No. 7

Republic of Indonesia

Master Plan
for
Land Erosion and Volcanic Debris Control
in the Area of Mt. Merapi

SUPPORTING II

G. PLANNING

March 1980

JAPAN INTERNATIONAL COOPERATION AGENCY

Republic of Indonesia

Master Plan
for
Land Erosion and Volcanic Debris Control in the Area of Mt. Merapi

SUPPORTING II

G. PLANNING

March 1980

JAPAN INTERNATIONAL COOPERATION AGENCY

SUPPORTING REPORT G.

PLANNING

CONTENTS

List of Tables

<u>List of Figures</u>

Chapter 1 GENERAL

1.1 Purpose of the Plan

The basic purpose of this master plan is to plan for land erosion and volcanic debris control works that will enhance the safety and stability of the area covered by the plan, increase its development potential, and build a firm foundation for regional growth.

Indonesia's first 5-year development plan, (Repelita-I), began in fiscal 1969, Repelita-II, which was based on its achievements, got underway in fiscal 1973, and Repelita-III was inaugurated in 1979.

Repelita-III differs from its predecessors in that it places more emphasis on raising the average national standard of living and increasing welfare for all as well as building a foundation for future development.

The area covered by the plan (Fig. 1) has favorable climatic, water, soil, and other natural conditions and has prospered as the central area of Java culture. As a result, however, its population has become extremely dense, with an average of 1,584 persons/km^2, and this has given rise to food shortages, unemployment, and other causes of social unrest.

In addition, the area covered by the plan has also often suffered disaster damage time and time again from eruptions of G. Merapi and the subsequent sediment discharge, causing enormous tangible and intangible loss. This study has determined that approximately 50% of the area of the foothills of G. Merapi, or 422 km^2, is subject to danger from nuée ardente (136 km^2) or lahar/banjir (286 km^2) and that the downstream areas of K. Progo and K. Opak suffer in many ways from sediment discharge resulting from eruptions of G. Merapi, including the burying of irrigation intakes and the decreasing of river channels. In order for the area to develop in the future it is necessary that these problems be solved.

In view of the damage that has been caused recently in this area by volcanic eruptions and subsequent sediment discharge as well as the socio-economic conditions resulting from it, this master plan calls for some resettlement of residents of hazard zones, improvement of land use in headwaters, improvement of the warning and evacuation system and provision of land erosion and volcanic debris control facilities and afforestation to increase the safety and stability of the area. Through multipurpose use of sabo facilities, this plan will raise the development potential of the region and build a foundation for promotion of long term regional growth.

1.2 Tasks Facing the Area Covered by the Plan

Because of its considerable population pressure, the area covered by the plan is in urgent need of mitigation of social unrest and promotion of regional development. Judging from present conditions in the area and the structure of the problems involved, it should be possible, through implementation of the plan for provision of land erosion and volcanic debris control, to reduce anxiety about volcanic disaster damage: actual damage due to sediment, and anxiety relating to living conditions in the area.

(1) Increase in Safety and Reduction of Anxiety About Volcanic Disaster Damage

It is necessary to reduce and prevent damage due to nuée ardente, lahar/banjir, and sediment discharge and reduce anxiety about such disasters by improving disaster prevention arrangements and providing land erosion and volcanic debris control works. This need is particularly urgent with respect to Type-I areas considering the periodicity of the activity of G. Merapi.

Approximately 50% of the area of the foothills of G. Merapi, or 432 km^2, is subject to nuée ardente or lahar/banjir hazards, and there are many problem spots in the main river areas further downstream as well. In order to mitigate and do away with the anxiety of the residents of such hazardous areas with respect to the probable occurence of disasters, it is necessary to improve disaster prevention arrangements, including resettlement of some of the residents of hazardous areas and improvement of the warning and evacuation system, to improve land use, and to provide land erosion and volcanic debris control facilities.

Records since 1800 indicate an activity cycle of G. Merapi of one eruption every 3-6 years if smaller eruptions are included, and one every 9-16 years of at least the proportions of the last major eruption in 1969. Hence the importance of early implementation of the master plan for land erosion and volcanic debris control in the Type-I areas on the southwest side of the mountain, where the crater is presently open.

(2) Reduce Sediment Damage

The volcanic debris and unstable sediment deposits in the headwaters are the source of discharged sediment which causes reduction of the river channels, unstable riverbeds, burying of irrigation intakes, etc. at the middle and lower portions of the tributaries as well as at the main rivers further down the mountain.

It is therefore necessary to provide sabo facilities for the sake of preservation of the headwaters and reduction of sediment production and discharge to reduce sediment damage and increase regional stability.

The main economic base of the area covered by the plan is agriculture. Therefore reduction of sediment damage to agricultural areas in the area and enhancement of their stability is indispensable to regional development.

The headwaters, particularly Type-I areas, receive the brunt of volcanic eruptions and the dischaged sediment that is mainly produced from volcanic debris and unstable deposits and causes large-scale damage of different kinds in downstream areas.

With improvement of land use in headwaters and provision of sabo facilities to check production and discharge of sediment, both the headwaters and the tributary areas will be stabilized, and this will in turn contribute to gradual stabilization of the main river areas.

(3) Build a Firm Foundation for Regional Promotion

The multipurpose use of sabo facilities and provision of associated works will improve production and the standard of living in the area as well as increase enthusiasm for development and raise development potential by building a base for promotion of regional development. All this will reduce anxiety relating to living conditions in the area.

With an inferior production base, the mountain slope areas have low productivity and living standards, and the economic gap between them and the flatland area appears to be widening. This trend is particularly pronounced in the Type-I areas where most of the damage resulting from volcanic activity has been occurring recently. Such repeated damage on top of unfavorable economic conditions has been a major drag on regional development and investment in the production infrastructure, and that is why provision of land erosion and volcanic debris control facilities are so important.

Furthermore, the low productivity and overly dense population in the mountain slope areas has resulted in very small farmland holdings (presently an average of only 0.29 ha/household), outflow of surplus labor (40 - 50%) to the cities, low wages, unemployment, and other causes of social unrest. Consequently, it is necessary not only to improve agriculture, the main production base of the area, but also to raise the development potential of the area and create temporary and permanent employment opportunities in both cities and rural communities.

1.3 Area Classification

1.3.1 Use of Grid Measurements

Although disaster prevention planning is based on the potential hazard and importance of an area, there is variation from place to place within the area covered by the plan with respect to natural local conditions and socio-economic conditions. Determination of the degree of hazard at each particular place within the area depends on its geographical conditions, and determination of the social and economic importance at each place depends largely on the state of provision of social and production base facilities; determination of the disaster prevention planning depends on the correlation between the measurement of hazard and importance in each area. In order to treat each place on a specific basis, a grid system (the grid size has been fixed at

0.5 km on a side, with a coordinate system based on latitude and longitude) has been used for the reasons listed below:

(1) For purposes of valid comparison it is necessary to standarize the units being compared without regard to administrative boundaries. Using meshes makes for geometric simplicity and easier comprehension of the phenomena with respect the different parts of the area are being compared.

(2) Since each of the meshes has the same area as the others, parties quantitative comparision between them is easy.

(3) Since the meshes are fixed and not affected by change in administrative boundaries, topography, or other attributes, they facilitate comparison over time.

(4) Since the meshes are all of the same shape, it is easier to comprehend how regional phenomena relate to one another, including position and shape.

(5) Meshes are convenient for data collection by specimen surveys and other means when there is insufficient existing data.

(6) Meshes make it possible for rapid and extensive processing, use, and expression of statistics with electronic computers and drawing machines.

1.3.2 The Expression of Degree of Hazard and Degree of Socio-economic Importance

The factors evaluated for each grid mesh are summarized follows:

(1) Degree of Hazard

The degree of hazard is expressed as a combination of the following factors:

(a) Degrees of lahar/banjir flooding (1-5)

Expression of the degree of flooding danger as determined by topography and land conditions.

(b) River Area Types (I-III) and Other Areas

Expression of frequency of disaster damage from volcanic eruptions and sedimentary debris.

(c) Nuée Ardente, Lahar, and Banjir Areas

Expression of degree of damage at times of diaster.

(2) Degree of Social Importance

The degree of social importance is expressed as a combination of the following factors regarding the extent of direct and indirect effect of disasters:

(a) Population density (by village unit)

(b) Distribution of social infrastructure and other important facilities (facility distribution map).

(c) Distribution of urbantly developed areas and hamlets (land use map).

(3) Degree of Economic Importance

The degree of economic importance is expressed as a combination of the following factors as an expression of present productivity and potential for future increase in production of the agricultural sector, the basic industrial sector in this area:

(a) Distribution of paddy fields (land use map).

(b) Crop yield indices (1976/1971).

