REPUBLIC OF INDONESIA

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

PROGRESS REPORT

MARCH 1979

JAPAN INTERNATIONAL COOPERATION AGENCY

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F O R E W O R D

BACKGROUND OF THE AREA

The Indonesian archipelago has more than 128 active volcanoes. The focus of this study is the Mt. Merapi area which contains two conflicting assets: Mt. Merapi, which is one of the most active volcanoes in the world, and the densely populated city of Yogyakarta, a center of Indonesian cultural heritage located only 30km south of the volcano.

The last volcanic eruption of Mt. Merapi in 1969 caused large scale damage to the infrastructure in the area. Without control, Mt. Merapi prevents the proper regional development required to support the large population of this extensive area which has already reached 780 persons/sq. Kilometer. A Master Plan for the construction of Sabo works is required in order to prevent and reduce the future posibility damage caused by Nuée Ardente and Lahar volcanic materials, to protect the cultural assets of the region and to allow intensive development of this region which is rich in natural resources.

PROJECT BACKGROUND

In response to request from the Government of Indonesia in 1975, the Government of Japan through its executing agency, the Japan International Cooperation Agency (JICA) agreed to undertake a three-year study (1977-1979) to develop a Master Plan for Land Erosion and Volcanic Debris Control as part of the Mt. Merapi Project to control and mitigate damage resulting from Nuée Ardente and Lahar volcanic deposits and flooding.

JICA organized a Study Team consisting of 16 professional experts with Mr. Isao Tani as team leader to be guided by a 5-member Supervisoty Committee under the chairmanship of Prof. Dr. Aritsune Takei. The Study Team went to Indonesia during the period June 12 - September 14, 1978 to conduct surveys covering hydraulics, hydrology, river engineering, topography, geology, socio-economics and disaster control. The Study Team held discussions on the project with Indonesian Government departments, private institutions and universities, collected data and information, and conducted various aerial and field surveys including in-depth interviews with villagers.

The area studied by the Study Team consisted of over $900km^2$ on the south and southeast slopes of Mt. Merapi (30km north of D.I. Yogyakarta) between the tributaries K. Pabelan and K. Woro, including areas defined as "trouble spots" along the rivers K. Progo and K. Opak.

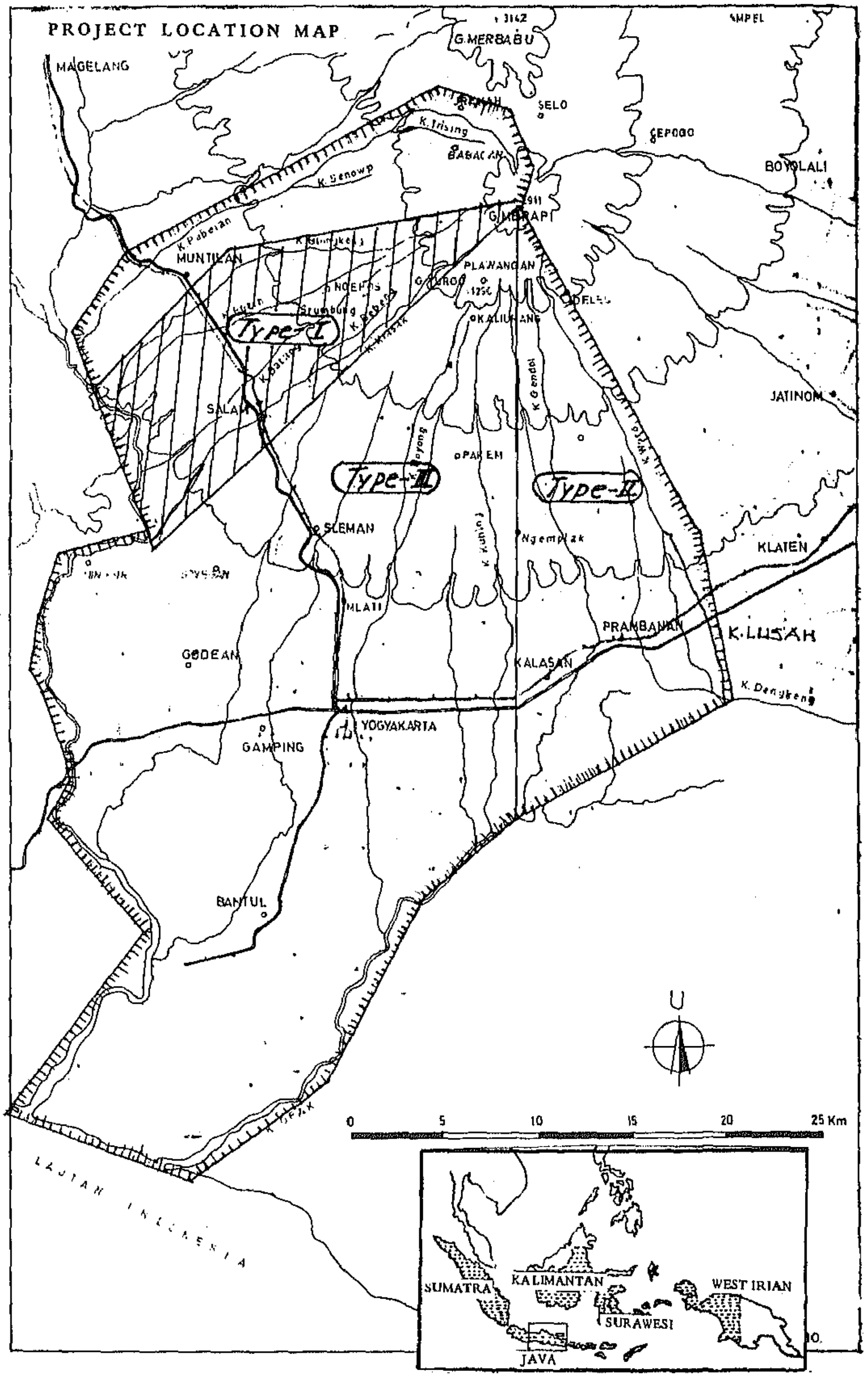
The findings of the Study Team have been presented in three Progress Reports listed below, of which this report is the third.

1. Progress Report March '78 - Preliminary results of initial survey from July '77 to February '78.
2. Progress Report Sept. '78 - Outline of activities and preliminary field analysis of the main survey June - Sept. '78.
3. Progress Report March '79 - In-depth analysis and summary of two years of study including presentation of a preliminary Disaster Prevention Plan.

The Study Team will present its Final Report, including the Master Plan, at the end of fiscal year 1979, after the performance of supplementary field surveys scheduled for 1979.

ACKNOWLEDGEMENTS

Through this report, we wish to express our sincere appreciation to the competent Indonesian authorities and other parties involved for the co-operation and hospitality extended to the Study Team during their stay in Indonesia which enabled them to carry out all investigations smoothly in spite of the very large area covered. We believe that this Master Plan Study not only contributes to Indonesian regional development, but also to the promotion of friendship between Indonesia and Japan.


PROJECT LOCATION MAP
MAGELANG
G.MERBABU
SELO
CEPOGO
BOYOLALI
K. Trising
BABACAN
K. Senowo
K. Pabelan
G.MERAPI
MUNTILAN
PLAWANGAN
Type-I
SALAM
JATINOM
PAKEM
Type-III
Type-II
SLEMAN
Ngemplak
KLATEN
MLATI
PRAMBANAN
K.LUSAH
GODEAN
KALASAN
K. Dengkeng
GAMPING
YOGYAKARTA
BANTUL
U
0
5
10
15
20
25 Km
SUMATRA
KALIMANTAN
WEST IRIAN
SURAWESI
JAVA

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PART 1 SCOPE OF STUDY

PART–1 SCOPE OF STUDY

1.1 Objectives

In 1978, which is the second year of the three-year program, study focused on fundamental data collection and analysis and formulation of alternative plans for the G. Merapi Project.

The main objectives of the study were as follows:

(1) To study the regional characteristics of the project area through analysis of survey findings and data obtained in the 1977 and 1978 investigations concerning topography, geology, hydraulics, hydrology, river engineering, and social and economic conditions;

(2) To establish planning criteria and goals based upon these analytical results;

(3) To prepare tentative plans for sabo facilities along the three rivers (K. Krasak, K. Woro and K. Boyong) which represent the three typical types of regions;

(4) To find solutions for trouble spots along the K. Progo and K. Opak; and

(5) To examine the socio-economic characteristics of the project region as a basis for drawing up the Master Plan;

1.2 Area Definition

The area studied for this Master Plan is as follows:

(1) All tributaries located between K. Pabelan and K. Progo on the south-western part of G. Merapi and between K. Woro and K. Lusah on the south-eastern part of G. Merapi.

(2) In regard to K. Woro, the studied area covers up to the confluence point of K. Lusah and K. Denkeng.

(3) The trouble spots along K. Progo and K. Opak, caused by erosion and sedimentation activity, are to be studied up to their respective estuaries.

1.3 Fields of Study

(1) Hydraulics and Hydrology

a) Determining design flood discharges

b) Study of riverbed variation and discharge capacity

(2) Problem Spots of K. Progo and K. Opak

a) Study of flood areas and types of damage

b) Study of problems along K. Progo and K. Opak

c) Determining countermeasures

(3) Geomophology

a) Outlining the lahar and banjir hazard area

(4) Geology

a) Estimation of the 1969 amount of sediment discharge

b) Estimation of annual amount of sediment discharge in the period 1977 - 1978

c) Design amount of sediment discharge for the plan

(5) Socio-Economics

a) Study of general, sociological and economic conditions of the region

b) Study of agricultural conditions of the region

c) Evaluation of the effects of disaster prevention works

(6) Aerophotography

Photographing Type-I area (approx. 150km including the summit of G. Merapi) at scale of 1:10,000

(7) Disaster Prevention Planning

a) Defining project objectives

b) Determining design basic points

c) Classification of the project area

d) Study of warning systems

e) Study of existing irrigation intakes and irrigation systems

(8) Sabo Facility Planning

a) Study of the effect of sabo facilities

b) Planning sabo facilities for K. Krasak, K. Woro and K. Boyong

c) Estimation of construction costs

PART 2 RESULTS OF INVESTIGATION

PART 2 RESULTS OF INVESTIGATION

2.1 Topography

The project area consists of the west and south sides of G. Merapi (2,968m), an active strato-volcano. Since the older Merapi surrounds its midriff on the north east to south east sides, the results of new volcanic activity are most pronounced on the south and west sides.

The main rivers flowing down from G. Merapi are listed below:

(1) K. Pabelan, K. Blongkeng, K. Putih, K. Bebeng, and K. Krasak on the west to southwest sides flowing into K. Progo

(2) K. Boyong, K. Kuning and K. Gendol on the south side flowing into K. Opak, and

(3) K. Woro, on the west side flowing into K. Denkeng.

Topographically, the area can be classified into upper (above 2,000m), middle (500-2,000m), and lower (under 500m) slopes (see Figs. 2.1.1 and 2.1.2). The characteristics of each slope is as follows:

"The upper slope area", which is formed from volcanic fragments and lava, is the area directly affected by the present volcanic activity. The gradient is very steep: more than 35 deg. Because of the constant eruptions and the addition of new volcanic material, there is no vegetation. Innumerable narrow gullies have developed on the fragment covered slope. At the present time the crater opens to the southwest side, along the formation of a long and extensive collapsed slope. Almost all of the eruptions flow into the rivers on the southwest side of the mountain (Type-1 rivers).

The topography of "the middle slope area" is complex because the slope is formed both from new volcanic materials and the old mountain formed by the Merapi volcano. In this area, nuée ardente and lahar have flowed down into the valley and changed the courses of rivers during major eruptions. When the volcanic activity subsided, the deposits were eroded and deep valley were quickly formed. As a result, there are numerous deep valley of this type extending away from G. Merapi in a radial configuration. The surface has rich small undulating hills with alternating gentle and steep slopes, gradually reducing their gradients as the elevation decreases. The steepest part of the slope has the form of concentric circles, the center being the top of the mountain.

"The lower slope area", which begins where the deep valley of the middle slope area disappear, is a relatively flat, gently sloping surface with a gradient of less than 3 deg. It too has been formed by the deposits of volcanic eruptions. An alluvial fan is evident along K. Boyong, K. Kuning, and K. Woro. There is a good correspondence between topographical conditions and the location of lahar/banjir.

The following specific topographical features were found to correspond to the main overflow points:

(1) Where there is a change in the gradient of rivers and where the rivers bend

(2) Where there is a change in the gradient of the slope of the terrain.

Furthermore, lahar and banjir have followed a cycle of overflowing from one valley and running into a smaller valley. This cycle has been repeated over and over again down the slope of the mountain.

