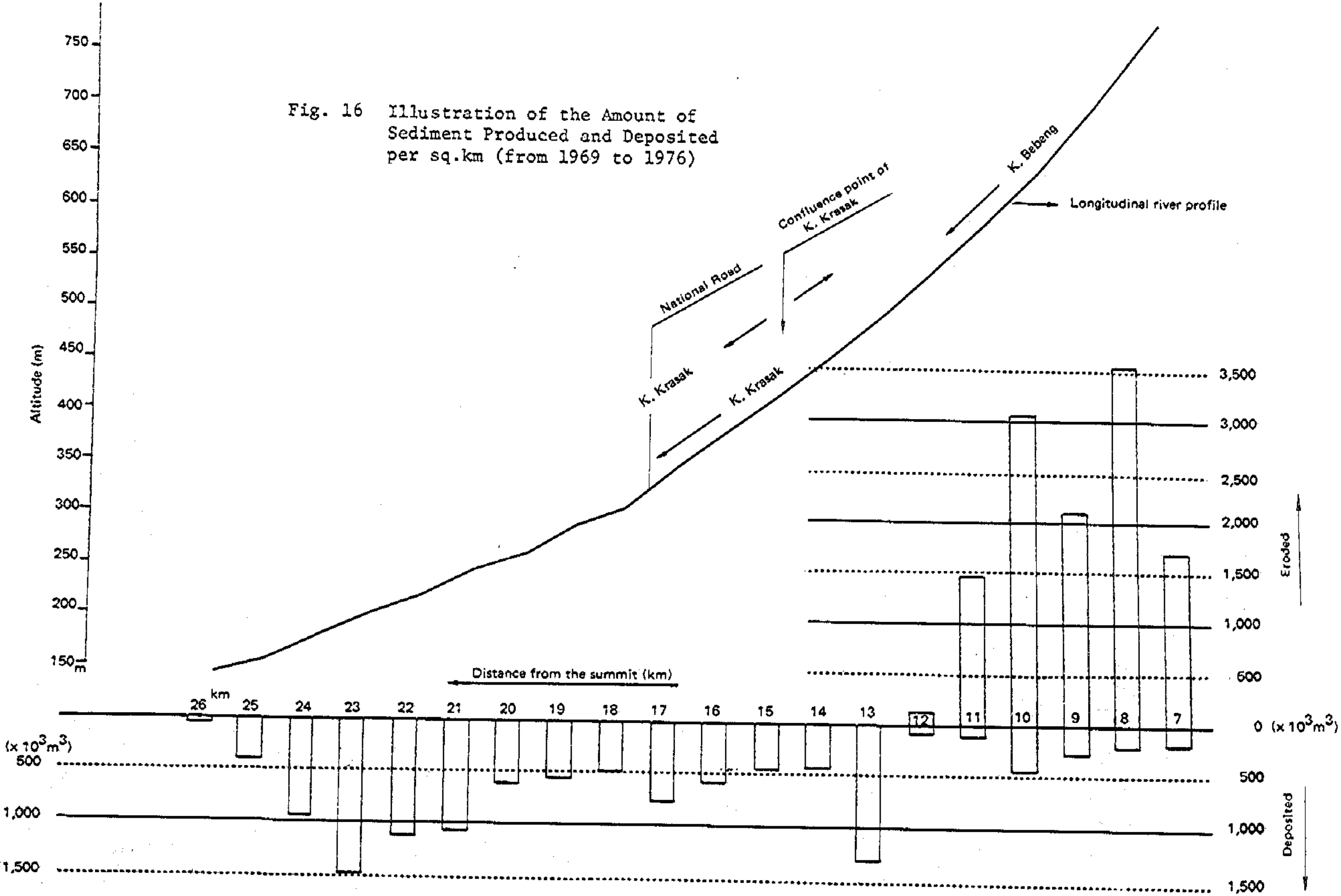


Fig. 16 Illustration of the Amount of Sediment Produced and Deposited per sq.km (from 1969 to 1976)

Fig. 17 Sediment Balance of K. Putih
(From 1969 to '70)

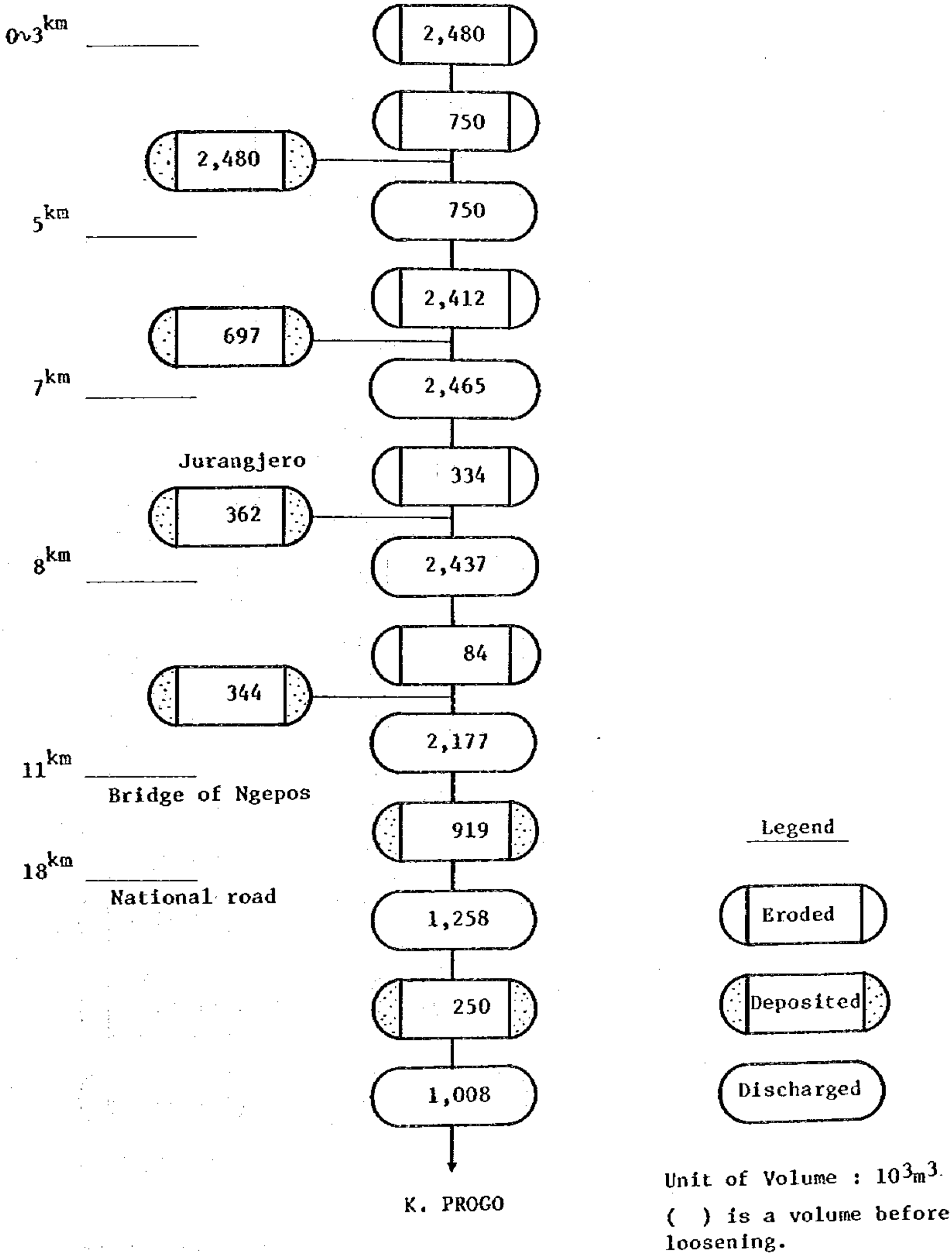


Fig. 18 Sediment Balance of K. Putih
(From 1969 to '76)

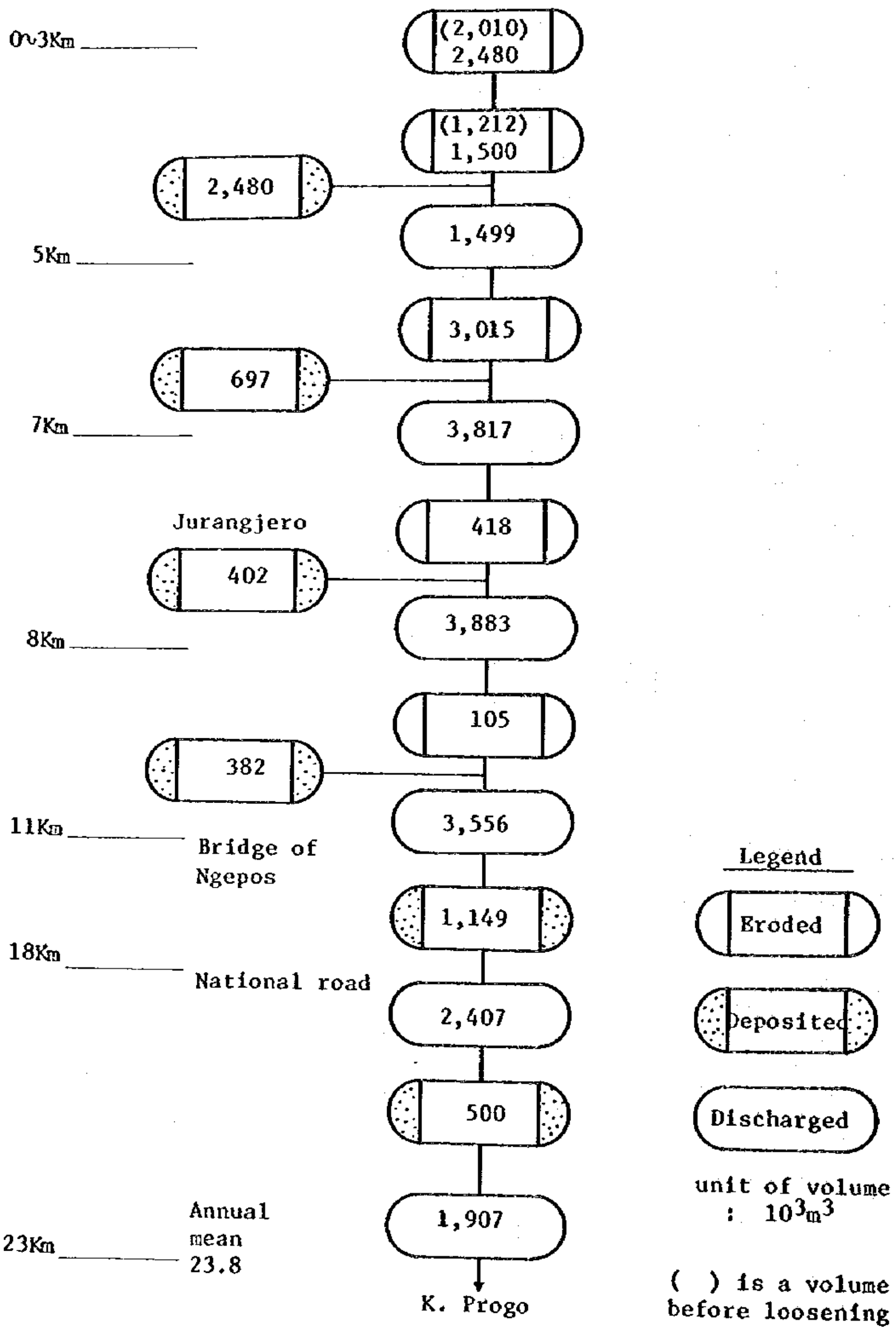
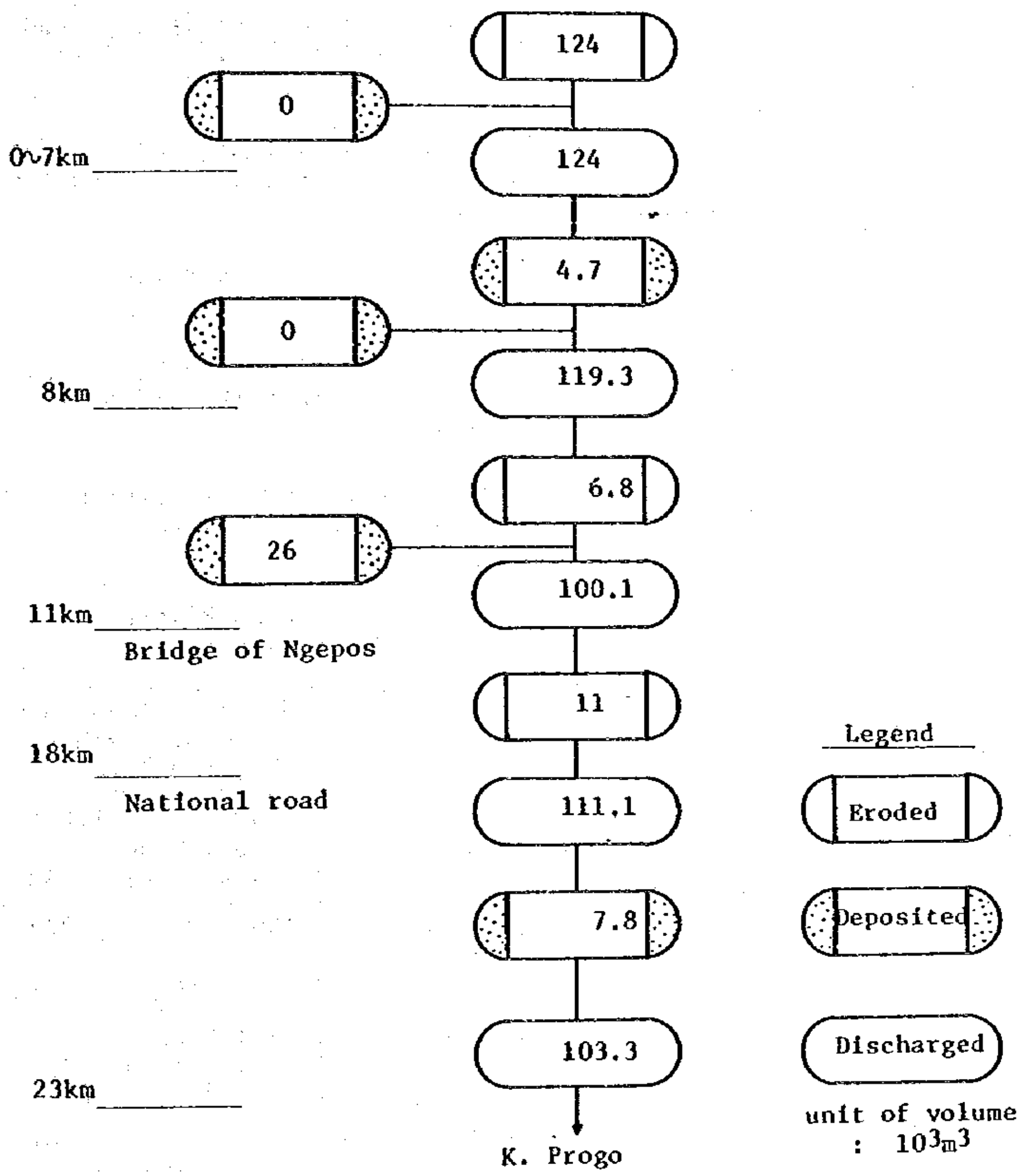