(c) Level of production of rice.

(d) Trend with respect to increase in rice yield (1981).

1.4 Area Classification and Countermeasures

On the basis of the measurement of degree of hazard and degree of socio-economic importance for each grid mesh and national policy goals for the region, the area covered by the plan has been divided into five planning zones (See Fig. 2). The location of each zone together with the undirected basic policy regarding countermeasures is descirbed in the following paragraphs:

Zones 1 and 2:

Area: Areas subject to nuée ardente damage.

(Countermeasures: Changes in Land Use and Resettlement and Relocation Plan)

This zone on the upper slopes of the mountain embraces those areas which lie within a radius of 9.0 km from the crater 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 checking sediment production.

Zone-3:

Area: Areas subject to damage from lahar or banjir.

(Countermeasures: Diaster Prevention Facilities and Warning and Evacuation Plan)

In areas subject to damage from lahar or banjir, diaster prevention 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 the amount of damage. At the same time, the regional development potential will be enhanced, and a foundation will be built for promotion of regional development.

Zone-4:

Area: Other Areas on Merapi's Slopes

(Countermeasures: Warning and Evacuation System)

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 diaster 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.

Zone-5:

Area: Other Areas Covered by the Plan (K. Progo and K. Opak Problem Spots)

(Countermeasures for each specific problem such as:
(1) Sedimentation to irrigation intakes and facilities.
(2) Insufficient interval drainage
(3) Stoppage of river mouth by drift of sand
(4) Erosion of river banks).

Table-1 summarizes the countermeasures for each zone as described above.

Table 1 Zones and Countermeasures

Zones	Relocation and land use improvement	Sabo works	Warning system	Associated works	Misc. appropriate works
1	+	+			
2	+	+			
3		+	+	+	
4			+	+	
5					+

1.5 Plan Targets

The targets of the diaster prevention master plan, based on the tasks facing the area and national and local government policy goals, are as follows.

1.5.1 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 (one eruption every 3 - 6 years if small eruptions are included or one ever 9 - 16 years if only major eruptions are considered) and the form that the disaster damage takes, the target year for the master plan for land erosion and volcanic debris control should be no more than 15 years, especially since disaster prevention facilities are urgently needed.

1.5.2 Areas Covered

The plan will be for the following two areas which were chosen on the basis of such considerations such as the tasks involved, effectiveness of the measures to be taken, and geographic unity (see Fig. 2):

(1) Main Planning Area: Regional Diaster 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 including planning zones 1 ∿ 4 which consist of the following administrative units:

D.I. Yogyakerata: Kota. Yogyakarta, Kab. Sleman, and part of Kab. Bantul.

Central Java: Part of Kab. Magelang and part of Kab. Klaten

(2) Secondary Planning Area: Problem Spot Countermeasure Areas

Problem spots located along K. Progo and K. Opak which comprise planning zone-5.

1.5.3 Goals for each Planning Area

1) Main Planning Area

On the slopes and foothills of G. Merapi approximately 422 km^2, or 50% of the total area covered by the plan (850 km^2), with a population of approximately a half a million, are exposed to danger from nuée ardente, lahar, banjir, and other causes of damage resulting from volcanic activity. The goals of the disaster prevention master plan are therefore improvement of the safety and stability of these areas and the building of a foundation for promotion of the region. The goals of the measures to be carried out are as follows.

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

(b) Preservation of the river basins through improvement of land use and reduction of damage and enhancement of riverbed stability through promotion of diaster prevention works, including provision of afforestation and sabo facilities.

(c) Enhancement of the development of the area covered by the plan on the slopes and foothills of G. Merapi and building of a foundation for promotion of regional development through multi-purpose use of the sabo facilities and provision of associated works.

2) Secondary Planning Area

The plan shows the directions to be taken with respect to basic countermeasures for coping with each kind of damage occurring at problem spots along K. Progo and K. Opak.

Fig. 1 Map of Project Area

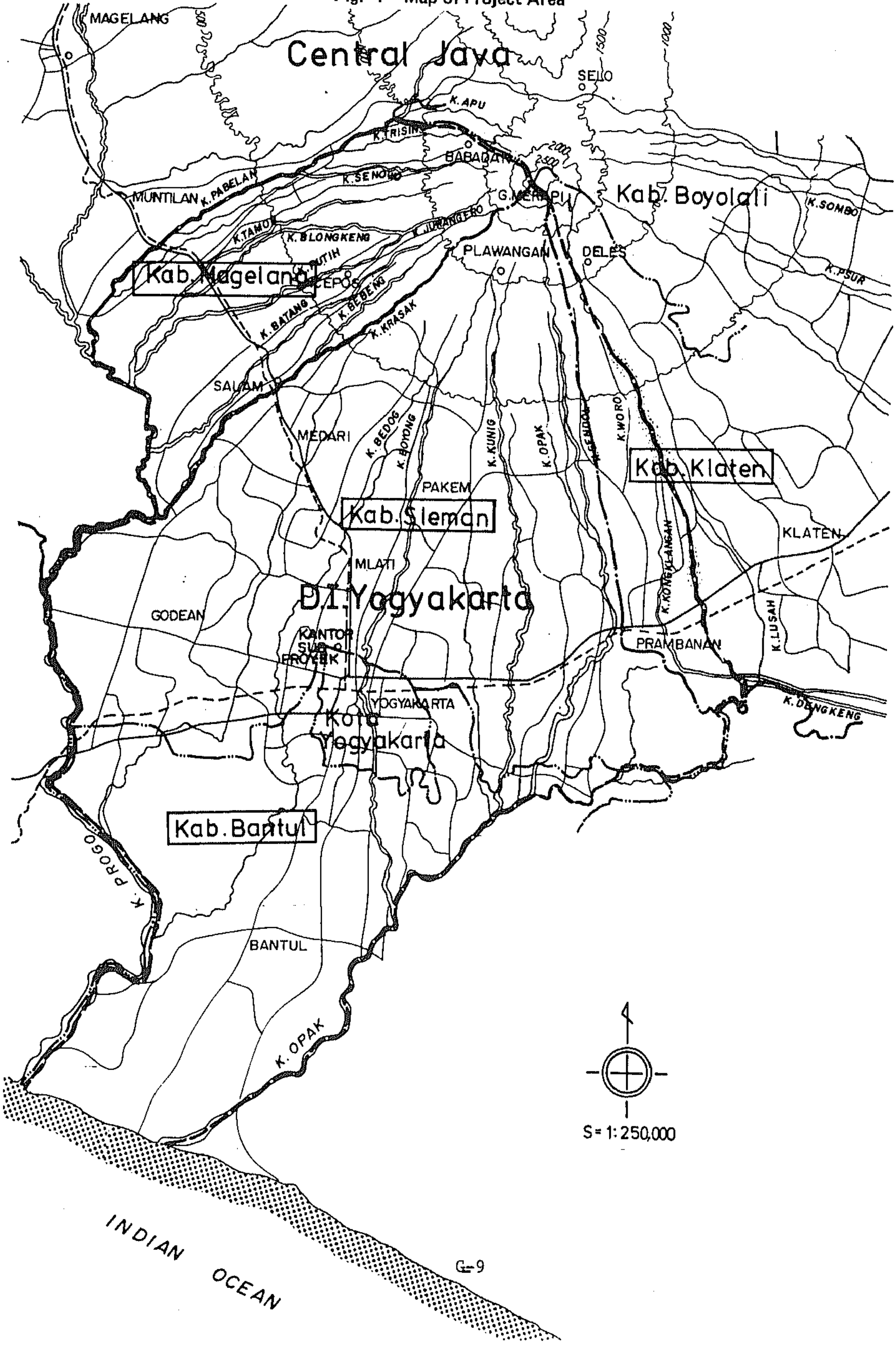
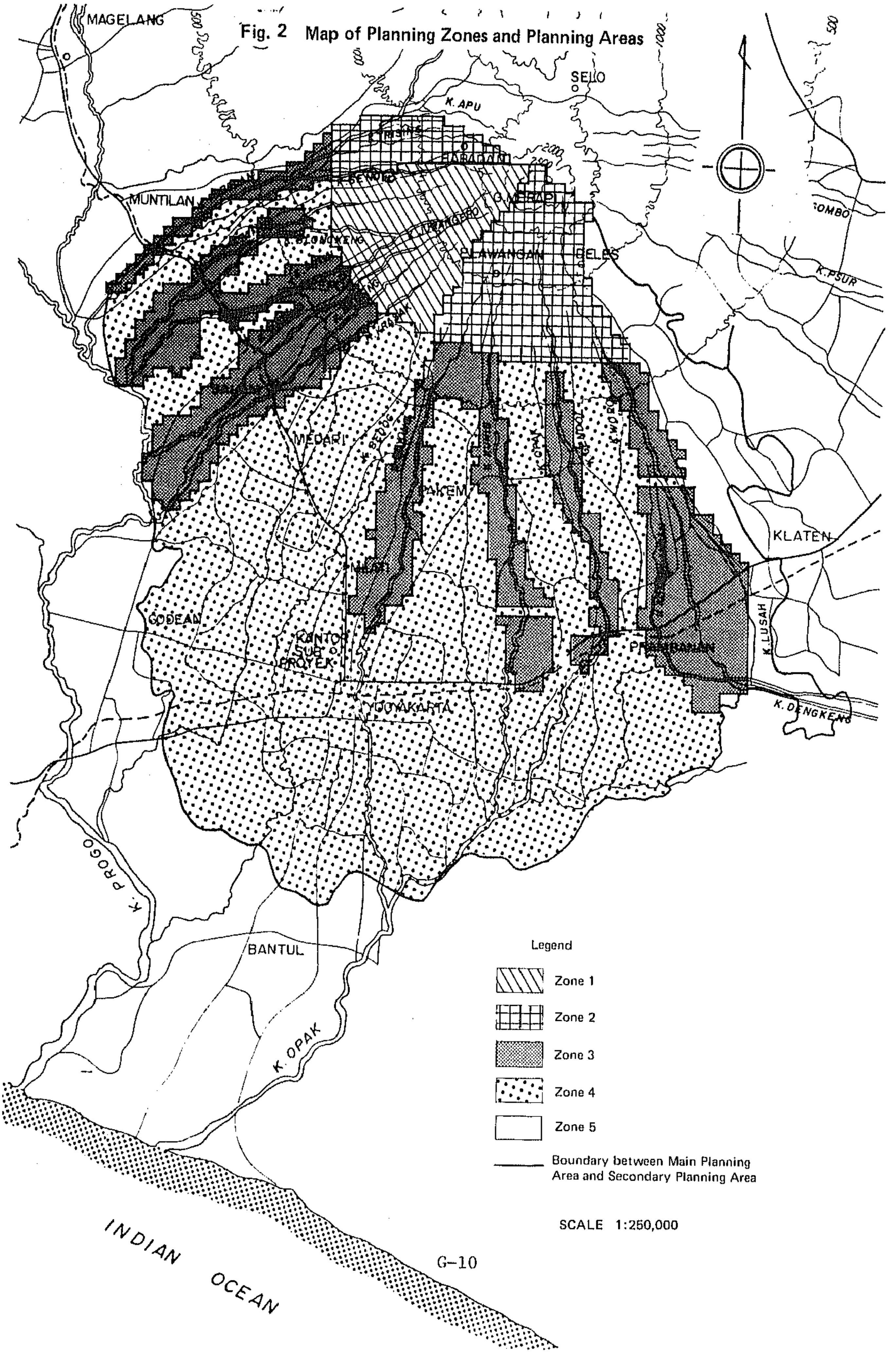