Fig. 2.1.1 Idealized Profile of the River and Slope

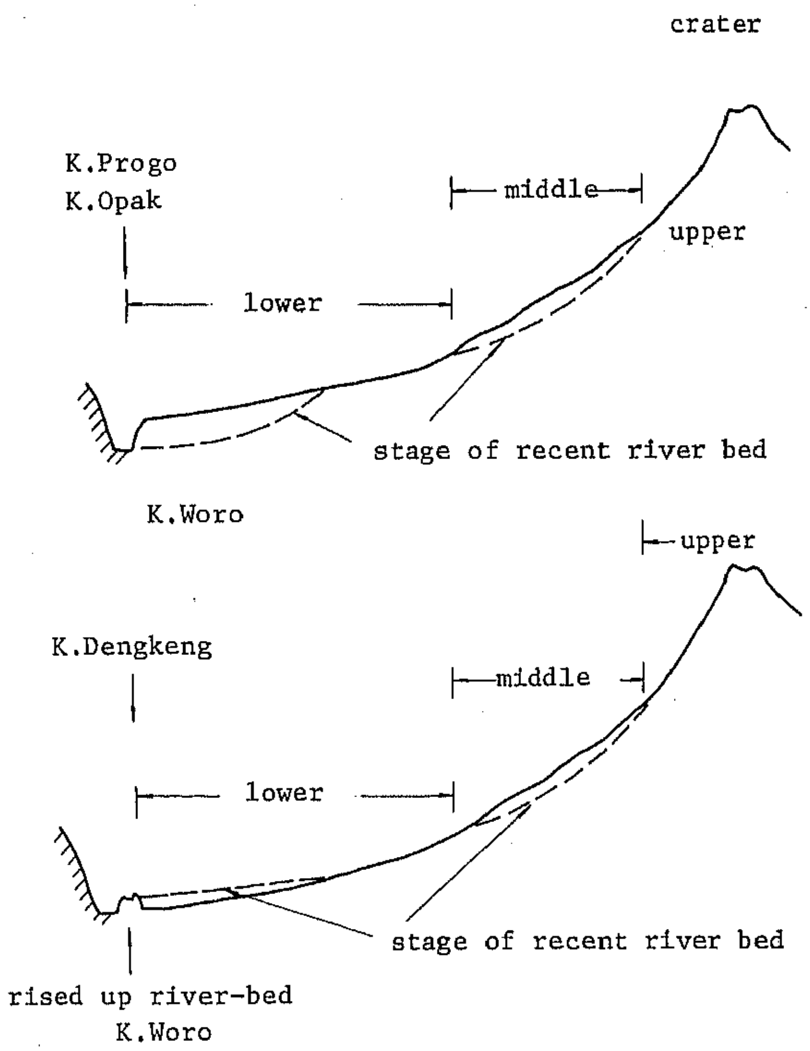
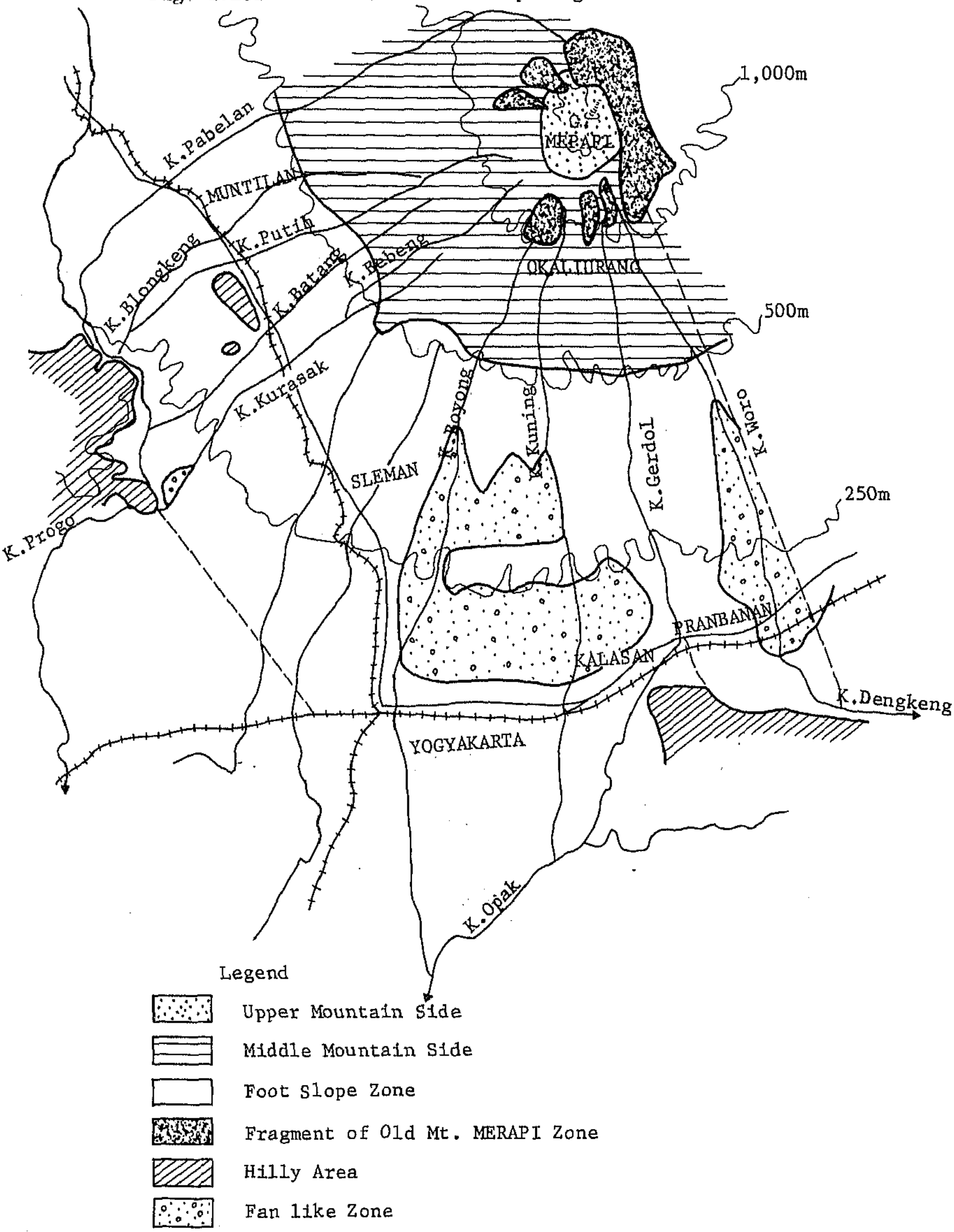


Fig. 2.1.2 General Idea of Morphological Condition



Legend

- Upper Mountain Side
- Middle Mountain Side
- Foot Slope Zone
- Fragment of Old Mt. MERAPI Zone
- Hilly Area
- Fan like Zone

2.2 Geology

2.2.1 Geologic Strata

The geology in the area of G. Merapi can be classified into the following five groups which are also presented in Table 2.2.1.

(1) Recent Volcanic Products from Eruptions of G. Merapi

This group consists mainly of lava flows and pyroclastic fragments from eruptions since 1888, the exact dates of which are known, and lahar that has occurred since 1930.

(2) Terrace and Other Unconsolidated Deposits

This group consists mainly of present river bed deposits, terrace deposits, fan-like deposits in the lower stream area, and alluvial deposits.

(3) Young Merapi Volcanic Products

This group includes lahar deposits and lava-flows before 1930 (exact dates are not known).

(4) Old Merapi Volcanic Products

This group consists of Old Merapi lava flow, intrusive and pyroclastic rocks.

(5) Base Rocks

This group includes volcanic rocks and deposits of the tertiary period which form the foundation of G. Merapi.

2.2.2 History of Volcanic Activity of G. Merapi

G. Merapi has had a long history of eruptions. There is a record of damage caused by a major lahar flow in 1006 on a stone monument with Sanskrit inscriptions of old Javan stories. There is also a record of some three thousand deaths caused by a major eruption in 1672 which produced glowing clouds and volcanic mud flows. A record of the mountain's volcanic activity after 1800 was kept by R.W. Bemmelen. This record is summarized in Table 2.2.2 along with the records for recent years.

The summary indicates a cycle of 1-7 years of activity followed by a dormant period of 1-6 years. Except for recent years, the exact scale of damage caused by such activity is unknown.

Records indicating the direction of laha flows in recent years is summarized in Fig. 2.2.1. This summary shows that there has been a shift in the direction from NW-W-SW-N-NW-W-SW. Since the old Merapi volcanic wall in the southeast remains, it can be expected to control lava overflows in that direction. The principal nuée ardente danger zone should continue to be in the direction of SW-W-NW.

2.2.3 Terminology of Volcanic Products

In this "Study for Making Master Plan" the terminology of volcanic products used by the Japanese Study Team is based on R.W. von Bemmelen, I. Suryo and field surveys by the team as shown Fig. 2.2.2.

(1) Nuées Ardentes: Avalanche Type ("Ladu")

During an active stage of G. Merapi, viscous lava may flow-over the crater rim and form a lava tongue. Parts of the unstable lava mass may callapse and red hot lava blocks will roll down the slope, breaking into numerous lava fragments. Some of the fragments will turn into glowing sand and ash, and form a suspension of glowing particles and hot air, which will descend as a dense cloud.

Von Bemmelen is of the opinion that lava blocks measuring about $100m^3$ do not cause nuées ardentes, but only common avalanches, and that the development of smoke and dust from such avalanches is small. If thousands of cubic meters of lava break off, the development of heat and pulverized lava is so great, that the avalanche appears to expand rapidly. This incandescent flow of volcanic debris is called "ladu" in Indonesia.

Such nuées ardentes of the avalanche type at G. Merapi usually move 1 - 3km from the crater, but big avalanches may reach a distance of 9kms. The avalanche may be one meter thick.

(2) Nuées Ardentes: Explosion Type

During volcanic explosions, lava masses may be emitted from the eruption vent. The lava is thrown upwards and a part of it flows over the crater rim and rushes down the slope. These flows of incandescent debris accompany the nuées ardentes. The thickness of these kind of nuées ardentes is about 50cm.

The difference between nuée ardentes of type 1 and 2 is that the explosion type is always accompanyed by a rising califlower cloud of volcanic ash.

(3) "Lahar" Mud Flows

The Indonesian term "lahar" is used to describe the volcanic mud flows on the Merapi and Kelut volcanoes. Lahar of Merapi are classified as rain lahar.

During or after eruption, a huge amount of volcanic material is deposited on the slope of the volcano. Rain water mixed with this unconsolidated hot volcanic material turns into a high density mass, which descends with increasing velocity and forms lahars in the middle and lower reaches. Such lahars are called hot rain lahars until they cool.

The concept of lahar is very similar to the Japanese "Dosekiryu", in respect to mass straight movement and inclusion of big blocks and thick and poorly sorted sediments.

(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.

2.2.4 Sediment Deposits

The sediment deposit characteristics as determined by surveys conducted in 1977 and 1978, mainly by K. Krasak and K. Bebeng, are summarized below and in Table 2.2.3 and Fig. 2.2.3 ∿ 2.2.5.

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

2) Porosity: 25-30%.

3) The angle of internal friction ranges widely between 10-33 degrees, probably due to the small size of samples taken.

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 river bed deposits are characterized by a low silt content. The sandpockets inspected by K. Krasak and K. Woro had a sand content of over 85% with fairly uniform grain size.

Samples were taken from the deposits listed below:

(1977/1978)

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

(1978/1979)

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

Table 2.2.1 Geological Strata 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.
	Fan-like deposit	Fl	"
Young Merapi volcanic products	Fan like deposit	Fu	Gravel, sand, etc.
	Pyroclastic deposit	YMp	Volcanic breccia, ash, etc.
	Lavas	YMl	Hyperthene-auguite andesite lava
Old Merapi volcanic products	Loam	L_o	Pumice bearing loam
	Pyroclastics	OM_p	Volcanic breccia, tuff breccia, tuff etc.
	Lavas	OMl	Olivine brearing hyperstene augite basalt and andesite
Base Rock	Bomelen formation	Tb	Andesitic lava and breccia
	Somilir formation	Ts	Tuff breccia, tuff, clay stone

Table 2.2.2 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	Lahar to Pabelan, Blongkeng in 1822
19-23	23-31 Jul. 22	4		
		8	23-31	
31-38		7		
		1	38-39	Lahar to Blongkeng in 1937. Accumulated on valleys 3 km long, 60 m wide and 25 m thick
39-40		1		
		5	40-45	
45-49	16-18 Nov. 45	4		
		5	49-54	
54-56	29. Aug. 54 Oct. Nov. Dec. 55	2		
		5	56-61	
61-67	Apr. 61. 23 May 63	6		
		4	67-71	Lahar down to the national road of Blongkeng
71-72	24 Apr. 71, 24 Sept. 71	1		
		4	72-76	
76-77	Aug. 76 ∿ Jun 77	1		
		4	77-82	
82-85	Dec. 83 12 Nov. 85	3		
		1	85-86	
86-89	31 Mar-3 May 86 19 Feb-19 Mar 88,27-29 Mar 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
1900-09	18 Apr. 04, 1 Nov.05. 17 Dec. 07	7		
		1	1907-08	
08-13	2 Nov. 11, 23 Jun. 31, Jul. 13	5		
		1	13-14	
14-16	1 Jul. 14, 5 May~Jun. 16	2		
		1	16-17	
1917-19	16-18 Jun. 17, 16 Sep.17 8~10 Mar.18, Aug.18 28 Feb~Mar.19			
		5	1919-24	
20-24		4		Lahar to Blongkeng, Batang and Senow in 1920
		2	24-26	
26-27	5~11 Feb. 27, 28, Apr. 27	1		
		2	27-30	A major disaster due to large-scale nuée ardante and Lahar in 1930 to 1931
30-35	May~Jun. 25 Nov. 1930 18-19 Dec. 30. 2 Jan. 31 27, Apr. 31. 17 Feb. 32. 21 Apr. 34	5		
		4	35-39	
39-40		1		lava dome 40
		2	40-42	
42-43	5~11 Apr. 43	1		
		4	43-47	
47-49		2		Lava 48
		4	49-53	
53-55	22 Mar.15, Apr. 53, 30 Jul. 53, 18-21, Jan. 54	2		Frequent occurence of Lava avalanches. Nuée Ardante to Trising and Senow in 1953 and to Apu in 1954
		2	55-56	
56-58	3 Jan. 56	2		Large damage by nuée ardente avalanche and Lava to Apu in 1956 and 1957. Frequent Lava avalanches in 1957 and 1958
		2	58-60	
60-61		1		Lahar to Batang and Blongkeng