Fig. 19 Sediment Balance of K. Putih
(From 1976 to '77)



APPENDIX--1

Characteristics of sediment products and discharges between Indonesia and Japan. The quantitative characteristics of the Indonesian rivers in G. Merapi area are compared with Japanese rivers of Sakura-jima and Osawa of Mt. Fuji in Table A.1 below. The results of the comparison are summarized as follows.

(1) The amount of discharge of K. Bebeng is larger than that of Japanese rivers even in ordinary years, and is five times as large as Sakurajima during a large-scale flood year.

(2) The values for K. Putih are almost the same as those for Sakurajima.

(3) In ordinary years the values for other rivers in G. Merapi area except K. Bebeng and K. Putih are less than 10 x $10^3 m^3/km^2$ which is similar to many Japanese rivers.

(4) K. Woro and K. Gendol are stable for present ordinary period, but they have a big potential for sediment production.

Table A.1 Comparison of Indonesian and Japanese Rivers Carrying Volcanic Sediment Discharge

River			Catchment Area (km^2) and Distance from Summit (km)	Specific Amounts of Sediment Discharge ($\times 10^3 m^3/km^2$)
INDONESIA	K. Bebeng		8.5km^2 Summit to 12km	1969 1,095 Annual Mean (1969-1976) 293
INDONESIA	K. Putih		9.6km^2 Summit to 11km	1969 227 A.M. (1969-1976) 46
INDONESIA	K. Woro		7.1km^2 Summit to 10km	Past Large-Scale Flood 594
INDONESIA	K. Gendol		10.5km^2 Summit to 13km	" 301
JAPAN	Sakura-jima	River Nojiri	2.48km^2	A.M. (1971-1976) 151∿227
JAPAN	Sakura-jima	River Kurokami - No.1	1.63km^2	" 136∿286
JAPAN	Osawa-of Mt. Fuji		5.0km^2	A.M. (1969-1978) 40∿100

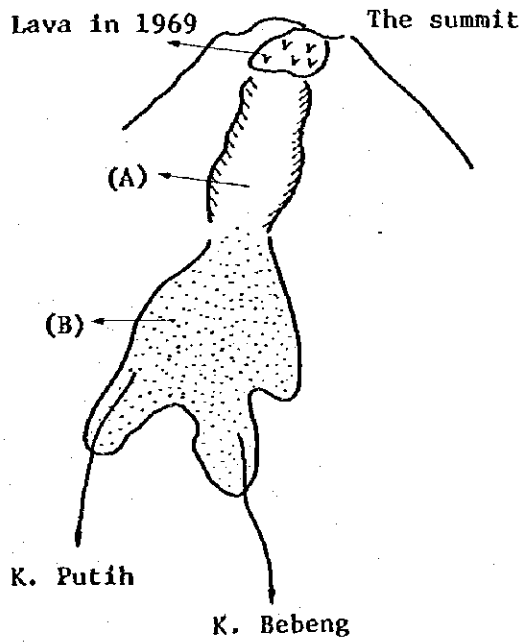
APPENDIX -2

1. The method of estimating the amount of sediment produced from the eruption in 1969. The amount of sediment produced in the master plan is based on the following assumptions;

   (1) Although the amount of volcanic materials directly produced from the eruption also not estimated as large, it is considered that a large amount of sediment was produced from the appear slope (A) above al altitude of 2,000 m where the slope was cut and eroded by the major pyroclastic flow. (see Fig. 2.1)

   (2) However, most of the sediment produced from the upper slope (A) was deposited on the slope (B) between the altitudes of 1,000 m and 2,000 m. Therefore the amount of sediment produced from area (A) is almost equal to the amount of sediment deposited at area (B)

Fig. 2.1 Estimated Areas of Sediment Production and Deposition of the Eruption in 1969



   (3) The rest of the sediment produced from the upper slope (A) flowed into K. Putih and K. Bebeng (K. Krasak) and grew by eroding riverbeds and riverbanks.

   The distribution area of the sediment from the area (A) was investigated and checked by photo-interpretation. The thickness of sediment deposited in area (B) was estimated by field inspection. The sediment amount from area (A) was calculated based on the distribution area and deposition thickness.

2. The mechanism of sediment transportation just after the eruption in 1969.

Since the wide area of the upper slope was burned and cleared by the Nuée ardente which formed a thin hard crust on the surface by cementation of volcanic ash and rain just after the eruption, the run-off percentage and discharge were substantially increased.

Although the streams once cut into the surface crust, the streams became concentrated into a few large channels which become deeper and turned into steep-walled valleys, and the processes of active sediment production and discharge began.

Therefore the run-off and the amount of sediment production and discharge were increased many fold after the eruption. In the case of K. Putih and K. Bebeng, the river basins were increased in size several times after the eruption with alteration of river courses due to river piracy. These rapid increases in the river basin area caused the heavy damage along these rivers.

3. The survey method for estimation of the amount of riverbed change sediment balance. The riverbed change volume survey was conducted to determine the volume of deposits moving from riverbed to riverbed, morphological secular-change of riverbed and abnormal change of riverbed at the time of flooding.

It was important for the sabo planning scheme to determine the riverbed change volume in a certain drainage area since it is vital to know the magnitude of change as the absolute value to determine the location, size and priority of sabo facilities.

Usually, the riverbed volume change survey is conducted on special comparative downstream sections of a river. Under this method, a difference between the inflow volume and the outflow volume is measured to be a change volume, but the absolute values of inflow volume and outflow volume cannot be detected.

On the other hand, the sediment balance survey method is designed to set a special point in the drainage area (junction point to a main river, sabo planning standard point or dam, etc.) as a standard and obtain the absolute values at that point of sediment inflow volume from the upperstream and outflow volume to the downstream to reveal the sediment inflow and outflow conditions at the point.

In order to collectively obtain the sediment balance of mountain, tributaries and main stream in a certain drainage area and to seek the absolute outflow volume of sediment at the special point, the following assumptions were made:

(a) In the case of most simple mountain stream without any tributaries, the sediment movement is as shown in Fig. 2.2.

O : Outflow volume of sediment from A point (end of downstream of mountain stream or special point).

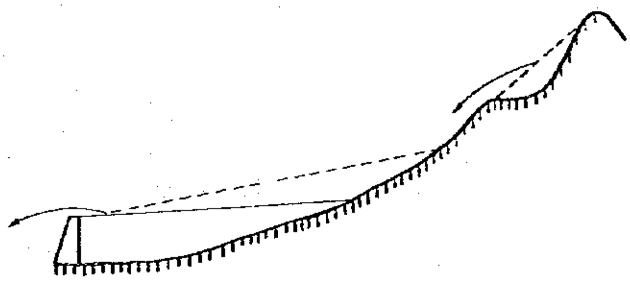
I : Volume of sediment supplied to mountain stream from the end of upperstream of mountain stream and from the mountainside directly connected to mountain stream.

I_1: Deposit volume on mountain streambed (in some period after a specified period, for instance, after a heavy rain).

$O = I \quad V_1 - V_2 \quad V_1 - V_2$ = Change in riverbed volume between the end of upperstream and the end of lowerstream of mountain stream.

Therefore, "O" can be calculated as the absolute volume when the outflow soil/sand volume from the mountainside and the change in riverbed volume are added.

Fig. 2-2 Sediment Balance Concept Profile-1



(b) Even when the drainage pattern is complicated with addition of tributaries, it is basically same as shown in Fig. 2-3.

O_A: Total of inflow sediment volume from A point (n + h order, end of upperstream of n order drainage areas) and outflow sediment volume from the end of downstream of (n - 1) order drainage areas.

O_B: Outflow sediment volume from B point (end of downstream of n order drainage areas).

ΣI: Volume of sediment supplied from mountainside area between A and B to a river channel.

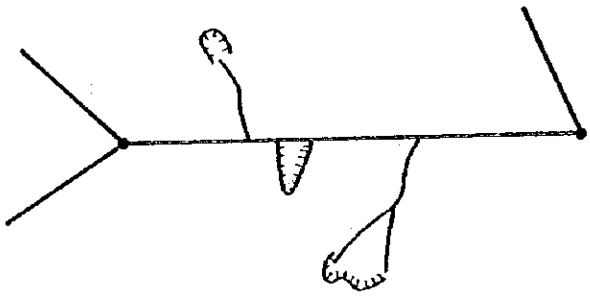
W_1: Deposit volume on riverbed between A and B (for example before a heavy rain).