Fig. 2 Map of Planning Zones and Planning Areas



Chapter 2 COUNTERMEASURES FOR MAIN PLANNING AREA

2.1 Land Use Improvement Plan

2.1.1 General

The main disaster prevention measures for areas threatened by damage from nuée ardente is land use changes and resettlement of some residents. These areas, which total approximately 136 km2, 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 are as follows:

(1) They are directly affected by nuée ardente at times of eruptions.

(2) In addition to lahar, these are the main areas of production of the sediment discharge that causes disaster damage downstream.

(3) They are the water source areas of numerous tributaries of K. Progo, M. Opak, K. Dengkeng, and other rivers.

The disaster prevention countermeasures for such areas are as follows:

(a) Resettlement of residents in hazardous areas.

(b) Preservation of river basins through planting and afforestation of waste land.

(c) Provision of land erosion and volcanic debris control facilities to check and control seliment production and discharge.

2.1.2 Plan for Improvement in Land Use

Table 2 and Fig. 3 show the present state of land use in nuée ardente hazard areas (136 km2), and Table 3, Fig. 4 give the plan for change in such land use.

1) Resettlement of Residents of Hazardous Areas

For the sake of the safety of residents and preservation of the river basins, there should be expeditious resettlement of people presently residing in such areas. This is particularly true of the Type-I areas on the south-western slopes where there is a high frequency of disaster damage and the river basins are in poor condition.

The Indonesian government has put these nuée ardente areas off-limits as being extremely hazardous and has been proceeding since 1960 with a resettlement plan for the residents, but quite a few still live in these areas and rely on farming for a living. The productivity of the farmland, however, is very low, and it would therefore be better to convert these areas into forested areas from the standpoint of diaster prevention and water source preservation.

2) Conservation Works for Head Water Areas

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

The long-term afforestation goal of D.I. Yogyakarta is for forest land to reach 33 % of the total in the river basins. Since high percentage of the land in the area covered by the plan are accounted for by wasteland, farmland, and other land uses, there is presently very little good forest land. Therefore, besides sabo facilities 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.

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

2.1.3 Implementation Plans

The land use improvement plan is to be excuted in two stages (See table 4)

1) Resettlement Plan

(1) Stage 1 : Resettlement of residents of Zone 1 area

	Number of residents
Central Java	11,800
D.I. Yogyakarta	4,100
Total	15,900

(2) Stage 2 : Resettlement of residents of Zone 2

	Number of residents
Central Java	18,000
D.I. Yogyakarta	16,500
Total	34,500

2) Afforestation Plan

(1) Stage 1 : Afforestation chiefly in Zone-1 areas and a pilot project involving research on kinds of trees to plant and planting methods, training of afforestation technical personnel, and publicity activities.

(2) Stage 2 : Afforestation chiefly in Zone-2.

Table 2 : 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 3 : 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 2. Dry field	520(19)	270(3)	790(6)
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)

