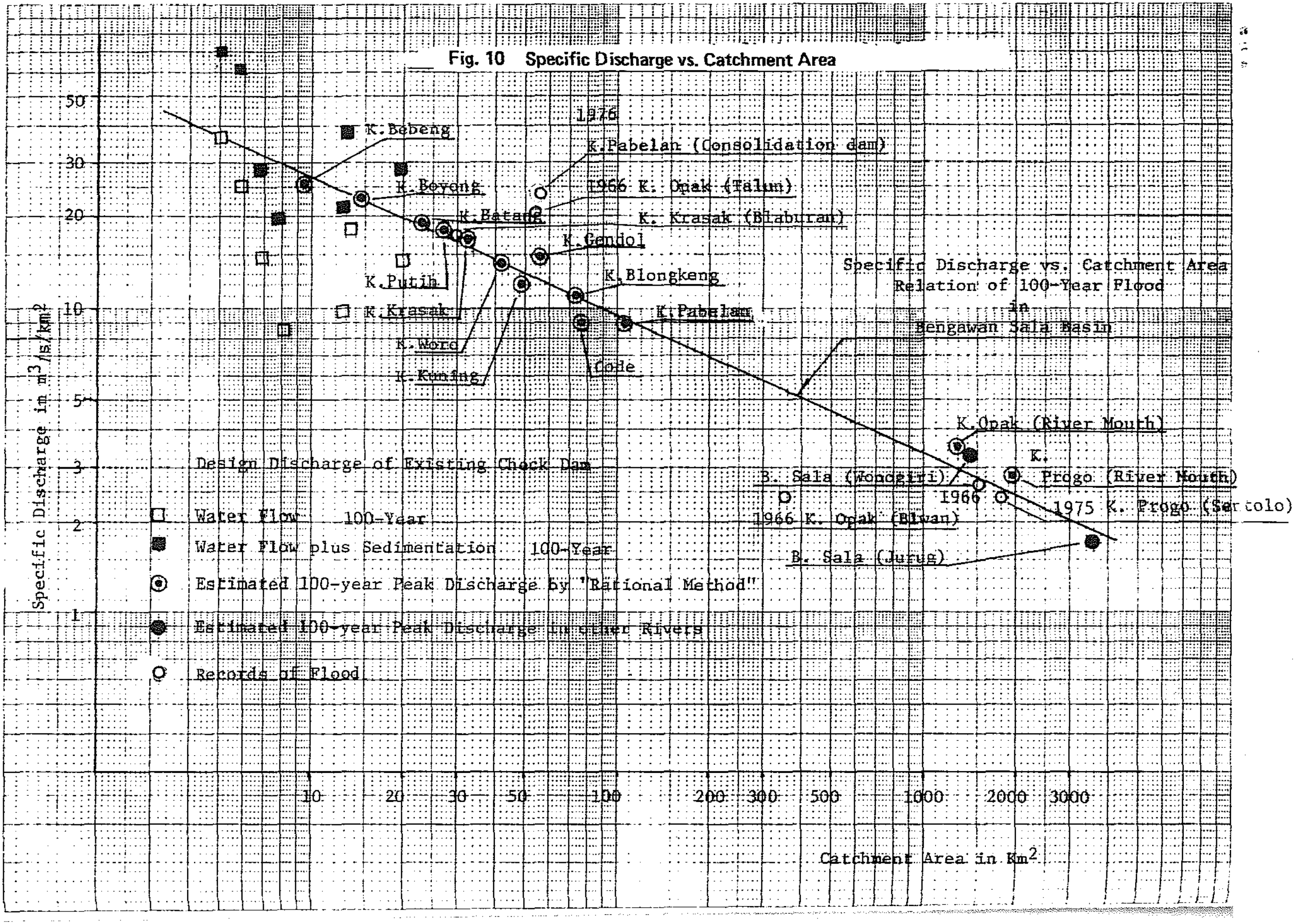
Fig. 10 Specific Discharge vs. Catchment Area



2.2.3 Rivers

1) General Description of Rivers and Riverbed Fluctuation Conditions

The rivers of the area covered by the plan form three river systems: the K. Progo river system, the K. Opak river system, and the K. Dengkeng river system (see Figs. 11 and 12).

a) K. Progo River System

K. Progo, with a catchment area of approximately 2,300km^2 and a length of about 140km, flows southward into the Indian Ocean from the area encircled by G. Sundoro (3,138m), G. Sumbing (3,296m), G. Merbabu (3,119m), and G. Merapi (2,968m). The tributaries flowing into K. Progo from G. Merapi between about the 60km and 40km points from the river mouth in upstream to downstream in order are K. Pabelan, K. Blongkeng, K. Putih, K. Batang, and K. Krasak.

These tributaries are those that are most affected by eruptions of G. Merapi and discharge large amounts of sediment downstream produced by rainfall after the eruptions. The sediment is very fine and therefore easily carried in large amounts by the currents of these tributaries even at normal times; at times of flood waters along these tributaries, the sediment discharge is particularly great, and it causes a tremendous amount of damage. At such times, large amounts of sediment are also discharged into K. Progo.

Although the riverbed gradient of K. Progo is only about 1/600 upstream of where K. Pabelan flows into it, from there to downstream of where K. Krasak joins it, it is about 1/100, which makes for a considerable sediment load capacity. Consequently, that section of K. Progo has a deep valley produced from gouging of the riverbed; the sediment discharged from the tributaries from G. Merapi is easily carried on downstream. Further downstream, particularly downstream of the 20km point from the river mouth, the riverbed gradient becomes a gentle 1/600 or so, and the river widens to 400-700m, which makes for considerable deposition of sediment and resultant obstruction of irrigation water intakes and flooding. Looking at the relationship between riverbed rise in the vicinity of the Kamijoro intake, which is 17.5km from the river mouth, and eruptions of G. Merapi since 1930, one sees that the riverbed rose soon after each major eruption and then gradually returned to its original level over a period of several years. It is estimated that approx. 7,000,000 m^3 of sediment was deposited downstream of the point where K. Krasak flows into K. Progo as a result of the eruption of 1969. Since then, however, the riverbed has returned nearly to its original level except for the areas furthest downstream. Thus, in the case of K. Progo, the main problem from sediment discharge resulting from eruptions occurs not long after the eruptions.

b) K. Opak River System

K. Opak has a catchment area of 1,250km^2 and a length of approximately 70km. After being joined by the tributaries K. Boyong, K. Kuning, and K. Gendol, which flow on the southern slopes of G. Merapi, it flows southward into the Indian Ocean, being joined from the left bank side at a point about 13km from the river mouth by another tributary, its largest, with a catchment area of about 700km^2. The river gradient is 1/780 within 12km of the river mouth, 1/450 for the 13km upstream from there, and 1/260 for 7km further upstream; the average width is 120m.

Since K. Boyong and the other tributaries of K. Opak from G. Merapi are not directly affected by eruptions, they do not have as much sediment production and discharge as the tributaries of the K. Progo river system and their valleys are generally deep. Nevertheless, there is some flood damage at bottlenecks at their middle sections due to depositing of sediment in the past. In years when there is major flooding, the riverbed of K. Opak generally rises because of sediment deposits, but in normal years the riverbed downstream declines rapidly because there is relatively little sediment discharge and there are many weirs upstream. Thus, it is only in years of major flooding that sediment discharge is a problem for K. Opak.

c) K. Dengkeng River System

K. Dengkeng is a large tributary of Bengawan Solo. Its tributary from G. Merapi, K. Woro, is not directly affected by eruptions, but it is surpassed in sediment production only by K. Krasak and K. Putih of the tributaries arising on G. Merapi.

In the vicinity of where K. Woro flows into K. Dengkeng the riverbed gradient of the latter is a very gentle 1/950, which makes for very poor capacity not only in flood years but even in normal years to carry downstream the sediment that is discharged from upstream. As a result, the sediment from upstream is deposited at the middle and downstream sections of K. Woro, forming broad fan-like areas. Furthermore, because of the many sand pockets and embankments that have been provided over the years the riverbed is higher than the ground base of the surrounding land, posing the danger of flooding. Thus, in the K. Dengkeng river system it is not the amount of sediment discharge from K. Dengkeng itself that is a problem, but rather the sediment discharge of its tributary K. Woro, including that which occurs in normal years.

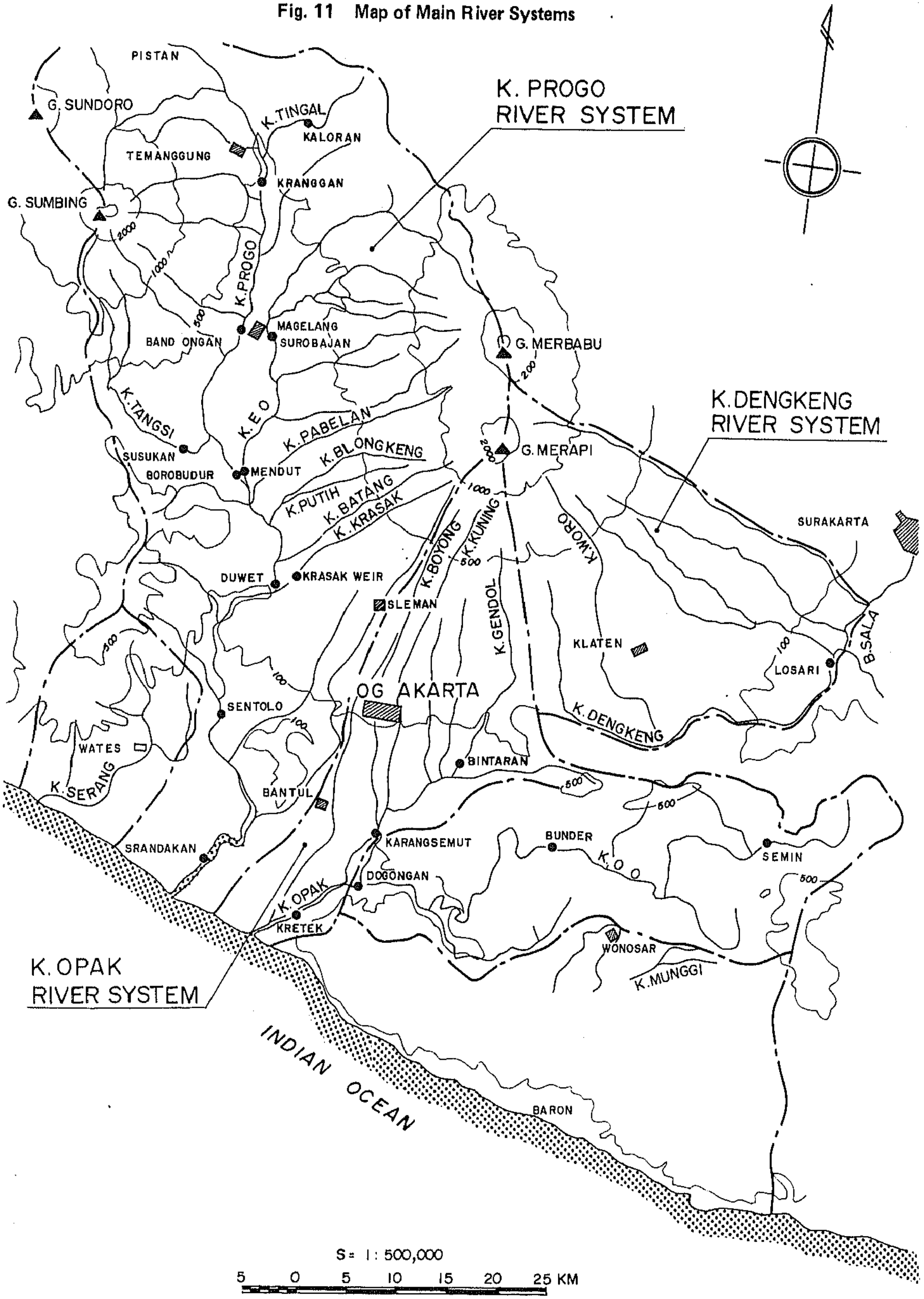
2) Riverbed Materials

The riverbed materials of the project area are generally affected by volcanics and the particles are very fine. Especially in the case of K. Krasak, K. Putih and K. Woro which have a lot of sediment discharge, the riverbed materials are composed of very fine particles with an average diameter of 10-30mm at upstream sections and 2-5 mm at downstream sections and become the causes of large amount of sediment discharge and unstable river courses.

In the case of rather stable rivers, fine particles of riverbed materials have already been discharged and sediment discharges are decreased. And the particle has become larger 20-30 mm in average diameter.

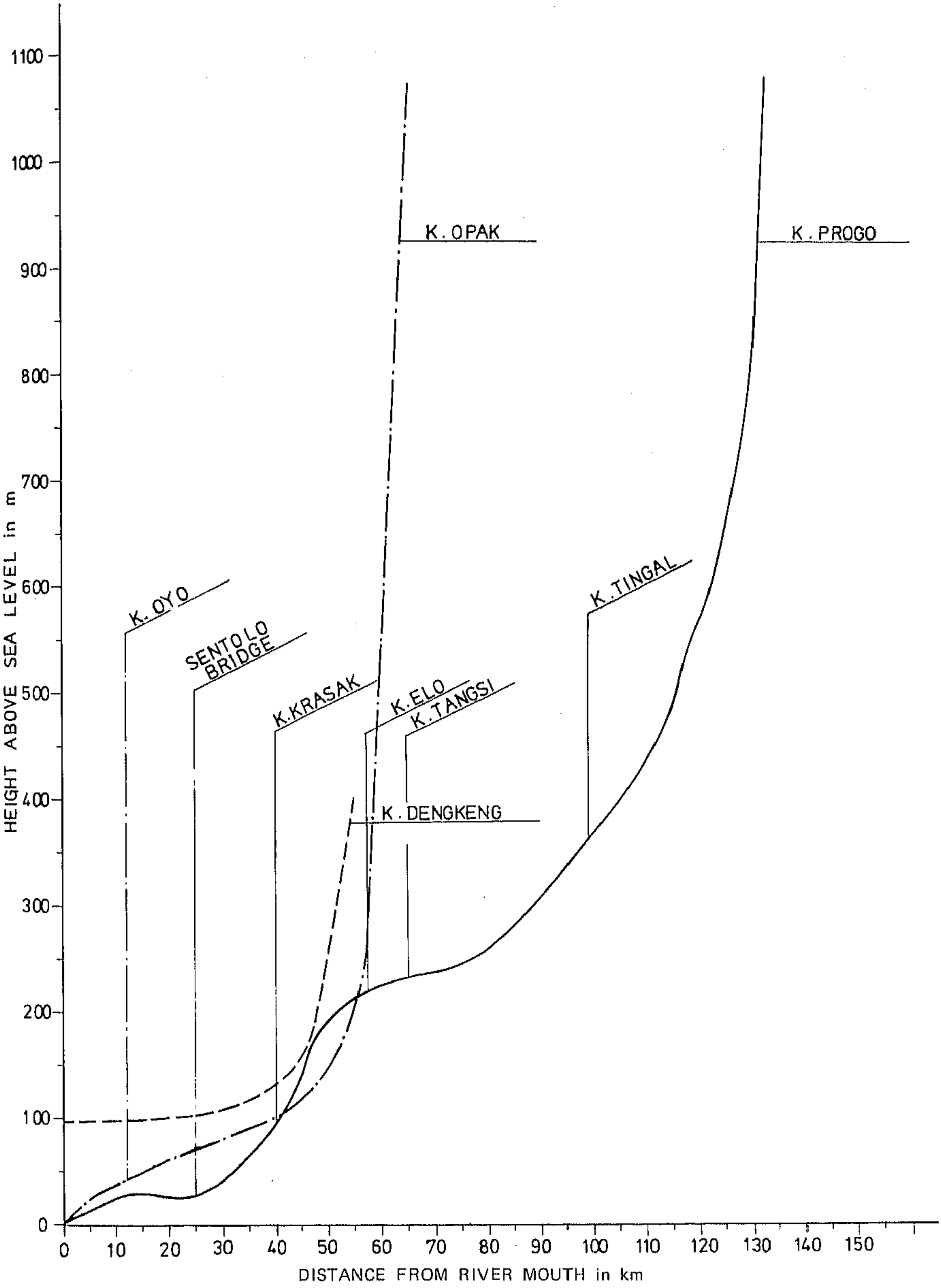
During major flooding after an eruption, the diameter of the particles of the sediment discharged can be expected to be even smaller than that of the present riverbed materials. This is the cause of large amount of sediment discharge just after an eruption.