W_2: Deposit volume on riverbed between A and B (for example after a heavy rain).

$O_B = O_A + \Sigma H + \Sigma K + W_1 - W_2.$

O_A and $\Sigma H + \Sigma K$ can be obtained by expanding the conception of 1) to the high order drainage areas in order, and $W_1 - W_2$ can be calculated from a change of the riverbed volume.

Fig. 2-3 Sediment Balance



In short, the absolute volume of sediment inflows and outflows in the n order drainage areas can be calculated by adding the change of riverbed volume (mountain streambed) from the lower ends of n order drainage areas to the upper ends of the whole lower drainage lines and the supply volume in the drainage areas from the mountainside. In other words, when it goes upstream to the end of upperstream where the inflow volume is "0", a change volume can be taken as the absolute volume. However, it was necessary to adopt a simplified method because it was not practical to survey the whole mountainsides for the whole water systems in view of the limited budget and time.

Fortunately, the above conception can be applied to the Type-I areas of Mt. Merapi because the five rivers subjected to the survey have simple patterns without any large tributaries in the downstream and mid-stream sections. However, as there are many branches in the upperstream and a large volume of sediment are supplied directly from the slopes of mountainside, attention was paid to the measuring method.

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SUPPORTING REPORT C

HYDRAULICS AND HYDROLOGY

CONTENTS

List of Tables

List of Figures

1. GENERAL

A series of surveys to establish the Master Plan for Land Erosion and Volcanic Debris Control in Area of G. Merapi were performed during the past three years from 1977 to 1979. The study on the hydraulics and hydrology was carried out during the first two years.

This section is the supporting report on hydraulic and hydrology showing the results of the following surveys performed in 1977 and 1978.

Surveys in 1977

- Climatological data collection.
- Daily and hourly rainfall data collection.
- Indian Ocean tide data collection.
- Location of installations for automatic rainfall gauging (4) and automatic river stage gauging stations (5).
- Transfer of technical knowledge for observation of discharge, bed load and suspended load, and collection of reference materials.

Surveys in 1978

- Rainfall analysis on probable rainfall and duration curve of rainfall.
- Run-off analysis on nine tributaries on G. Merapi by means of Rational Method.
- Run-off analysis on two main rivers by means of Storage Function Method.
- Analysis on sedimentation conveyed from five tributaries to K. Progo, K. Opak and K. Dengkeng.
- Transfer of technical knowledge.

2. OUTLINE OF STUDY AREA

2.1 Study Area

The project area extends from the southeast to the western slope of G. Merapi which is located in the middle of Java, Indonesia. G. Merapi is one of the most active volcanoes in the world.

The rivers in the project area comprise three river systems: the K. Progo, K. Opak and K. Dengkeng river systems. Among them, the K. Dengkeng river system is in turn one of the largest tributaries of the Bengawan Sala.

G. Merapi has affected the surrounding area primarily through its volcanic activities and Lahar floods which originate from the heavily deposited volcanic material on the mountain slopes and are turned into sand debris flows during heavy rain downpours. During the Lahar in Nov. 25, 1976, 28 persons died along the flooded K. Krasak basin. Furthermore, the heavy sedimentation conveyed from the mountain slope to the downstream areas of rivers has caused river functions to deteriorate. A typical example of such functional blockage can be seen at the Kamijoro irrigation intake located downstream in K. Progo. The intake was constructed around 1924, however, the intake has completely stopped functioning as a supply of irrigation water since about ten years ago due to a large rise in the height of the riverbed.

The study area of the hydraulic and hydrology sector covers the watersheds of the K. Progo, K. Opak and K. Dengkeng to obtain the fundamental data for the Project. The extent of the study area is shown in Fig. 1.

2.2 Topography

The study area is bounded by several high mountains such as G. Merapi (2,968 m) and G. Merbabu (3,119 m) in the north central region and G. Sundoro (3,138 m) and G. Sumbing (3,296 m) in the northwest region. The area in the southwest direction of the study area is flat open land facing the Indian Ocean. The area consisting of the watershed of the K. Ojo, a main tributary of K. Opak, is surrounded by hilly mountains and shows a variation from the typical hydrological characteristics of the area due to the lesser amount of rainfall and different geological conditions.

2.3 River Systems

The three river systems (K. Progo, K. Opak and K. Dengkeng) comprise the study area. Among them K. Progo and K. Opak have their river mouths in the Indian Ocean. However, K. Dengkeng is one of the largest tributaries of the Bengawan Sala which runs from the Middle Java to the East Java and has its mouth north of Surabaja City.

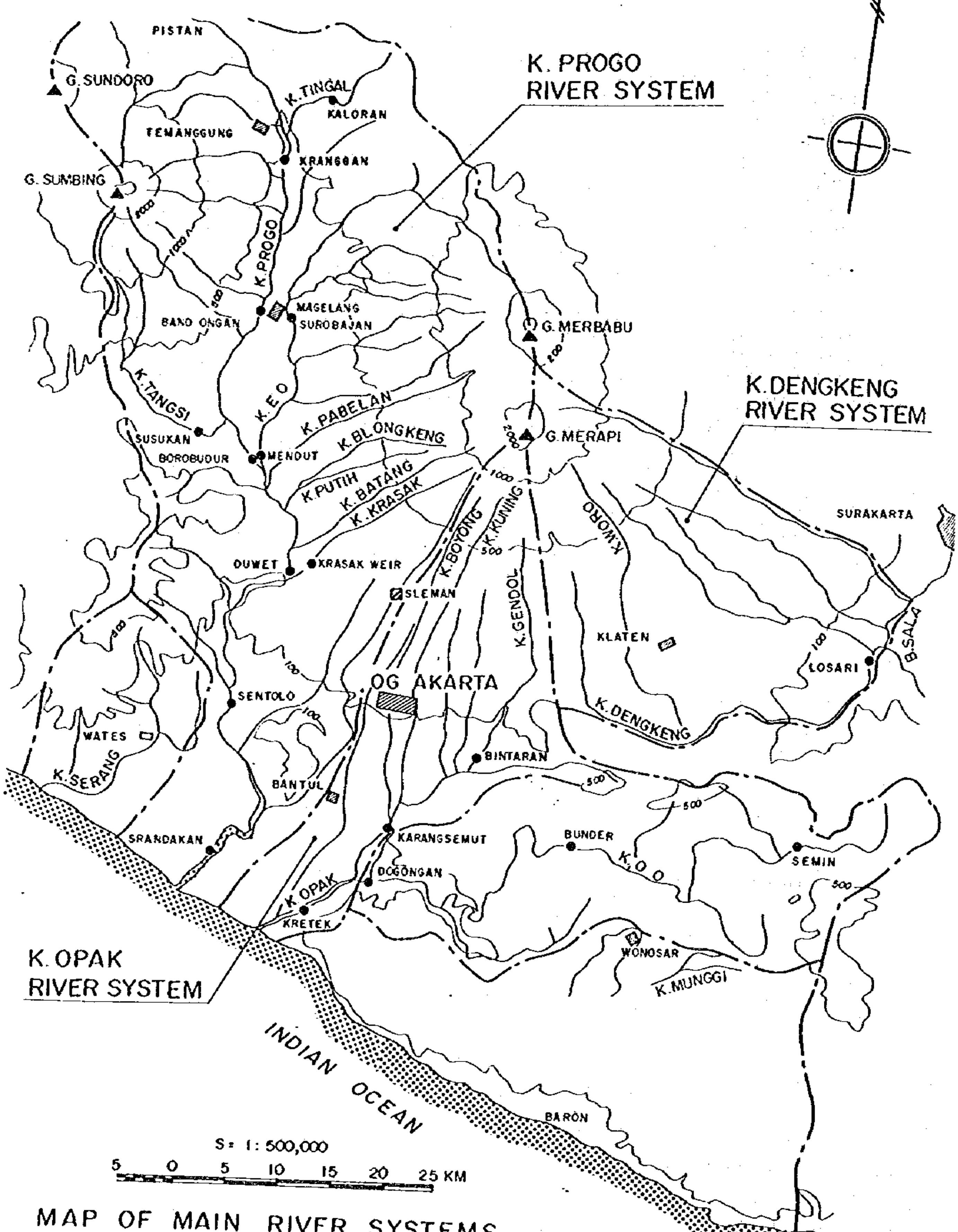
The extent of watersheds and the length of the main rivers are given in Table 1 and the longitudinal profiles of the respective rivers are shown in Fig. 2.

The slope of the rivers are generally steeper in the upper and middle reaches and abruptly change to gentle in the downstream areas; however, the magnitude of the river slope keeps within 1/500 on the average, even near the river mouth.

The rivers, K. Progo and K. Opak, run in U- or V-shaped river channels with rather high banks on both sides; therefore, flood waters seldom overflow their banks. This river channel condition is maintained along almost all the rivers except for a 10 to 20 kilometer section up from the river mouth. Consequently, the inundated areas along the K. Progo and K. Opak have been limited only to the areas around the river mouth.

As for K. Dengkeng, the shape of the bank and discharge capacity are generally inadequate in the project area. Because of severe sediment deposits, the river bank stands about 10 meters high above the ground at a section in the reach especially near the confluence points with K. Simping and K. Lusa about 45 km upstream from the river mouth where the slope decreases sharply.

Fig. 1 Map of Main River Systems



MAP OF MAIN RIVER SYSTEMS

Fig. 2 Longitudinal Profiles of Main Rivers

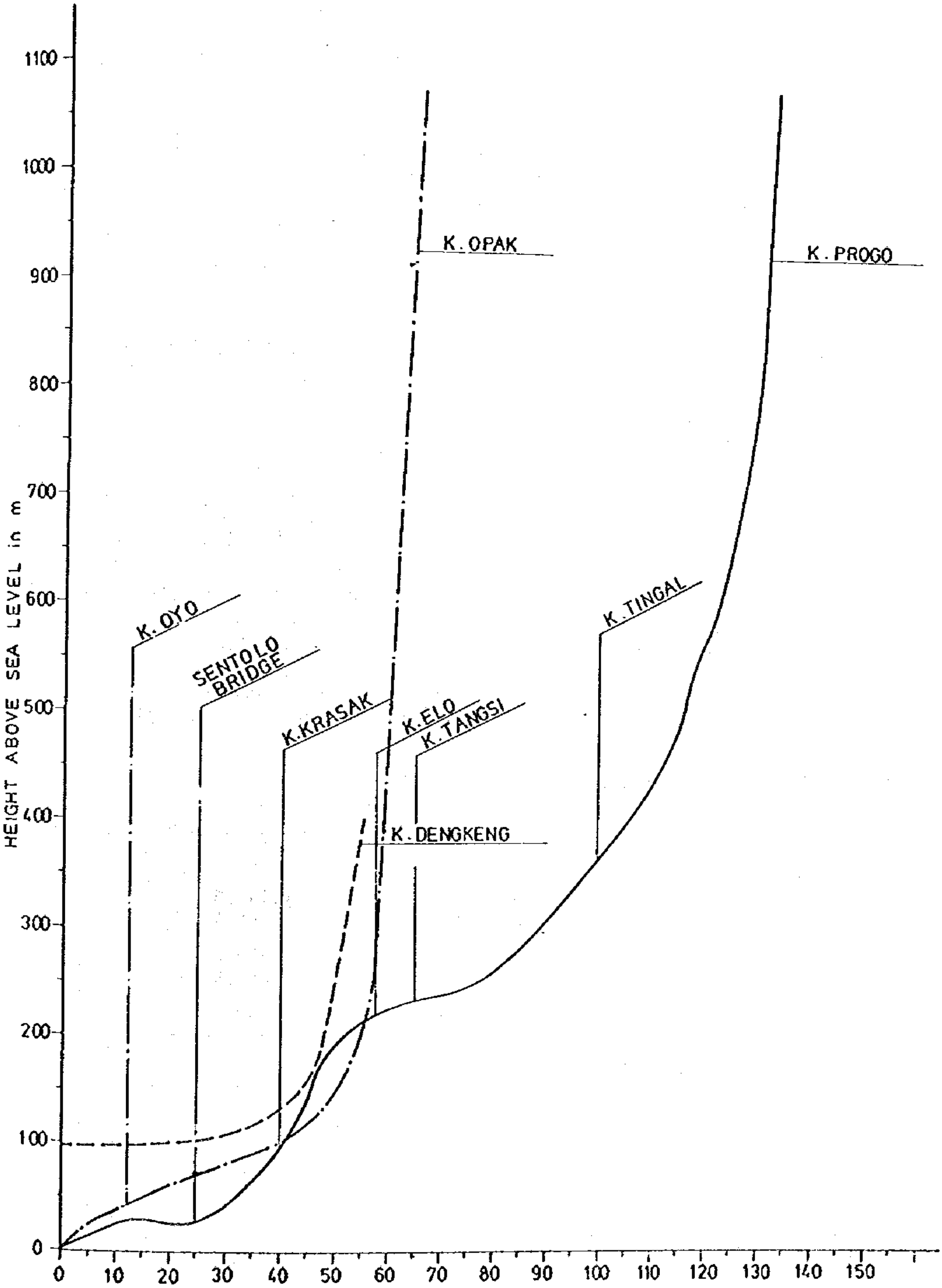


Table 1. Watershed and Length of Main Rivers and Tributaries in the Project Area

(1) Main Rivers

Main Rivers	Watershed	Length of Main River
K. Progo	2,296.9 km^2	135 km
K. Opak	1,255.9	65
K. Denkeng	830.0	55