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

Fig. 2.2.1 Direction of Lava Flow in Recent Years

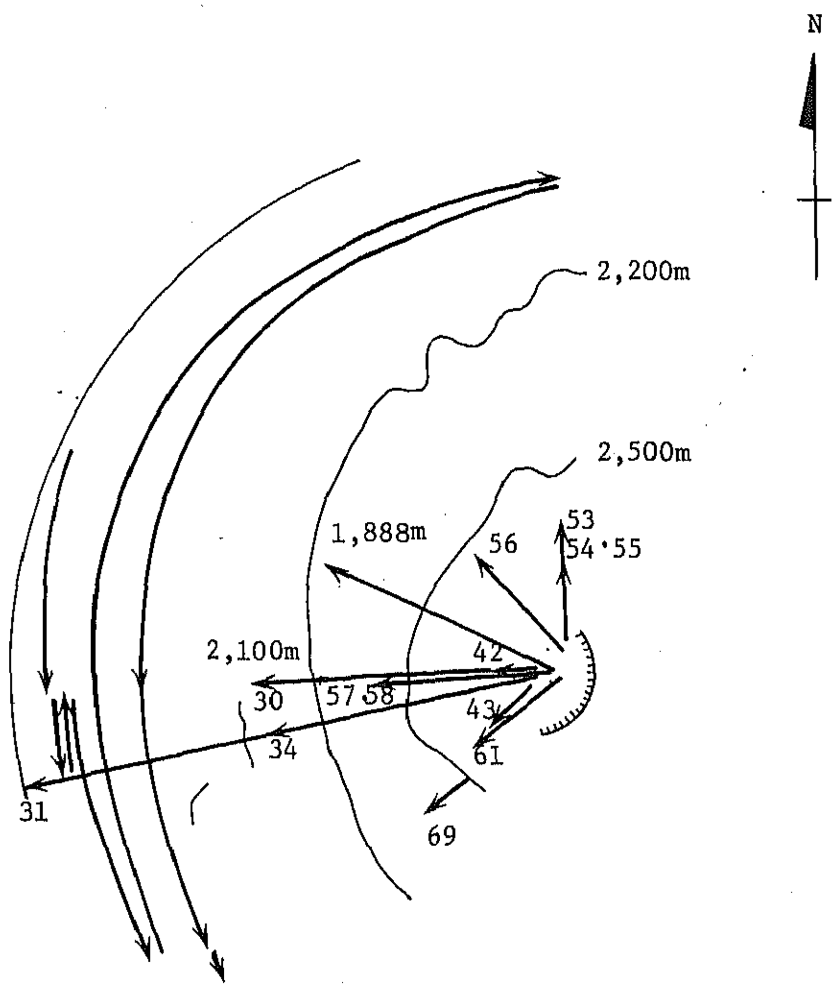
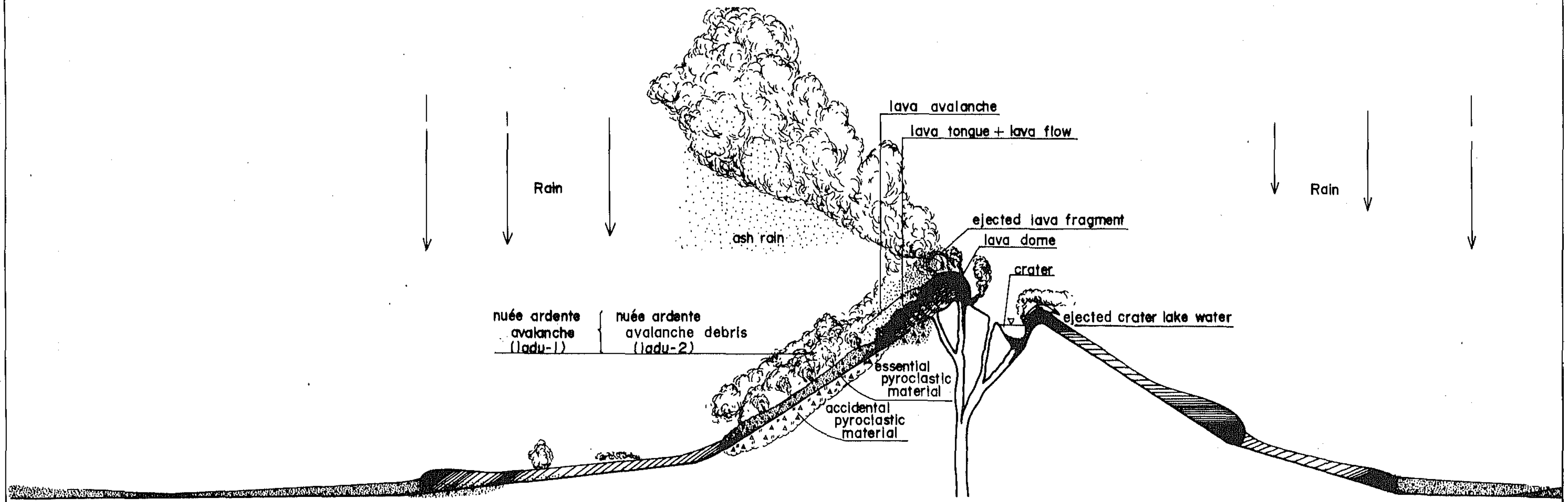


Fig. 2·2·2 模式的土石流状態名称図
(Figure showing the schematic states of Lahar)



気象条件(weather condition)	Wet		Dry	Dry + crater water	Wet
連続的に流下する場合の名称 (names of Lahar in a state of continuous motion)	banjir ←	rain lahar (secondary lahar)	nuée ardent avalanche (nuée ardente) (avalanche debris)	eruption lahar (hot mud flow) (primary lahar)	secondary mud flow (secondary lahar) banjir
日本語 (Japanese)	洪水流 ← 土砂流	← 土石流	pyroclastic flow (火砕流)	volcanic mud flow (火山泥流) lahar (土石流) → 土石流 (泥流)	→ 土砂流
運搬型式 (Type of sediment)	A.各個運搬 (掃流運搬) (浮流運搬) individual objects (bed load) (suspended load)	B.掃流状集合運搬 tractive-mass (bed load and massive flow) C.集合運搬 massive flow	debris deposit (岩屑堆積物) pyro-volcanic deposit (ladu-3) 火山砕屑物特に谷底に推積したもの (ladu-4)	lahar deposit (泥流堆積物)	lahar deposit (泥流－土石流堆積物)
活動範囲 (Range of Activity)	——— A ——— B	——— A ——— B ——— C	A B ——— C		

Masaichi Nakayama

Fig. 2.2.3 Map Location of Test Pits

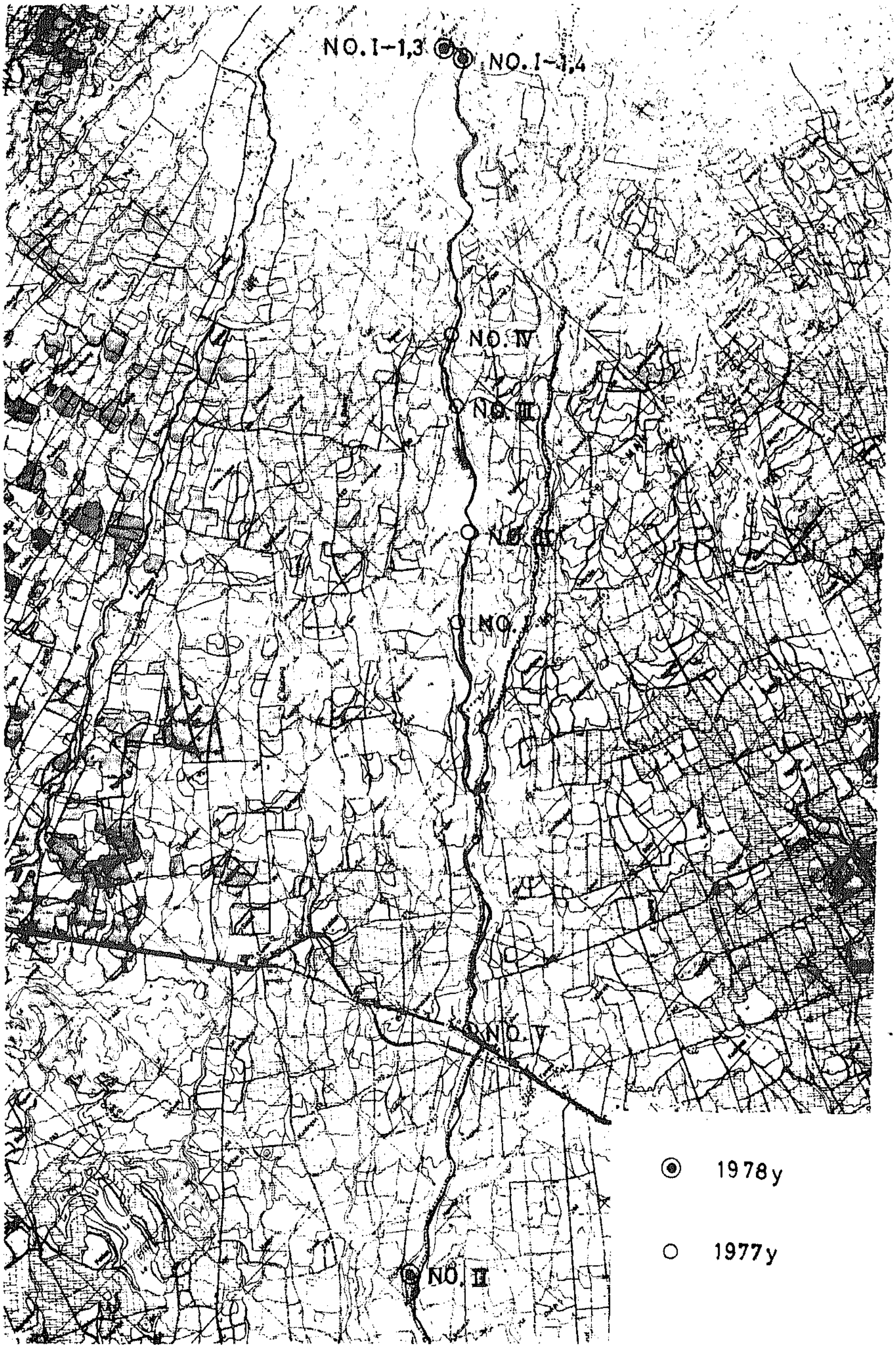


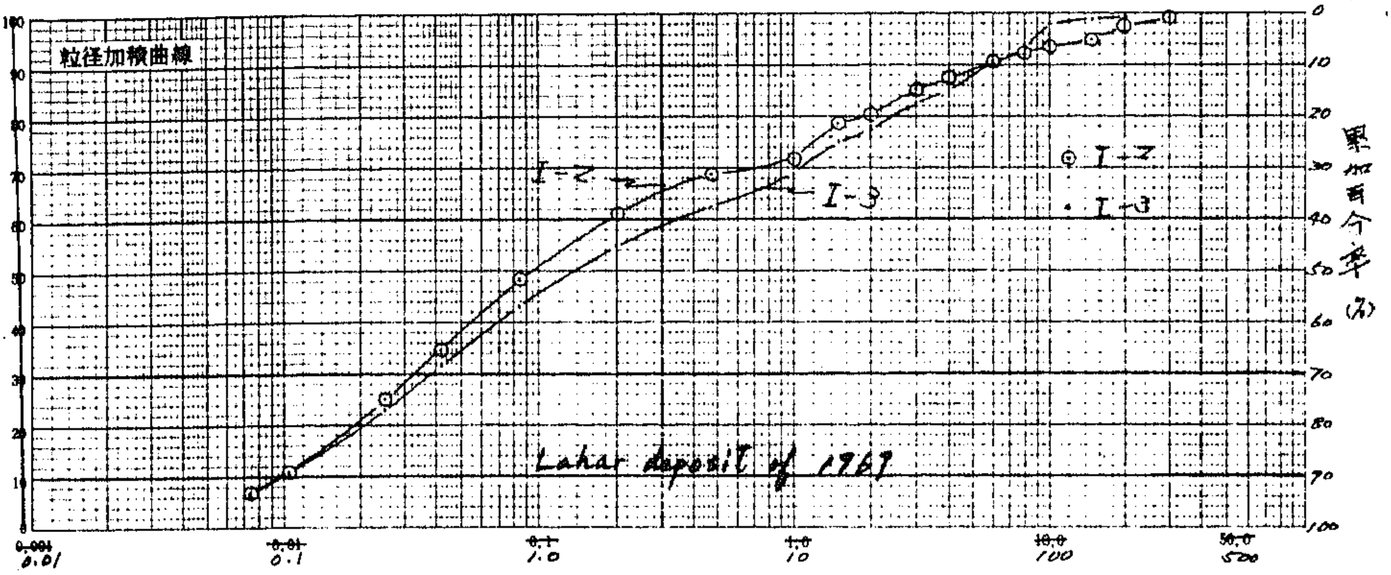
Table 2.2.3 Results of Soil Tests (1978)

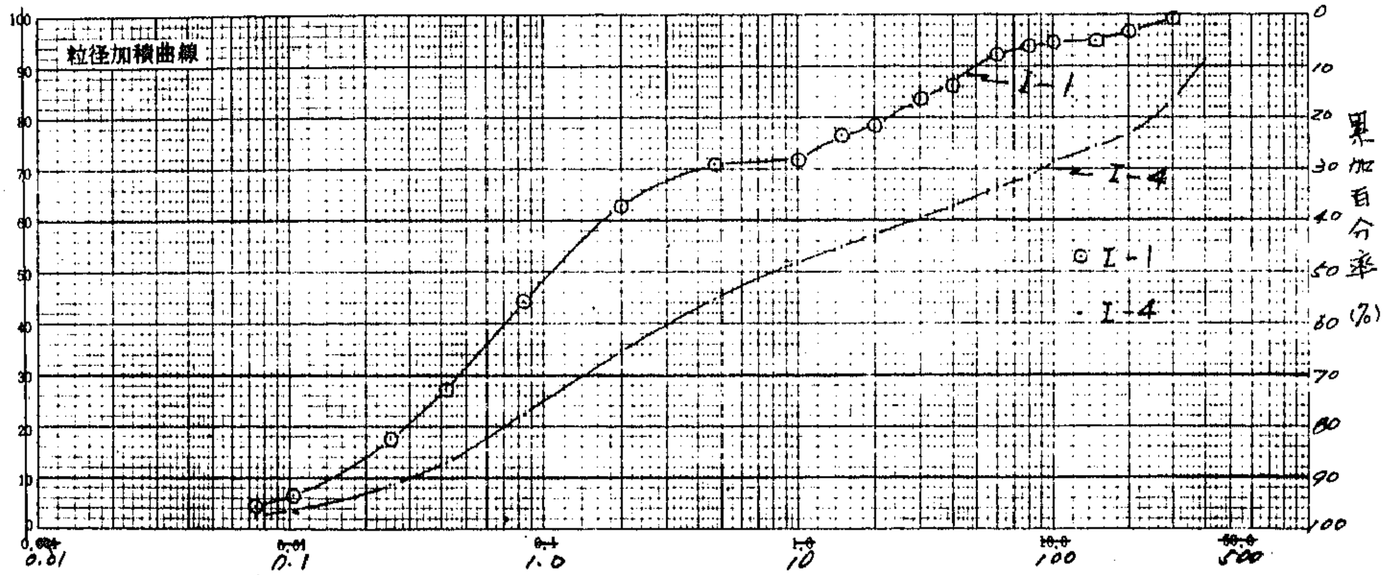
Location and Sample No.			K. Bebeng				K. Krasak	K. Woro	
			I - 1	I - 2	I - 3	I - 4	II - 1	III - 1	III - 2
Grain size	Gravel (> 2.00 mm)	(%)	37.3	38.8	45.0	64.9	10.3	3.6	11.4
	Sand (0.074 ~ 2.00 mm)	(%)	58.4	54.0	48.2	32.5	88.7	93.3	84.0
	Silt and clay (< 0.074 mm)	(%)	4.1	7.0	6.9	2.3	1.0	3.1	4.7
Water 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. 2.2.4 Grainsize Accumulation Curves (1978)