Fig. 11 Map of Main River Systems



MAP OF MAIN RIVER SYSTEMS

Fig. 12 Longitudinal Profiles of Main Rivers



2.2.4 Sediment Production and Discharge

In the area covered by the plan, sediment production and discharge occurs in the rivers that flow down the slopes of G. Merapi. These rivers can be classified into three types, on the basis of how such sediment production and discharge is influenced by eruptions and the kind of damage that is caused.

1) Summary of Catchment Areas

a) Type-I Areas (K. Krasak (K. Bebeng), K. Batang, K. Putih, and K. Blongkeng)

The rivers in these areas have their waterheads in the direction of the eruption outflow. Presently their sediment discharge is very pronounced, with two of them (K. Krasak and K. Putih) suffering considerable disaster damage and the other threatening similar damage.

In these areas most of the sediment produced by eruptions stops temporarily at an elevation of 1,900-900m. Most of the sediment discharged downstream is produced by erosion of these deposits and earlier deposits as the result of rainfall.

Accordingly, the river system network in these areas is not fixed, with change in catchment areas and river courses after each eruption. Since there has been little valley depth made, there is little difference in height between the riverbeds and the river banks. Moreover, in the case of K. Krasak and K. Putih the riverbeds have risen as a result of the considerable amount of sediment discharged since 1969, and this poses the very great danger of flooding.

All of the rivers in these areas have experienced considerable damage from nuée ardente and lahar because of change in the direction of eruption since 1930. Since the state of the crater would seem to indicate a high probability of further damage of this kind, all of them should be treated together in sabo planning.

Furthermore, since all of these rivers flow into the middle stream section of K. Progo and have a high riverbed gradient and hence a high sediment load capacity, K. Progo is very much affected by them in terms of sediment discharge.

b) Type-II Areas (K. Woro and K. Gendol)

Although these two rivers are not directly affected by eruptions as the rivers in Type-I area are, only K. Krasak and K. Putih have more sediment discharge than K. Woro and K. Gendol. Of the three river types, this type has the deepest river valleys, K. Woro having a U-shapted valley with a depth of over 100m upstream in the vicinity of elevation 1,100m. This is no doubt due to the fact that there has been no large-scale supply of sediment from eruptions for a long while. Presently the sediment production is mainly due to erosion of the riverbeds and riverbank deposits. Although Type-III areas have also been free of direct influence from eruptions for a long time, Type-II areas are characterized by considerably more sediment discharge from the erosion of large amounts of unstable lahar deposits still remaining in the river courses from eruptions after 1930 and of volcanic ash found above elevation 2,000m. Furthermore, K. Woro has considerable deposit areas in its middle and lower sections from the fact that K. Dengkeng, into which it flows, has a gentle riverbed gradient and hence is without sediment load capacity. For a long time now those sections have been provided with embankments for disaster prevention purposes. As a result, the riverbed there is higher than the surrounding land, and there is therefore considerable danger of major damage from flooding.

c) Type-III Areas (K. Kuning, K. Boyong, and K. Pabelan)

The rivers in these areas have little sediment discharge and stable configurations. The their upstream sections, the valleys are deep, and in the case of K. Kuning and K. Boyong, fan-like deposit terrain begins at about elevation 450m. The same two rivers have little sediment production in their upstream sections because of the fact that their fountainheads consist of lava rock, which is not easily eroded and the fact that the Old Merapi blocks the downward flow of volcanic debris. Since, however, there still remain unsteady deposits in the riverbeds and riberbanks upstream, there is danger of sediment discharge at times of major flooding.

In middle sections of these rivers, there are some places where past deposits have made the cross-sectional area of the river small and the course of flow unsteady, giving rise to localized danger of flooding and bank collapse. Unlike K. Kuning and K. Boyong, K. Pabelan was affected by an eruption in 1950, but since it has a large water flow and erosion progressed very rapidly, it is relatively stable now.

2) Characteristics of Sediment Production and River Discharge

a) Characteristics of Sediment Production

(1) Every five to seven years there is a direct supply of large quantities of lava and volcanic ash from Merapi's crater.

(2) As for the vertical section gradient, debris from Old Merapi found on the riverbed of each of the rivers forms a sort of erosion standard surface (stable gradient), with little progression of downward gouging below that surface. Accordingly, lateral erosion is the main source of sediment production in the case of rivers where that surface has already been reached.

(3) Since the banks of all of these rivers consist of loose volcanic deposits, they represent an almost unlimited

source of sediment production by latenal erosion. Hence, for the most part the valleys are U-shapted.

(4) Since there is a great deal of silt and clay mainly from volcanic ash on the riverbeds, large to gigantic boulders are easily rolled downstream.

(5) Sediment production is presently most active between 3km and 12km from the summit in the case of Type-I area rivers and between 3km and 8km from the summit in the case of Type-II and -III area rivers.

b) Characteristics With Respect to Form of Discharge

(1) There is a close connection between the amount of sediment discharged and the volcanic activity. In other words, lahar occurs more easily on a large scale when the upstream area is supplied of unstable volcanic materials and devastated by nuée ardente.

(2) When nuée ardente and large-scale lahar occur, there is frequent river course piracy at upstream sections, with small rivers easily being made into larger rivers as a result of large-scale washing.

(3) The lahar has a massive form of downward flow in which the sediment is mixed with water.

(4) The banjir is a flood in which the contents of sediment is very high and flooded widely along tributaries.

c) Characteristics Relating to Amount of Sediment Production and Discharge (see Figs. 13 and 14).

(1) The amount of sediment production and discharge due to rainfall immediately after eruptions are very great in the cases of the Type-I area rivers (K. Krasak and K. Putih). In fact, they are the greatest in sediment discharge among all the active volcanos that we know about.

(2) The amounts of sediment production and discharge become peak right after the eruptions and then gradually daminish logarithmically.

(3) The rivers in Type-II areas are stable in normal years, but at times of major floodings they have considerable sediment production capacity.

(4) The rivers in Type-III areas are also stable in normal years, and although they have some sediment production capacity at times of major flooding, such capacity in smaller than in the case of rivers in Type-II areas.

(5) The rivers that are presently active in terms of sediment production also have a considerable amount of sediment discharge in normal years because the sediment carried consists of fine particles.

3) Amounts of Sediment Production and Discharge in Type-I Areas

a) 1969-1970

As a result of the eruption of 1969 there were several instances of occurrence of nuée ardente as well as hot lahar. Furthermore, immediately after the eruption, there was flushing out of the riverbeds and banks on a large scale, which caused large amounts of sediment to be supplied all along the downstream sections of the rivers. One lahar flow went from K. Bebeng to K. Krasak, and another blocked K. Blongkeng at Jurangjero and then flowed into K. Putih.

The amounts of sediment production and discharge for K. Krasak and K. Putih as calculated on the basis of existing data and field surveys and the characteristics with respect to the amounts of sediment production and discharge were as follows: (see Fig. 15).

(1) Most of the sediment production was due to river erosion, and there was very little direct sediment production from the volcano.

(2) In the case of K. Krasak the sediment production section extended down to the 12 km point from the summit, and there was a great deal of depositing between the 13 km and 15 km points. In the case of K. Putih the sediment production section extended down to the 9 km point.

(3) There are large amounts of unstable sediment at the upstream section of K. Putih.

(4) The amount of sediment production and discharge for K. Krasak and K. Putih.

K. Krasak:	Amount of sediment production	11,804 x 10^3m^3
	Amount of sediment deposits	5,452 x 10^3m^3
	Amount of sediment discharged into K. Progo	6,379 x 10^3m^3
K. Putih :	Amount of sediment production	6,060 x 10^3m^3
	Amount of sediment deposits	5,052 x 10^3m^3
	Amount of sediment discharged into K. Progo	1,008 x 10^3m^3

b) 1976-1978

After the lahar flows of 1969 (from 1970 to 1976), the erosion of river banks progressed at the upstream sections, continuing to supply large quantities of sediment downstream, but there was no new sediment production from eruptions. In 1976 there was relatively large-scale occurrence of lahar/banjir, with widespread flooding in the upper parts of K. Krasak and middle parts of K. Putih. Thereafter the riverbed also rose in the lower parts of K. Krasak, causing repeated flooding on a small scale. The amount of sediment during this period are calculated on the basis of aerial photographs for 1976, 1977, and 1978 and the results of field surveys; the results are summarized as follows (see Table 5 and Fig. 16).

(1) Except for K. Krasak, the annual amount of sediment discharge for each river was in the range of 50~100 x 10^3m^3, and this amount of sediment discharge can be expected to continue fairly constantly so long as there is no major change at the upstream sections.

(2) In this three-year period only 128 x 10^3m^3 of sediment was discharged from K. Krasak into K. Progo. If it had not been for flooding and depositing of sediment in the downstream section, however, such sediment discharge would no doubt have amounted to more than 1,000 x 10^3m^3.

(3) In 1977-1978 the amount of sediment discharged into K. Krasak was 558 x 10^3m^3, which was far greater than that for any other of the rivers in question.

c) 1969-1977

The amounts of sediment production and discharge for the period 1969-1977 are calculated on the basis of the following: measurement of the present cross-sectional areas of the rivers at their upper and middle sections, reproduction of the cross-sectional areas for before 1969 through questioning of local people, data concerning riverbed rises in upstream sections, and other information. The results of the investigation are as follows (see Table 6).

(1) The total amount of sediment discharged from Type-I area rivers into K. Progo in the nine-year period 1969-1977 was 13 x 10^6m^3.

(2) K. Krasak accounted for about 77% of the total, and K. Putih 15%.

(3) There was large-scale sediment discharge in the case of K. Krasak immediately after the major lahar flow of 1969, with a gradual decrease each subsequent year.

d) Amounts of Sediment Production and Discharge for the Upstream Section of K. Krasak (above the point of confluence with K. Bebeng) and for K. Lamat.

The amounts of sediment production and discharge for this section of K. Krasak and for K. Lamat have been calculated in the same manner as for the Type-II and -III area rivers since there has been no occurrence of lahar flow there recently and river valley depth has progressed quite far.

4) Amounts of Sediment Production and Discharge in Type-II and -III Areas

a) Present Amount of Unstable Sediment

Among the kinds of unstable sediment presently to be found in Type-II and -III areas are new volcanic ash, rock fragments, talus, and fan-like deposits on the mountain slopes and in terrace deposits, and present riverbed deposits in the river courses. In the middle and upstream sections of the rivers the banks themselves are composed of unconsolidated and semi-consolidated loose volcanic ash and breccia strata, but these materials have not been included as unstable sediments for the present purpose. The method employed in the calculations was determination of the surface distribution of the different kinds of deposits by analyzing aerial photographs and checking the deposit thicknesses by means of field surveys. In the case of present riverbed deposits, a depth of 2m was assumed as the average value obtained in the riverbed fluctuation survey carried out in Type-I areas. The total calculated amount of unstable sediments was approx. 6,000 x 10^3m^3 for Type-II area rivers and 2,000-3,000 x 10^3m^3 for Type-III area rivers (see Table 7)

b) Amount of Sediment Production

The amount of sediment discharge each year for each of the rivers in the Type-II and -III areas is estimated at several thousand to several ten thousand cubic meters, as in the case of the rivers in Type-I areas other than K. Krasak and K. Putih. In the case of K. Woro and K. Gendol, however, there was large-scale occurrence of lahar and banjir around 1930 and again around 1969, with formation of terraces at the upstream sections and large-scale sediment flooding and depositing in middle and upstream sections. Accordingly, for the purposes of planning for prevention of future disasters the amounts of sediment production and sediment discharge should be calculated in terms of the amounts that would result in the event of large-scale flooding. The kinds of inevitable sediment that have been taken into account in calculating the amount of sediment production as those kinds that would be involved in sediment production and discharge at times of major flooding: unstable riverbed deposits, low terrace deposits, and medium and high terrace deposits, the sediment involved in river bank collapse, and some of the volcanic ash and rock fragments to be found in the fountain-heads.

The calculated amounts of sediment production are 4,219 x 10^3m^3 (594 x $10^3m^3/km/km^2$) for K. Woro and 3,158 x 10^3m^3 (301 x $10^3m^3/km^2$) for K. Gendol, both of which are Type-II area rivers, and 1,500-2,000 x $103m^3$ for rivers in Type-III areas (see Tables 7 and 8). In the case of Type-II area rivers the breakdown of the amount of sediment production by the place where it is produced is roughly 40% at the upstream sections (within about 5km of the crater), another 40% from the river bank terraces, and 20% from the riverbed. In the case of rivers in

Type-III areas, the breakdown is 10-20%, 50-60%, and 20-30%, in the same order. These results indicate that there is more sediment production in upstream sections and from medium and high terrace deposits in the case of rivers in Type-II areas than in the case of those in Type-III areas and that erosion takes place mainly upstream the 10km ∿ 13km points from the crater (see Table 8).

Table 5 Sediment Balance for the Cumulative Period

unit: x $10^3 m^3$

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

Table 6 Riverbed Variation by Aerial Survey

unit: x $10^3 (m^3)$

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 flood deposit near point 11km	-124 +26	7km-23km	-5	103
	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

Table 7 Summary of Present Unstable Deposits in Type II and Type III Areas

	Name of river	Distance from the summit (Km)	Recent Riverbed deposits ($x10^3m^3$)	Lower Terrace deposits ($x10^3m^3$)	Middle and upper terrace deposits ($x10^3m^3$)	Other unstable deposits ($x10^3m^3$)	Total volume ($x10^3m^3$)
Type - II	K. Woro	0 ~ 12	1,198	(343) 424	(1,875) 2,316	(1,900) 2,347	6,285
	Sandpocket of K. Woro	12 ~ 17	1,375	4,500	–	–	5,875
	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
	K. Boyong	0 ~ 17	755	(519) 641	(484) 598	(128) 158	2,152
	K. Senowo (A)	0 ~ 12	610	(324) 399	(685) 846	(366) 452	2,307
	K. Trising (B)	0 ~ 19	1,112	(1,817) 2,243	(212) 262	(186) 230	3,847
	K. Pabelan (C)	0 ~ 13	300	(303) 373	(114) 141	(278) 343	1,157
	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
	K. Lamat	0 ~ 12	510	(23) 29	–	–	539

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

Table 8 Summary of Possible Sediment Discharge Volume in Type II and Type III Areas

	Name of river	Area of basin (Km^2)	Distance from the summit (km)	Recent riverbed deposits ($x10^3m^3$)	Lower terrace deposits ($x10^3m^3$)	Middle and upper terrace deposits ($x10^3m^3$)	Other unstable deposits ($x10^3m^3$)	Volume of sediment products ($x10^3m^3$)	Specific probable Volume ($x10^3m^3/Km^2$)
Type - II	K. Woro	7.1	0 ~ 10	637	(343) 424	(1,500) 1,853	(1,057) 1,305	4,219	594
	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
	K. Boyong	10.3	~ 13	445	(349) 431	(332) 410	(114) 141	1,437	140
	K. Senowo (A)	8.8	~ 12	510	(323) 399	(548) 677	(223) 275	1,861	211
	K. Trising (B)	12.4	~ 12	400	(483) 597	(170) 210	(123) 152	1,359	110
	K. Pabelan (C)	52.0	~ 13	300	(303) 373	(92) 113	(169) 204	990	19
	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
	K. Lamat	14.2	~ 12	430	(23) 29	–	–	459	32