Table- 4 Implementation Schedule for Land Use Improvement

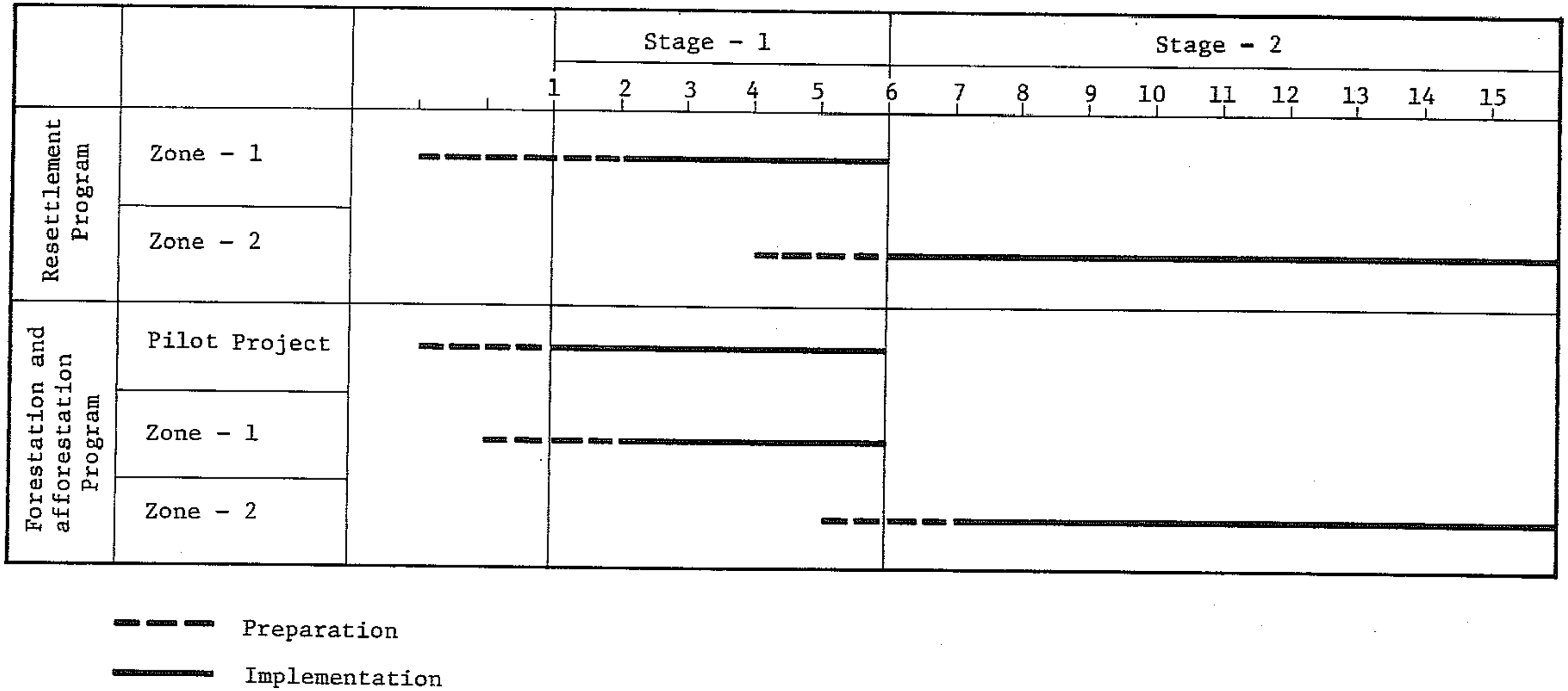


Fig. 3 Present Land Use in Nuée Ardente Area

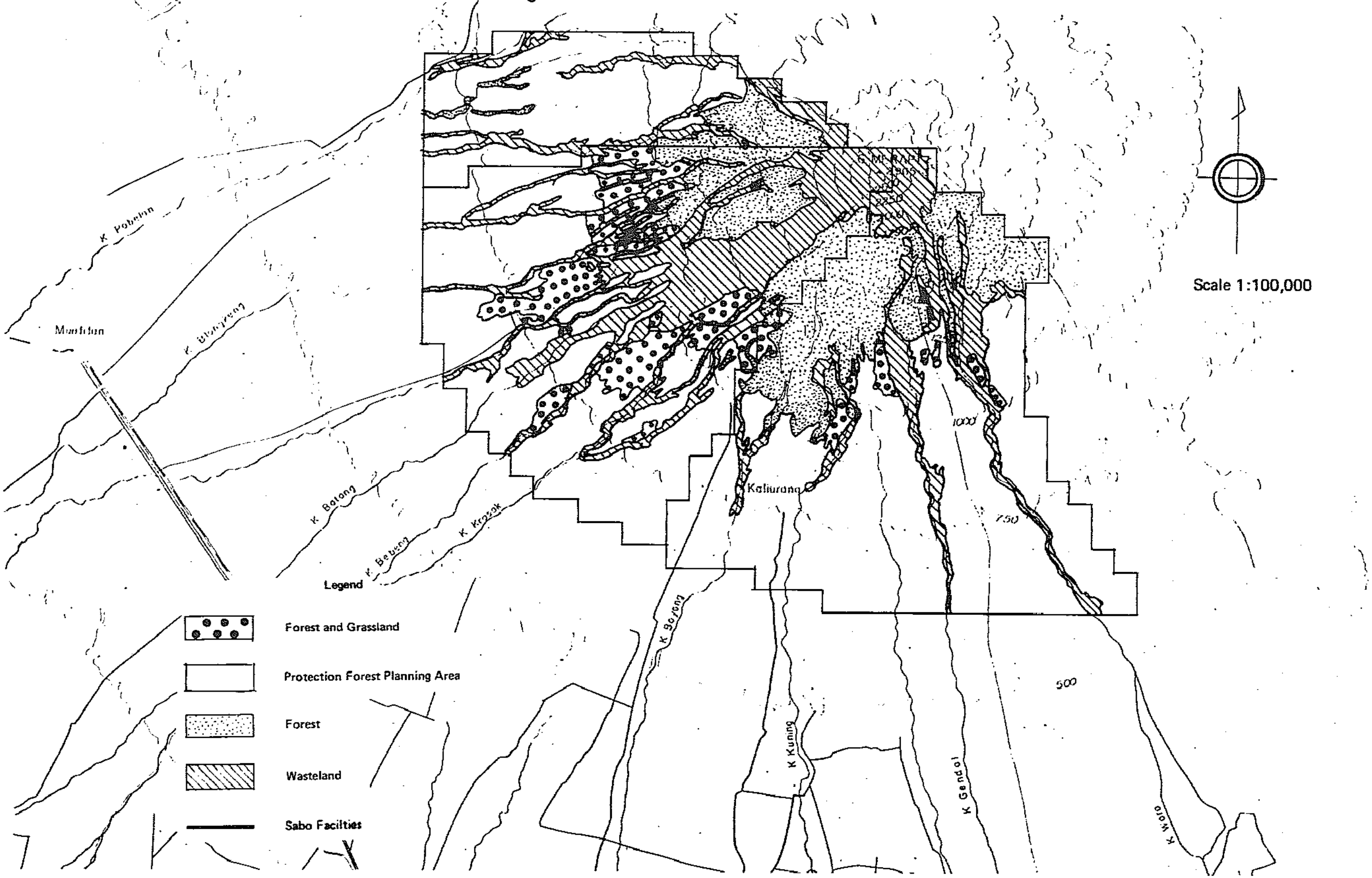
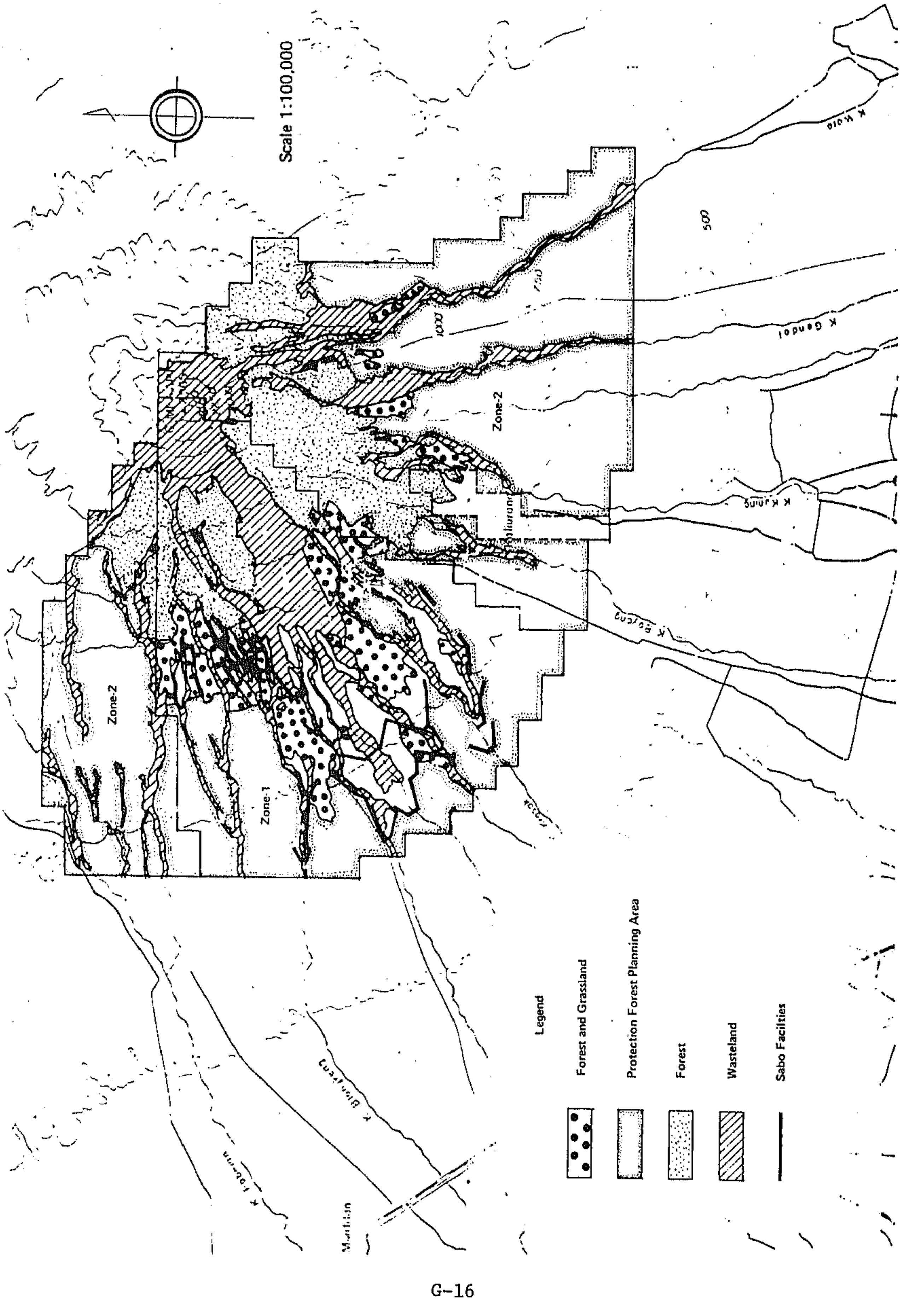


Fig. 4 Planned Land Use in Nuée Ardente Area (Zones 1 and 2)



2.2 Warning System Improvement Plan

2.2.1 General

Only by means of provision of Sabo facilities and other disaster prevention activities and the establishment of a disaster prevention system that includes as improved warning and evacuation system will it 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) Telemetric observation for data collection and monitoring needed for more accurate forecasting and forecasting criteria.