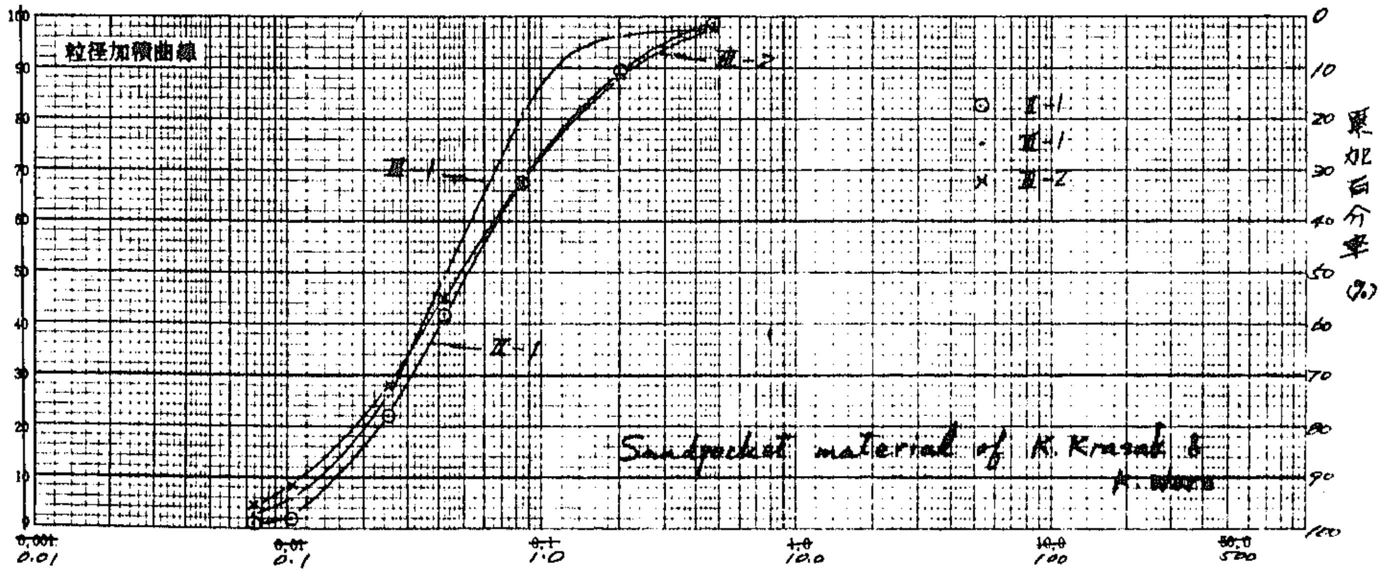
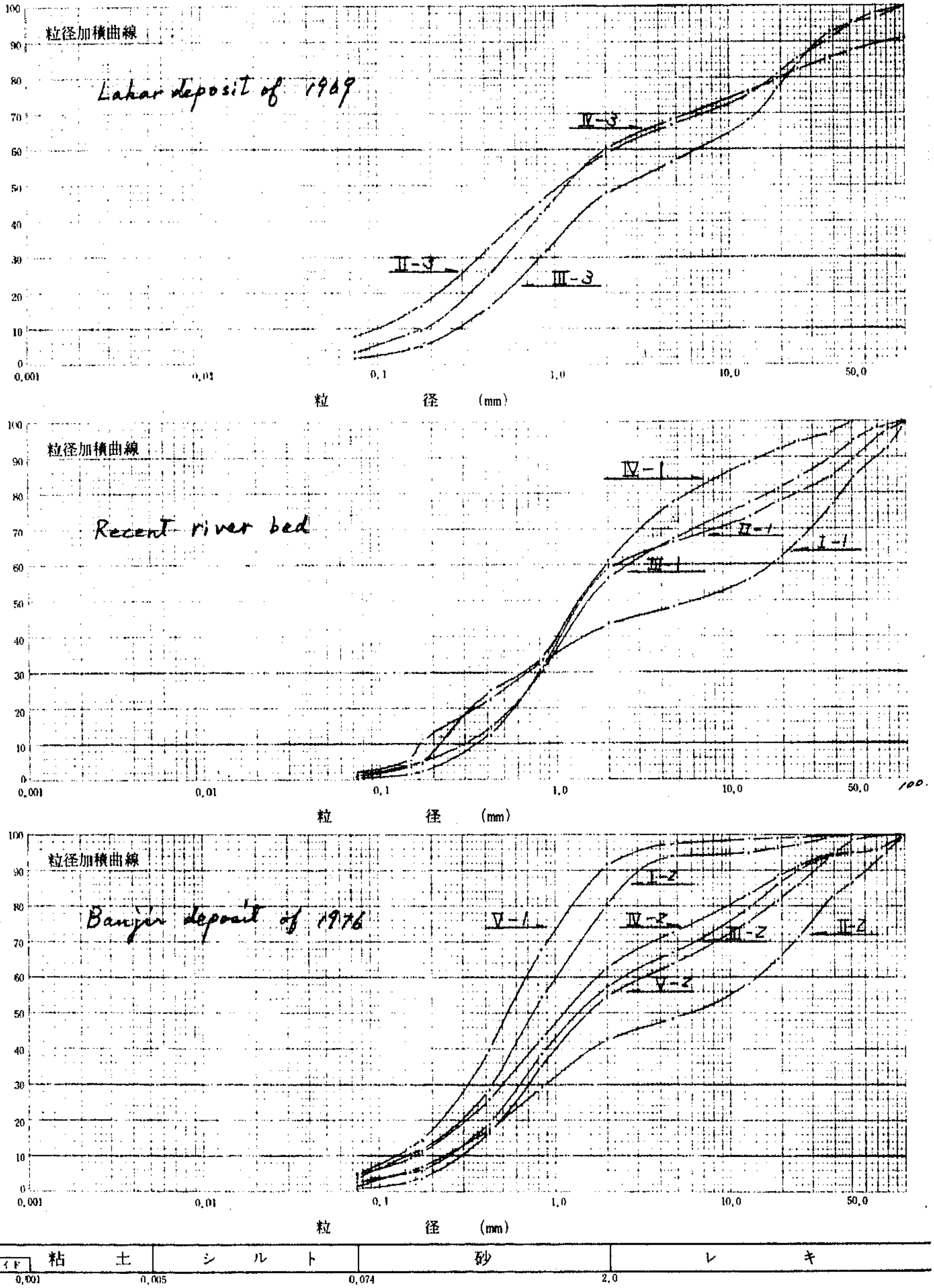


Fig. 2.2.5 Grainsize Accumulation Curves (1977)



 only less than 100mm

2.3 Hydraulics and Hydrology

2.3.1 Rainfall

The following data outlines the rainfall characteristics of the area:

(1) Seasonal Variation

The area has a dry season that extends from May through October and a rainy season from November through April. The annual range of precipitation is 1,500-4,500mm 80% of the rainfall occurs during the rainy season.

(2) Geographical Distribution

Rainfall distribution in the G. Merapi area largely follows isometric lines, with almost uniform distribution in the east-west direction.

A survey of the hyetal region in the middle stream area of K. Denkeng has shown that daily rainfall covers an area from 50 to 100 sq.km, with highest frequency concentrated in the 30 - 50 sq.km central area.

(3) Distribution by Altitude

Annual rainfall is highest at 1500m elevation and decreases at elevations above and below that.

Altitude	Rainfall
100 meter	2,000mm/year
1,500 "	4,000 "
3,000 "	3,000 "

(4) Hourly Distribution of Daily Rainfall

Approximately 60% of the daily total falls between 14:00 and 18:00 with peak intensity between 15:00 and 17:00.

(5) Probable Daily Rainfall

Probable rainfall has been calculated for the Srumbung area using the Gumbel method of analysis and is summarized in Table 2.3.2 and shown in Figs. 2.3.1 and 2.3.2.

(6) Hourly Rainfall Intensity

The following formula based on rainfall data in the area indicates Rainfall intensity distributed around the mean peak daily rainfall;

$$R_A = \frac{108.48}{t + 1.353}$$

where R_A = Rainfall intensity (%/hr)

t : Duration from the mean rainfall (hrs)

The rainfall intensity curve obtained from the above expression and the design hyetograph with a concentrated pattern are shown in Figs. 2.3.3 and 2.3.4 respectively.

Table 2.3.1 Probable Rainfall Area and Number of Stations

Case	Probable Rainfall Area	Number of Stations	Remarks
1	Point rainfall	1	Srumbung station
2	$78km^2$ (D = 10km)	4	
3	$314km^2$ (D = 20km)	9	
4	$707km^2$ (D = 30km)	16	
5	$2,247km^2$	31	Whole of K. Progo basin
6	$4,383km^2$	55	Whole of K. Progo; K. Opak; K. Denkeng

D: Diameter from center of point rainfall's station.

Table 2.3.2 Relation Between Probable Daily Rainfall and Area

(unit=mm)

Period (yrs)	S = Number of stations and A = Area in km^2					
	S = 1 A = 1	S = 4 A = 78	S = 9 A = 314	S = 16 A = 707	S = 31 A = 2,247	S = 55 A = 4,383
2	113	77	54	47	46	43
10	164	102	92	77	76	72
50	209	124	109	103	102	97
100	228	133	120	114	113	108
150	238	138	126	121	119	114
200	247	142	130	125	124	119

Fig. 2.3.1 Probable Daily Rainfall
(Point Rainfall, Srambang)

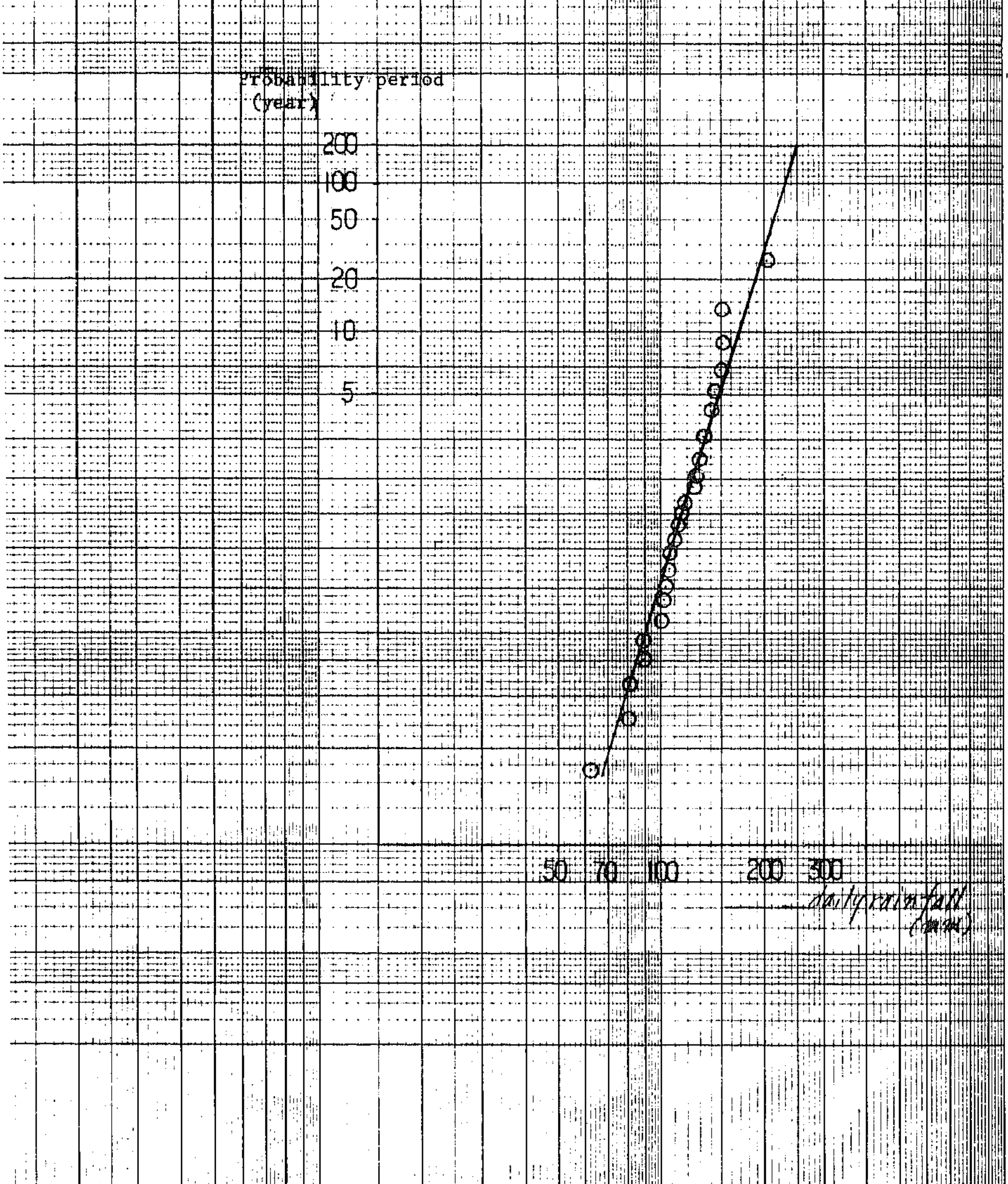


Fig. 2.3.2 Relation Between Probable Reinfall and Area (1)