(2) Tributaries

River	River System	Watershed (sq.km)
1. K. Pabelan	K. Progo	103.23
2. K. Blonkeng	"	71.20
3. K. Putih	"	26.60
4. K. Batang	"	22.82
5. K. Krasak 1/	"	31.70
6. K. Boyong 2/	K. Opak	14.14
7. K. Kuning	"	47.68
8. K. Gendol	"	14.59
9. K. Woro 3/	K. Dengkeng	442.14

1/ K. Bebeng is a tributary of K. Krasak with a watershed 9.43 sq.km

2/ Upper stream of K. Code (tributary of K. Opak)

3/ Upper stream of K. Simpin (tributary of K. Dengkeng)

(3) Catchment Area of Stage Stations

River	Station	Catchment Area
K. Progo	Duwet	1,748.4 km^2
	Sentro	1,961.6
	Srandakan	2,296.9
K. Opak	Karangsemut	453.2
	Kretek	1,255.9
K. Ojo*	Dogongan	740.5

* A tributary of K. Opak

3. METEOROLOGY

3.1 Available Data

The meteorologic elements such as rainfall, temperature, humidity, sunshine, evaporation, and wind have been observed at 9 stations in the study area. The list of the stations is given in Table 2 together with the elements observed and the available data period. The meteorologic data has been compiled in the following book.

<u>RB-1</u> ... DAILY METEOROLOGIC DATA BOOK
VOLUME 1-1 1977
MERAPI PROJECT OFFICE

In addition to the above, the following book is available for checking on the meteorological conditions in and around the study area.

<u>RB-2</u> ... KALI PROGO BASIN STUDY
SUPPORTING REPORT OF
CLIMATE AND HYDROLOGY JUNE 1971

The 135 ordinary rainfall stations and 17 automatic rainfall stations in the study area are still in operation today. The rainfall records have been compiled in the following books.

<u>RB-3</u> ... DAILY RAINFALL DATA BOOK
MERAPI PROJECT OFFICE 1977
(16 Volumes)

<u>RB-4</u> ... HOURLY RAINFALL RECORDS
MERAPI PROJECT OFFICE 1977
(5-volumes)

As to historical rainfall data, the following are available.

<u>RB-5</u> ... RAINFALL IN INDONESIA
VERHANDELINGEN NO.37

<u>RB-6</u> ... RAINFALL IN INDONESIA
VOLUME 83A

3.2 Rainfall

The general pattern of annual and monthly rainfall is mentioned here while the detailed study of rainfall is explained in the next chapter.

The mean monthly rainfall records at 8 stations in the study area given in Table 3.2 all show the same annual rainfall pattern. The mass curve of rainfall shown in Fig. 3 indicates that on average 83% of the annual rainfall falls in the rainy season, November to April, and the balance of 17% in the dry season, May to October.

The difference of magnitude in annual rainfall is mainly due to the differences in altitude at respective rainfall stations. The relation of annual rainfall vs. altitude shown in Fig. 4 substantiates that annual rainfall increases with the increase of altitude; however, only up to the critical altitude of around 1,300 m above sea level, after which it decreases gradually despite further increases in altitude.

The following are the relations of annual rainfall vs. altitude which were taken from figure 4.

Altitude	Annual rainfall
0 m	2,000 mm/year
500	3,200
1,300	3,800
2,500	2,800

The isohyetal map of the annual rainfall in the study area is shown in Fig. 5 in which the above-mentioned rainfall distributions in altitudes are taken into consideration.

3.3 Temperature

Maximum and minimum temperatures were observed at two stations in the study area. The monthly means values are given in Table 4 (1). The table shows no significant variation of temperature throughout a year.

The temperature falls at the rate of about 1°C for every 160 meters increase in altitude. (refer to reference book RB-2 page 17)

3.4 Humidity

Humidity was measured at two stations. The monthly mean values are given in Table 4 (2).

The highest humidity is observed in December and the lowest humidity in September.

3.5 Sunshine

The sunshine records were complied at two stations in the reference book RB-1; however, some records appear unreasonable. Therefore, the sunshine record shown in Table 4 (3) is quoted from the reference book RB-2 in which the sunshine records at Magelang and Wedi Birit, near Klaten, were compiled.

3.6 Wind

The wind record at Adisucipto is shown in Table 4 (4). The wind is calm throughout a year.

3.7 Evaporation

The evaporation is quoted from the reference book RB-2 in which the evaporation at Klaten is based on the Penman Equation. The details of the estimation are given in Table 4 (5).