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

Fig. 13 Tendency of Annual Produced and Deposited Volume in K. Krasak

unit: million m^3

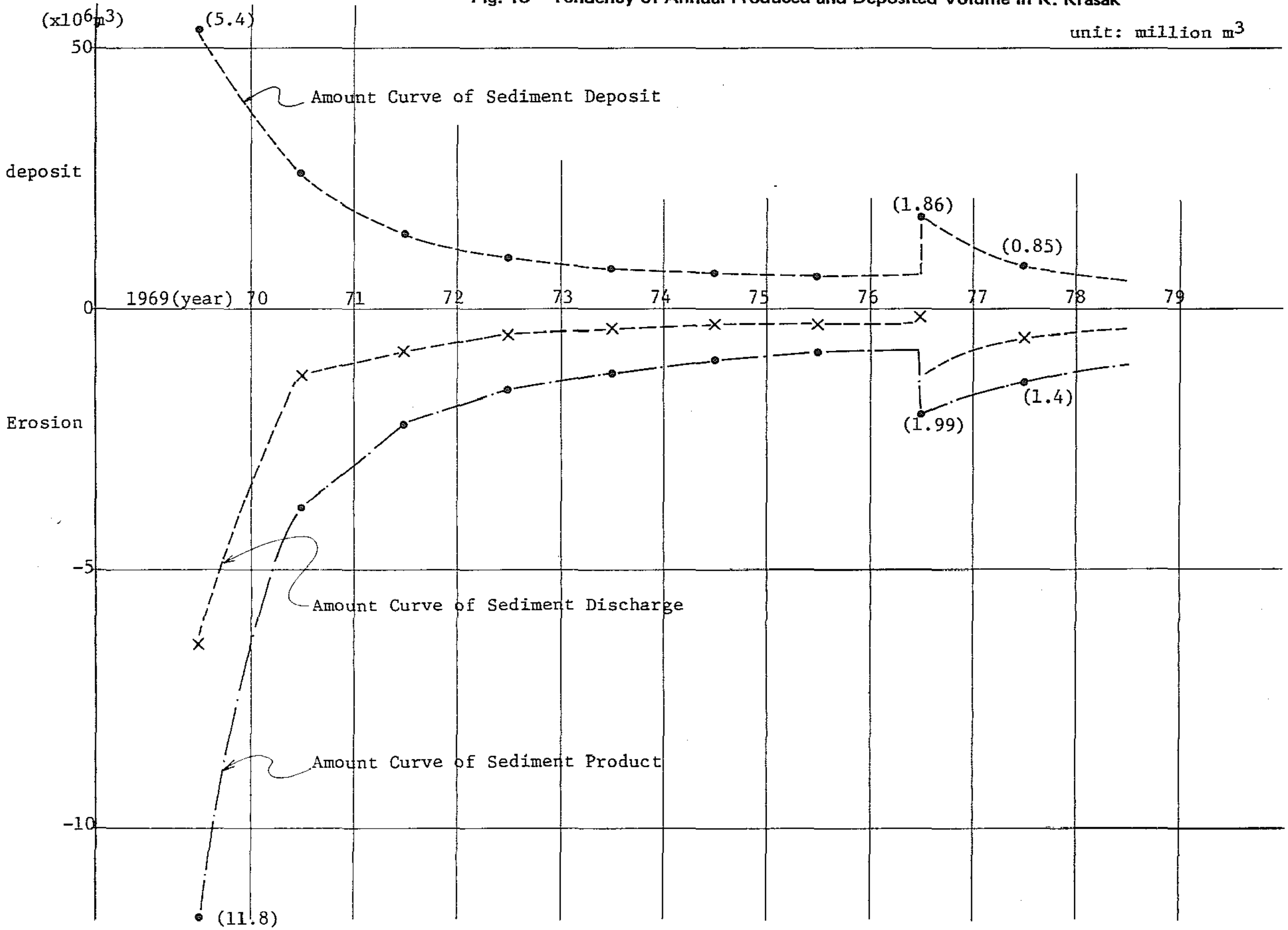
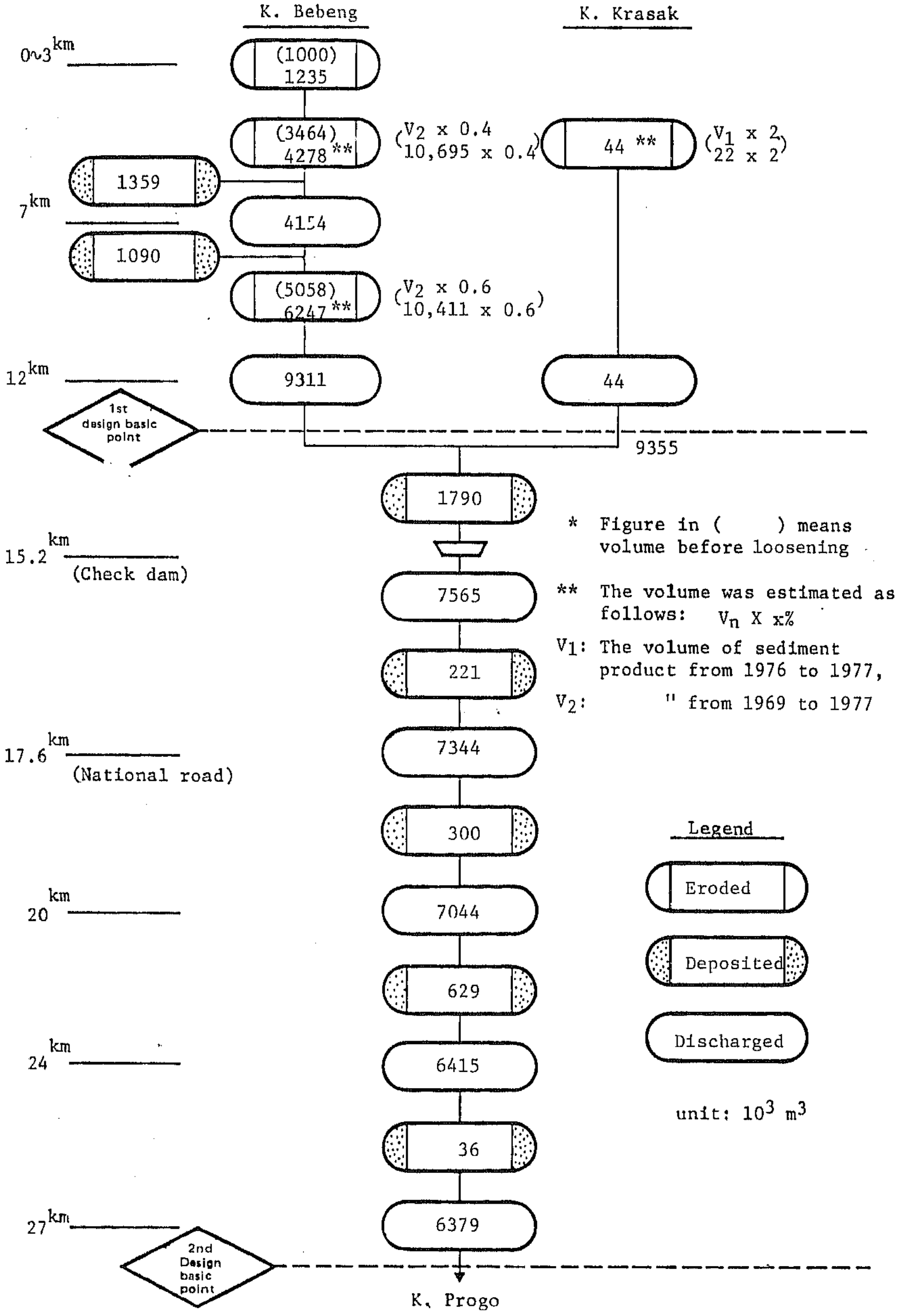


Fig. 14 The Balance of Sediment Produced and Deposited (from 1969 to 1970)



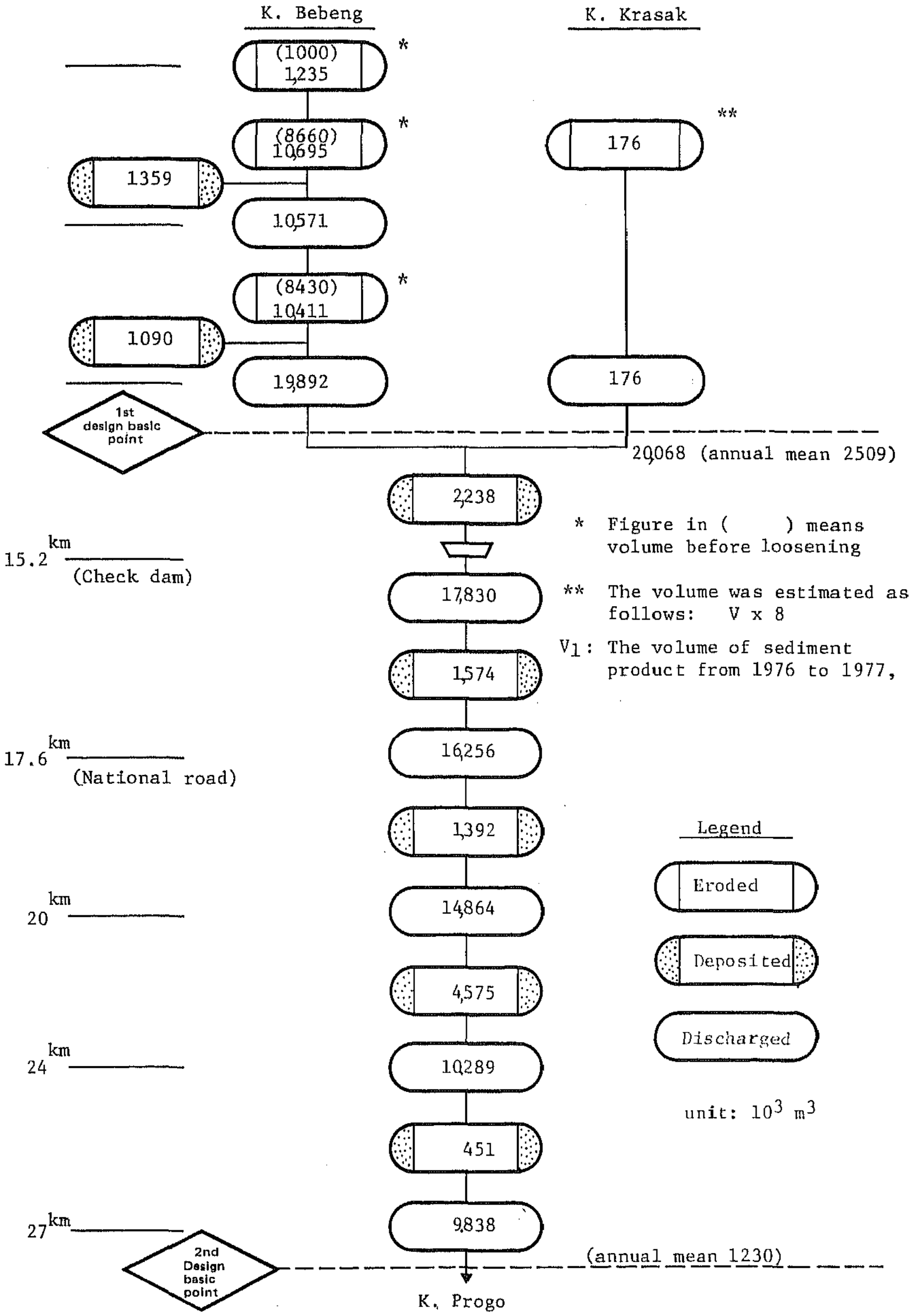
* Figure in ( ) means volume before loosening

** The volume was estimated as follows: V_n X x%

V_1: The volume of sediment product from 1976 to 1977,

V_2: " from 1969 to 1977

Fig. 15 The Balance of Sediment Produced and Deposited (from 1969 to 1976)

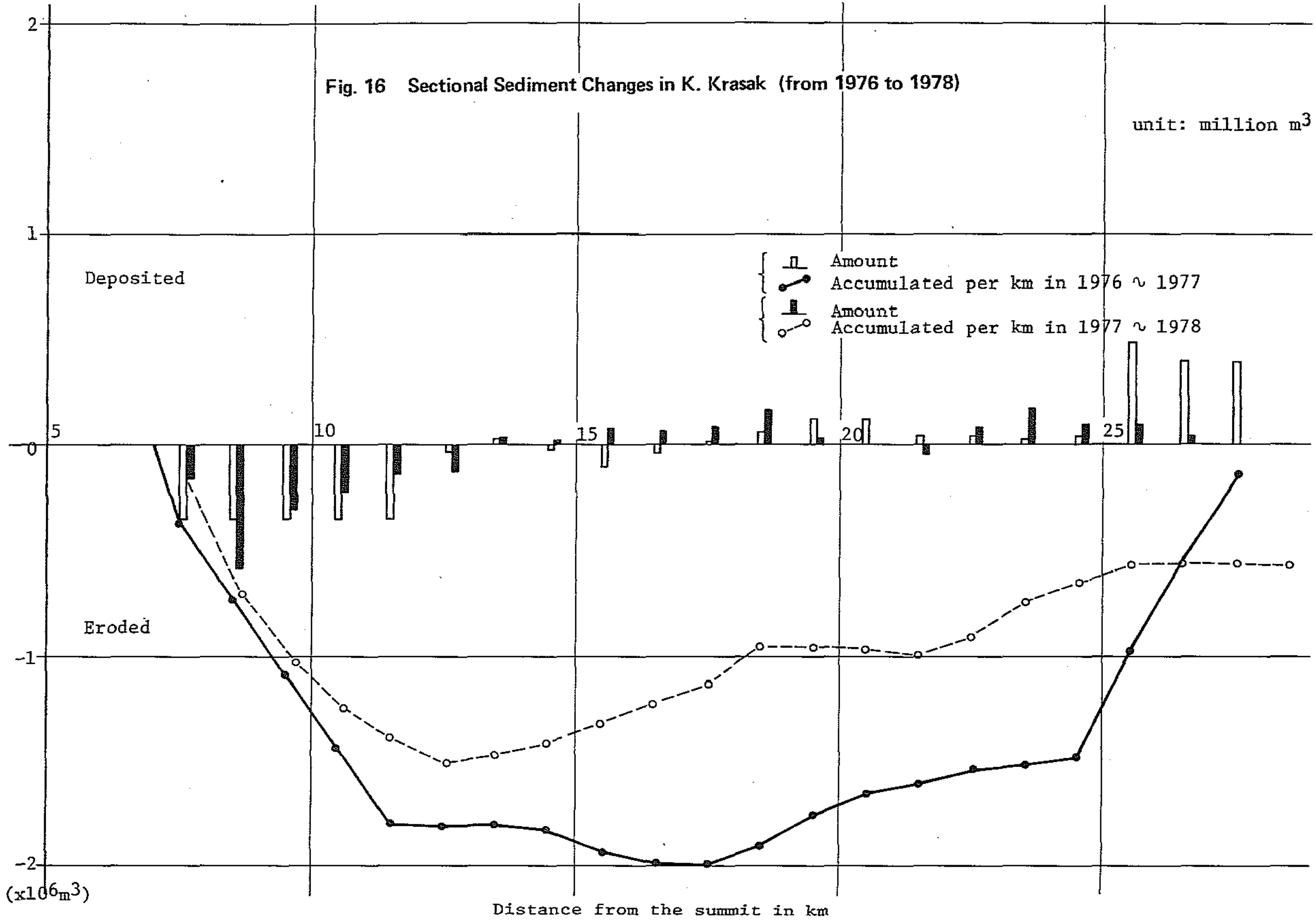


* Figure in ( ) means volume before loosening

** The volume was estimated as follows: V x 8

V_1 : The volume of sediment product from 1976 to 1977,

Fig. 16 Sectional Sediment Changes in K. Krasak (from 1976 to 1978)



2.3 Social and Economic Conditions

2.3.1 Population and Labor Force

The population and population density of the entire area covered by the plan (1,300 km2) are 18 million persons and 1,400 persons per square kilometer. For the main planning area (i.e., the 846 km^2 part of the area covered by the plan that is located on the slopes of G. Merapi) the population and population density are 13 million persons and 1,584 persons per square kilometer, respectively. Almost a third of the population of the main planning area, or 440,000 persons, live in nuée ardente and lahar/banjir hazard areas (422 km^2, with a population density of 1,013 persons per square kilometer).