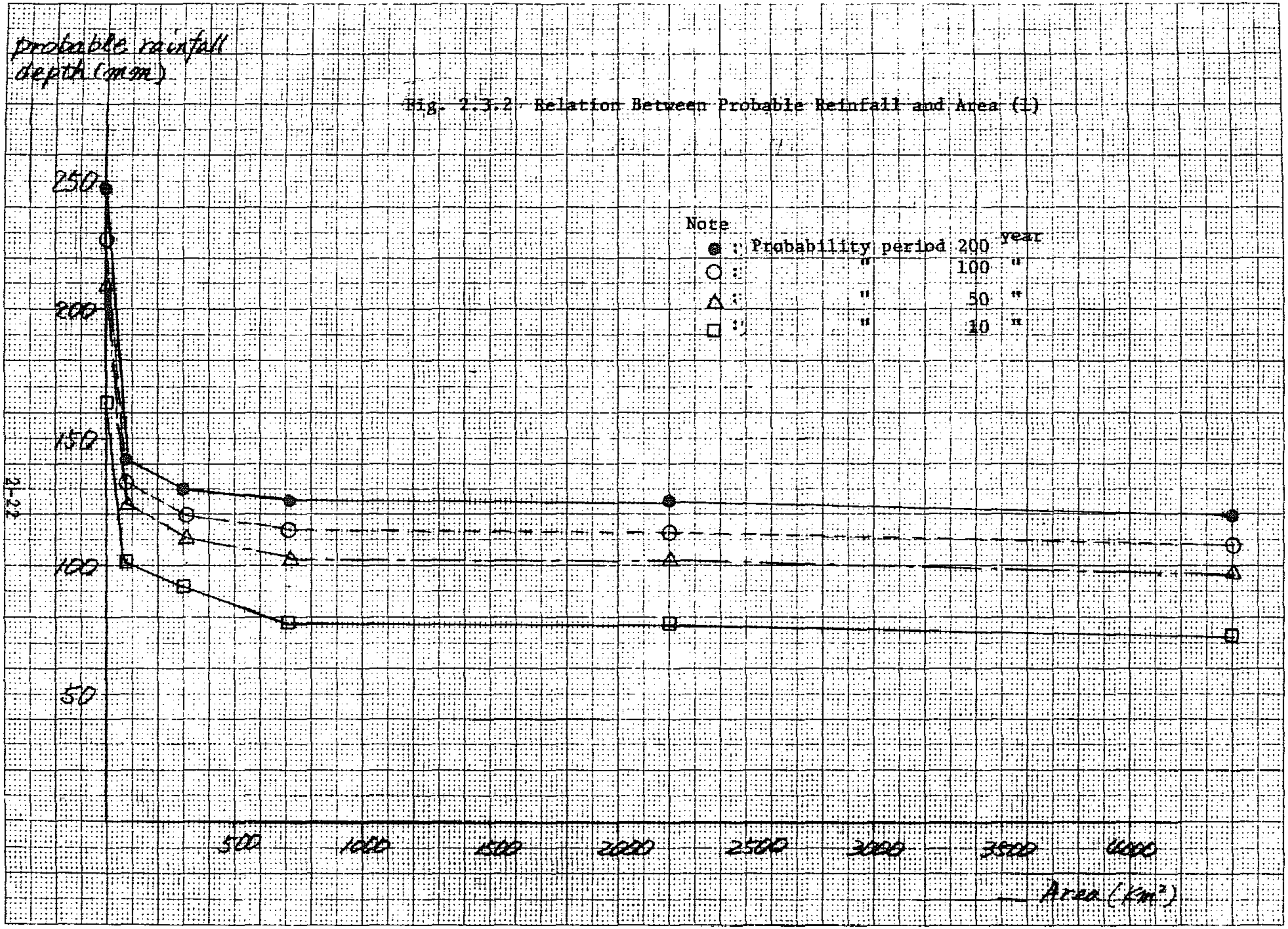
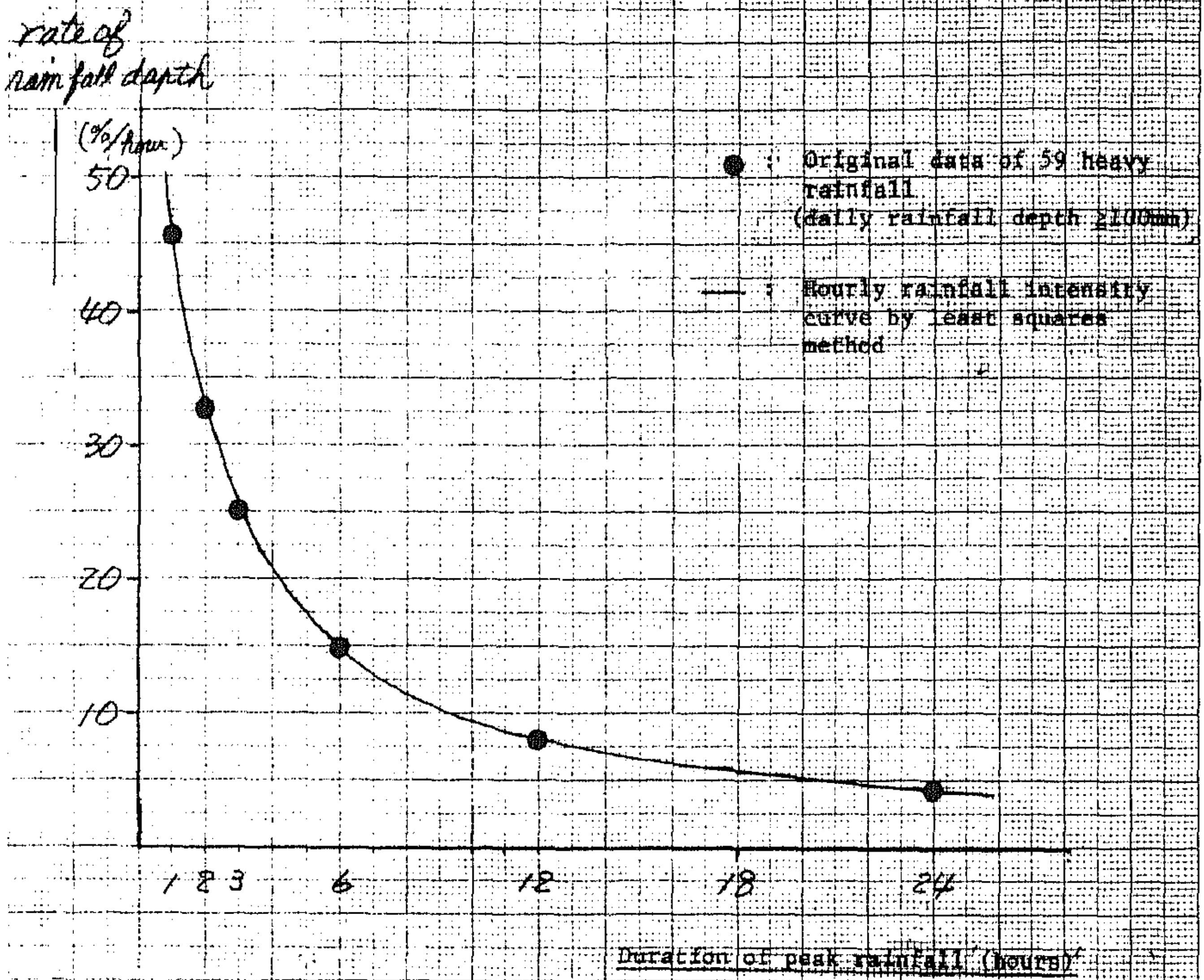


Fig. 2.3.3 Hourly Rainfall Intensity Curve (%/hr)



Equation: $Rt = \frac{108.48}{t+1,350}$ (%/hour)

where

Rt; intensity of rainfall (%/hour)

t; duration from the mean rainfall (hours)

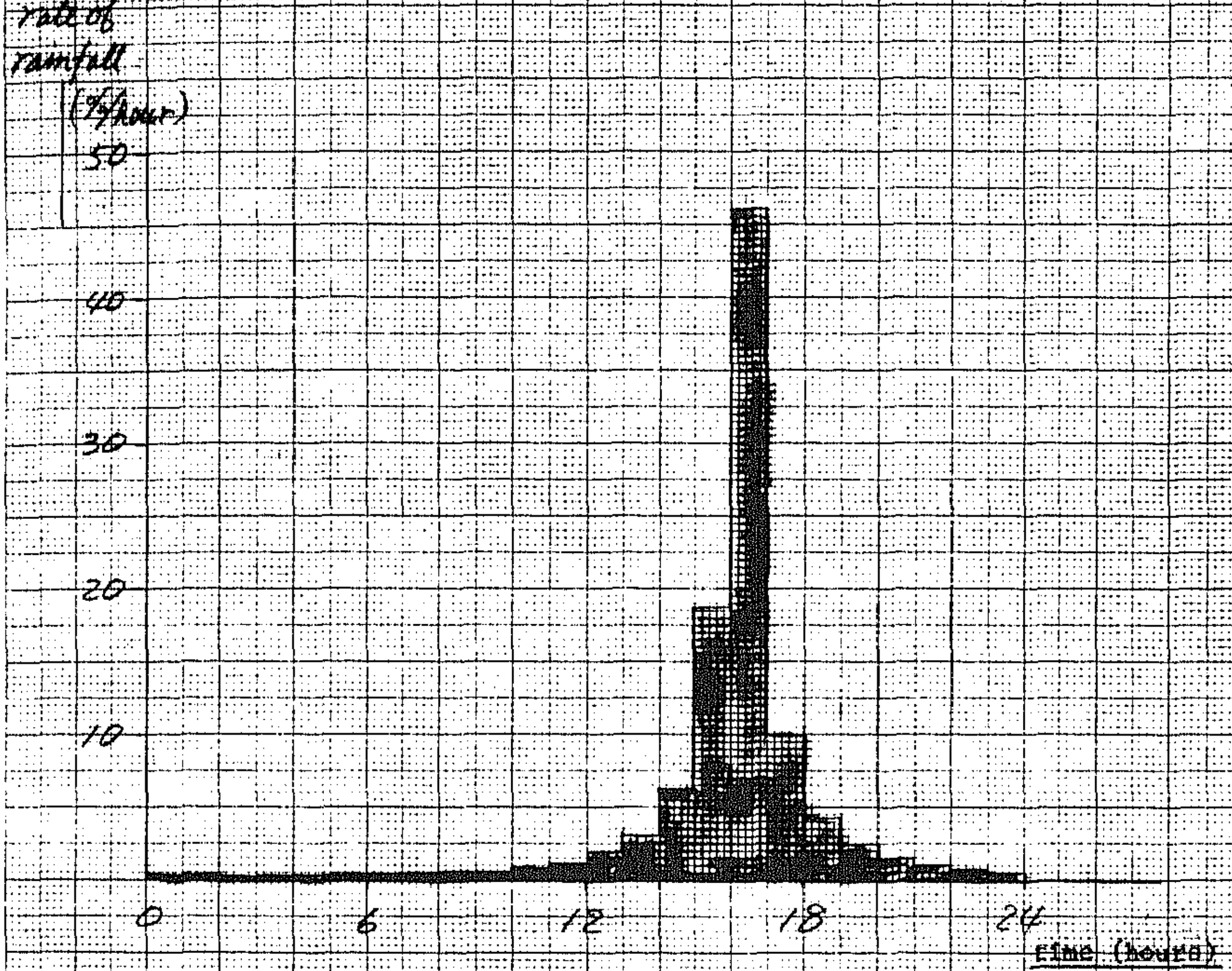


Fig. 2.3.4 Design Hydrograph by Hourly Rainfall Intensity Curve

2.3.2 Design Flood Discharge

(1) Tributaries (Nine Tributaries, including K. Krasak)

The following formula gives the design flood discharge for tributaries:

$$Q = \frac{1}{3.6} \cdot f \cdot R_f \cdot A$$

where Q : Design flood discharge (m^3/s)

f : Runoff coefficient

Rt : Rainfall intensity (mm/hr)

A : Catchment area (sq.km)

The design flood discharge characteristics for each tributary on the basis of rainfall probability of 100 years is given in Table 2.3.3.

(2) Design flood discharge for K. Progo and K. Opak

The design flood discharge for K. Progo and K. Opak has been obtained by storage functions method. The model of river basin storage functions and the results of the hydrograph analysis are showed in Fig. 2.3.6 and Fig. 2.3.7 respectively.

Table 2.3.3 Design Flood Discharge (1/100)

Tributary	Name of point (C.D=Check Dam, N.R=National Road, C.P=Confluence point)	Catchment area (sq.km)	Rainfall Probability (mm/hr)	Stream length (Km)	Mean stream gradient (°)	Mean velocity (m/s)	Time of concentration (hr.)	Rainfall intensity (%/hr)	Rainfall intensity (mm/hr)	Design flood discharge (m^3/s)	Specific run-off
K. Krasak	Upper part	6.90	219.6	4.25	0.10	11	0.5	58.5	128.6	185	27
	C.D	23.0	200.0	10.25	0.0375	7	"	"	117.1	562	24
	N. R.	24.9	197.9	12.53	"	7	0.75	51.6	102.0	530	21
Whole a	Whole area	31.7	189.4	22.03	0.022	5	1.25	41.7	78.9	530	17
K. Bebeng	Whole area	9.43	216.5	13.45	0.173	15	0.5	58.5	126.8	250	26
K. Batang	N. R.	8.07	218.2	11.05	0.0455	8	0.75	51.6	112.5	190	23
	No. 1	9.06	217.0	13.55	0.075	6	"	"	111.9	210	23
	C. P.	16.86	207.5	"	"	"	"	"	107.0	375	22
	No. 2	19.65	204.1	16.30	"	"	1.0	46.1	94.1	385	20
	Whole area	22.82	200.2	18.80	"	"	"	"	92.3	442	19
K. Putih	C.D. 1	7.70	218.6	6.33	0.0625	9	0.5	58.5	128.0	205	20
	C.D. 2	8.58	217.5	"	"	"	"	"	127.4	230	26
	No. 1	12.46	212.8	15.98	0.0333	6	0.15	51.6	109.8	285	23
	N. R.	14.21	210.7	"	"	"	"	"	108.7	320.	23
	No. 2	15.65	208.9	17.78	0.01	4	1.0	46.1	96.3	315	20
	C.P. 2	24.60	198.0	"	"	"	"	"	91.3	470	19
	N. R.	25.77	196.6	19.86	"	"	1.25	41.7	81.9	"	18
	Whole area	26.60	195.6	21.84	"	"	1.5	38.0	74.4	"	18
K. Boyong	C. D.	6.15	220.5	5.75	0.125	12	0.50	58.5	129.1	165	27
	B. R.	12.33	213.0	12.45	0.0529	8	0.50	58.5	124.7	320	26
	Whole area	14.14	210.8	18.20	0.0308	7	0.75	51.6	108.7	320	23
	K. Code	76.0	135.4	37.0	0.0143	4	2.0	32.4	43.8	695	9