(2) Study for early establishment of forecasting criteria.

(3) Emergency notification system that will not involve any unnecessary loss of time.

(4) Evacuation routes for expeditious evacuation in times of danger.

(5) Independent arrangements on the part of individual residents to be able to cope at anytime with any danger that might arise.

2.2.2 Organization of a Lahar Warning and Evacuation System

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 study and the necessary facilities for observation and forecasting of natural phenomena will be needed for more accurate forecasting criteria and forecasting, greater accuracy and dependability with respect to localized forecasts, and expeditious issuance and communication of forecasts and warnings. Furthermore, it is necessary that the residents themselves make independent arrangements for coping with whatever emergencies they are notified of by such a warning system.

1) Observation and Monitoring System

With introduction of telemetric monitoring, a centralized observation and monitoring system will be possible. The observation and monitoring system and organization, with additional telemetric observation posts in the areas where the lahar occurs and surrounding areas, is shown in Fig. 5.

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 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.

The following are characteristics of such a telemetric control system:

(1) Labor-saving.

(2) Vital on-line work such as measurement and monitoring done by machine.

(3) Simultaneous collection of information from the many different points required for accurate forecasting.

(4) Speed accurate and centralized collection of data to make timely and precise judgments and decisions.

Although the range of the rainfall is very narrow, within a radius of about 3 - 5 km, it should be possible to forecast the peak of the rainfall several hours in advance if the rainfall area is determined fairly early since the rainfall is directional and its speed of movement is fairly slow. Accordingly, short-period forecasts will be more reliable when rainfall measurements are obtained for each hour using such an observation and monitoring network. There is also the possibility of determining the rainfall area by means of radar echo.

Forecasting of the amount of rainfall by radar echo is effective for short-period rainfall forecasting since it is possible to continue to observe the amount of water content of the rainfall. It is particularly suitable for forecasting and monitoring small-scale thunderstorm phenomena. The order of hourly rainfall can be determined by the echo reflection intensity; however, since there is large quantitative error, such radar echoing can be effectively used only with a telemeter monitoring system.

2) Warning Communication System

The warning communication system that is to be established will make it possible for the residents of lahar 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, there will have to be a considerable number of substations -- about ten to fifteen in the case of Type-I area.

Since the area does not have a supply of electricity, microgenerators and emergency batteries will have to be used. Each kabupater is to have one main stations in the warning communication system. Fig. 6 and 7 show the location and the system of centers for Type-I areas.

3) Evacuation Routes

Main village roads and farm roads should be improved for construction of sabo facilities and associated works and be used for evacuation routes.

4) Residents and Technical Guidance Organizations Disaster Prevention Activities

(1) Resident Disaster Prevention Activities

Although the central and local governments are chiefly responsible for disaster prevention arrangements, the whole disaster prevention system will be more effective if the residents of the areas in question are willing to actively cooperate and participate in activities of this kind on their own initiative. Accordingly, there will have to be publicity of disaster prevention activities, including the dangers and the areas involved and the need to take good care of disaster prevention facilities.

(2) Technical Guidance Organization

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 technical guidance center should be undertaken from a broad viewpoint in an established center that includes not only G. Merapi but also other active volcanos.

2.2.3 Implementation Plan

The warning and evacuation system is to be established in two stages (see Table 5):

(1) In the first stage, the emphasis will be on exp itious evacuation of mainly Type-I areas, where the frequency of disasters is high, and on collection and analysis of basic data.

(2) In the second stage, the whole warning and evacuation system for the area covered by the plau will be established on the basis of the results of the first stage.

(Stage 1)

1) Publicity Activities

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

2) Improvement of the Warning Communication System

Since not much can be expected for the time being with respect to forecasting the occurrence of lahar, the warning communication system will have to be improved so as to enable immediate evacuation whenever it might occur.

3) Provision of Evacuation Routes

The road system within the areas concerned is to be improved along with provision of construction roads in order to enable sale and swift evacuation.

4) Provision of Observation and Monitoring Facilities

A network of telemetric observation and monitoring facilities is to be established.

5) Basic Study

Basic study is to be undertaken with respect to rainfall criteria for occurrence of lahar and other matters.

(Stage 2)

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

Table 5 Implementation Schedule for Warning System Improvement

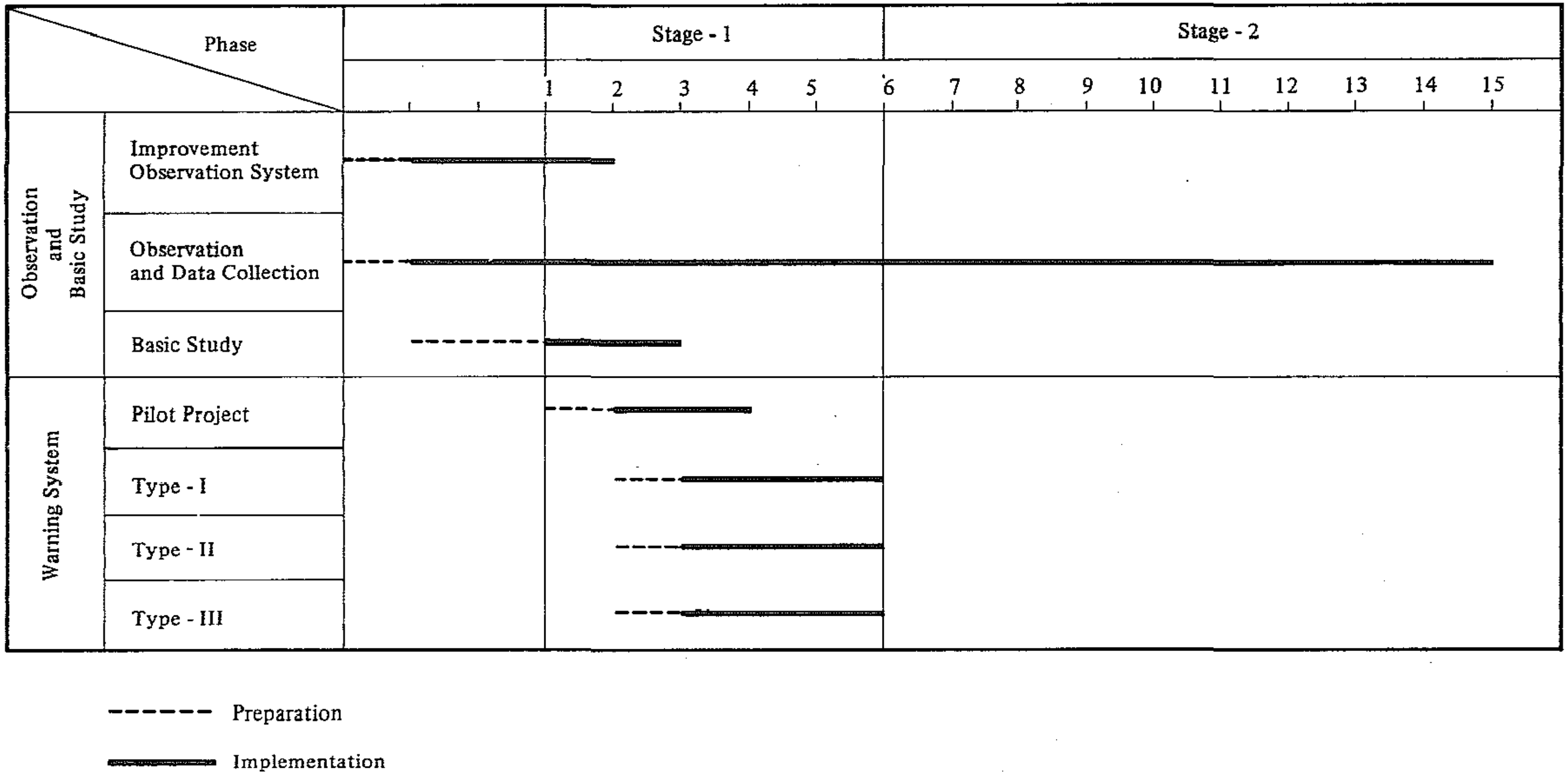


Fig. 5 Location Map of Observation Posts, Raingages, Information Centers and Planned Telemetric Observation Posts