The main production base of the area is agriculture, which employs most of the population. Because of the dense population, however, the average farmland holding of farm households is less than 0.3 ha, versus an average for Central Java as a whole of 0.6 ha. Living and income standards of residents of the area are low: 40% of the agricultural areas being below the standard of 240 kg of rice per person. Furthermore, there are a great many people who are latently unemployed since there are not enough employment opportunities in the area, and since the population structure by age is normally distributed, employment needs can be expected to be even greater in the future.

2.3.2 Road Network and Social Infrastructure

1) Road Network

In the area covered by the plan the national road running east-west between Yogyakarta and Klaten and the one running north-south between Yogyakarta and Magelang as well as three provincial roads serve as trunk roads. These roads carry a considerable amount of traffic since road transportation if about the only means of transportation that can be relied upon. These are no good harbors on the Indian Ocean side and the other means of land transportation, railway transportation, is out of commission in this area because the bridge girder (at K. Krasak) of the branch line connecting Semarang (with provincial capital of Central Java and a port city) with Yogyakarta via Magelang was washed away by lahar flow.

It is indispensable to the maintenance and development of the various kinds of activities of the area that this road network be protected from disaster damage and also improved.

2) Domestic Facilities

There are hardly any domestic facilities such as domestic water supply, sewerage systems, and electricity supply in the area other than in parts of Kota. Yogyakarta. The electricity supply of D.I. Yogyakarta depends primarily on thermal power generation stations and the Tuntang electrical power supply system. Only parts of Kota. Yogyakarta itself, however, are supplied; the suburbs and the slopes of G. Merapi are still outside the range of supply. At the present time only two micro power stations have been built in the mountain slope areas.

The same picture holds for domestic water supply and sewerage systems. Accordingly wells, springs, and rainwater are depended upon for water for household use, and irrigation canals and rivers for sewage disposal. Needless to say, this situation is very much in need of improvement in order to raise the living standards of rural areas in the area covered by the plan.

3) Social and Cultural Assets

As a cultural city Kota. Yogyakarta has many educational institutions and cultural assets. Furthermore, Repelita III calls for further enhancement of its function as an educational and cultural center.

The most important archeological monuments are the complexes of Prambanan and Borobudur which figure among the most valuable cultural assets of the whole country in terms of attraction of both domestic and foreign tourists.

Protection and stabilization of the area is very important in terms of promotion of tourism, which is an important industry in this area.

Needless to say, it is also very important to the area that its medical care and health facilities, sports and recreational facilities, mosques and other religious facilities, public halls, meeting places, and other public buildings be protected from disaster damage.

2.3.3 Agriculture

1) Land Use and Cropping Pattern

Almost all of the arable land in the area is already being used: farmland accounts for 62% and yard for 24% of the total. Furthermore, approximately 70% of the farmland is utilized for paddy fields.

The cropping pattern is one of combining dry field crops with rice, the main crop. Although practically all of the paddy fields are planted with rice in the rainy season, only where irrigation conditions are good can this be done in the dry season. Therefore there are wide gaps between different places in the area in terms of the annual rate of paddy field use which varies between 0.93 and 2.57 times a year.

There is considerable variation from year to year in what second crops are grown, but the main ones in terms of the acreage involved are maize, cassava, sweet potatos, groundnuts, and soybeans, with some cultivation as well of sugarcane, tobacco, and other cash crops.

2) Irrigation Area

The main production base of the area is agriculture centering on rice. The main boundaries agricultural infrastructure of the area as it exists today were practically completed in the first half of the 19th centure. Farmland accounts for 60% of the land in the area, and in the K. Progo and K. Opak river systems there are innumberable irrigation network of all sizes. On the slopes of G. Merapi, the tributaries with relatively stable river channels are used as the source of irrigation and other water. The agricultural areas in the area covered by the plan can be classified into the following four types on the basis of the state of irrigation facilities and irrigation management:

(1) Technical Irrigation Areas

These are areas in which the construction and management of intake facilities and primary and secondary irrigation canals are undertaken by the national government whereas the construction and management of tertiary or lower class irrigation canals are undertaken directly by the villages that benefit from them. These areas are to be found on the south side of the Mataram irrigation canal (irrigation area of 15,000 ha), which was served from K. Progo and represent high productivity areas that have a high protection priority in the disaster prevention plan.

(2) Semi-technical Irrigation Areas

These are areas in which the national government has undertaken construction and management only of intake facilities, all other irrigation facilities being the responsibility of the villages that benefit from them.

They are widely distributed in Kab. Bantul and Kab. Sleman.

(3) None-technical Irrigation Areas

The areas are widely distributed on the middle and lower slopes of G. Merapi. The units of irrigation are very small, often less than 10 ha, and the agricultural technology is also relatively unsophisticated, with plenty of room for improvement.

The difference in production level between the technical areas and the nontechnical areas is apparent in terms of the stability of supply of irrigation water, the level of agricultural technology employed, the number of crops grown per year, and the yield per unit of farmland.

It is very important that the river courses be stabilized and the amount of irrigation water that can be supplied by increased by means of the disaster prevention works.

The agricultural roads in the area are generally narrow and in poor condition. Furthermore, there are very few roads running laterally across the area; most of them in the same direction as the rivers. It is very important in terms of disaster prevention and promotion of economic activity that the roads and the road network of the area be substantially improved.

3) Farmland Holdings

In the area covered by the plan, 91% of the farm households have farmland holdings of less than 1 ha, and 50% of them have less than 0.2 ha. This is even worse than the situation for Central Java as a whole (83% under 1 ha and an average of only 0.6 ha), which is characterized by relatively small holdings. As for the breakdown between independent farmers and tenant farmers, the farmer account for about 85%.

4) Agricultural Production

a) Stability of Agricultural Production

Crop production statistics for area during the 10-year period 1967-1976 have been used to calculate the yield fluctuation coefficients for each kecamatan for the main crops (irrigation paddy, dry paddy, maize, peanuts, soybeans, cassava, and sweet potatos). Except for a very few kecamatan, production of irrigation paddy has been stable, with a fluctuation coefficient of around 15% or less. Among the dry field crops, the yields for soybeans and sweet potatos have been relatively stable (16% fluctuation), but those of dry paddy, maize, and cassava less so. This can be attributed mainly to the fact that the cultivation conditions for such nonintensive crops are not very good in this area.

b) Land Productivity

In areas where the ratio of farmland area to agricultural manpower is low, it is necessary to raise the productivity of the land as high as possible. Looking at the comprehensive crop yield indices for different parts of the area, one sees that for Type-I areas of Kab. Magelang, where volcanic disaster damage is most frequent and infrastructural facilities are most lacking, the crop yield index was quite low, without a single kecamatan surpassing the standard yields for different crops in Central Java or D.I. Yogyakarta (100) in 1976 and even a decline from 1971. The indices for Kab. Klaten and Kab. Sleman, however, were quite a bit higher, reflecting their relative stability.

c) Specialization of Agricultural Production

The direction of modernization of agricultural production is specialization in cultivation of those crops that are best suited to local conditions and hence most profitable. In the area covered by the plan irrigation paddy is the most highly specialized of the six main crops, followed by sweet potatos and peanuts; maize has a low degree of specialization.

d) Trend of Increase in Yield

The main crop of the area is rice, and in view of the density of population in the area this crop is extremely important in terms of increasing the food supply capacity. Furthermore, increase in production of rice is necessary to increase farm income and to raise the regional development potential through capital accumulation of an economic surplus.

Since there is very little possibility of increasing the agricultural acreage in the area, an increase in agricultural production can only be brought about by increasing the yield per unit of farmland. Taking the average rice yield for three years at time, one sees that in the case of 85% of the kecamatan in the area the yield, which is presently 4.6 t/ha for the area as a whole, is increasing at an annual rate of 1.7%. This is an indication that there is still room for increase in the yield of irrigation paddy in the area, that is to say, for further intensification of its cultivation, and that the area has a very high agricultural potential.

2.4 Past Disaster and Hazard Areas

2.4.1 Past Disasters

From only the many traces left on the slope terrain of G. Merapi by nuée ardente, lahar, and so on, one can tell that this has been a very active volcano that has frequently given rise to disasters, including indirect disasters due to the movement of sediment. It is only since the last major eruption, that of 1969, however, that a detailed record has been kept of the damage incurred. One can conclude, however, from the distances reached by nuée ardente and lahar flows in the past and the numbers of deaths occasioned by major eruptions that the damage due to lahar and banjir that has been observed more recently. Another point that should be kept in mind in this connection, is the fact that there is now more and more at stake in preventing disaster damage of this kind since the social, production, and other infrastructural facilities of the area have been and are continuing to increase and its farmland productivity is rising year by year.

2.4.2 Hazard Areas

The disasters stemming from volcanic activity of G. Merapi are due to nuée ardente, lahar/banjir, and excessive sediment discharge. Judging from records of past damage and topographical characteristics, the hazard areas are explained as follow (see Figs. 17 and 19).

1) Nuée Ardente Hazard Areas

The extent of these areas is as follows as determined on the basis of records for the period 1930-1969:

(1) A distance of 9 km the crater, or an elevation of the 650 m on the western slopes (Type-I areas).

(2) A distance of 11 km from the crater, or an elevation of 550 m on the southeastern slopes (Type-II and -III areas).

These hazard areas amount to approximately 136 km^2 on the middle and upper slopes of the mountain, or about 16% of the total area of the slopes of G. Merapi.

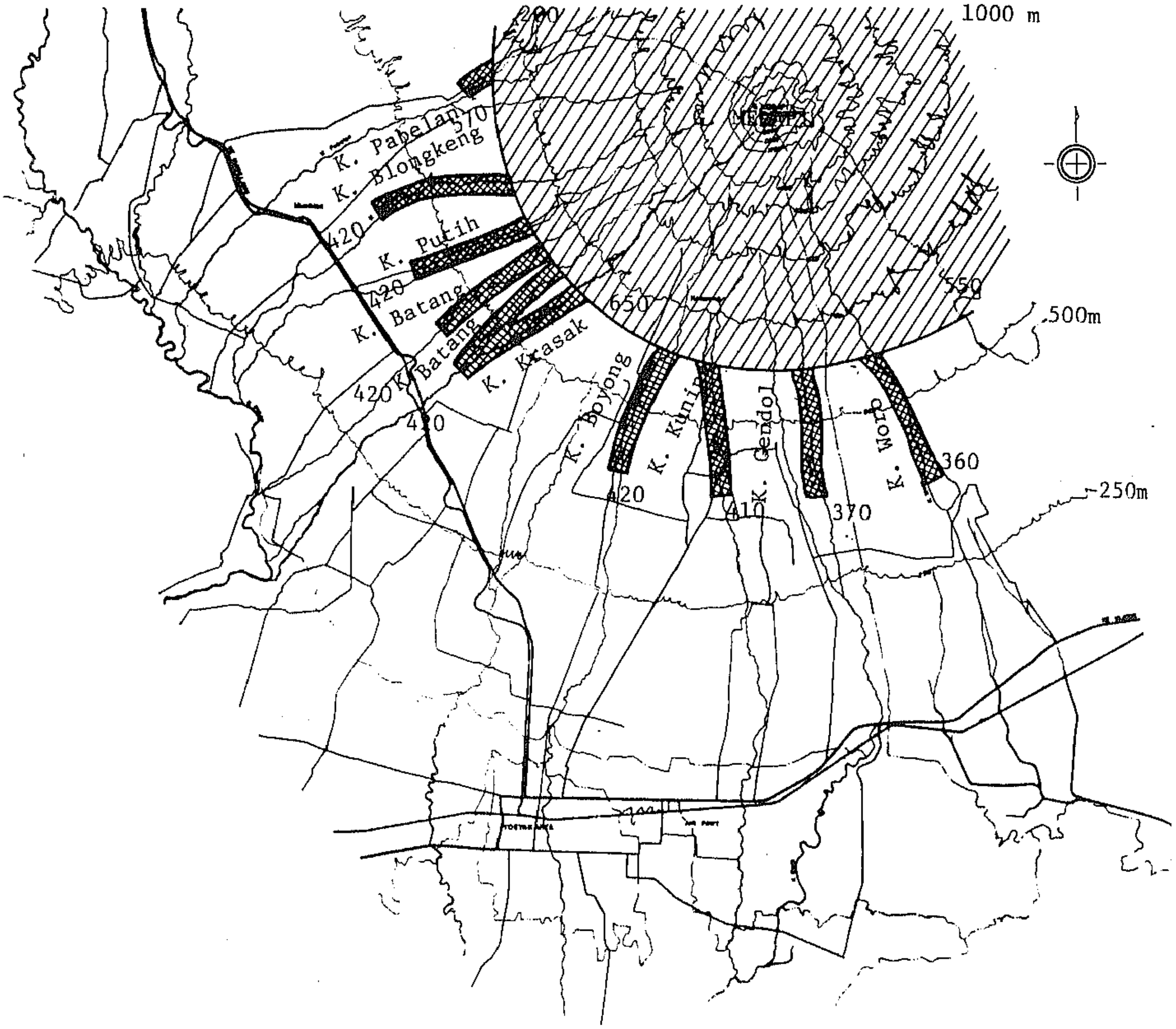
2) Lahar and Banjir Hazard Areas

Lahar flow starts on the upper middle slopes of the mountain between 1,000 m and 2,000 m in elevation. The damage caused by it occurs in the hamlet and farming areas on the middle and lower slopes. Such lahar flows occur repeatedly after an eruption, and the damage wrought by them is enormous. The range of the lahar flows, as determined on the basis of past records, topographical conditions, and theoretical study is for the most part slope degree 2° and elevation 360 m to elevation 420 m, as indicated in Fig. 18. This is also the range of occurrence of banjir.

"Banjir" usually means flooding, but in the tributary areas of G. Merapi the relatively steep gradient makes for a very high sediment content in such flood waters. The damage is done mostly by an intermediary form of flow between lahar and flood.

A survey on the basis of topographical analysis and records of past flooding has resulted in the determination that approx. 286 km^2, or 34% of the total area of the slopes of the mountain, represent lahar/banjir hazard areas.