Tributary	Name of point *	Catchment area (sq.km)	Rainfall Probability (mm/hr)	Stream length (Km)	Mean stream gradient (∘)	Mean velocity (m/s)	Time of concentration (hr.)	Rainfall intensity (%/hr)	Rainfall intensity (mm/hr)	Design flood discharge (m^3/s)	Specific run-off
K. Kuning	C. D.	7.20	219.2	7.05	0.125	12	0.50	58.5	128.3	195	27
	No. 1	15.74	208.8	21.63	0.0455	8	1.00	46.1	96.3	315	20
	C.P. 1	22.93	200.1	"	"	8	1.00	46.1	92.2	440	19
	No. 2	26.84	195.3	26.81	0.01	4	1.50	38.0	74.3	415	16
	C.P. 2	34.23	186.3	"	"	4	1.50	38.0	70.8	505	15
	No. 3	36.49	183.6	27.76	"	4	1.50	38.0	69.8	530	15
	Whole area	47.68	169.9	34.74	"	4	2.00	32.4	55.0	545	12
K. Gendol	C.D. 1	10.37	215.4	8.35	0.786	10	0.50	58.5	126.1	275	26
	C.D. 2	12.86	212.3	12.18	0.050	8	0.50	58.5	124.3	335	26
	C.D. 3	13.06	212.1	13.28	"	8	0.75	51.6	109.4	300	23
	C.D. 4	13.25	211.9	14.38	"	8	0.75	51.6	109.3	305	23
	Whole area	14.59	210.2	19.38	0.03	6	1.00	46.1	96.9	295	20
	C.D. 5	55.5	160.4	"	"	6	1.00	46.1	73.9	855	15
K. Blongkeng	Upper part	13.40	211.7	12.50	0.0429	7	0.75	51.6	109.2	305	23
	C.P. 1	17.93	206.2	"	"	7	0.75	51.6	106.3	400	22
	N. H.	21.38	202.0	14.65	0.025	6	0.75	51.6	104.2	465	22
	No. 1	22.16	201.0	16.23	"	6	1.00	46.1	92.7	465	21
	C.P. 2	36.41	183.7	"	"	6	1.00	46.1	84.7	645	18
	No. 2	41.35	177.6	22.43	0.0143	4	1.50	38.0	67.5	645	16
	No. 3	69.15	143.8	"	"	4	1.50	38.0	54.7	790	11
	Whole area	71.20	141.3	"	"	4	1.50	38.0	53.7	795	11

Tributary	Name of point *	Catchment area (sq.km)	Rainfall Probability (mm/hr)	Stream length (Km)	Mean stream gradient (o)	Mean velocity (m/s)	Time of concentration (hr.)	Rainfall intensity (%/hr)	Rainfall intensity (mm/hr)	Design flood discharge (m^3/s)	Specific run-off
K. Pabelang	Upper part	35.86	184.3	25.50	0.0714	9	1.00	46.1	85.0	635	18
	C.P. 1	42.09	176.7	"	"	9	1.00	46.1	81.5	715	17
	C.D. 1	51.44	165.3	30.88	0.0375	7	1.25	41.7	68.9	740	14
	" 2	62.3	152.1	"	"	7	1.25	41.7	63.4	825	13
	C.P. 2	65.07	148.7	"	"	7	1.25	41.7	62.0	840	13
	" 3	73.18	138.9	"	"	7	1.25	41.7	57.9	880	12
	N.R.	81.98	132.8	40.01	0.0240	5	1.75	35.0	46.3	880	11
	No. 2	83.44	132.7	43.39	0.0107	4	2.00	32.4	42.8	"	"
	C.P. 4	90.71	132.3	"	"	4	2.00	32.4	42.7	"	"
	N.R. 2	91.81	132.2	44.79	"	4	2.00	32.4	42.7	"	"
	No. 3	92.37	"	45.89	"	4	2.25	30.1	39.7	"	"
	C.P. 5	100.51	131.8	"	"	4	2.25	30.1	39.6	"	9
	Whole area	103.23	131.6	"	"	4	2.25	30.1	39.5	"	"
K. Woro	Planning dam	10.29	215.5	11.5	0.092	11	0.50	58.5	126.1	270	26
	Sand pocket	12.82	212.4	16.0	0.0385	7	0.75	51.6	109.6	295	23
	C. D.	17.06	207.2	22.8	0.0278	6	1.00	46.1	95.5	340	20
	Sinpin	17.43	206.8	27.2	0.0125	4	1.50	38.0	78.6	285	16
	Whole area	42.14	176.7	"	"	4	1.50	38.0	67.2	590	14

Table 2.3.4 Design Flood Discharge for K. Progo and K. Opak

(K. Progo)

Probability	Kranggan (A=424sq.km^2)		Borobudor (A=994sq.km)		Kendat (A=441sq.km^2)		Duet (1,763sq.km)		Sentro (A=1,962sq.km)		Estuary (A=2,296.9sq.km)	
	Flood discharge	Specific run-off	Flood discharge	Specific run-off	Flood discharge	Specific run-off	Flood discharge	Specific run-off	Flood discharge	Specific run-off	Flood discharge	Specific run-off
1/10	1,200	2.8	2,100	2.1	500	1.1	3,100	1.8	3,500	1.8	3,700	1.6
1/30	1,600	3.8	2,800	2.8	600	1.4	3,900	2.2	4,300	2.2	4,800	2.0
1/50	1,700	4.0	3,100	3.1	300	1.8	4,600	2.6	5,100	2.6	5,700	2.5
1/100	2,000	4.7	3,600	3.6	900	2.0	5,300	3.2	5,800	3.0	6,500	2.8

(K. Opak)

Probability	Karangsemut (A=453.2sq.km)		Dogongan (A=740.5sq.km)		Estuary (A=1,225.9sq.km)	
	Flood discharge	Specific run-off	Flood discharge	Specific run-off	Flood discharge	Specific run-off
1/10	1,600	3.5	1,650	2.2	2,900	2.3
1/30	1,800	4.0	2,050	2.8	3,500	2.8
1/50	2,000	4.4	2,300	3.1	3,900	3.1
1/100	2,200	4.9	2,600	3.5	4,000	3.5

Fig. 2.3.5 Comparison of Rainfall Peak and Design Discharge

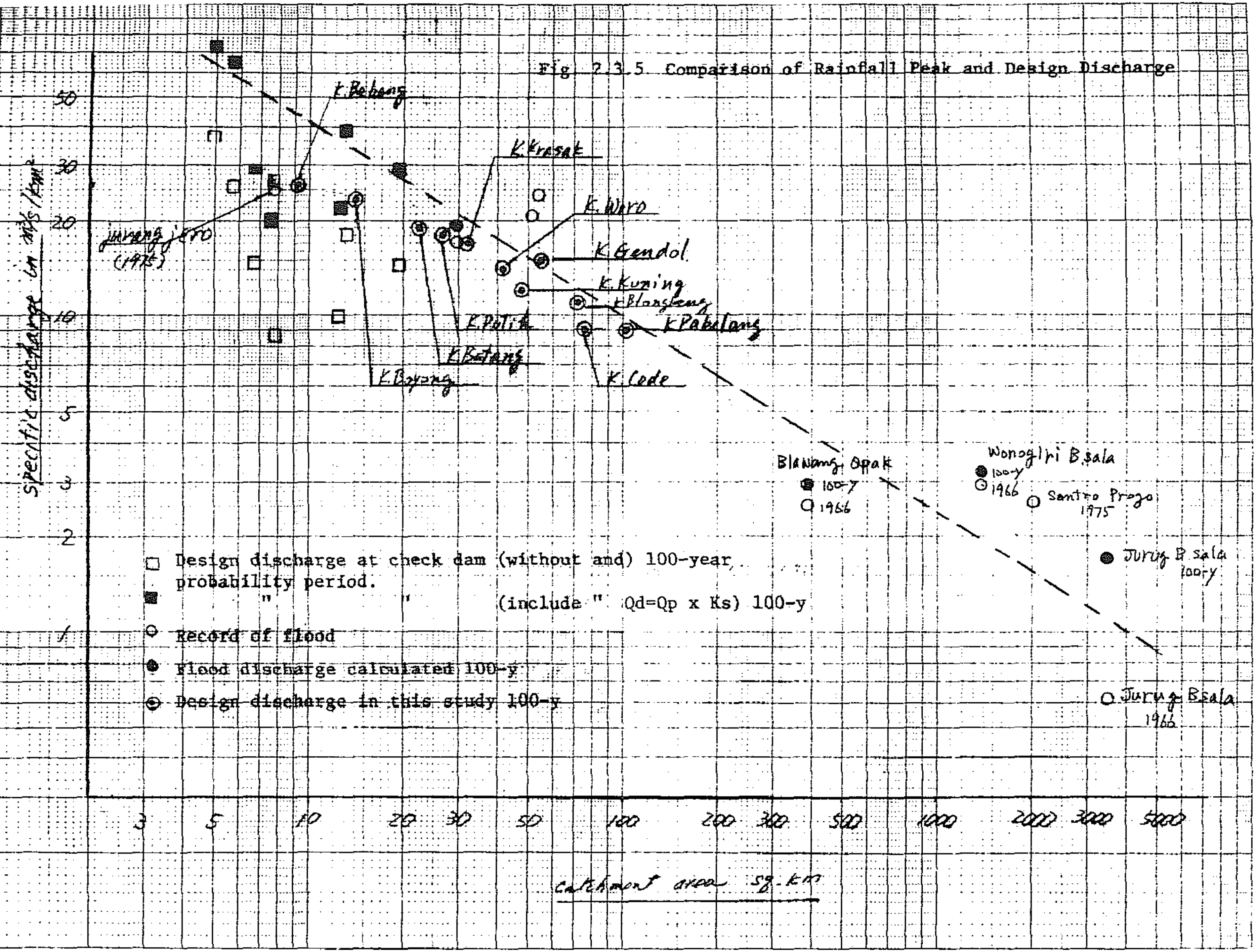


Fig. 2.3.6 Model of River Basin Storage Functions

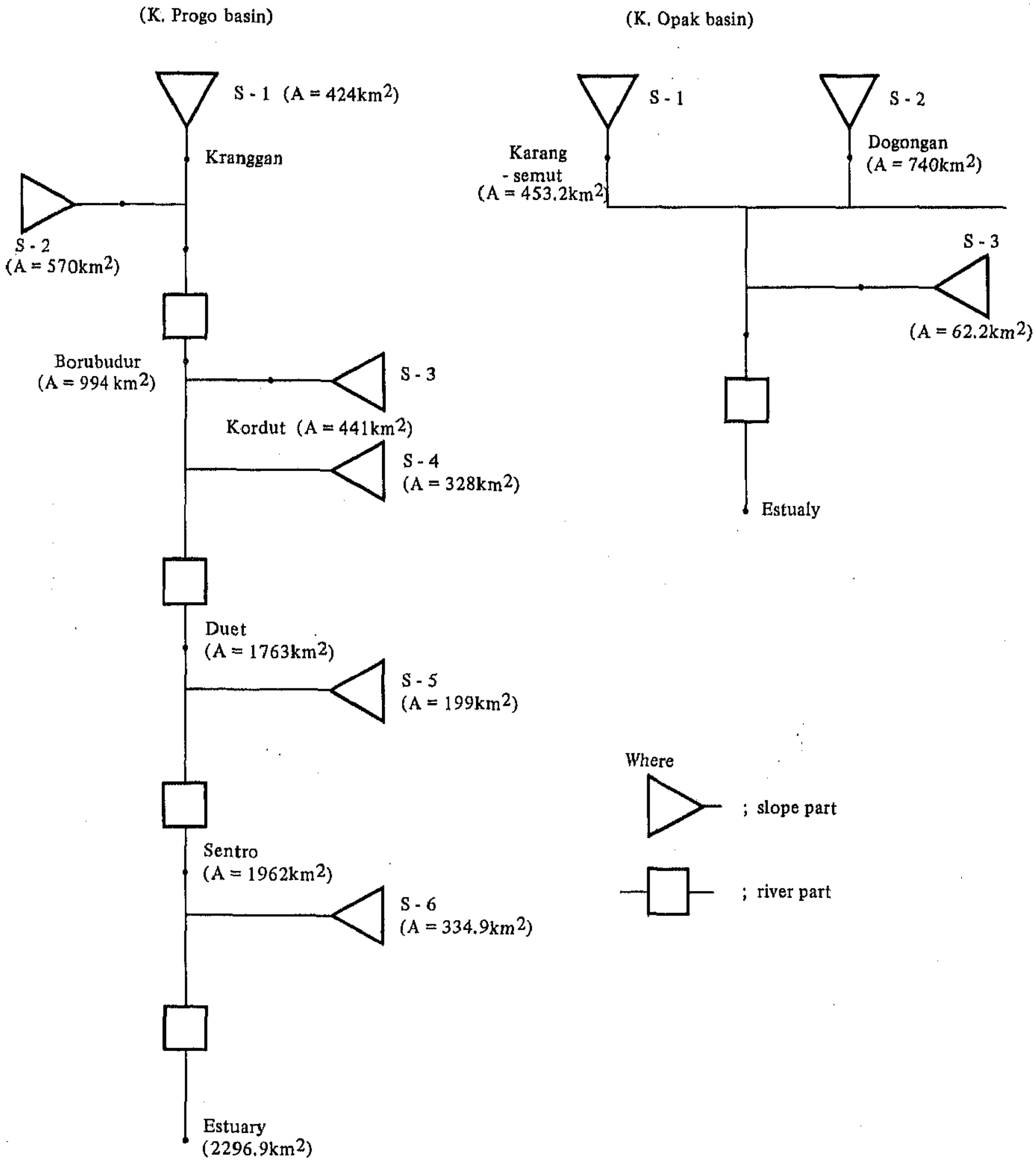
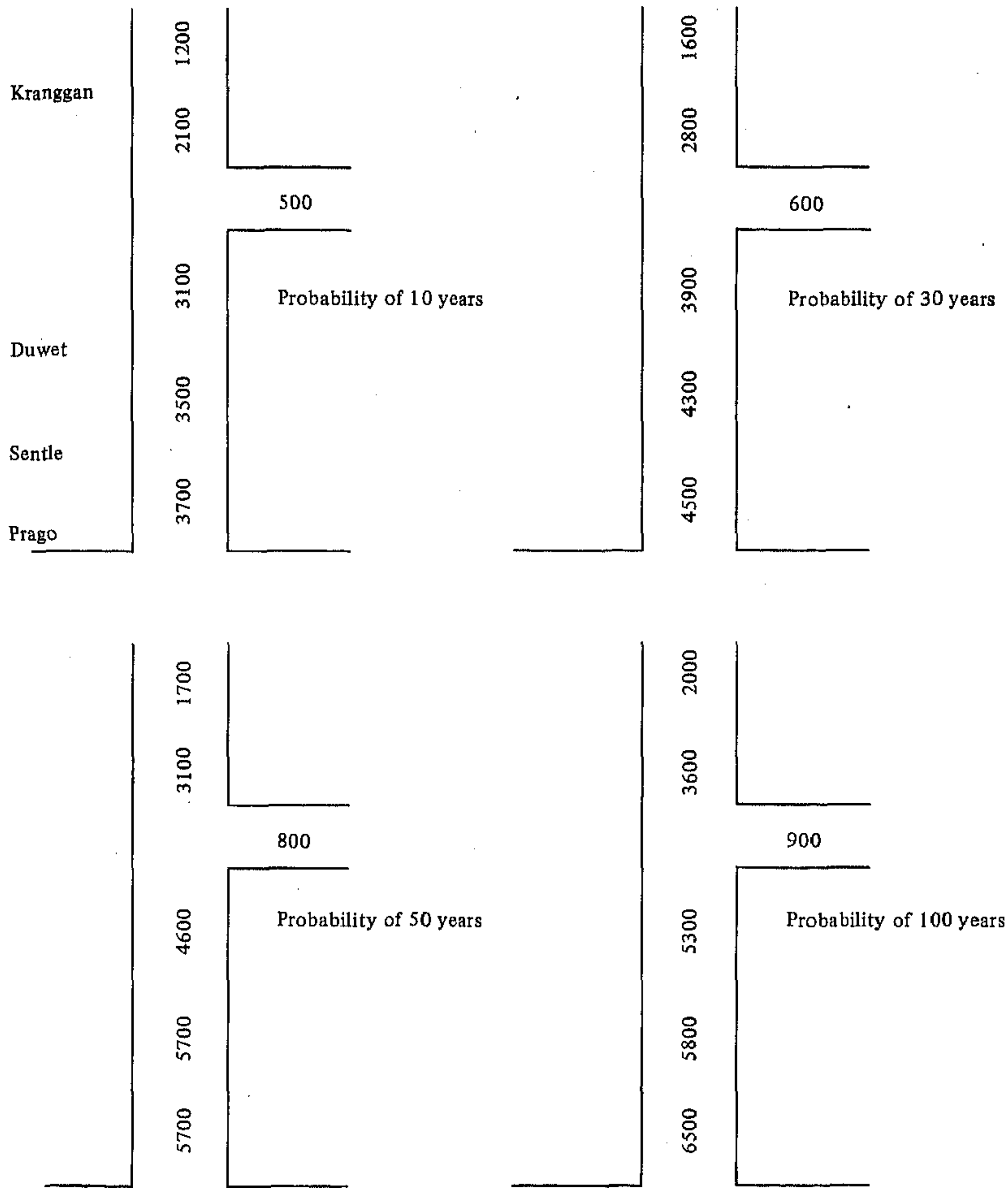