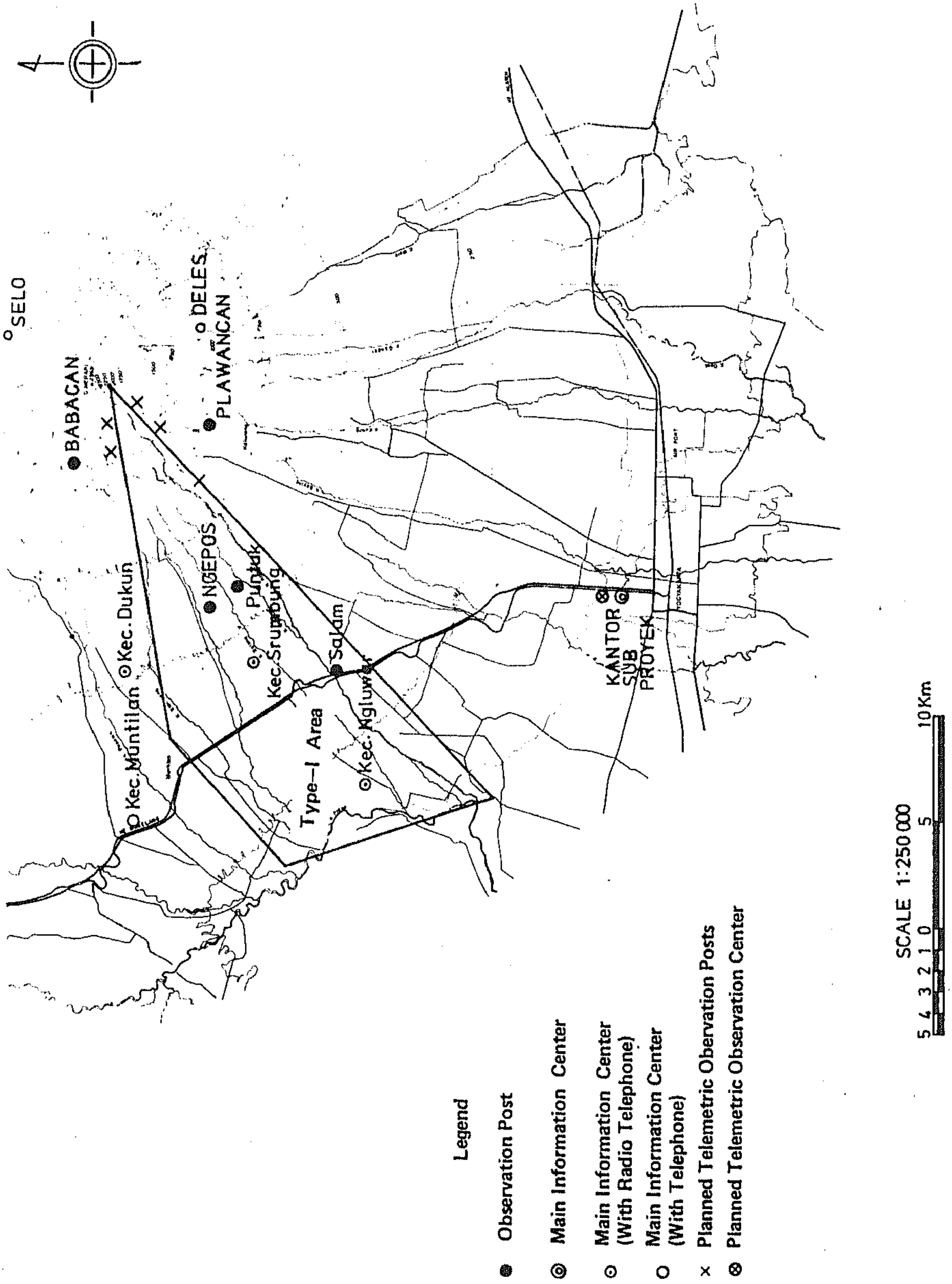


Fig. 6 Location of Planned MWarning Communication Substations in Type-I Area

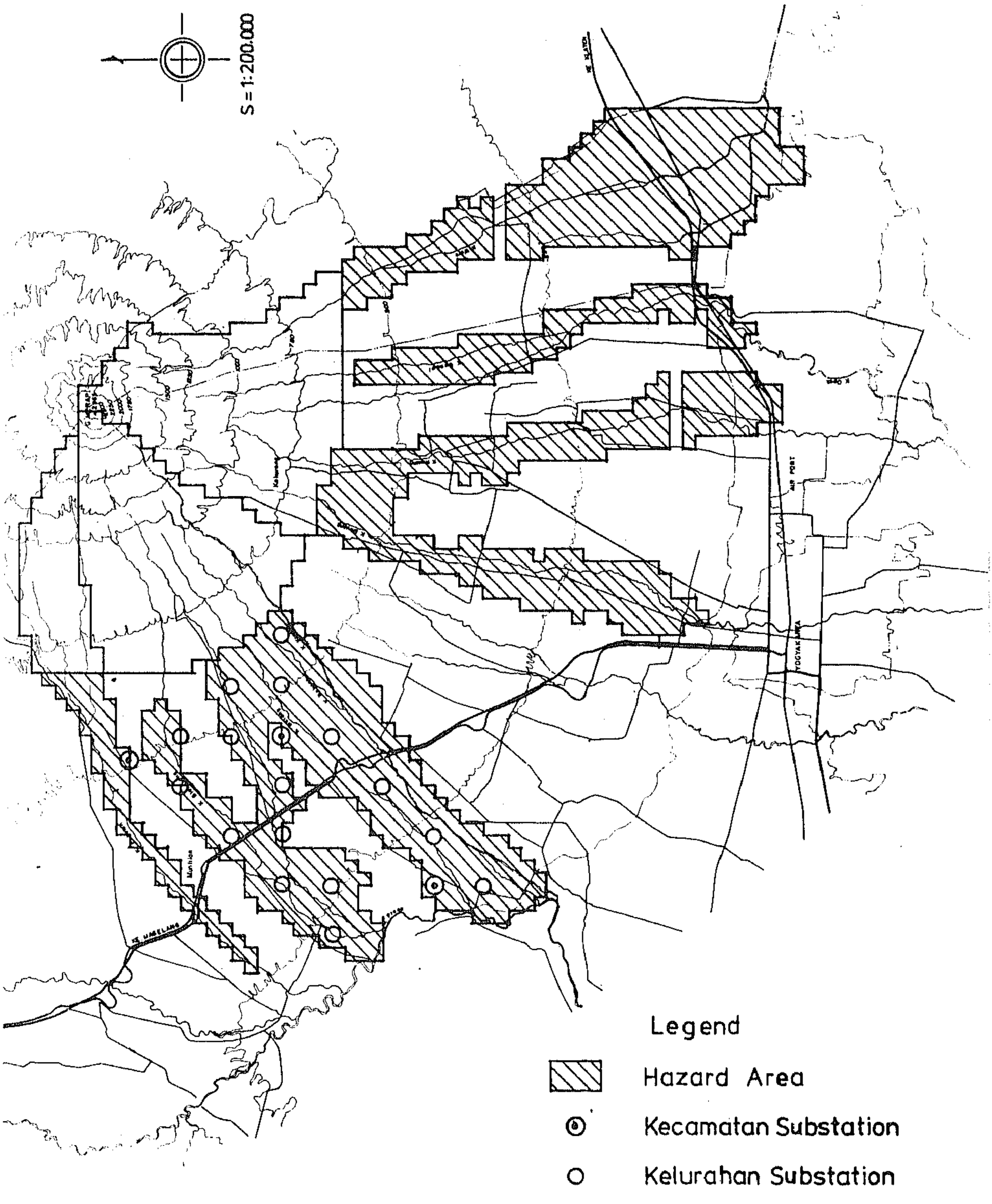
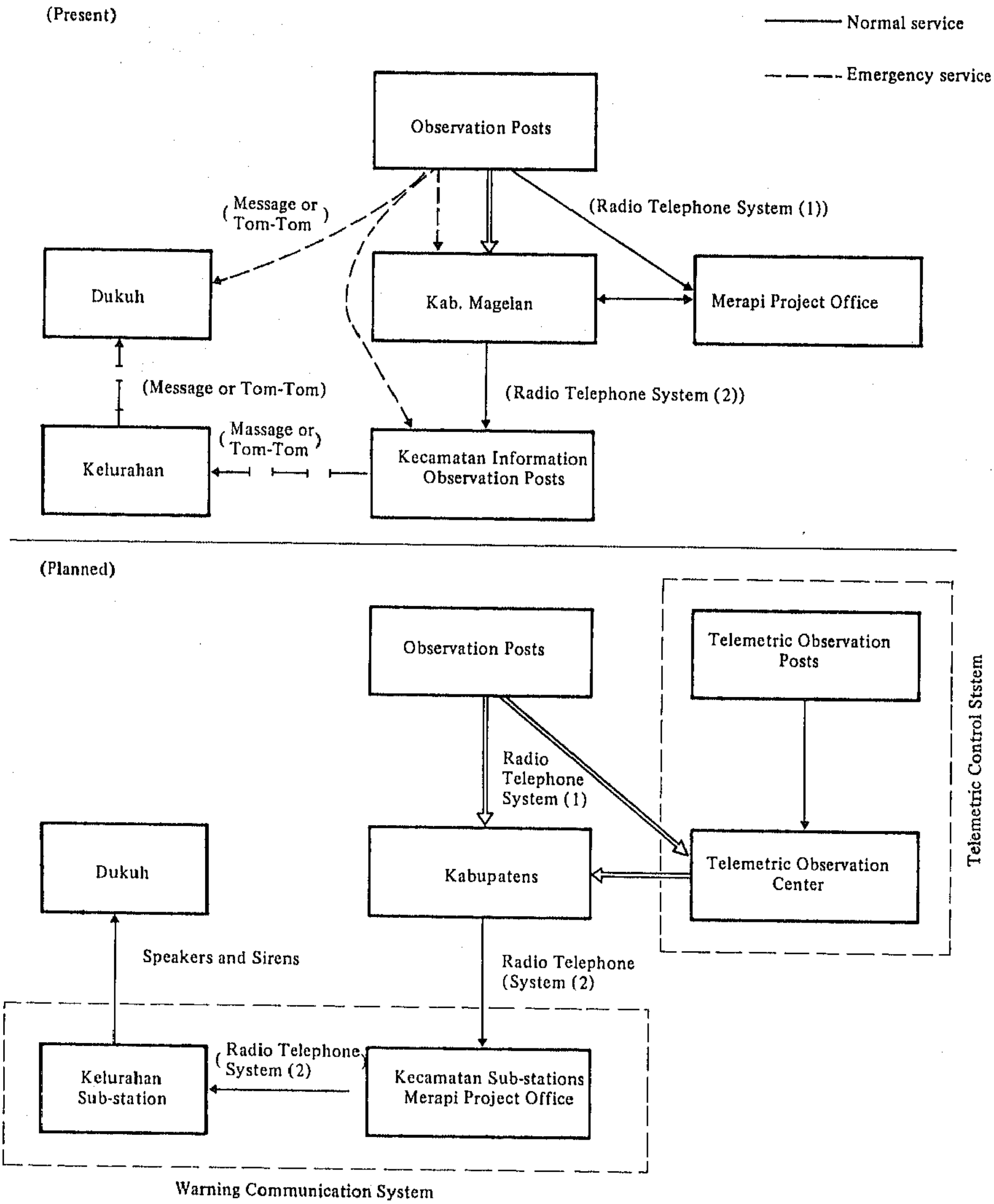