Fig. 17 Distribution Map of Nuée Ardente and Lahar



Legend

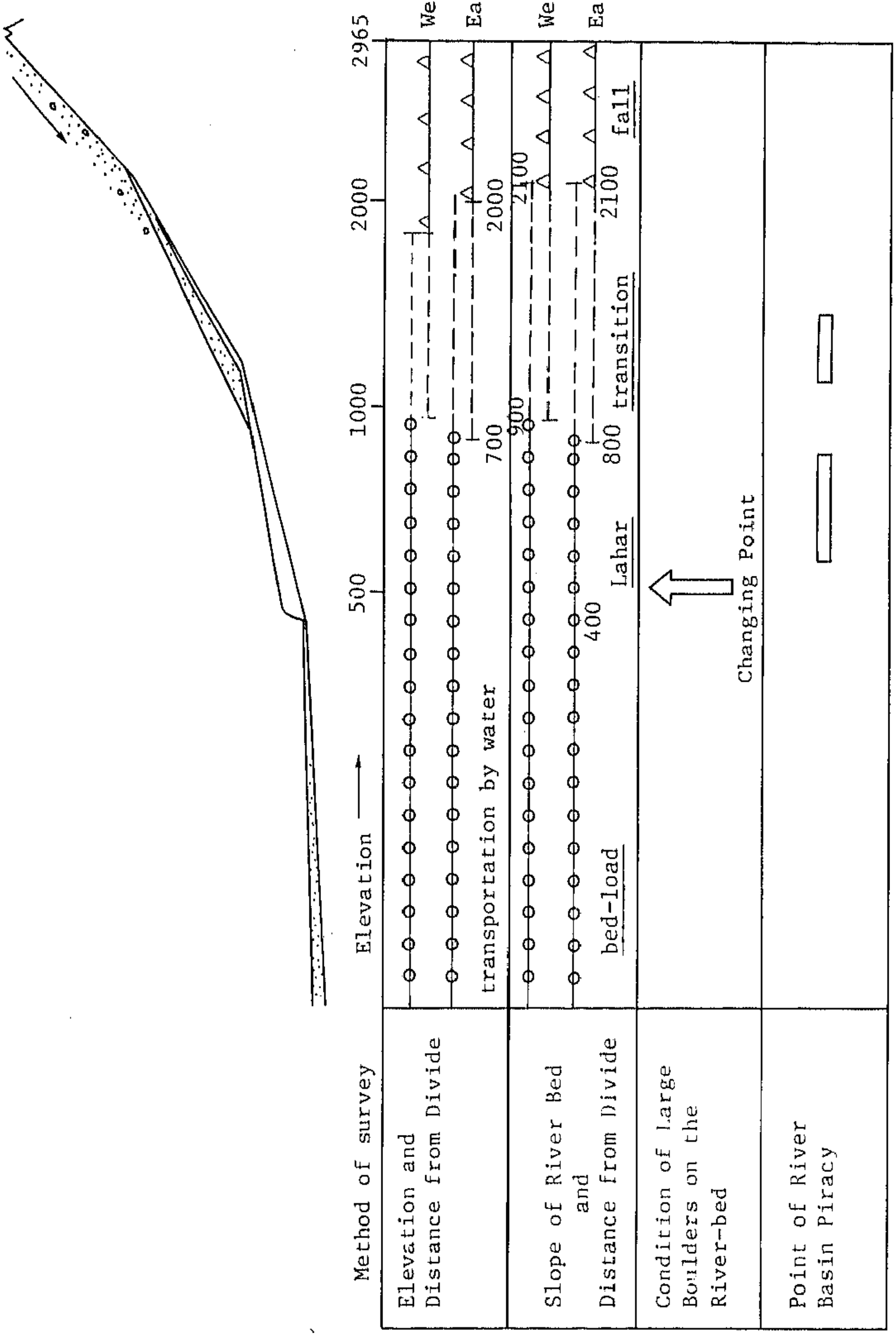
▨ : Nuée Ardente Zone

▦ Lahar Zone

: Banjir Zone

Scale: 1:250000

Fig. 18 Characteristics of Sediment Locations



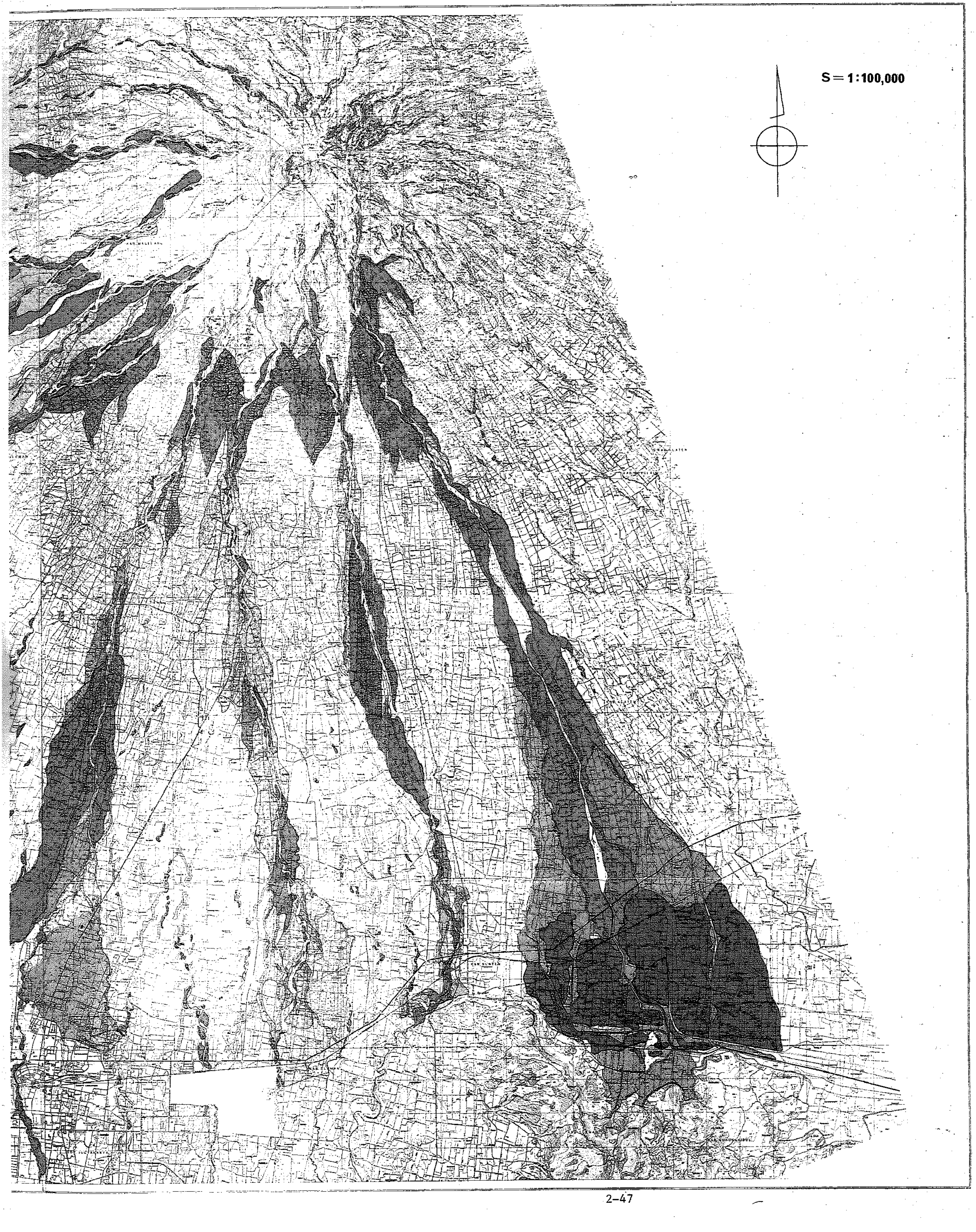
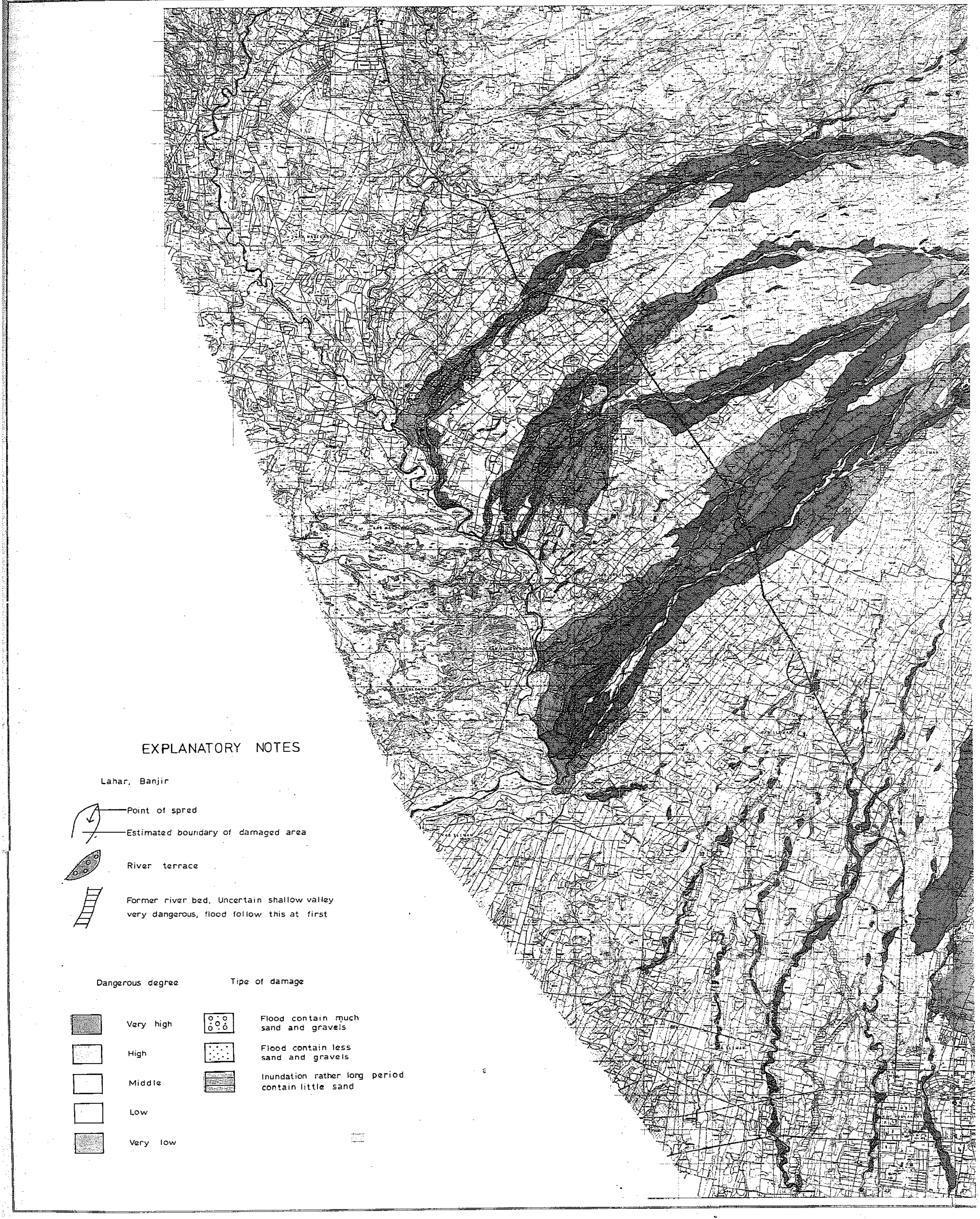

S = 1:100,000

Fig 19 PROBABLE ENDANGERED AREA MAP
(Lahar/Banjir Hazard Area)



CHAPTER 3

DISASTER PREVENTION PLAN

CHAPTER 3 DISASTER PREVENTATION PLAN

3.1 General

3.1.1 Area Classification and Countermeasures

On the basis of the measurement of degree of flooding danger and degree of socio-economic importance and national policy goals for the region, the area covered by the plan has been divided into five planning zones. The location of each zone together with the indicated basic policy regarding countermeasures is described in the following paragraphs: (see Fig. 3 in chapter 2)

1) Zones 1 and 2

Area	:	Area subject to Nuée Ardente damage which lie within a radius of 9.0km from the crater (about $136km^2$)
Countermeasures	:	Changes in land use, resettlement and relocation plan and sabo works.

This zone, on the upper slopes of the mountain embraces those areas where the risk of direct damage from *nuée ardente* is high. As a zone in which habitation is to be prohibited for reasons of safety, an active effort is to be made to resettle the people now living there elsewhere. The areas cleared by such resettlement and barren areas in this zone are to be reforested for the sake of soil and water conservation.

2) Zone 3

Area	:	Areas subject to damage from Lahar or Banjir along main tributaries (about $286km^2$)
Countermeasures	:	Sabo facilities, warning system and associated works.

In areas subject to damage from lahar or banjir, sabo facilities will be provided for active checking and control of sediment production and discharge, and the warning and evacuation system will be improved in order to mitigate the damage. At the same time, the regional development potential will be enhanced, and a foundation will be built for promotion of regional development.

3) Zone 4

Area	:	Other areas on Merapi's slope (about $424km^2$)
Countermeasure	:	Warning system and associated works.

Since there is little danger of damage from lahar or banjir in these areas, at least for the time being, it will not be necessary to provide any active disaster prevention countermeasures other than improving the warning and evacuation system, however measures should be taken to enhance development potential and built a foundation for promotion of regional development.

4) Zone 5

Area : Other Areas covered by the Plan (K. Progo and K. Opak problem spots)

Countermeasures : Control of sediment discharge and improvement river course with appropriate works.

Along K. Progo and K. Opak, there are such specific problems as:

(1) Sedimentation to irrigation intakes and facilities
(2) Land side water inundation
(3) Stoppage of river mouth by drift of sand
(4) Erosion of river banks

To solve these problems, sediment discharge will be controlled in the tributary area and improvement of river course and adequate maintenance should be performed.

The following table summarizes the countermeasures for each Zone as described above.

Planning Zones and Countermeasures

Zone	Relocation and Land Use Improvement	Sabo Works	Warning System	Associated Works	Appropriate Works
1	+	+			
2	+	+			
3		+	+	+	
4			+	+	
5					+

3.1.2 Areas Covered

The plan will be for the following two areas which were chosen on the basis of such considerations as the tasks involved, effectiveness of the measures to be taken and geographic unity (see Fig. 3).

1) Main Planning Area: Regional Disaster Prevention Master Plan Area

Tributary areas principally of K. Progo, K. Opak and K. Dengkeng on the slopes and foothills of G. Merapi, covering approximately 850 km^2 and Planning Zones 1-4 which consist of the following administrative unit:

D.I. Yogyakarta:	Kota. Yogyakarta	Whole area
	Kab. Sleman	Whole area (except two kecamatan)
	Kab. Bantul	Five kecamatan
Central Java:	Kab. Magelang	Five kecamatan
	Kab. Klaten	Six kecamatan

2) Secondary Planning Area: Problem Spot Countermeasure Area

Problem spots located along K. Progo and K. Opak which comprise planning zone, which mainly belongs to Kab. Bantul of D. I. Yogyakarta.

3.1.3 Plan Targets

1) Planning Target Year

Normally the target year for a master plan of this kind is about 10-20 years, but considering the periodicity of the volcanic activity of G. Merapi after 1800 (one eruption over 9-16 years if only major eruptions are considered), the form that the disaster damage takes and that already 10 years has passed since the last major eruption in 1969, the master plan should be started and completed as early as possible. The planning target year should be 15 years.

2) Goals for Each Planning Area

a) Main Planning Area

The goals of the measures to be carried out are as follows:

(1) Improvement of the safety of residents of hazard zones through better disaster prevention arrangements, including some resettlement and organization of a better warning system.

(2) Preservation of the river basins through improvement of land use and reduction of damage and enhancement of riverbed stability through promotion of disaster prevention works.

(3) Stabilization of regional agricultural products through enhancement of stability of river courses and irrigation intakes by disaster prevention works.

(4) Promotion of regional development through multipurpose use of the sabo facilities and provision of associate works.

b) Secondary Planning Area

The plan shows the directions to be taken with respect to basic countermeasures for coping with each kind of damage occuring at problem spots.

3.2 Main Planning Area Countermeasures

3.2.1 Land Use Improvement Plan

1) Resettlement and Afforestation

The main disaster prevention measures for the area threatened by damage from nuée ardente is land use improvement and resettlement of some residents. These area, which total approximately 136 km^2 or 16% of the area covered by the plan, are extremely important from the standpoint of river basin control and preservation and other aspects of disaster prevention. Their main features and countermeasures are at follows (See Tables 9, 10, and Fig. 20).

a) Resettlement of Residents From off-Limits Zones

Since it would be technically difficult to prevent direct damage from nuée ardente and other direct influences of volcanic eruptions, nuée ardente hazard areas zones 1 and 2 have been zoned as off-limits. The Indonesian government has put these nuée ardente areas off-limits as being extremely hazardous and has been proceeding since 1960 with resettlement plan for the residents, but not a few still live in these areas and rely on farming for a living. The productivity of the farmland, however, is very low. This is particularly true of the Type-I areas on the western slopes where there is high frequency of disaster damage and the river basins are in poor condition.

For the sake of the safety of residents and preservation of the river basins, there should be expeditions resettlement of the river basins, there should be expeditions resettlement of people presently residing in such areas. This will involve relocation of 11,000 homes and resettlement of 50,400 persons for their own safety.

b) Afforestation of Vacated and Waste Lands

For the sake of the stability of water source areas and preservations of river basins, there is to be active afforestation of waste land, farmland and sites vacated by resettlement. As the result the amount of forested land will be increased from the present 7% to 51%. This will involve the conversion of 6,010 ha by afforestation.