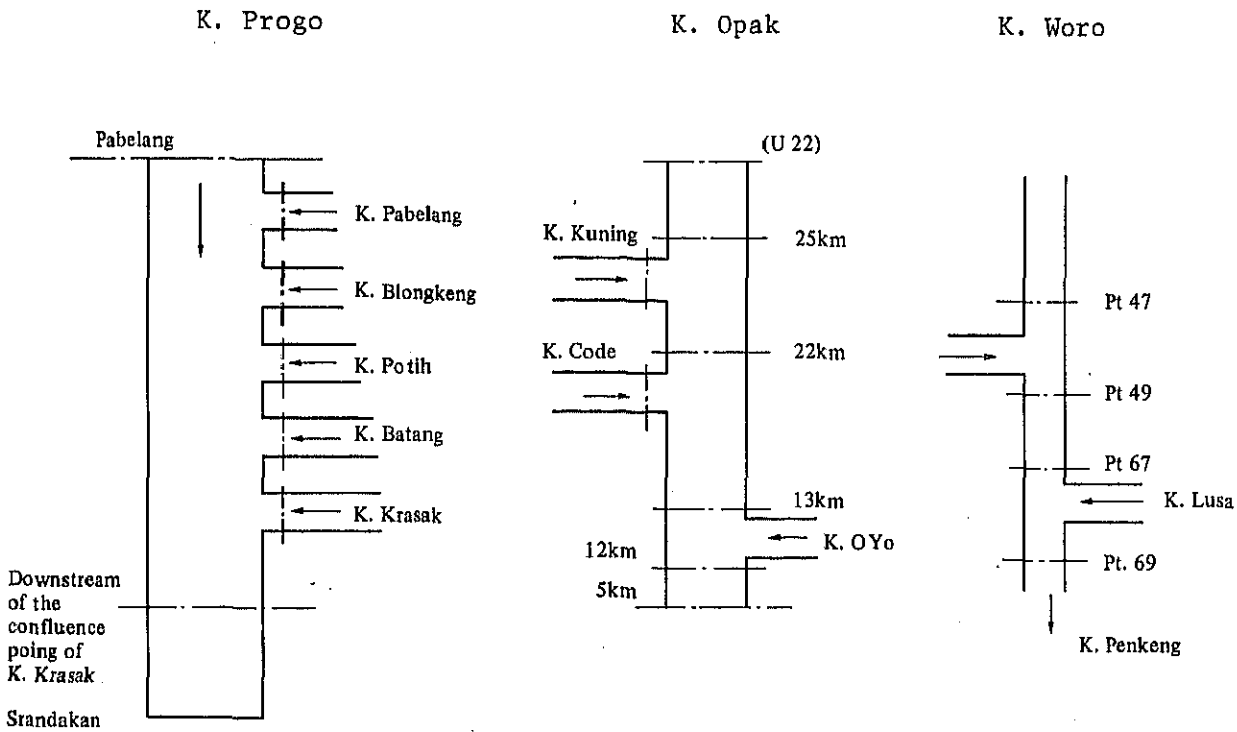
Fig. 2.3.7 Design Run-Off Distribution



2.3.3 Sediment and Suspended Load Capacities

Sediment and suspended load capacity at main points of K. Progo, K. Opak and K. Dengkeng can be obtained using the following formulas since the a river cross section has been measured near the points where tributaries flow into main rivers (see the diagram below):

a) Discharge capacity - Manning formula
b) Sediment load - Broun formula
c) Suspended load - Lane and Kalinske formula



The average particle diameter, critical friction velocity and relationship of discharge amount, and suspension and sediment load amounts at each point, are given in Table 2.3.5 and Table 2.3.6.
All of the rivers show a tendency to deposit, except the K. Progo between the confluence point of K. Pabelang and that of K. Krasak.
This fendency is based on the factors listed below including the results of calculations summarized in Table 2.3.6.

1) The calculation points are those indicated in the diagram above.

2) The annual flow conditions for each point are estimated in terms of catchment area ratios on the basis of those at the Krangan point of K. Progo.

3) Calculations are made for four years: 1965, 1966, 1969 and 1971

4) The Brown formula has been used to calculate sediment balance since the sand and silt content of the discharge is high.

Table 2.3.5 Basic Data for Study of Suspension and Sediment Loads

River System	Name of point	Catchment area (sq.km)	Mean Stream gradient	Mean Grain size (cm) *	Critical Tractive force (cm/s) cm/s	Falling Velocity (cm/s) cm/s
K. Progo	K. Pabelan	103.2	1/93	2.534	14.95	54.7
	K. Blongkeng	71.2	1/70	"	"	"
	K. Putih	26.6	1/10	0.415	6.49	21.0
	K. Batang	22.8	1/40	2.53	14.95	54.7
	K. Krasak	31.7	1/45.5	0.475	6.47	21.0
	K. Progo (up stream of Pabelan)	1,435.0	1/667	0.093	2.36	9.4
	" (down stream of K. Krasak)	1,794.7	1/189	"	"	"
	" (Srandakan)	2,096.9	1/610	0.040	1.72	5.4
K. Woro	Pt. 47	17.43	1/600	0.185	3.68	14.0
	Pt. 48	42.14	"	"	"	"
	Pt. 67	57.74	1/943	"	"	"
	Pt. 69	76.14	"	"	"	"
K. Opak	K. Opak (U_{22})	55.5	1/36	2.98	16.21	57.0
	K. Kuning	47.7	1/259	** 0.876	8.79	"
	K. Code	76.0	1/70	"	"	"
	K. Opak 25KK	329.5	1/450	"	"	"
	" 22 "	377.2	"	"	"	"
	" 13 "	453.2	"	0.492	6.59	23.0
	" 12 "	1,193.7	1/780	"	"	"
	" 5 "	1,255.9	"	"	"	

* Soil test data from K. Boyong.

** Soil test data from K. Opak middle stream

Table 2.3.6 The Result of Calculation of Sediment Balance

(Unit: $10^3 m^3$)

		1969 (14.0)	1971 (19.0)	1975 (28.0)	1976 (13.9)
K. Progo	K. Pabelan (A=103.2Km²)	253.1	343.6	506.3	251.3
	K. Blongkeng (A=71.2 ")	228.0	309.4	456.0	226.4
	K. Putih (26.6 ")	197.5	268.0	395.0	196.1
	K. Patang (22.8 ")	209.4	284.1	418.7	207.9
	K. Krasak (31.7 ")	672.5	912.6	1,345.0	667.7
	Total value of tributaries	1,560.5	1,833.6	3,121.0	1,489.4
	K. Progo (Upstream of Pabelan : 1,453km)	3,749.2	5,088.2	7,498.4	3,722.4
	" (Downstream of K. Krasak : 1,794.7)	25,008.8	33,940.5	50,017.6	24,830.2
	" (Srandakan: 2,297)	2,242.2	3,301.4	5,197.2	2,227.1
	Downstream of K. Krasak – Upstream of Pabelan	(–) 19,699.1	(–) 27,018.7	(–) 39,398.2	(–) 19,618.4
	Srandakan – Downstream of Krasak	(+) 22,760.6	(+) 30,639.1	(+) 44,820.4	(+) 22,603.1
K. Woro	Pt 47 (A = 17.43km²)	4.3	5.8	8.6	4.3
	Pt 49 (A = 42.14)	48.3	65.5	96.5	47.9
	Pt 67 (A = 67.74)	15.7	21.3	31.4	15.6
	Pt 69 (A = 76.14)	14.1	19.1	28.2	14.0
	Pt 49 – Pt 67	+32.6	+44.2	+65.1	+32.3
K. Opak	U22 (A = 55.5km²)	501.2	679.9	1,002.0	497.4
	K. Kunig (A = 47.7)	28.4	38.5	56.8	28.2
	K. Code (A = 76.0)	714.4	969.5	1,428.8	729.3
	K. Opak (25km A=329.5)	33.4	45.3	66.8	33.2
	" (22km A=377.2)	31.4	42.6	62.8	31.2
	" (13km A=423.2)	82.3	113.1	182.6	81.6
	" (12km A=119.7)	70.5	97.7	146.6	69.9
	" (5km A=1,255.9)	65.8	90.2	134.1	65.3
	25km ∿ U22	+467.6	+634.6	+935.2	+464.2
	22km ∿ 25km	+ 32.4	+41.2	+60.8	+30.2
	13km ∿ 22km	±663.5	+694.0	1,309.0	+658.9
	5km ∿ 12km	+4.7	+7.5	+12.5	+4.6

2.3.4 Riverbed Variation of K. Progo

(1) Riverbed Variation at Kamijoro

The riverbed variations at Kamijoro are closely correlated with volcanic eruptions of G. Merapi. The amounts of sediment deposited increase sharply after a major eruption; however, after a few years the deposits were scoured and the riverbed returned to its former stage.

The variation of riverbed at Kamijoro during 1933 - 1977 are shown in Table 2.3.8.

(2) Sediment discharge and flow capacities in a flooding year and an ordinary year.

1) As estimated by Brown's formula, the sediment discharge capacity of K. Progo sharply decreased at Srandakan.

2) In 1971 (an "ordinary" year), sediment discharge from K. Krasak and other tributaries balanced with the river discharge capacity at Srandakan. The river course was observed as a graded stream.

3) However, in 1969 - 1970 (a "flooding" year) yearly sediment discharge exceeded the discharge capacity and the riverbed increased. The sediment discharge from K. Krasak and other tributaries was estimated as two and half times larger (i.e. 7,956,000m^3) than that of ordinary years. Most of this (i.e. about 6,653,000m^3) was deposited down streams along the river mouth of K. Krasak. (See Table 2.3.7)

Table 2.3.7 Sediment Discharge Capacity and Sediment Discharge

(unit: 1,000m^3)

Location	Sediment Discharge Capacity		Sediment Discharge	
	1969-1970	1971	1969-1970	Ordinary Years
1. Upper stream of the river mouth of K. Pabelan	7,498.4 (1.5)*	5.088.2 (1.7)*	3,192.0	3,192.0
2. Tributarise of Type I Area	3,121.0 (0.5)*	1,651.0 (0.7)*	7,957.0	1,304.0
K. Pabeland	506.0	343.6	211.0	211.0
K. Blong Keng	456.0	228.0	191.0	191.0
K. Putih	395.0	197.5	1,001.0	165.0
K. Batang	419.0	209.4	175.0	175.0
K. Krasak	1,345.0	672.5	6,379.0	562.0
3. Down stream of the river mouth of K. Krasak	50,0176.6 (10.3)*	33,940.5 (11.1)*	11,149.0	4,496.0
4. Srandakan	4,496.4 (1.0)*	3,301.4 (1.0)*	11,149.0	4,496.0