Fig. 7 Warning Communication System



2.3 Sabo Facilities Plan

2.3.1 General

1) Purpose of Sabo Facility Plan

G. Merapi is made up of easily eroded volcanic debris which often turns into lahar after it rains. This lahar erodes the sediment of riverbeds and banks and acquires considerable proportions and enormous energy on its way down the mountain, overflowing and causing considerable damage to life, houses, farmland, roads, irrigation facilities, etc.

The large amount of sediment that is brought down by the lahar accumulates in riverbeds, raising their bottoms and giving rise to banjir flooding. Furthermore, this sediment is also carried further down to K. Progo and the other main rivers, again causing rise of the riverbeds, instability of the river courses, obstruction of irrigation facilities, and flooding.

The sabo facilities have been planned for the purpose of checking and adjusting the surplus sediment discharge that causes such disaster damage and stabilizing river course and preventing flooding by allowing for smooth conveyance of flood waters and sediment load.

In this way the direct damage to life, houses and property, farmland, roads, railroads, irrigation facilities, etc. and the indirect damage and loss resulting from instability of supply of irrigation water, increase in the cost of maintenance and management of irrigation facilities, stagnation of socio-economic activity as a result of disaster damage, and so on can be mitigated, and in some cases even prevented. Furthermore, enhancement of the safety of the area will raise its social development potential, and multipurpose use of the sabo facilities, including use for irrigation purposes, will contribute to promotion of the development of the area. The construction work for the sabo facilities will also provide stable employment opportunities which will be a great boon to these low-income mountain areas. Thus, the sabo works can be considered to play a very important role in narrowing the gap between these mountain areas, where there are few development investment opportunities, and the plains areas.

2) Area Covered by the Plan

The area to be covered by the plan for sabo facilities consists of the slopes and foothills of G. Merapi and the basins of its nine rivers (see Fig. 8).

Name of Tributaries	River System	Area Type
1. K. Krasak	K. Progo	I
2. K. Batang	"	I
3. K. Putih	"	I
4. K. Blongkeng	"	I
5. K. Pabelan	"	III
6. K. Gendol	K. Opak	II
7. K. Boyong	"	III
8. K. Kuning	"	III
9. K. Woro	K. Denkeng	II

3) Description of Sabo Facilities Plan

a) Purposes of Plan

(1) Mitigation and prevention of lahar/banjir disaster damage on the slopes and foothills of G. Merapi.

(2) Reduction of sediment discharge from tributaries on the slopes and foothills of G. Merapi into K. Progo, K. Opak, and K. Dengkeng.

b) Amounts of Sediment Discharge to be Handled by the Plan

(1) Type-I Areas

The maximum annual amount of sediment discharge (m^3/year) as the amount that can be expected from an eruption on the scale of the one in 1969.

(2) Type-II and -III Areas

The maximum annual sediment discharge (m^3/year) with the unstable sediment now deposited in the upstream areas as the production source.

In the case of K. Woro, the average amount of sediment discharge per year (m^3/year) for normal years.

c) Sediment Disposal Plan and Location Plan for Sabo Facilities

(1) Planning of check dams and other sabo facilities for the purpose of reducing the amount of sediment discharge to an amount that can be safely conveyed.

(2) Planning of embankments, bank revetments, and other facilities for smooth conveyance of flood waters and discharged sediment within the river course.

d) Effect of Sabo Facilities

Calculation of amount of sediment discharge to be reduced, amount of sediment to be controlled, and amount of areas of flooding to be prevented, all by the sabo facilities.

e) Cost of Works

Calculation of the total costs involved in the construction of the sabo facilities.

f) Implementation Plan

Preparation of construction schedule, including order of priority of the different facilities. The life of structures is estimated as fifty years.

Fig. 9 shows the planning process.