To check sediment production, it is necessary that land use be actively improved, including afforestation of wasteland, sites vacated by resettlement, and even poor farmland and improvement of low-quality existing forests. Research is now being done at Bogol Agricultural University in Indonesia to determine what kinds of trees are best suited for such afforestation. For the time being, pine trees and acacia, which are widely distributed in these areas, can be used for this purpose.

However there are some opinions from the past experience trees will good die due to the ash and dust from the volcano (rain, ash/dust). Investigation for proper kind of trees for this purpose should be performed.

Although such forests will be mainly for disaster prevention purposes, those in peripheral areas can be multipurpose, including some for timber production and cattle breeding.

c) Sabo Works

In addition to labor, these area the main areas of production of the sediment discharge that causes disaster damage downstream. Provision of check dams, consolidation dams and training levees is proposed.

The large amounts of sediment discharged to the downstream areas of planning zone-3 do not directly result from eruptions, but are for the most part produced by erosion resulting from rainfall; they nonetheless cause the major part of the damage in the project area. However the implementation works in this area should be studied carefully before the implementation.

2) Implementation Plans

(1) Resettlement Plan

Number of Residents (unit: person)

	Zone-1	Zone-2	Total
Stage-1	15,900	-	15,900
Stage-2	-	34,500	34,500
Total	15,900	34,500	50,400

(2) Afforestation Plan

Afforestation Area (unit: ha)

	Zone-1	Zone-2	Total
Stage-1	1,290	-	1,290
Stage-2	-	4,720	4,720
Total			6,010

In stage-1, a pilot project involving investigation on best suited trees to plant and planting method, training of afforestation technical personnel and publicity activities should be performed.

Table 9 : Present Land Use in Zones 1 and 2 Areas

unit: ha (%)

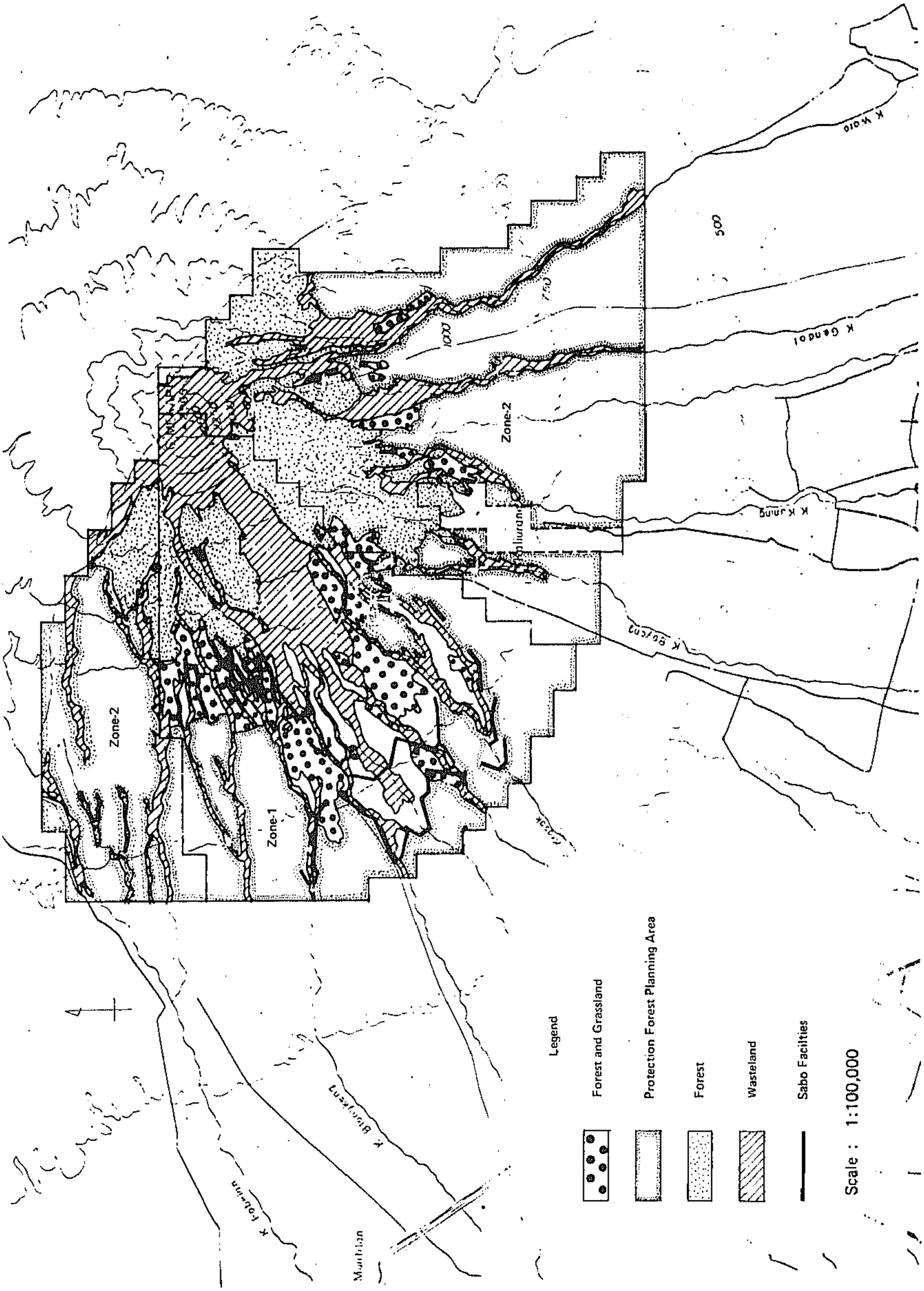
Type of area / Land use categories	Type-I area (Zone-2)	Type-II and III area (Zone-2)	Total
1. Paddy field	670(11)	1,120(15)	1,790(13)
2. Dry field	720(12)	2,840(36)	3,560(26)
3. Yard	420(7)	1,030(13)	1,450(11)
4. Protection Forest	780(13)	200(3)	980(7)
5. Forest or grassland	810(14)	520(7)	1,330(10)
6. Others	2,600(43)	1,890(26)	4,490(33)
Total	6,000(100)	7,600(100)	13,600(100)

Table 10 : Planned Land Use in Zones 1 and 2 Areas

Unit : ha (%)

Type of area / Land use categories	Type-I area (Zone-1)	Type-II and III area (Zone-2)	Total
1. Paddy field	520(19)	270(3)	790(6)
2. Dry field			
3. Yard	-		
4. Forest (Protection Forest)	2,070(34)	4,920(65)	6,990(51)
5. Forest or Gassland	810(14)	520(7)	1,330(10)
6. Others	2,600(43)	1,890(25)	4,490(33)
Total	6,000(100)	7,600(100)	13,600(100)

Fig. 20 Planned Land Use in Nuée Ardente Area (Zones 1 and 2)



3.2.2 Warning System Improvement Plan

1) Improving Observation System

Only by means of provision of sabo facilities, other disaster prevention activities and the establishment of a disaster prevention system that includes improved warning system it will be possible to ensure the safety of residents in Lahar and banjir hazard areas.

Improvements will have to be made with respect to the following matters for establishment of a better disaster prevention system:

(1) For the establishment of a better warning and evacuation system, it will be necessary to have more precise forecasting criteria a better observation and monitoring system, a more reliable and expeditious notification system, and smoother and speedier evacuation arrangements. Basic research and the necessary facilities for observation and forecasting of natural phenomena will be needed.

With introduction of telemetric monitoring, a centralized observation and monitoring system will be possible. The observation and monitoring system and organization, with additional four telemetric observation posts in the area: where the lahar occurs or surrounding area, is shown in Fig. 21.

For accurate and timely forecasting of occurrence of Lahar, it is necessary to determine the relationship between lahar and rainfall. Furthermore, for such forecasting to be of use it is necessary that the occurrence of the lahar should be forecasted 1,5 ∿ 2.0 hours beforehand considering the flow speed and the amount of time it takes for the warning process to be completed.

For short-period forecasting of amount of rainfall, it is necessary to be able to keep abreast of actual rainfall conditions at all times, and this will require drastic improvement of the observation and monitoring system, including the introduction of telemeters.

For forecasting of the amount of rainfall, there is also the possibility of determining the rainfall area and rainfall intensity by means of radar echo, however, since there is large quantitative error, such radar echoing can be effectively used only with a telemeter monitoring system.

2) Improving Warning Communication System

The warning communication system that is to be established will make it possible for the residents of lahar and banjir hazard areas to be notified quickly of danger by speakers and sirens. Considering the size of the area and the range of the speakers and sirens, approximately 1.0 km, there will have to be a considerable number of substations, 10 ∿ 15 substations in the case of Type-I area.

(See Figs. 22 and 23) Since the area does not have a supply of electricity, microgenerators and emergency batteries will have to be used.

3) Provision of Evacuation Routes

Road networks for construction and maintenance works of sabo and associated facilities are also to be used for evacuation routes.

4) Publicity Activities

Getting the residents of the endangered areas to completely realize, the nature and extent of the hazards they are facing.

5) Basic Study

The establishment of forecasting criteria is a very basic requirement of the warning and evacuation system. Since, however, this is a pioneer area of science, it is better that such study be undertaken from a broad viewpoint in an established sabo technical center in Indonesia.

6) Implementation Plan

An improvement of warning and evacuation system is to be established in two stages.

(1) Stage 1

The emphasis will be on expeditions evacuation of mainly Type-I area, where the frequency of disaster is high, and on collection and analysis of basic data. Main activities of the Stage 1 is explained as follows:

(a) Publicity of the hazard areas completely to the residents.

(b) Improvement of the warning Communication system by provision of substations, so as to enable immediate evacuation whenever it might occure. Since not much can be expected for the time being with respect to forecasting to occurrence of Lahar.

(c) Provision of evacuation routes by improving road network for construction works in order to enable safe and swift evacuation.

(d) Provision of Observation and monitoring facilities with a network of telemetric system.

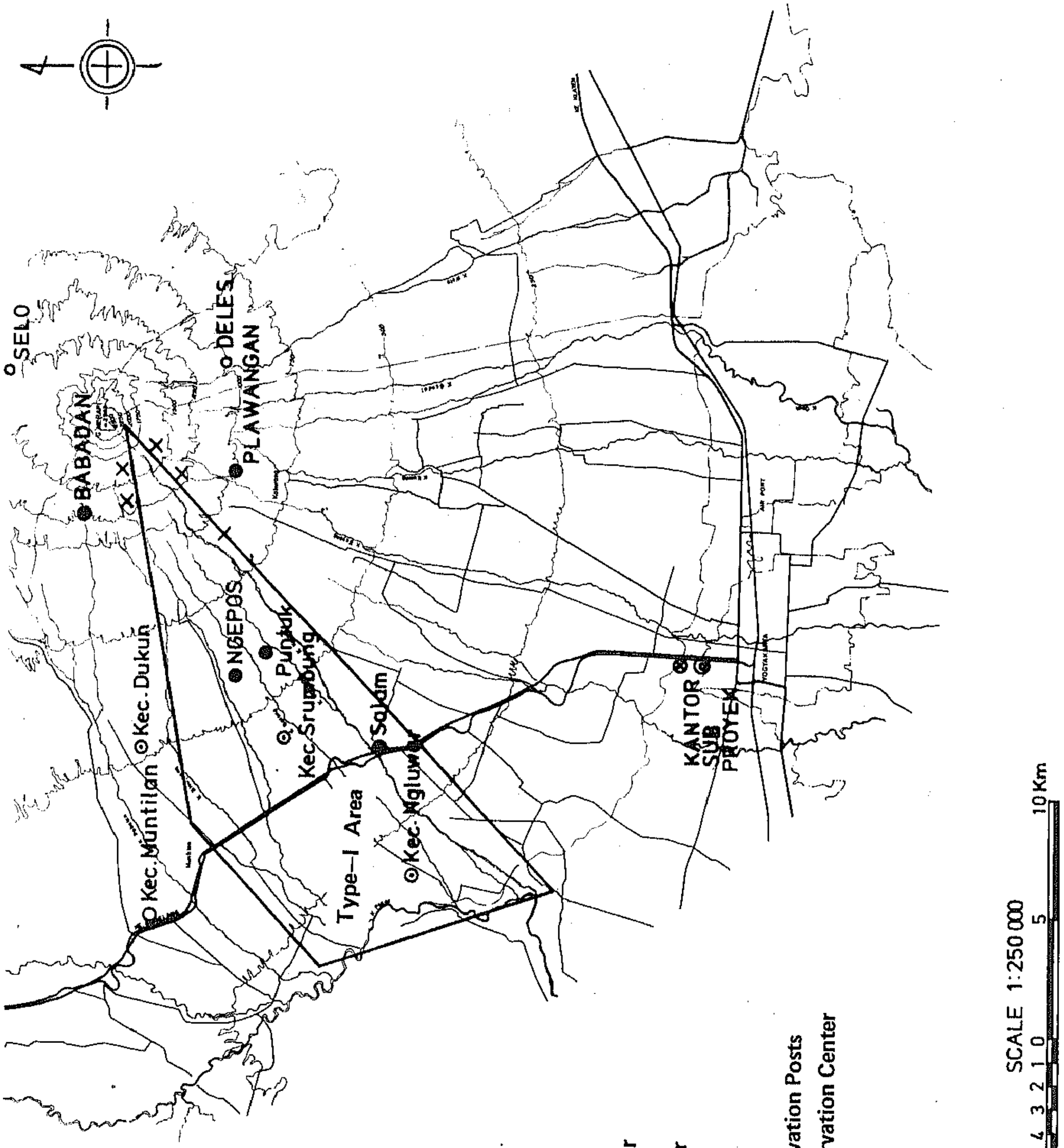
(e) Basic research with respect to rainfall criteria for occurrence of lahar and other matters.

(f) Pilot warning system

(2) Stage 2

Establishment of the whole warning and evacuation system for the area covered by the plan.