Fig. 3 Distribution of Monthly Rainfall

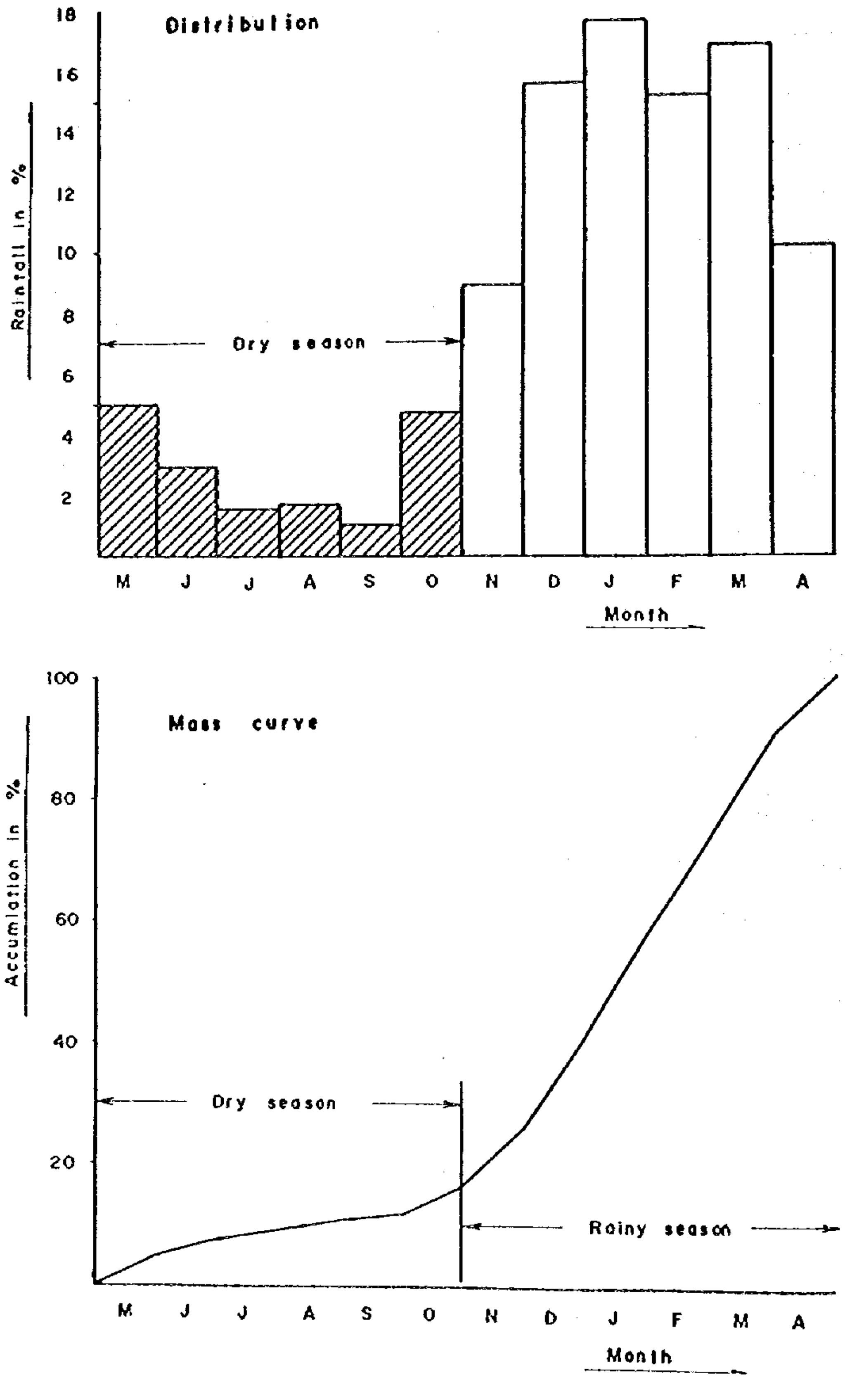


Fig. 4 Annual Rainfall vs. Altitude

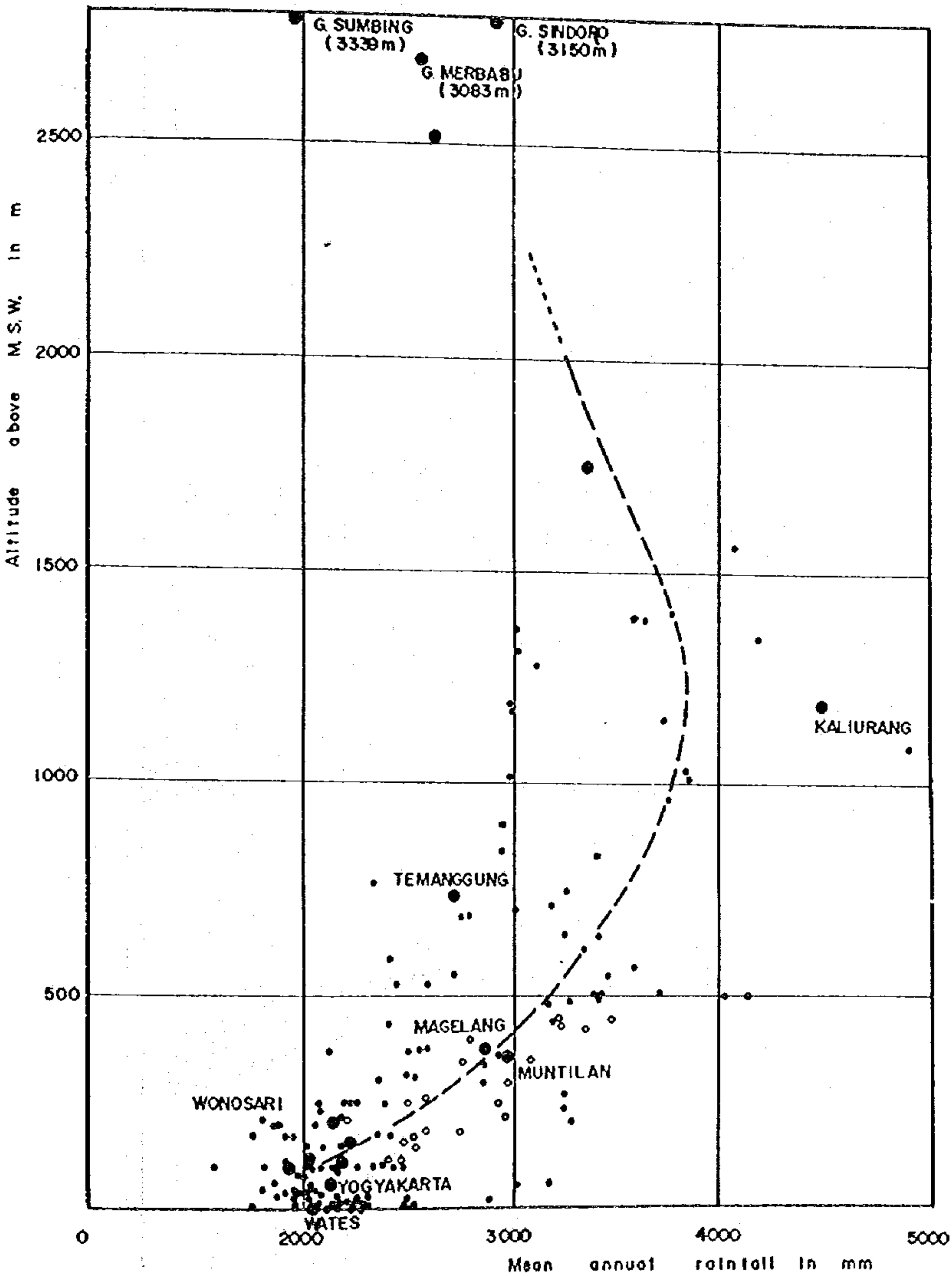


Fig. 5 Isohyetal Map of Annual Rainfall

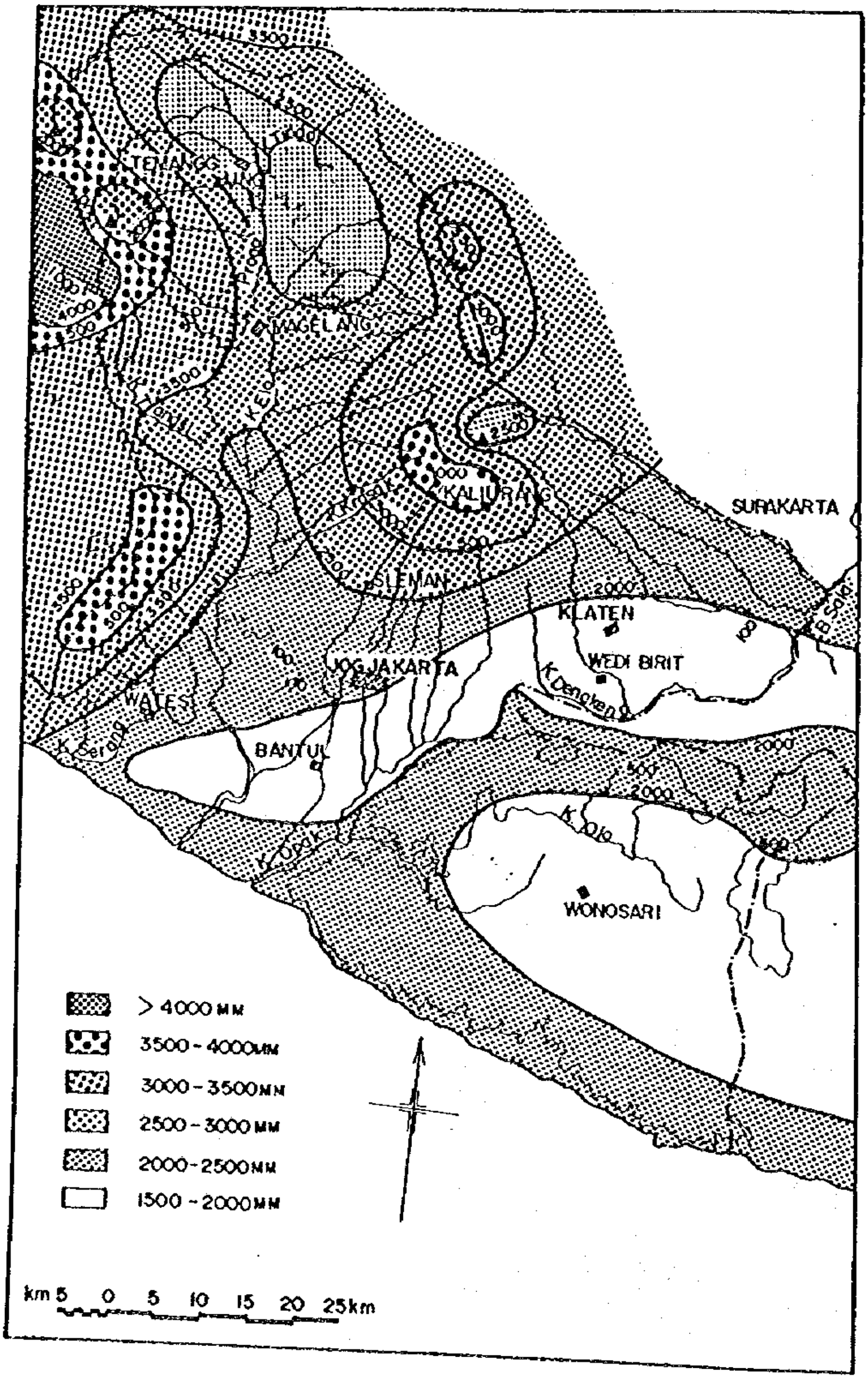


Table 2 Meteorological Stations

Station	Start of Data collected	Rainfall	Temperature	Humidity	Sunshine	Evaporation	Wind
1. Adisucipto	1972	o	o	-	-	-	-
2. Wates	1972	o	o	Δ	Δ	Δ	Δ
3. Kaliurang	1971	o	o	o	o		Δ
4. Gadjah Mada University	1971	o	o	o	o	-	o
5. Seneng	1975	Δ	Δ	-	Δ	-	-
6. Kleobung	1971	o	o	o	Δ	Δ	o
7. Borobudur	1972	-	o	o	o	-	-
8. Playan	1976	Δ	Δ	Δ	Δ	Δ	Δ
9. Mt. Merapi Project Office	1974	o	o	o	-	-	

Note: o : Available

Δ : Available but not throughout the entire year

- : Not observed

Table 3 Mean Monthly Rainfall

Unit: mm

Station	Elevation	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1. Temanggung	580 m	1961-1970	372	315	377	281	110	56	52	48	33	130	191	340	2,305
2. Borobudur	237	1961-1970	400	318	325	229	82	72	32	52	21	107	235	430	2,303
3. Kaliurang	-	1961-1965	518	515	605	354	162	100	47	51	48	184	351	492	3,515
4. Wates	22	1961-1969	340	287	306	156	65	83	29	37	20	84	125	246	1,778
5. Adsucipto	-	1961-1970	386	324	342	160	80	34	22	28	12	100	169	324	1,919
6. Wonosari	-	1961-1970	365	318	307	180	81	55	16	27	10	106	170	308	1,943
7. Deles	-	1962-1970	565	382	479	263	212	79	31	32	25	85	230	381	2,767
8. Klaten	188	1961-1970	288	288	320	217	121	63	39	37	17	65	155	324	1,937

Data source: Rain Observation in Indonesia, Volume 83A

Elevation of St. in ( ) shows estimated value in 1:50,000 map

Table 4 Meteorological Conditions in the Study Area

(1) Temperature Unit: °C

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
Magelang	24.7	24.7	25.1	25.3	25.4	25.0	24.2	24.5	24.8	25.3	24.9	24.5	24.9
Wedi Birit	25.0	24.9	25.2	25.6	25.5	25.1	24.7	24.7	25.2	25.8	25.4	25.1	25.2

(2) Humidity Unit: %

Magelang	85.0	85.0	84.0	83.0	81.0	81.5	78.5	76.0	75.0	79.0	83.0	86.0	81.4
Wedi Birit	86.0	86.0	84.0	83.0	82.0	80.0	79.0	77.0	77.0	79.0	83.0	85.0	81.8

(3) Sunshine Unit: %

Magelang	45.0	50.0	55.0	61.0	67.0	69.0	78.5	73.5	75.0	69.0	61.0	57.0	63.4
Wedi Birit	43.0	43.0	51.0	62.0	61.0	69.0	72.0	72.0	66.0	63.0	54.0	52.0	59.0

(4) Wind Velocity Unit: m/s

Adisucipto	2.4	2.1	2.2	2.8	2.6	2.2	2.1	2.8	2.6	3.1	2.9	2.8	2.6

(5) Evaporation Unit: mm/day

Klaten	4.6	4.7	4.8	4.5	4.2	3.9	4.1	4.7	5.2	5.5	5.0	4.9	4.7

4. RAINFALL ANALYSIS

The peak magnitude of flooding in the study area is mainly controlled by the magnitude of daily rainfall over the river basins, even in the K. Progo which has the largest extent of the watershed in the study area.

Besides the magnitude of the daily rainfall, the other control factors of flooding are intensity and duration of rainfall over the river basins.

Accordingly, rainfall analysis is to establish a duration curve for the study area which express a relation between intensity, duration and area of rainfall. The relation will be utilized to estimate peak flood discharge from the basins for use in the next chapter.

4.1 Available Data

Besides the reference books listed in Chapter 3, the following are available for rainfall analysis.

RB-7 ... STUDY FOR MAKING MASTER PLAN FOR LAND EROSION AND VOLCANIC DEBRIS CONTROL IN THE AREA OF MT. MERAPI.

HYDRAULIC AND HYDROLOGY PROGRESS REPORT 1977.

RB-8 ... REPORT ON RIVER ENGINEERING SECTOR WONOGIRI MULTI-PURPOSE DAM PROJECT, PART THREE DESIGN OF FLOOD FORECASTING AND FLOOD WARNING SYSTEMS, DECEMBER 1978.

4.2 Diurnal Distribution of Rainfall

The diurnal distribution of daily rainfall based on the record at Deles shows the same diurnal pattern of distribution as in the Bengawan Sala basin.

According to the data shown in Fig. 6, 60% of the daily rainfall was concentrated during 6-hours from 13:00 to 19:00 hours.

4.3 Magnitude of Daily Rainfall

The magnitude of daily rainfall was based on the frequency analysis of daily rainfall observed at 4 stations in the study area. The stations are Temanggung, Srumbung, Kaliurang and Yogyakarta. The results of the frequency analysis are shown in Fig. 7 and Table 5.

The results show that the probable daily rainfall for 100 years at 4 stations distribute around 200 mm/day and show small local deviation in the magnitude of the daily rainfall.

Table 5 Frequency Analysis of Daily Rainfall

Unit: mm/day

Return Period	Temanggung	Srumbung	Kaliurang	Yokyakarta
2-year	105	113	145	115
5	130	164	175	135
10	150	173	190	150
50	190	209	230	175
100	200	228	245	185

4.4 Hyetal Area of Rainfall

The extent of a rainfall area, hyetal area, is generally small in Indonesia due to the nature of tropical rainfall. The small extent of the hyetal area in the study area was determined by scattered plots in the daily rainfall correlation graphs between the two rainfall stations which are shown in Fig. 8.

The study of the hyetal area examined was based on isohyetal maps of daily rainfall over the southeastern slope of G. Merapi centered around Klaten city where 22 rainfall stations are installed covering an average area of 250 Sq. km (only 200 sq. km in case of heavy rainfall areas).

4.5 Area vs. Daily Rainfall Relathinship

Average daily rainfall over a basin decreases with an increase of an area of the basin. The relationship was studied based on the total of 55 daily rainfall station records using the following procedures.