* Discharge Capacity at Srandakan equals 1 unit

Fig. 2.3.8 Variation of Amounts Deposited at Kamijoro

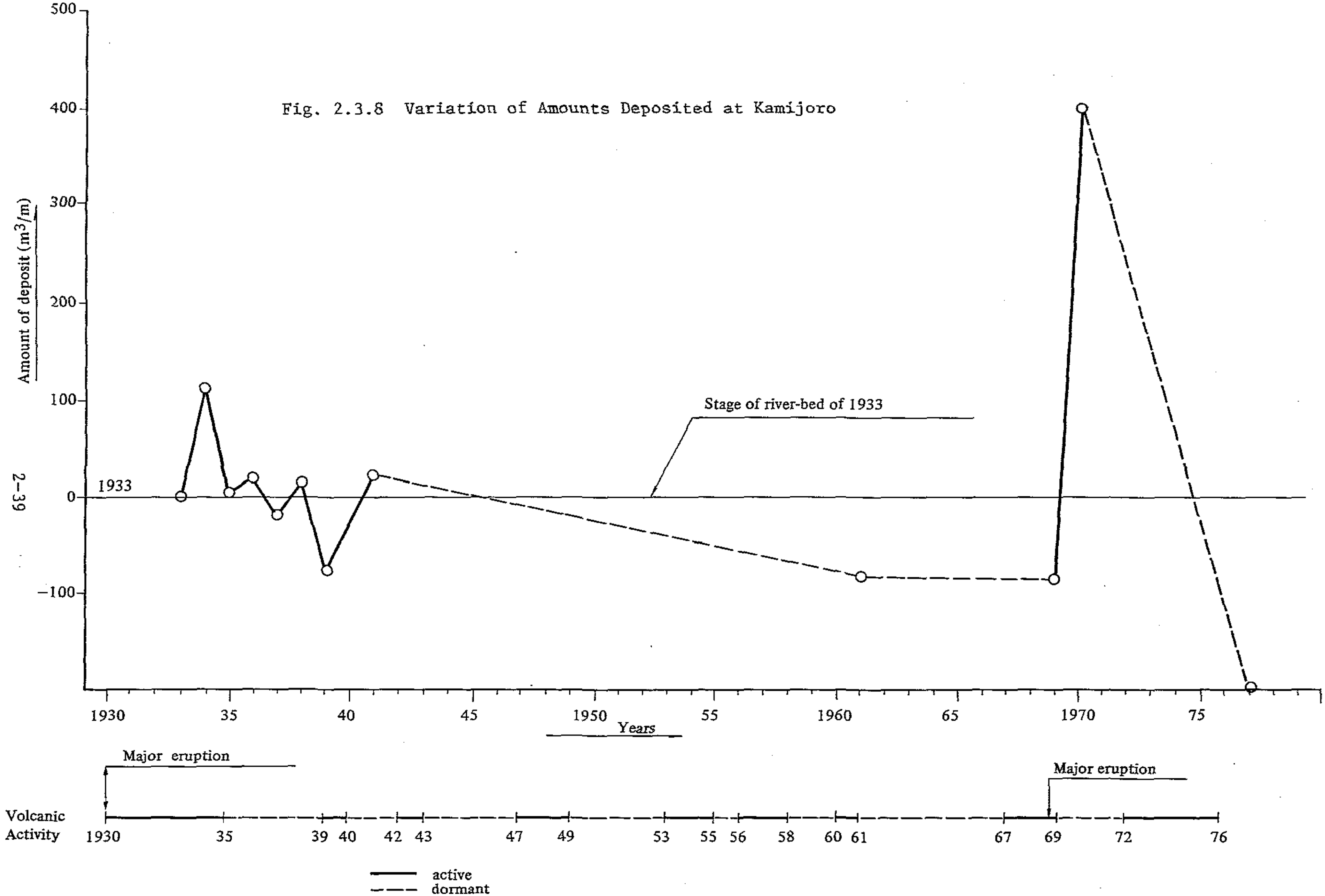
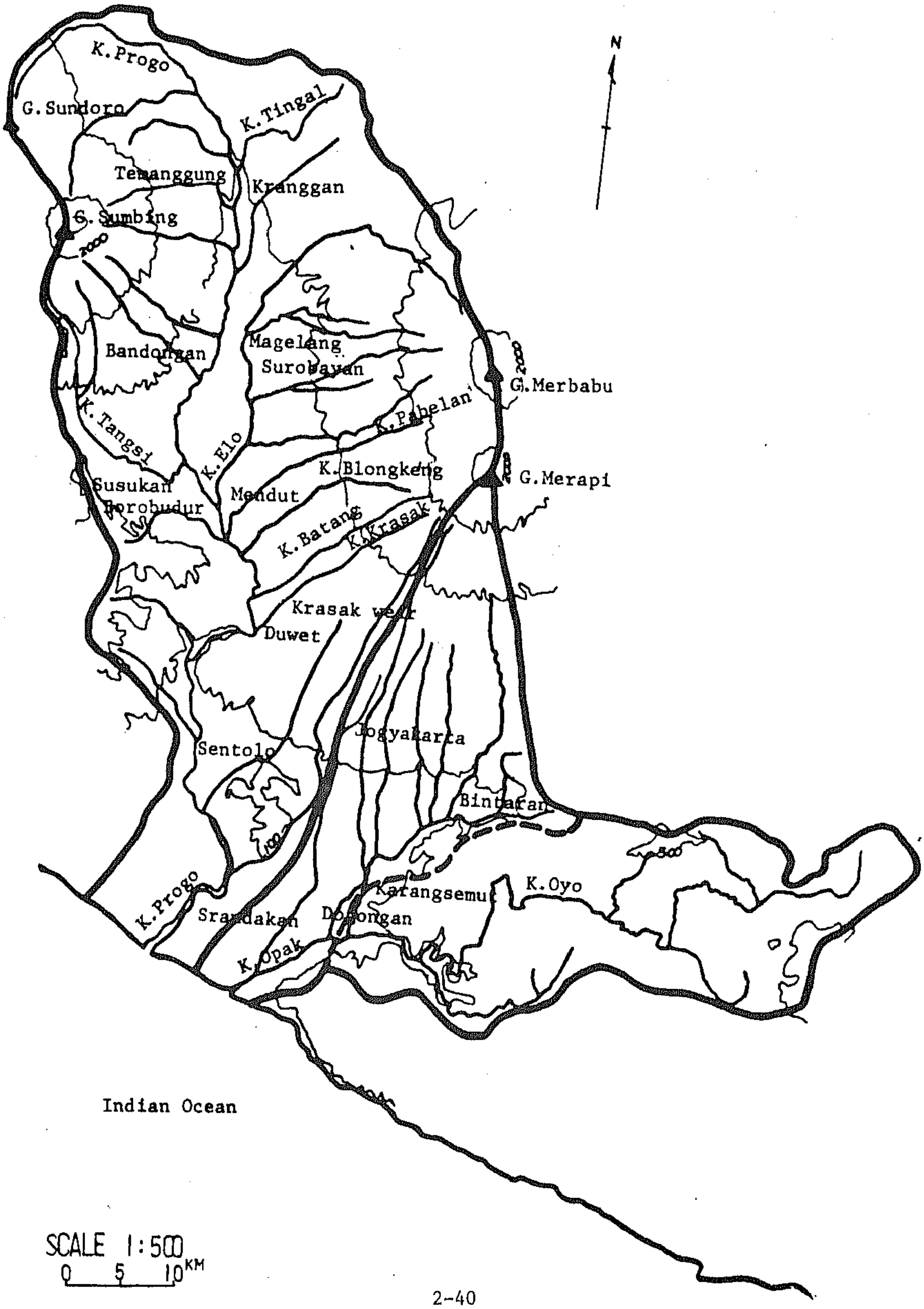


Fig. 2.4.1 River Systems



2.4 Problem Spots of K. Progo and K. Opak

Since K. Progo and K. Opak from upstream to the river mouth are strongly influenced by volcanic materials from the eruptions of G. Merapi, they were surveyed as probable problem spots affected by flooding and volcanic eruptions.

2.4.1 General River Characteristics

(1) K. Progo

The basin of K. Progo covers an area of 2,300km^2. Its total length is approximately 140km, including the stretch of about 40km from the river mouth to the point where K. Krasak flows into it. The boundaries of the basin on the west are G. Sundoro and G. Sumbing, and G. Merababu and G. Merapi on the east. The river flows from north to south into the Indian Ocean. Along the way, many tributaries flow into the K. Progo (K. Pabelan, K. Blongkeng, K. Putin, K. Batang, and K. Krasak). According to cross section measurements made in 1977, the river gradient is approx. 1/600 over the last 20km upto the river mouth. Over the same stretch, the width of the river is about 400m, narrowing to about 200m at the point where K. Krasak flows into it.

(2) K. Opak

The basin of K. Opak covers an area of 1,250km^2. The river is approximately 70km long. On the southern slope of G. Merapi, this river flows into the Indian Ocean along with the tributaries K. Boyong, K. Kuning, K. Gendol and a large tributary with a basin area of about 700km^2 which meets it about 13km from its mouth. The stream gradient from the mouth to a distance of about 12km is 1/780, and from there to a distance of 18km, 1/450, and for an additional stretch of 7km upstream, 1/260. The breadth of the river averages 120m.

(3) Inundation Area

The size of inundation area depends on the flow capacity of the channel, including the state of repair of the river course and the scale of flood discharge. In this connection, discharge capacity has been reduced by a rise in the level of the river bed due to sediment deposits from G. Merapi.

In 1969, 1974 and 1975 about 1,000ha were inundated on both sides of K. Progo in the protected lowland at a point approximately 10km from the river mouth. In the case of K. Opak, floods in 1965 and 1966 inundated about 2,000ha and caused a great deal of damage.

(4) Inundation and Damage Conditions

a) K. Progo

- In recent times, there was flooding of this river in 1969. 1974, and 1975
- The flood of March 1969 was the most serious, with the following damage mentioned in local surveys and other available information:
  - Inundated area — 880 ha (330ha on the right bank and 500ha on the left bank)
  - Number of houses destroyed — 26
  - Number of houses flooded — 392
  - Depth of flooding — 1.0 - 1.5m
- Flood damage figures are given in Table 2.9

b) K. Opak

- Recently, this river flooded in 1965 and 1966.
- The flood of 1966 was the more serious, causing the following damage:
  - Inundated area — 1,800ha (500ha on the left bank)
  - Number of houses destroyed — 330
  - Number of houses flooded — 5,700
  - Number of deaths — 8
  - Depth of flooding — 2-2.5m

(5) Flow Capacity of the River Course

a) K. Progo

- The stretch covered extends about 20km lock from the mouth of the river, the first 13km or so being a flood plain and the rest being a mountainous area.

- The hydrological and hydrographical team studied data from non-uniform flow calculations with a coefficient of roughness of n=0.035 based on various arbitrary discharge amounts and cross sections of the river at intervals of 1km over the entire 20km stretch from the river mouth surveyed in 1977.

- In 1976-1978 an embankment was built along a 4km stretch extending downstream on the left bank from Srandakan Bridge, which is situated about 8km from the river mouth. Discharge capacity before and after completion of the embankment was estimated as follows:

	Approximate Discharge Capacity (cu m/sec)	
Embankment	Before	after
Left Bank	1,000	5,000
Right Bank	2,000	

b) K. Opak

- The stretch studied is from the river mouth to a distance of about 37km upstream, including a flood plain extending to about 20km from the river mouth and from there giving way to a mountainous area.

- The hydrological and hydrographical team studied data from non-uniform flow calculations with a coefficient of roughness of n=0.035 based on various arbitrary discharge amounts.

- After the 1966 flood, embankments were built along the right bank from a point 17km from the river mouth all the way downstream and over part of the same 17km stretch on the left bank. Flow capacity before and after completion of the embankment was estimated as follows:

Embankment	Approximate Discharge Capacity (cu m/sec.)	
	Before	After
Left Bank	500	1,000
Right Bank	300	2,500 - 3,000

(6) River Bed Variation

The record of past river bed variation is based on cross levelling measurement at bridges and weirs, and questioning local people.

a) K. Progo

The variation of the K. Progo river-bed in the year 1969 between the estuary and the confluence of the K. Krasák has been estimated; however, it may be necessary to conduct a further study survey since the data so far obtained is far from complete.

- In a representative cross sectional area of river-bed, about 400sq.m of deposits were observed at the Kamijoro Intake between 1961 and 1970 (including the effects of the eruption of G. Merapi in 1969).

- On the other hand, only approx. 200sq.m of deposits were observed at the Bantar Bridges located relatively close to the Kamijiro Intake during the seven years, 1971 - 1978.

- Two different types of change in river-bed evolution were distinguished: normal years and years when G. Merapi had volcanic activity.

- Based on the above, the bed variation at the Kamijoro Intake in 1969 has been conservatively estimated at 200sq.m of deposits.

- The length of the channel of the K. Progo between the estuary and the confluence of the K. Krasak is about 40km. Of this length, the river-bed variation is prominent along 35km, except for a section upstream where the tractive force on the bed is higher. Across sectional area of the river-bed was also estimated at 200sq.m of deposits.

- In conclusion, the volume of river-bed evolution is extimated to be about 7,000,000cu.m.

Site	Location	Past Record	Bed Variation Sectional Area (sq.m)
Srandakan Bridge	From the estuary to the point abt. 8km. upwards	Comparative studies of the cross levelling data in 1966 and 1978	700
Kamijoro Intake	From the estuary to the point abt. 17.5km upwards	Comparative studies of the cross levelling data in 1924 and 1978	-212 (1924-33) +109 (1933-34) +4 (1934-35) +19 (1935-36) -19 (1936-37) +14 (1937-38) -79 (1938-39) +43 (1939-41) -84 (1941-61) +400 (1961-70) -200 (1970-77)
Bantar Bridge	From the estuary to the point abt. 28km upwards	Comparative studies of the cross levelling data in 1971 and 1978	+200

Note: + shows rising tendency: "deposit"

- shows declining tendency: "scouring"

b) K. Opak

The rock base of the river bed in the middle and lower slope areas of K. Opak looks scoured because a large quantity of sediment has been deposited by many weirs in the upper stream area. According to local people questioned, variaiton in the river-bed is the result of deposits. The amount of variation is indicated below. These deposits, however, most likely occur only only at certain times of the year.

Location	River-Bed Deposit Variation (cm/yr)
Keringan-Tulung	25
Jiwan	8
Panjangrejo	4 - 8

(7) Estimate of Flood Discharge

a) K. Progo

It is estimated that the discharge of the March 1969 flood, the most serious one in recent years, was about 5,000m^3/s. This estimate is based on the present discharge capacity of the river course, the amount of increase in the river-bed up to the present time, and the depth of the flood waters at that time.

b) K. Opak

Assuming that there was almost no change in the river-bed, the flood discharge of this river during March 1969 was about 1,500m^3/s. This estimate is based on the present discharge capacity of the river-bed and the depth of the flood waters at that time.

(8) Flooding Conditions

a) K. Progo

The flow capacity since completion of the embankment has been about 5,000m^3/s. If there is no marked change in the river-bed, there should be little danger of flood overflows comparable to those at the time of the 1969 flood.

b) K. Opak

On the right bank (where houses are concentrated), the flow capacity since completion of the embankment is estimated to be 2,500-3,000m^3/s. If there is no marked change in the river-bed, there should be little danger of overflows in the future since the flow, even at the time of the 1966 flood, was only 1,500m^3/s.

2.4.2 Types of Problem Areas

A detailed survey of trouble spots along the rivers revealed the following problem areas: damage to irrigation intakes caused by silt deposit, embedding, estuary block-ups, landside water inundation, lateral river bank erosion, etc. The sections below discuss these problem areas in detail.