Fig. 21 Location Map of Observation Posts, Raingage Information Centers Telemetric Observation Posts



Legend

- ● Observation Post
- ◉ Main Information Center
- ⊙ Main Information Center (With Radio Telephone)
- ○ Main Information Center (With Telephone)
- × Planned Telemetric Observation Posts
- ⊗ Planned Telemetric Observation Center

Fig. 22 Location of Warning Communication Substations in Type-I Area

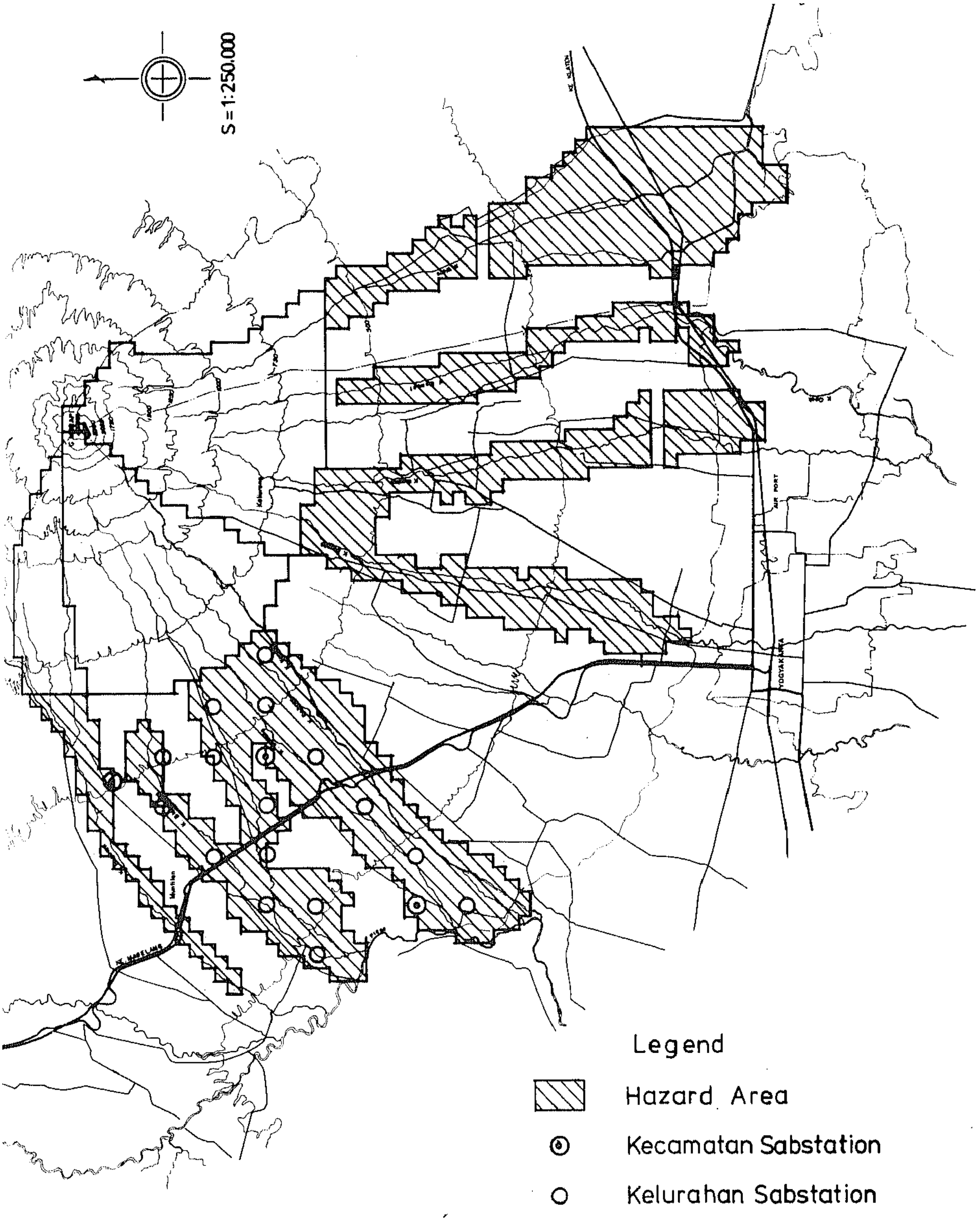
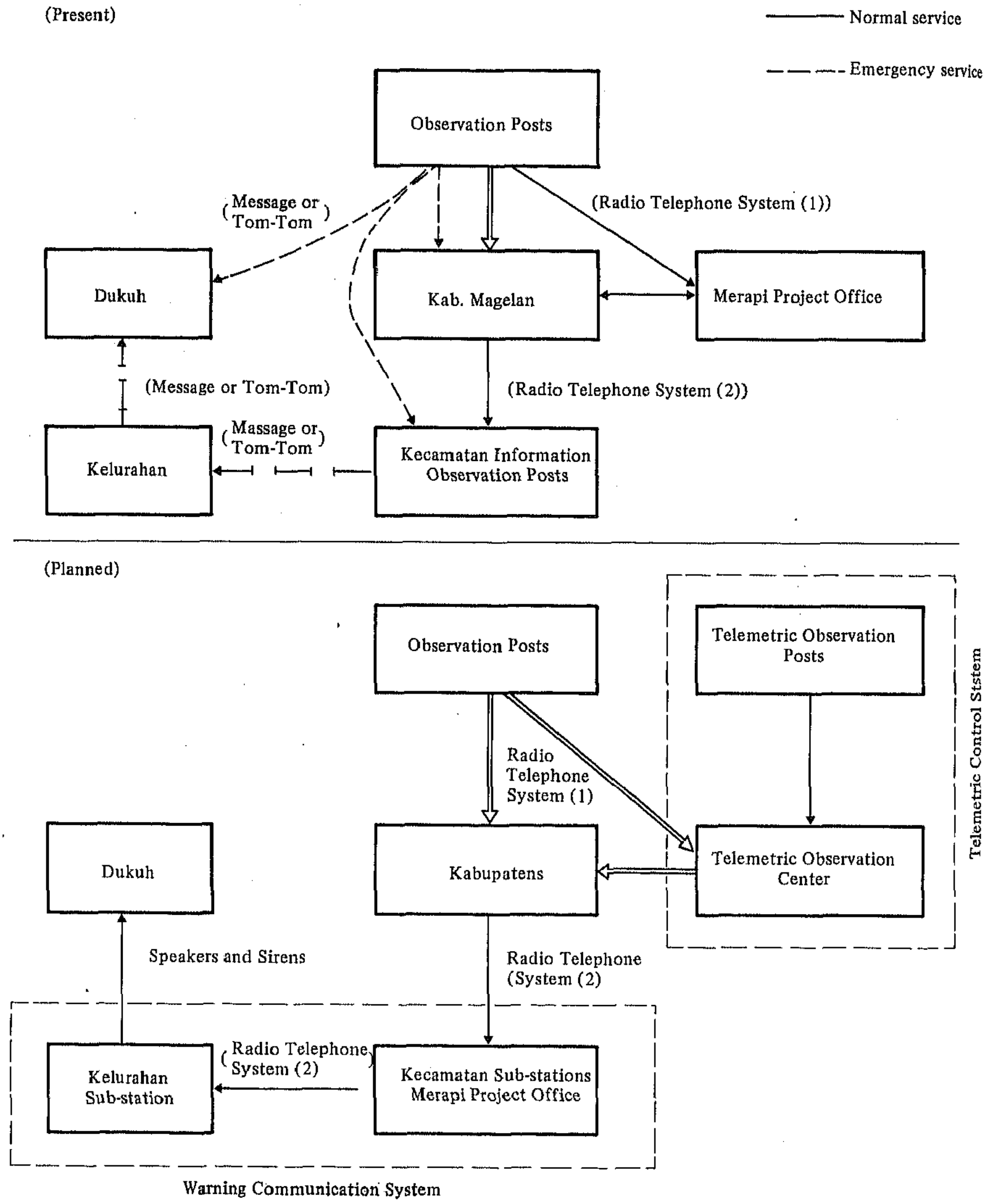


Fig. 23 Warning Communication System



3.2.3 Sabo Facilities Plan

1) General

The disaster prevention facilities to be provided in the present plan are meant to reduce and prevent damage from lahar and banjir flooding along K. Krasak and eight other tributaries on the slopes of G. Merapi and to reduce the amount of sediment discharged form them into K. Progo, K. Opak, and K. Dengkeng in view of the problems that such sediment causes, including damage and obstruction of irrigation facilities.

The main cause of damage is the large amounts of sediment discharge that takes place as a result of the flooding and sediment production after volcanic eruptions. Accordingly, the plan calls for the elimination or control by the sabo facilities of that amount of the maximum annual sediment discharge taht is expected to cause damage. In the case of K. Woro, however, the amount of sediment discharge in normal years is also subject to reduction and control in view of the fact that it presents a problem in terms of riverbed rise.

The scale and Locations of sabo facilities are planned to be effective for the structure life of 50 years. And as a rule multi-purpose uses of check dams and consolidation dams are planned, especially for irrigation water.

2) Basic Policies and Criteria

a) Objectives of Sabo Facilities

The objectives of sabo facilities are to mitigate or reduce the sediment disaster caused by Lahar and Banjir. Disaster caused by Nuée ardente is not included in the objective since control of the volcanic eruption is technically unfeasible.

b) Assumptions about the Coming Major Eruption

Volcanic hazard areas and amounts of sediment are largely dependent on the direction of colcanic activities. Although a prediction of the direction of colcanic activities is very difficult, it is not practical to plan countermeasures against every possible direction of volcanic activity. The Master Plan is based on the following assumptions:

(1) The direction of major volcanic activities will continue to be towards the type I areas.

(2) The scale of sediment amount will be approximately equal to the amount produced from the eruption of 1969.

(3) The cycle of major eruptions is 12.5 years based on the data of eruptions since 1800.

c) Proposed basic Amount of Sediment

The amounts of sediment produced and discharged are mostly dependent on the volcanic activities rather than on the scale of rainfall and runoff. The proposed sediment amount for each of the main tributaries is based on the following assumptions:

(1) Tributaries in Type I Areas

K. Krasak and K. Putih :	The maximum annual sediment discharged will be equal to the amount produced from the eruption of 1969.
K. Batang :	The sediment discharged will be equal to the amount transported by K. Bebeng which is one of the main tributaries of K. Krasak. Although K. Batang experienced very little sediment discharge from the eruption of 1969 and although it seems rather stable from the viewpoint of its topographic conditions, the possibility of river course alteration with K. Bebeng charging its channel to K. Batang in a future major eruption is high based on historical data.
K. Blongkeng:	The sediment discharge amount will be equal to the amount handled by K. Putih. Although an alteration of river course occurred to K. Putih with the plugging of K. Blongkeng in 1969, the possibility of a similar alteration of river course in the future is very high.

(2) In Type II Areas, and III

The maximum annual sediment discharge will be produced from the unstable sediment presently deposited upstream, except for K. Woro, where the average annual sediment discharge for normal years will also be considered in the proposed amount.

d) Basic Policies for Sabo Facilities Planning and their Characteristics

From the hazard areas and the scale of sediment discharge, the planning area was divided into two zones: Zone I (Type I areas) and Zone II (Type II and III areas). The basic policies for each zone are explained as follows:

(1) Valley Mouth Fixation Works at Upper Slopes (Upper Stream 10 km from the Summit)

In the upper reach of the tributaries where river piracy is pronounced, stream systems are not yet developed and will change very easily according to the influence of volcanic activities. Large amounts of sediment that will cause major damage to down-steam areas, will be eroded and discharged. By provision of training levees and check dams and consolidation dams at the valley mouths, the course of debris flows will be guided into the present channel.

(2) Reduction of Lahar Damage

Lahar flows of unstable volcanic debris erode the river banks and beds, carrying large amounts of sediment and causing tremendous damage.

Lahar occurs above an elevationof about 100 m. Although it is difficult to check its occurrence, sabo facilities will reduce erosion and prevent the Lahar from developing too much energy bu fixing riverbeds, rising riverbeds, making riverbeds wider and lowering the riverbed gradient.

(3) Reduction of Excess Sediment

If the amount of sediment discharged exceeds the possible river capacity for transport of sediment, the sediment accumulates in the riverbeds and raises riverbed levels. The amount of sediment that exceeds the river capacity to transport are to be reduced and controlled by checking and controlling sabo facilities.

(4) Improvement of River Courses

River courses will be improved with consolidation dams and embankments at the places where there is pronounced flooding due to poor conditions of drainage and river structure.

e) Area Characteristics and Basic Countermeasures

i) Area Characteristics

(Type I Area)

(1) In Type I areas the supply of sediment from eruptions continues.

(2) Piracy of river channels is pronounced, with change in basin area and course of flow and sharp change in amount of flow and amount of sediment discharge a very high possibility.

(3) For work safety considerations in connection with such change in course of flow, there is a limit to what works can be provided for prevention of the erosion by Lahar which is the source of production of the sediment that is discharged.

(4) The riverbed gradient is relatively large, which means that the sediment discharge capacity is also large.

(Type II and III Areas)

(1) There is little influence from eruptions and both basins and courses of flow are fixed.

(2) Production of sediment is based primarily on erosion of riverbed and riverbank deposit.

(3) Except for K. Woro, there are flooding danger spots along the middle stretches.

(4) K. Dengkeng, which is the main river of K. Woro, has very small sediment load capacity, and therefore at the middle and lower stretches of K. Woro, the riverbed is rising year by year so that it has become higher than the surrounding land.

ii) Basic Countermeasures

(Type I Area)

(1) Fixation of valley mouth upstream.

(2) Reduction of sediment production and discharge. Since there is a limit to reduce the sediment production and discharge, the remaining amount is to be rapidly conveyed into K. Progo.

(3) Improvement of the middle and lower streches of the rivers so that flood waters can flow down smoothly.

(4) The planning must be flexible enough to allow for changes depending on eruption and riverbed changed conditions.

(Type II and III Areas)

(1) Reduction of sediment production and discharge.

(2) Improvement of middle and lower st retches of the rivers to allow for smooth flow of flood waters.

(3) Coping with the sediment discharge of normal years in the case of K. Woro.

f) Project Life and Frequency of Major Sediment Discharge during the Project Period

(1) Project Life

The proposed project life is set at 50 years which is the same as the life of a structure.

(2) Frequency of Sediment Discharge Affecting Project Scale

Frequency depends on the possibility of direct influence from the volcanic activity which was decided as follows:

(i) Type I Areas

The proposed frequency of major sediment discharge is a period of 25 years. Although the major eruption chcle is 12.5 years, this cycle is based on the assumption that each river will be affected by about every other major eruption as in the past.

(ii) Type II Areas

The frequency is once in fifty years.

(iii) Type III Areas

The cycle is a period of 100 years, and once in the project life.

3) Proposed Basic Amount of Sediment

In the area covered by the plan the amount of sediment discharge is summerized as follows (see Table 12):

Proposed maximum annual sediment discharge is 51,011 x 10^3 m^3/year, however 16,035 x 10^3 m^3/year of it is to be controlled on river courses, and 2,606 x 10^3 m^3/year is to be discharged to main rivers without any harm. Then the rest amount of 32,370 x 10^3 m^3/year has to be handled by the plan.

In the case of K. Woro, the amount to be handled by the plan is 18 x 10^3 m^3/year that is the difference of the proposed normal annual sediment discharge (24 x 10^3 m^3/year) at Wono Boyo Check dam.

4) Plans for Handling the Sediment

For coping with the proposed amount of excess sediment discharge, the proposed amount of discharged sediment is to be reduced to the allowable amount of discharged sediment, the following are basic countermeasures:

(1) Plans for Reducing Sediment Production

This plan is for reducing the production of sediment by riverbed and riverbank erosion, collapsing, etc. by means of check dams and other facilities. Since this means reduction of the absolute amount of sediment discharge, it is the most drastic countermeasure and one that will have a permanent effect.

(2) Plan for Reducing Sediment Discharge

Since this plan is for reduction of sediment discharge through storage of sediment by check dams, sand pockets, and other facilit ies and excavation, there is a limit to how effective it will be.

The scale of the facilities is planned to effective during the life of faciltiës (fifty years).

(3) Plan for Controlling Sediment Discharge

This plan is for controlling the large amounts of sediment discharge at times of flooding by means of check dams and other facilities.

Usually check dams have the effect of controlling sediment discharge even after accumulated to a proposed level. There must be a considerable difference between the sand accumulation gradients during flooding and after flooding, and plenty of time for the sand accumulation gradient during flooding to returned to the ordinary gradient.

This plan is applied to the tributaries in Type III and K. Lamat in Type I, however not applied to other tributaries in Type I and II Areas where ordinary sediment discharge amounts are comparatively large.

(4) Plan for Improvement of River Courses

River courses will be improved at placed where the danger cannot be entirely handled with the above plans for coping with sediment alone.

This plan will apply mainly to areas downstream of the proposed first standard point. This where sediment is conveyed and deposited and where there is pronounced flooding due to damage to embankment and revetment works resulting from the insufficient drainage capacity of the rivers and scouring of the banks as well as pronounced bank collapse due to meandering and deviating river flows. There are two case of insufficient drainage capacity. One is that in which the riverbed rises owing to sediment deposits and the cross-sectional area of the river is reduced, and the other is that in which an eruption, river channel piracy, or other case results in a rapid increase in runoff and sediment load.

The following works are therefore to be provided so that there will be little riverbed fluctuation or meandering or deviation of flow, no flooding or bank collapse, and smooth conveyance of flood waters and sediment downstream.

For this purposes, consolidation dams, embankments, revetments and groins are planned.