- The frequency analysis of the daily rainfall was conducted to estimate the probable rainfall at a specific point. The Srumbung station which is located near the center of the study area and at 500 m in altitude above sea level was used to present the nature of point rainfall.

- The frequency analysis of the average daily mean rainfall over three circular areas centred at Srumbung station with diameters of 10 km (=79 sq. km), 20 km (=314 sq. km) and 30 km (=707 sq. km) were estimated. To construct the rainfall versus area relationship, the annual maximum rainfall series was constructed based on arithmetic mean of the daily rainfall in the respective areas. The number of the stations included in respective areas are 4, 9 and 16.

- To obtain the further area versus daily rainfall relationship, annual maximum series over the K. Progo basin (2,296.9 sq. km) and the whole K. Progo plus K. Opak basins were constructed in accrodance with the same procedure and analyzed. The number of the rainfall stations were 31 and 55 respectively. The annual maximum series of the daily rainfall in every case consisted of 24-year records over the period of 1953 to 1976 and the Gumble Method was applied to the frequency analysis. The probable daily rainfall versus area relation thus obtained is given in Table 6.

Table 6 Probable Daily Rainfall vs. Area

Unit: mm/day

Return Period	0.0 sq.km. (Point Rainfall)	79 sq.km	314 sq.km	707 sq.km	2297 sq.km	4383 sq.km
2-year	113	77	54	47	46	43
10	164	102	82	77	76	72
30	195	120	101	95	87	89
50	209	124	109	103	102	97
100	228	133	120	114	113	108
150	238	138	126	121	191	114
200	247	142	130	125	124	119

Note: (1) Point Rainfall is based on Srumbung Station.
(2) Data utilized is 26 years during 1951 to 1976.
(3) Frequency analysis method is Gumbel Method.

4.6 Duration vs. Rainfall Intensity Relationship

The previously mentioned procedure is usually made to obtain a duration versus rainfall intensity relationship over a basin. However, the procedure is inapplicable to the study area, since the operating periods of the hourly rainfall stations are too short.

Therefore, the relation was estimated using the following procedures.

- To determine the rainfall condition in a downpour, hyetographs of 55 rainfalls when daily rainfall exceeded 100 mm/day were selected.
- The maximum hourly rainfall in 1-hour and in successive 2-, 3-, 6-, 12- and 24-hours were selected from the respective hyetographs and their respective daily rainfall were calculated.
- The mean of the ratios to respective duration was expressed by a curve best fitting the rainfall ratio versus duration data as shown in Fig. 9. The equation of the curve is given as $\bar{\gamma} = 1.0848/(t+1.353)$, where $\bar{\gamma}$ denotes a rainfall intensity expressed in ratio to a daily rainfall and t denotes duration of rainfall in hours.

4.7 Rainfall Duration Curve

The relation shown in Table 6 expresses the reduction of mean rainfall over a river basin due to the expansion of its area. The equation $\bar{\gamma} = 1.0848/(t+1.353)$ represents the reduction effect of mean rainfall intensity over a rainfall site area. The conjunctive use of the two relations, expressed in the following equation, represents the mean rainfall intensity over the arbitrary extent of a river basin for an arbitrary duration of rainfall.

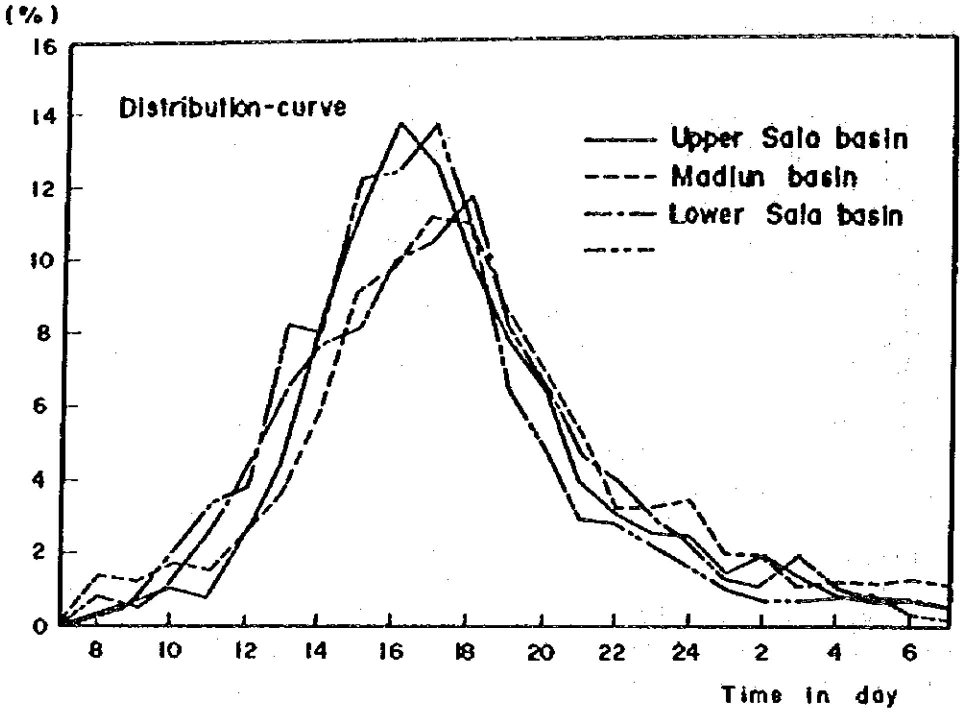
$$\frac{\bar{\gamma}}{R} = \frac{1.0848}{t + 1.353} \quad \ldots\ldots\ldots (4.1)$$

where: $\bar{\gamma}$: Average rainfall intensity over a basin in mm/hour corresponding to the return period of R

t : Duration of rainfall in hours

R : Probable daily rainfall over a basin in mm/day which is given in Table 5.

Fig. 6 Distribution of Hourly Rainfall



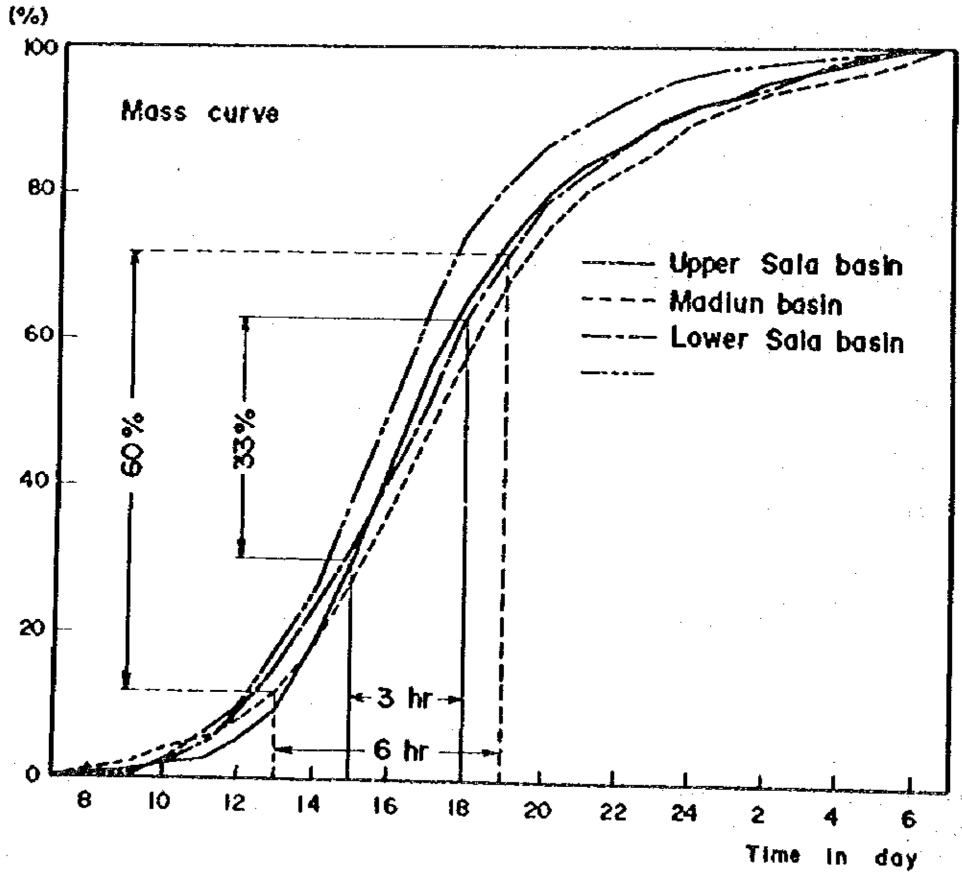


Fig. 7 FREQUENCY ANALYSIS of DAILY RAINFALL (1)

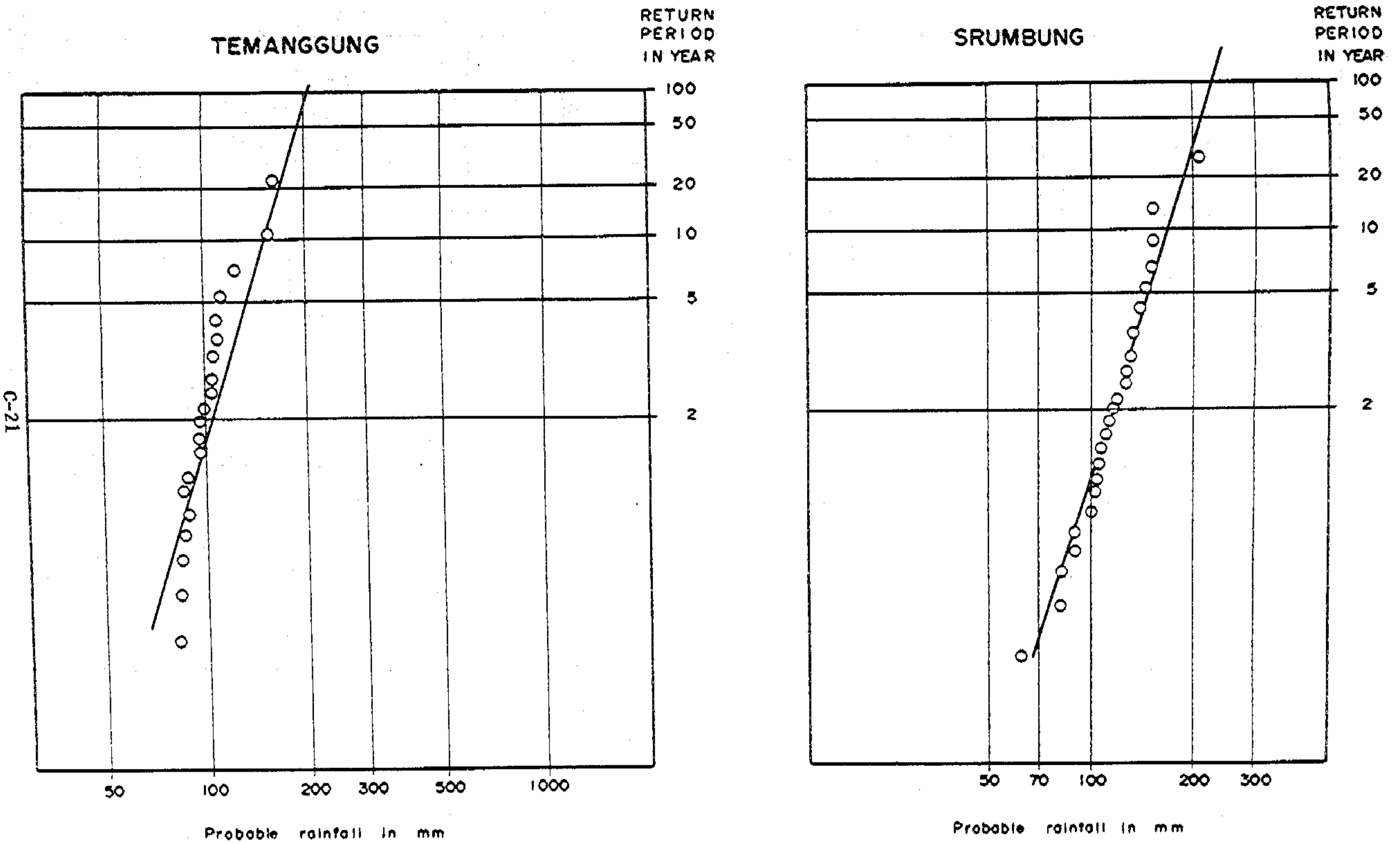
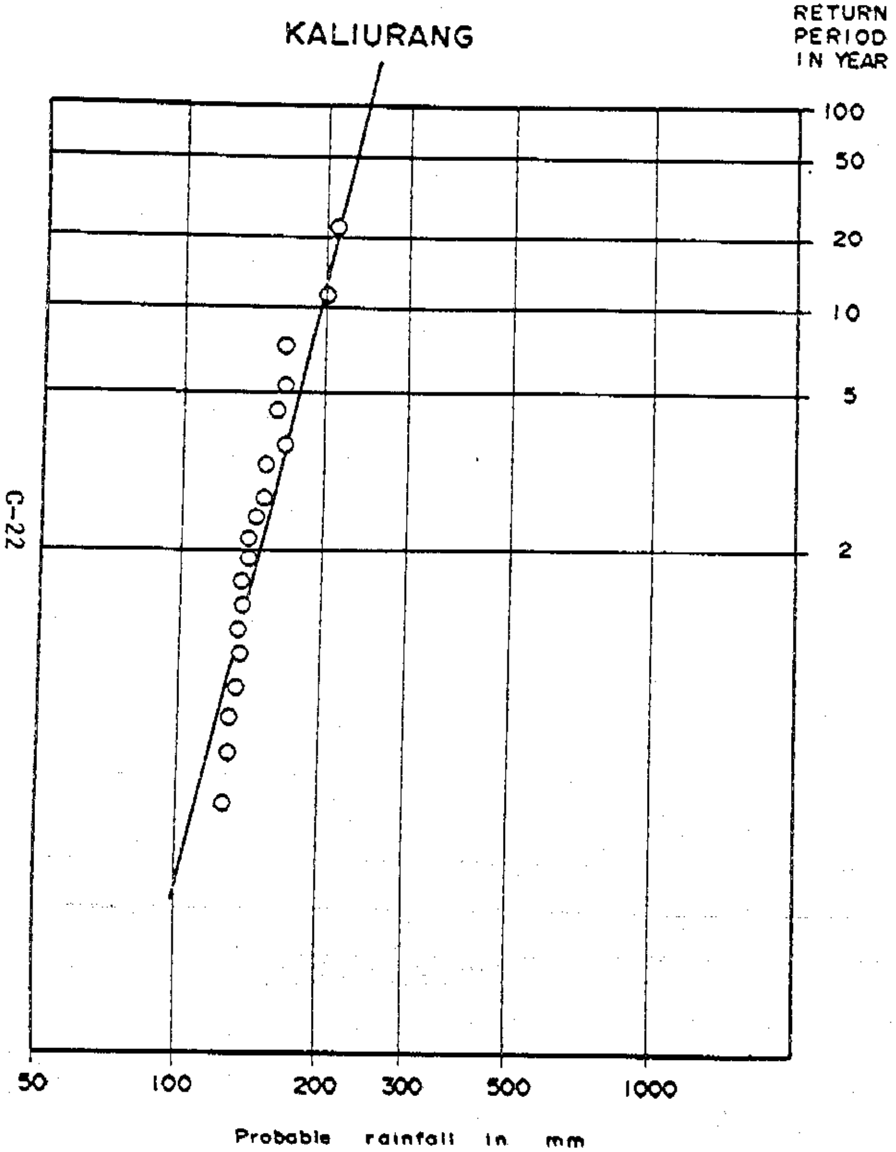


Fig. 7 FREQUENCY ANALYSIS of DAILY RAINFALL (2)



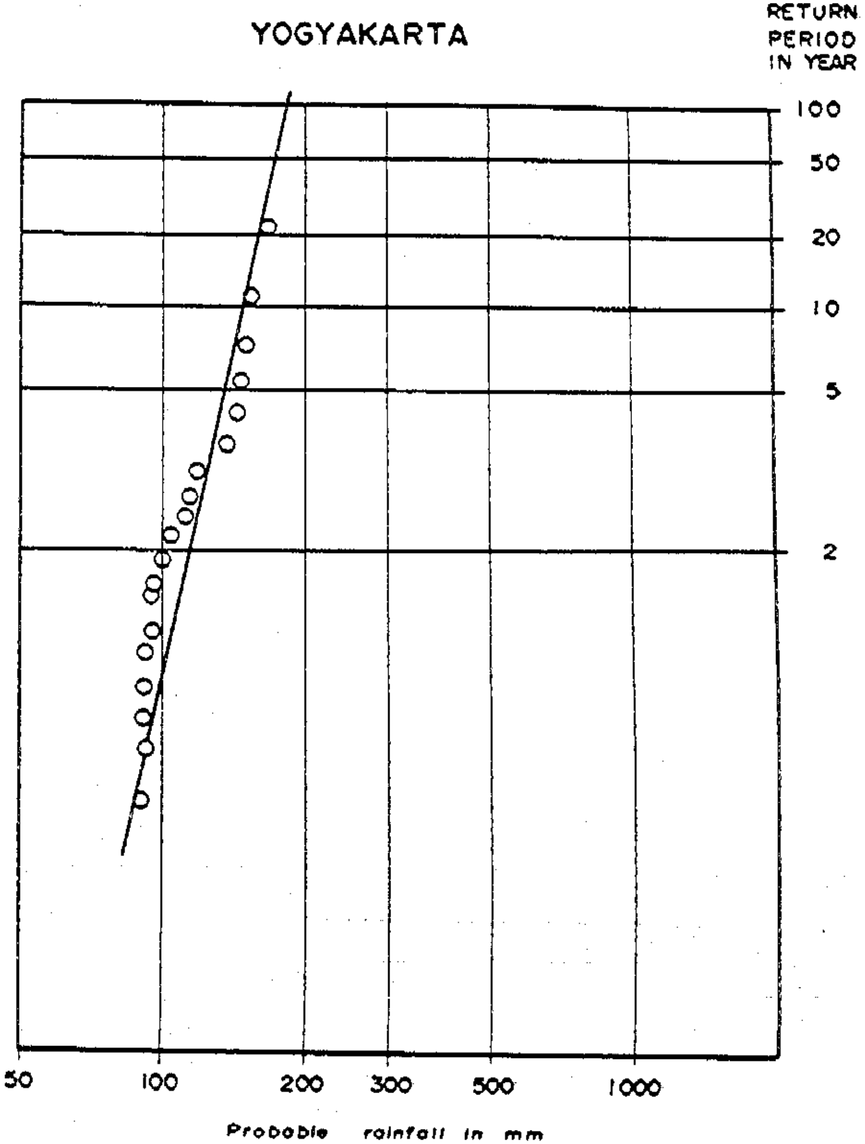


Fig. 8 GAUGE RELATION OF RAINFALL

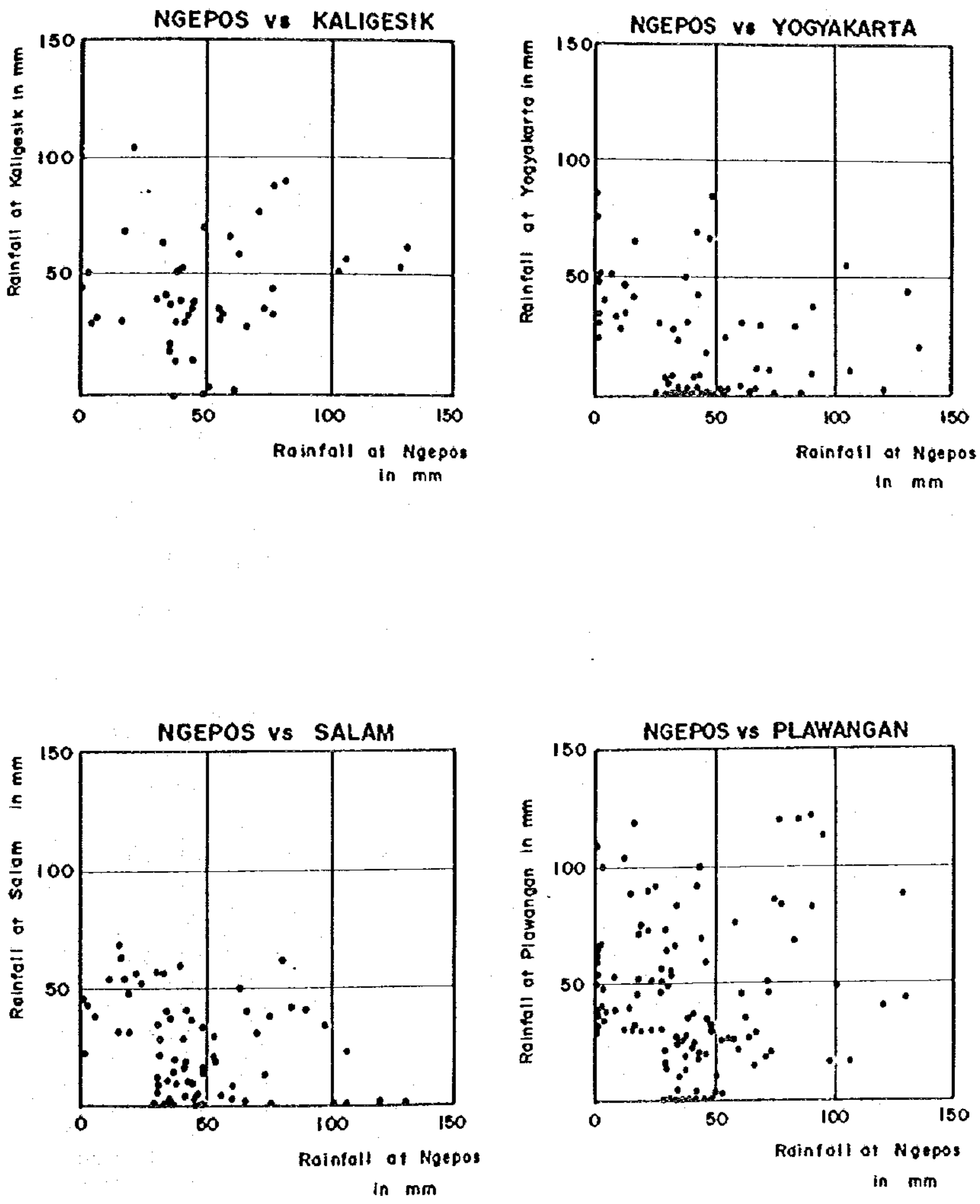
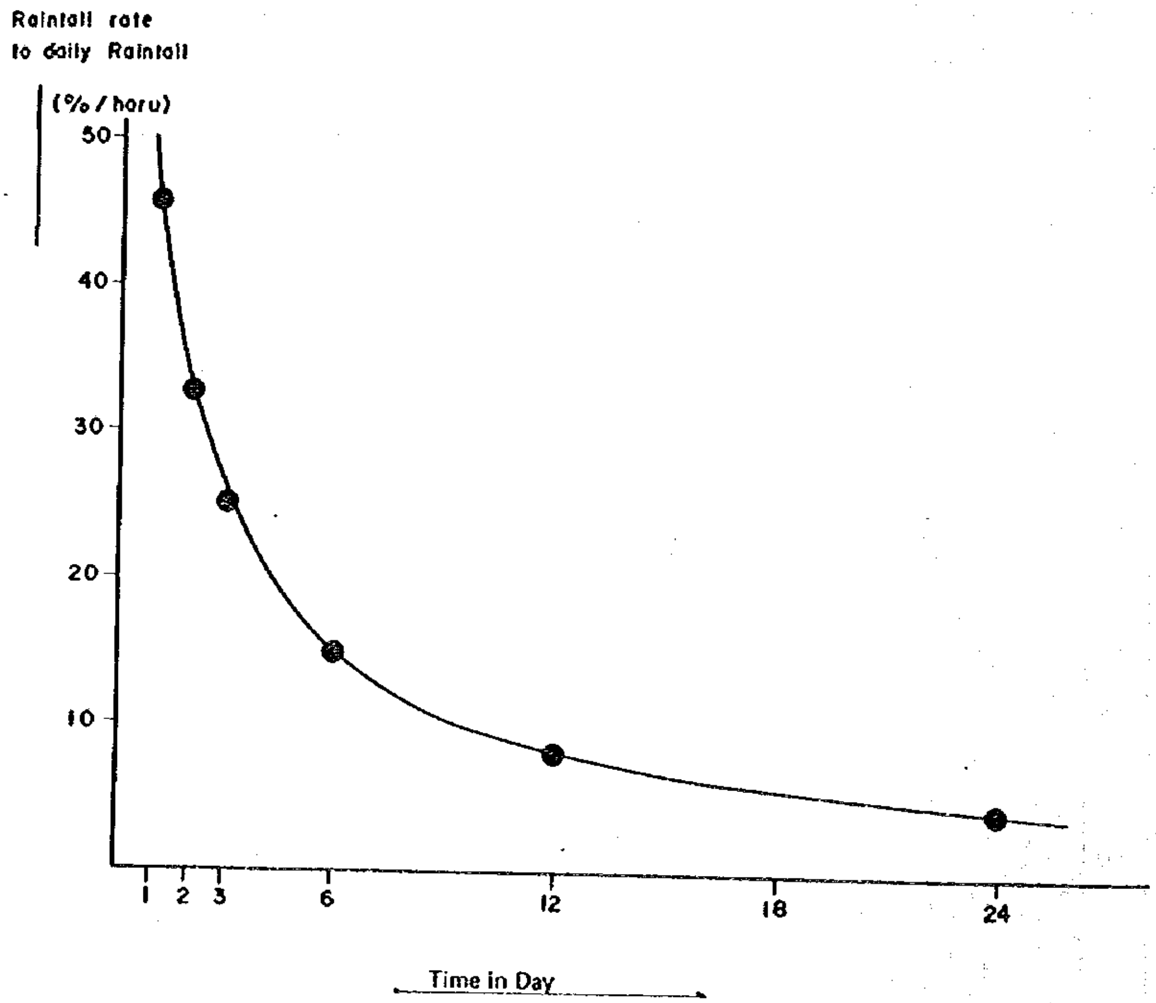