5) Structural Planning Policy

a) Height of Check Dams

The around base for the foundations of the check dams consists mostly of unsolidified lahar deposits and Nuée ardente deposits, and generally the ground bearing capacity is low and the permeability is large; it is scoured easily. In short, the ground base for such foundations is not very good. Accordingly, the height of the check dams can be no more than 15 m. If a height of more than 15 m is necessary, a second dam will have to be built on top of the stored sediment of a dam, and since this ground or foundation base will be even less ideal, its height cannot exceed 10 m. Furthermore, if there is insufficient bearing capacity or creep length, the base of the dam will have to be widened and aprons and cutoffs increased.

b) Freeboard of Check Dams, Consolidation Dams, Embankments, and Bank Protection Works

In determining the amount of freeboard, such factors as the proposed amount of high water flow and the riverbed gradient are taken into account. In the area in question it will have to be 1 m in view of the marked riverbed fluctuation and other circumstances. Furthermore, in order to prevent lahar from flowing over the top of the check dams, the crowns of the wings of the dams and the bank height are to be at least 5 m.

c) Scouring Prevention Works for Check Dams and Consolidation Dams

Because of decline in sediment load and other changes in hydrological conditions due to check dams and other facilities, downword scoring of the foot of such facilities is inevitable, particularly in view of the fact that the riverbed matter consists of fine particles. Accordingly, from the outstart sufficient provision must be made for scouring prevention works, including provision of a second apron in most cases.

d) Foot Protection Works for Revetment and Groin

Foot protection works are to be provided at places where revetment groins can be expected to be scored. Furthermore, revetment works will be needed where groins are installed.

e) Protection Works for Wings of Check Dams

Since the wings of dams are easily damaged by the shock of lahar flow, banking and bank protection works will be necessary to protect the wings from the direct shock of the lahr flow.

f) Protection of Crowns of Check Dams and Consolidation Dams

Since the crowns of the dams will be subject to great deal of abrasion from the sediment load, they will have to be reinforced with rock materials, intensive concrete, and other such materials.

g) Materials and Implementation of Construction

For economy and from the standpoint of providing local employment opportunities, such materials as rock, earth and sand, bamboo, and wood are to be used for the structures and the construction is to be done mostly manually.

h) Flexible Staged Implementation of Plan

Sabo works have a great influence on sediment load, riverbed variation, and so on. Since there are many phenomena that cannot be foreseen at the time of planning, it is necessary to carry out the construction work in a flexible manner while observing actual river conditions. For instance, construction of a dam might be divided into two stages: Stopping after the construction of the first stage to observe the effects of it before proceeding with the second stage, and if advisable, even adding a dam that was not originally planned for between the first and second stage.

i) Multi-purpose Use of the Sabo Facilities

These facilities are to be planned in such a way that they can also be used for irrigation water intakes and other purposes. This means that as a rule intkes and approach channels are to be provided as a part of the check dams and consolidation dam. Passageways, washing places, and other everyday facilities for use by local residents are also to be provided.

6) Facility Location Plan for Each Tributary

a) K. Krasak (Type I)

The following facilities are to be provided for protection against lahar flow at times of eruption, whether it occurs in the K. Bebeng river system or in the K. Krasak river system.

(1) Facilities for Reduction of Sediment Production

In the sediment production section from the summit down to the 12 km point, training levees are to be provided at the 9 km and 10 km points for valley mouth fixation, and check dams and consolidation are to be provided in series for prevention of erosion.

(2) Facilities for Reduction of Sediment Discharge

Sand pockets are to be provided at the 15 km point with a sediment storage capacity sufficient to cope with the amount of the expected excess sediment that cannot be prevented by the above facilities for reduc-reduction of sediment production.

(3) River Course Improvement Facilties

Downstream of the 15 km point the river course is to be improved for safe and expeditious flushing of the discharged sediment into K. Progo. Between the 20 km and 24 km points, intake weirs are to be removed and a low water course is to be fixed in order to increase sediment load capacity and lower the riverbed. In the case of fixation of a low flow channel, the permanent works should be carried out only after the riverbed has been stabilized with bamboo gabion and other temporary. Furthermore, the river course is to be improved in the vicinity of the national road, which is particularly important, and bank protection works are to be provided for protection of the Mataram canal.

b) K. Batang (Type I)

(1) Facilities for Reduction of Sediment Production and Sediment Discharge

Upstream of the 11 km point from the summit the valley mouth is to be fixed by means of check dams and training levees and sand pockets are to be provided. The stored sediment of the check dams will increase the effect of the dam. In addition, riverbed fixation works are to be provided upstream of the point 12 km from the summit in order to reduce erosion.

(2) River Course Improvement Facilities

Consolidation dams, revetment works, and groin works are to be provided downstream of the 12 km point from the summit to prevent riverbed rise and correct the river course. Channel works are also to be provided for an interval of about 3 km downstream of the national road and a total interval of 0.6 km above and below the Mataram canal.

c) K. Putih (Type I)

(1) Facilities for Reduction of Sediment Production and Sediment Discharge

Upstream of the 11 km point from the summit check dams to make the riverbed rise as high as possible, training levees for valley mouth fixation, and sand pockets for reduction of sediment are to be provided. These facilities are also meant to prevent the river from changing its course of flow and running into K. Putih.

(2) River Course Improvement Facilities

Consolidation dams, revetment works, and groin works are to be provided downstream of the point 11 km from the summit to lower the riverbed and to correct the river course. A shortcut is to be made at an interval of about 2.4 km in the vicinity of the national road, with provision of Channel works.

d) K. Blongkeng (Type I)

(1) Facilities for Reduction of Sediment Production and Sediment Discharge

Works for checking lahar inflow at the section downstream of the point 6 km from the summit have been considered as facilities for K. Putih. In the plan for this river, check dams and training levees for valley mouth fixation and sand pockets are to be provided upstream of the point 10 km from the summit to guard against possible lahar inflow at the section upstream of the point 6 km from the summit.

(2) River Course Improvement Facilities

Riverbed fixation works, bank protection works, and water regulation works are to be provided downstream of the point 10 km from the summit to prevent riverbed rise and correct the course of flow. Such works will be particularly necessary for a stretch of about 2 km in the vicinity of the national road for protection of the road and of the urbanly developed sections of Muntilan. Also, training levees are to be provided at the point where the river flows into K. Progo.

(3) Plan for K. Lamat

A check dam is to be provided downstream of the point 10 km from the summit for reduction of sediment production and control of sediment discharge.

e) K. Woro

(1) Facilities for Reduction of Sediment Production

Consolidation dams and check dams are to be provided in series upstream of the 10 km point from the summit.

(2) Facilities for Reduction of Sediment Discharge

Existing sand pockets and check dams are to be imporved and reinforced to reduce sediment discharge.

(3) River Course Improvement Facilities

Besides reinforcement of existing embankments and bank protection works, bank protection works are to be provided for fixation of a minor bed so as to increase bed-load capacity downstream of the check dams.

(4) Measures for Coping with Sediment Discharge in Normal Years

Excavation work is to be done in the vicinity of the check dams in order to cope with expected amount of excess sediment in normal year (18×10^3 m^3/year downstream of the check dams). Since some 50,000 m^3

of sediment is presently being quarried for connection of such quarrying should be encouraged, and, it might be a good idea to provide subsidies or conveniences with respect to loading.

f) K. Gendol (Type II)

(1) Consolidation dams and check dams are to be provided in series upstream of the point 13 km from the summit.

(2) Facilities for Reduction of Sediment Discharge

Sand pockets are to be provided downstream of the 13 km and 16 km points from the summit.

(3) River Course Improvement Facilities

Flow course works are to be provided for an interval of 1 km downstream of the 18 km point from the summit. In the vicinity of the Prambanan monuments along K. Opak bank protection works are to be provided, placing emphasis on harmony with the scenery, and the environment in the vicinity is to be improved in accordance with the park plan.

g) K. Pabelan, K. Boyong, and K. Kuning (Type III)

(1) Facilities for Reduction of Sediment Production and Control of Sediment Discharge

Check dams are to be provided at the sediment production sections of these rivers for reduction of sediment production and control of sediment discharge.

(2) River Course Improvement Facilities

Consolidation dams, embankment and revetments, and groins are to be provided for prevention of riverbed rise and localized bank collapse and flooding. On K. Boyong and K. Kuning, bridges are to be remodelled where they present bottlenecks. As for the places along K. Boyong within Kota Yogyakarta where there are many houses within the river bounds that are frequently inundated, steps must be taken to prevent the riverbed from rising any more than it already has. This will suffice for the time being, but in the future such houses should be relocated and the vacated sites turned into riverside parks from the standpoint of enchancement. Furthermore, a bridge is to be built across K. Pabelan at the 14 km point from the summit where consolidation dams are to be provided in view of the importance of that point in terms of evacuation, management of sabo facilities, and regional development.

7) Check of the Adequacy of the Plans for Coping with Sediment

Tables 13, 14 and Fig. 25 show the figures calculated for the amounts of sediment that will be reduced or controlled by the planned sabo facilities. They satisfy the requirements of the plans coping with sediment that were described above. As for the sediment discharge at the sand pockets, those for Type I area rivers will have a capacity more than double that of the planned scale of sediment discharge, and those for Type II area rivers will have a capacity somewhat in excess of that scale of discharge. In both cases the sand pockets will continue to function adequately throughout the 50-year period that is the life of the project.

Although the sand pockets of K. Putih have a capacity 6.70 times the planned scale of sediment discharge, they will function indirectly as training levees for valley mouth fixation works in addition to their direct function to reduce sediment production and discharge. The effects of sand pockets as valley mouth fixation works for reducing sediment production were included in the effects of check dams and training levees whereas their effects for reducing sediment discharge were attributed to sand pockets directly.

However, the sand pockets in downstream areas are only to have effects for reducing sediment discharge because they are planned at a sediment deposition area.

The sand pocket sediment discharge reduction capacities have been fixed on the basis of the following:

(1) Assuming a cycle of 12.5 years for major eruptions and assuming that each river in Type I areas will be affected by every other major eruption on the average, the planned scale of sediment discharge will occur once every 25 years, or twice in the 50-year life span of the project. In the case of rivers in Type II areas it has been assumed that the planned scale of sediment discharge will occur only once in 50 years.

(2) Basing on data for rivers that have had a great amount of sediment discharge as a result of major eruptions as indicated below:

Type I : K. Batang and K. Blongkeng in 1930
K. Krasak and K. Putih in 1969

Type II : K. Woro and K. Gendol in 1930

7) Disaster Prevention Effect of the Sabo Facilities

The amount of reduction of sediment discharge and the amount of area protected from flooding on the slopes of G. Merapi have been taken as indices of the disaster prevention effect of the sabo facilities.

a) Amount of Reduction of Sediment Discharge for the Whole Area Covered by the Plan

Before the disaster prevention plan the maximum annual sediment discharge has been 34,976 x 10^3 m^3. This is to be reduced by 32,370 x 10^3 m^3, or approximately 92.5%, by provision of disaster prevention facilities, leaving only 2,606 x 10^3 m^3.

b) Amount of Reduction of Sediment Discharge for K. Progo and K. Opak

i) In the case of K. Progo, assuming that only K. Krasak and K. Putih are affected by future eruptions as in 1969, the maximum annual sediment discharge before the disaster prevention plan of 12,715 x 10^3 m^3 is to be reduced by 10,625 x 10^3 m^3, or approx. 84%, to 2,090 x 10^3 m^3.

ii) In the case of K. Opak, assuming that K. Boyong, K. Kuning, and K. Gendol have their maximum annual sediment discharges in the same year, the maximum annual sediment discharge before the disaster prevention plan of 4,718 x 10^3 m^3 is to be reduced by 4,378 x 10^3 m^3, or approximately 93%, to 340 x 10^3 m^3 by the sabo facilities.

In the case of K. Dengkeng almost all of the present potential sediment discharge is being eliminated or controlled with sand pockets and other facilities on K. Woro; the disaster prevention facilities planned for it are only for the purpose of maintaining the function of these existing facilities. Accordingly, they are not considered to have a sediment discharge reduction effect.

c) Reduction of the Amount of Area Flooded on the Slopes of G. Merapi

Fig. 26 shows the amount of area (134.6 km^2) threatened by Lahar and Banjir at the time of flooding of the planned scale. In Type I areas the degree of flooding damage in such cases has been set as 5 and 4, and in Type II and III areas it has been set at 5 (see Fig. 19 and Supporting Report A-13). The disaster prevention facilities are to be allocated in such a way as to way as to prevent flooding of such areas. The prevention of flooding during the course of construction of such facilities, has been calculated in the following terms:

i) By preventing riverbed rise through reduction of sediment discharge by means of sediment reduction and control.

ii) By improving the river course at places where the flooding cannot be prevented by the sabo facilities in (1) above alone. Since this second effect will apply over the long term only if the first effect exists, it will be considered only for after completion of the facilities connected with the first effect.

Table 11 Dimensions of the Tributaries Basins

	Character of landform * / River	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Comment
Type I	K. Blongkeng	conver-gence	600m	much	narrow	medium	medium	loss	no	strong	weak	falling	lowered	small	no	no	Lahar deposits of 1969 filled up K. Blongkeng in neighborhood of Juran-Jero, so downstream part had insufficient capacity. For this reason, from middle to lower stream developed many terraces and it's surfaces are utilized as paddy field.
	K. Putih	diver-gence	600m	much	wide	medium	small	yes	no	weak	strong	rising	lowered	large	no	no	After 1969, K. Putih was suddenly supplied a large quantity of debris due to blocking of the upper part of K. Blongkeng. Therefore, the riverbed from middle to downstream rose and overflowed; damage was frequently repeated to area where the height is shallow.
	K. Batang	diver-gence	600m	much	wide	large	small	yes	no	strong	weak	falling	lowered	small	no	no	K. Batang was a wide and large river before 1961. After Lahar of 1961 filled up the valley of upper part, K. Batang from middle to downstream had insufficient capacity.
	K. Bebeng	diver-gence	600m	much	medium	large	medium	yes	no	weak	strong	rising	lowered	large	no	no	K. Bebeng grew suddenly and became wild after the activity of 1961 because it was blocked in the upper part of K. Krasak. In addition, it supplied large quantities of debris from upper part of K. Batang.
	K. Krasak	diver-gence	600m	much	wide	large	large	yes	yes	medium	weak	rising	raised a little	large	yes	no	The river condition of upper stream from confluence point of K. Bebeng was very stable after 1961, but lower stream of this confluence point is filled by much new debris mainly supplied from K. Bebeng.
Type II	K. Gendol	conver-gence	400m	little	narrow	large	medium	yes	no	weak	medium	falling	lowered	medium	yes	no	In the upper stream, the deposit in 1976 filled riverbed full, but big bounders are few. The general river condition is stable and valley walls are covered by vegetation. A part of the middle stream has a sand pocket.
	K. Woro	diver-gence	400m	little	wide	large	small	yes	yes	weak	medium	rising	raised	medium	yes	yes	Magnitude of valley is biggest in main river. A source of present sediment discharge is considered the erosion of dike side of upper stream. Large quantities of sediment, carried in fluid condition, are deposited in the "Woro triangle" and the lower stream which makes riverbed rise.
Type III	K. Boyong	diver-gence	400m	little	wide	large	medium	yes	yes	weak	weak	falling	lowered	small	yes	yes	The condition of river looks stable because terrace and channel are utilized as paddy field or cultivated land. The depth of rivers is relatively deep, but a part of middle stream have narrow and shallow channels.
	K. Kuning	diver-gence	400m	little	wide	large	medium	yes	yes	weak	weak	falling	lowered	small	yes	yes	The uppermost part is covered by dominant vegetation; for this reason, the river flows with abundant water. The riverbed condition is generally stable and it's used as paddy field, etc.
	K. Pabelang	diver-gence	600m	medium	wide	large	large	loss	no	weak	medium	falling	lowered	medium	no	no	The development of the upper valley is very good (width: 100 ∿ 200m, depth: 40 ∿ 50m) and terrace utilized as paddy field. Differential height of confluence point of K. Senowo is about 3 ∿ 5m, so frequently the damage of flooding occurs (for example Lahar of 1969).

* Character of landform
1. Valley and original plane.
2. Boundary between middle slope area and foothill area.
3. Degree of river channel change.
4. Width of original plane.
5. Magnitude of upper valley.
6. Magnitude of lower valley.
7. Disappearance of valley in middle ∿ footfill area.
8. Formation of alluvial fan.
9. Character of insufficient capacity.
10. Influence of present volcanic activity.
11. Changing tendency of foodhill area and riverbed.
12. Riverbed raised or lowered.
13. Activity of bed load transportation.
14. Outbreak of Nuée ardente since 1930.
15. Outbreak of Lahar Banjir since 1930.