Fig. 9 TIME VS. HOURLY RAINFALL INTENSITY



5. RUNOFF ANALYSIS

Flood runoff analysis was carried out for the tributaries in the project area and for the main rivers in the study area in terms of Rational Method and Storage Function Method respectively.

5.1 Available Data

The following are available for estimation of flow conditions of tributaries and main rivers in the study area.

(1) River Stage and Discharge Data

There are a total of 16 river stage stations along the main rivers of K. Progo, K. Opak and K. Dengkeng as follows: five automatic river stage stations, six ordinary river stage stations with rating curves and five ordinary river stage gauging stations without rating curves. The data was mainly collected from the automatic river stage records which started their operation in 1969.

In addition to the collected data, estimated run-off in K. Progo by SSARR run-off simulation during the period of 1969 to 1976 is also available.

(2) Flood Records

Flood records in main rivers are collectable only for K. Progo because of the existence of river stage stations. In K. Progo, the flood records were collected in total of 11 floods at four gauging stations. The flood which occured March 10-11th, 1975 was the largest during the available data period of 1973 to 1977.

Flood conditions in the tributaries can be estimated based on of flood marks found on structures. This information was collected at Krasak weir on K. Krasak, Blawang weir on K. Opak and Jurang Jero weir site on K. Putih to estimate the peak discharge of floods.

5.2 Flow Regime in Main Rivers

Flow regime to show the annual condition of flow rate in rivers was estimated based on daily mean discharge records at Duwet site on K. Progo. Although Duwet station has the longest record for a river stage station with a rating curve, it has a rather low range of flow stage and is unstable due to the lack of significant river bed movement from year to year.

The estimated daily mean discharges were arranged from high to low by amount of year discharge in order to select the 1st, 95th, 185th, 235th and 355th largest discharge. The values indicating the flow regime during 1969 to 1976 are compiled in Table 7. Among the years, the flows regime curves in 1969, 1971, 1975 and 1976 are shown in Fig. 10.

5.3 Frequency Analysis of Peak Flood Discharge

The frequency analysis of the peak flood discharge was carried out based on the collected data from the tributaries in the Project area. As to the main rivers, the frequency analysis was difficult to carry out due to the lack of availabile rating curves especially in the higher range corresponding to flood stages.

The frequency analysis was carried out for two sites: at the Krasak weir in the K. Krasak and the Blawang weir in K. Opak.

The data of the highest observed annual stages were collected for the respective weirs and the corresponding discharges to the stages were estimated by the following equation.

$$Q = 2.27\ H^{1.5}\ B \quad \text{.............................} \quad (5.1)$$

where, Q : Discharge in m^3/sec
H : Observed overflow depth from weir in m^3/sec
B : Width of weir in meter

The above equation has been applied by The Public Works Department for design of weirs with the standard weir crest shape.

The discharge data thus estimated was used to carry out the frequency analysis, the results of the analysis are shown in Fig. 11 and Table 8.

A similar analysis has been carried out in the Reference Book, RB-8 about weirs located in the Bengawan Sala basin through same procedures mentioned above.

The results shown in Fig. 11 indicate the relation of area vs. specific discharge for the 100-year design return period.

5.4 Probable Discharge on Tributaries

Flood peak discharge corresponding to a specific return period and probable discharge may be estimated by many formulas. For rivers with smaller watersheds, the Rational Formula is generally applied. The Weduwent Method is also widely used in Indonesia. These two methods are based on the same idea; however, the Weduwent Method results in a ra rather small peak discharge as compared with the Rational Method. Therefore Rational Method was adopted in this report to maximize the safety to structures.

The discharge of tributaries may be estimated by the Rational Method, and Duration Curves studied in Chapter 4.

$$Q = \frac{1}{3.6} \cdot f \cdot \bar{\gamma} \cdot A \text{ .... Rational Method .... (5.2)}$$

$$\frac{\bar{\gamma}}{R} = \frac{1.0848}{t + 1.338} \text{ .... Duration Curve ..... (4.1)}$$

In the above-mentioned equations, the catchment area "A" of a basin is given and the probable daily rainfall "R" corresponding to "A" is given in Table 1. The runoff coefficient "f" and the basin lag of flood, "T", of a basin are, however, unknown. The results of studies on "f" and "T" are as follows:

(1) Run-Off Coefficient: "f"

For the run-off coefficient "f", the value of 0.75 was adopted from the following two study cases.

- The peak flood discharge for the flood of December 25, 1975 was estimated at 193 cu.m/sec. at the Jurang Jero check dam while the maximum rainfall at Ngepos, just downstream of the Jurang Jero, was 60 mm/hr. Since the flood was a sand debris flow, it was estimated that it contained about 50% of sand in the flow. Therefore, peak water discharge was estimated as 96.5 cu.m/sec., (i.e., 193 x 0.5). This data gives a run-off coefficient of 0.75 since "f" is expressed as $Q \times 3.6/\bar{\gamma}$ A.
- The probable peak discharge of flood at the Krasak weir, catchment area (31.3 sq.km) was estimated at 600 cu.m/sec. for the 100-year return period. While the rainfall intensity for the 100-year period was estimated at 84.2 mm/hr based on Table 5.2 (Equation (4.1)) with a basin lag of 1.4 hour and sand contents up to 10%. These provide a run-off coefficient of 0.75.

(2) Basin Lag of Flood: "T"

The basin lag of flood may be estimated by computations based on flow condition in basins. The estimated basin lags are compared with basin lag versus the area relationship observed in Bengawan Sala River basin to check weir data reliability.

The basin lag of a flood can be expressed by the duration of propagation time for a flood wave to flow over a slope in a basin and through a river channel. The propagation time was calculated from the following equations assuming that the propagation velocity obeys Manning's mean velocity formula:

$$T \;:\; T_s + T_r$$

$$T_s \;:\; L_s/V_s = L_s \cdot N/(R_s^{0.67}\, I_s^{0.5}) \quad \text{.........} \; (5.3)$$

$$T_r \;:\; L_r/V_r = L_r n/(R_r^{0.67} \cdot I_r^{0.5})$$

where:

- T : Basin lag of flood
- T_s : Propagation time of flood wave on slope
- T_r : Propagation time of flood wave in river channel
- L_s : Mean width of slope
- N & n : Manning's "n" value on slope and river channel respectively
- R_s & R_r : Hydraulic mean depth of flood on slope and in river channel respectively
- I_s & I_r : Mean slope of basin and river channel respectively

The following values are given to estimate the basin lag of flood based on the topographic features of tributary basins and on the flood condition in tributary at downpour which may produce as large a flood as the design flood.

Slope			River Channel		
I_s	=	1/10	I_r	=	*
R_s	=	0.1m	R	=	2m
N	=	0.1	n	=	0.045
L	=	500 m	L	=	*
V	=	0.56 m/s	V	=	*
T	=	15 min	T	=	*

Note: * depending on tributary conditions

Although T_s was fixed at 15min. for all the tributary slopes in the study area, T_r depends on topographic conditions of the tributaries such as mean slope and length of the tributaries.

When peak discharge of flood is required to be estimated at several sites along a tributary, the basin lag of flood may also have to be estimated at the respective sites by solving the above equation using the intervals of the adjacent two sites as "L", the mean slope of river channel in the interval as "I" and summing the "T" from the upstream end of the basin to the site.

The basin lag is computed for the ten tributaries: K. Krasak, K. Bebeng, K. Batang, K. Putih, K. Boyong, K. Kuning, K. Gendol, K. Blongkeng, K. Pabelan and K. Woro. The results are given in Table 9 and the relations between catchment area and estimated basin lags are plotted in Fig. 12.

The results are compared with the relation obtained in the Upper Bengawan Sala basin*, from the Wonogiri dam basin up to Surakarta City, located to the east of the Merapi area. The basin lag of the Bengawan Sala shown in Fig. 12 is made up of points observed in the catchment areas larger than 100 sq.km. The extended line of the observed points runs through the center of the plots of the Merapi area cases was drawn to verify the reliability of the estimated basin lags using equation (5.3).

(3) Probable Discharge

The probable discharge in the tributaries was estimated for the return period of 100-year in terms of Eq. (4.1) and Eq. (5.2).

The methodology used to obtain the probable discharge of the tributaries is outlined as follows:

- Interpolate a probable daily rainfall for 100-year, R_{100}, which corresponds to the catchment area of a tributary basin based on Table 6.

- Read to obtain a basin lag, "T", corresponding to the basin in Eq. (5.3) or Fig. 12.

- Compute the average rainfall intensity, $\bar{\gamma}$, by substituting R_{100} and "T" into the Eq. (4.1).

- Compute the peak discharge by substituting "A", "$\bar{\gamma}$" and "f" (fixed to 0.75) into the Eq. (5.2).

The computation was carried out for ten tributaries and the peak discharge was also estimated at significant sites along the tributary such as junctions with main tributaries, with main streams, check dam sites and sites at which main structure are located. The result of estimation is given in Table 9.

The reliability of the computation is verified by the coincidence of the specific discharge versus catchment area line for 100-year period in the Upper Bengawan Sala and in the K. Madiun basin (which is also drawn in Fig. 13). Since the line obtained is based on an actual long period of hydraulic data at weirs located along the tributaries.

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* Refer to Reference Book RB-8.