Fig. 8 Map of Design Basic Points for Sabo Plan and Types of River Areas

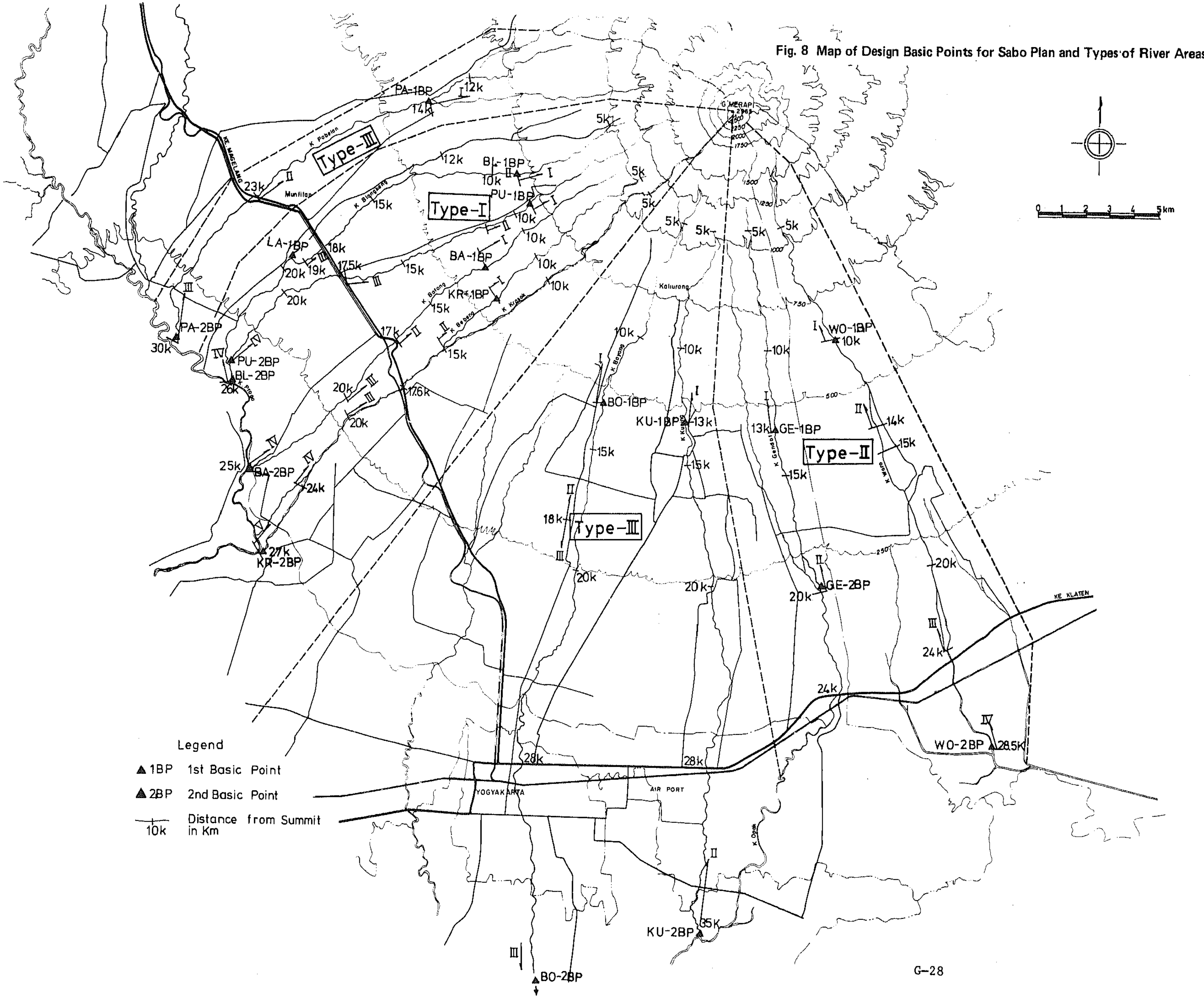
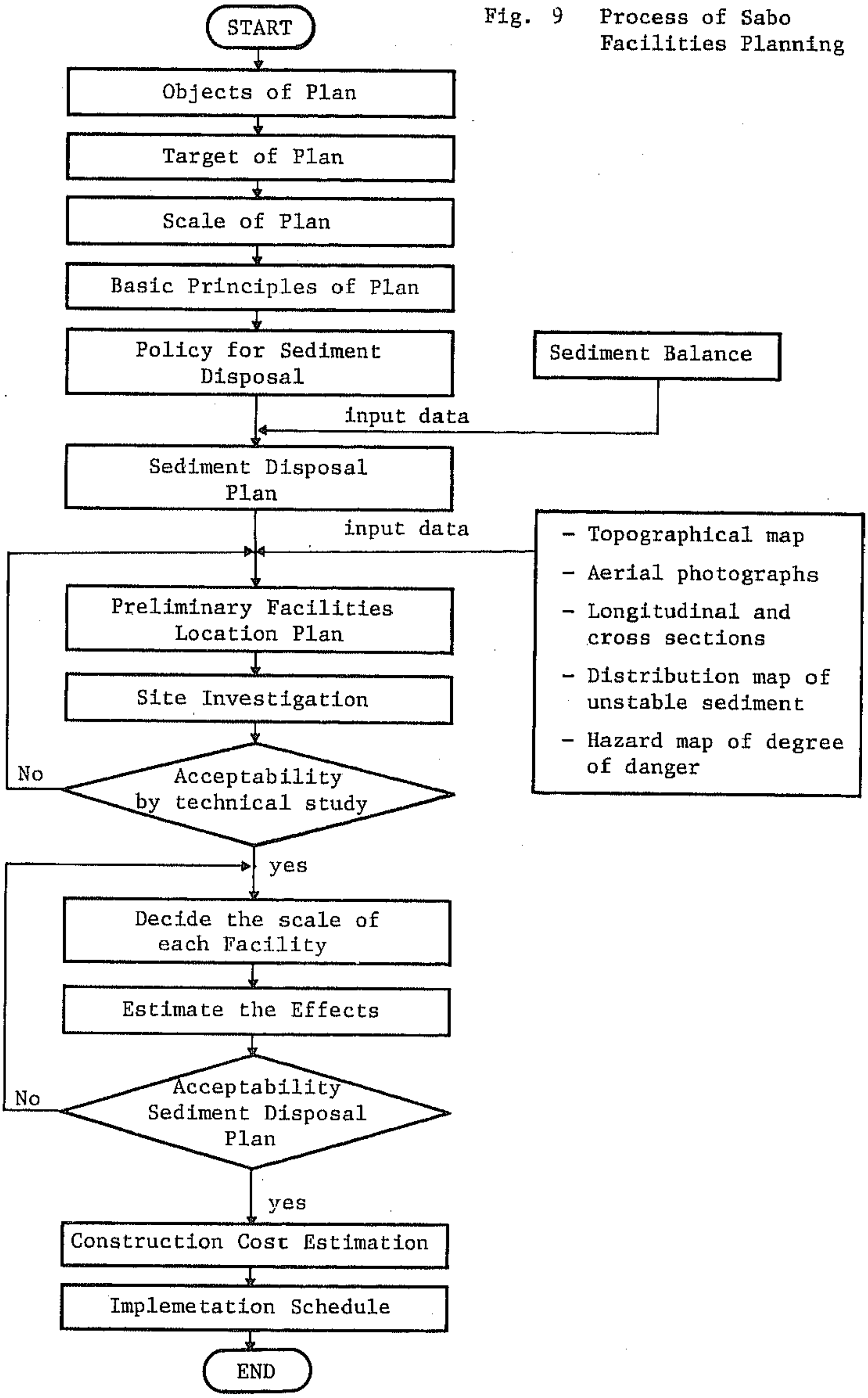


Fig. 9 Process of Sabo Facilities Planning



2.3.2 General Description of Basins

1) Dimensions of Basins

Table 6 gives the dimensions of the river basins covered by the plan.

2) Type Classification and Characteristics of the Rivers

G. Merapi is a Strato-volcano, the area around which has uniform topography and soil conditions. Although there is hardly any difference in the distribution of rainfall between different parts of it, its rivers each have their own particular characteristics and features, primarily due to the different amounts of time that have elapsed since last supply of sediment by eruptions and the balance between the amount of such supply and erosion. Accordingly, the river areas have been classified into three types of areas on the basis of their characteristics regarding erosion, sediment discharge, and disaster damage

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

The rivers in Type-I areas have waterflows in the direction of the eruption flow and are presently characterized by a large amount of sediment discharge. Two of the rivers (K. Krasak and K. Putih) are presently experiencing considerable disaster damage, and there is considerable danger of similar disaster damage from the other rivers (K. Batang and K. Blongkeng).

In these areas most of the sediment produced by eruptions stops temporarily at an elevation of about 1,800 - 900m. Most of the sediment discharged to downstream areas is produced by stream erosion of the above mentioned deposits and past deposits. Consequently, in these areas the river system network is not fixed and the basins and courses change after every eruption. Valley deepening has not progressed very far, and there is little difference in height between riverbeds and river banks. Furthermore, the riverbeds of K. Krasak and K. Putih have risen as a result of large amounts of sediment discharged since 1969 which means that there is considerable danger of flooding.

Because of change in the direction of eruptions since 1930, all of the rivers in these areas have experienced considerable disaster damage from nuée ardente and lahar, and since there is a strong probability of more such diaster damage in the future considering the state of the crater, all of these areas should be grouped together in the land erosion and volcanic debris control facilities plan.

The rivers in these areas flow into K. Progo where the riverbed gradient is large and the sediment discharge capacity is high, which means that K. Progo is greatly affected by sediment discharge.

A feature of the riverbed materials of K. Krasak and K. Putih is that the particles are very fine: averaging 4 - 5 mm in diameter downstream and almost the same (10 ∿ 20 mm) upstream.

Because of armoring, granular size is larger in the case of K. Batang and K. Blongkeng than in the case of K. Krasak. Furthermore, considering the fact that the volcanic debris consists of fine particles, the size of the discharged sediment particles at time of flooding immediately after eruptions can be expected to be still smaller. As for the large boulders (of about 2 m diameter) many are to be found scattered in riverbeds in these areas. It is believed that they have been rolled down by the lahar upstream and the moving strata of fine-particle sediment downstream.

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

Although these two rivers are not directly affected by eruptions as the rivers in the Type-I areas are, they rank behind only K. Krasak and K. Putih in terms of amount of sediment discharged. Of the three types of areas, the rivers in Type-II area have the most pronounced valley depth. In the case of K. Woro the valley is over 100 m deep and of a U-shape upstream of about the 1,100 m elevation.

The probable reason for this is that there has not been very much supply of sediment from eruptions for quite some time. At the present time the sediment production is chiefly due to erosion of the riverbeds and riverbank deposits. The rivers in these areas have more sediment discharge than those in Type-III area which also have not been directly affected by eruptions for a long time. The reason source of erosion of Type-II riverbeds is the large amount of unstable lahar deposits remaining in the river courses from the 1930 and other eruptions
is to be found upstream of elevation 2,000 m. Furthermore, in view of the fact that the riverbed gradient of K. Dengkeng, into which K. Woro flows, is gentle with no sediment discharge capacity, a large amount of sediment has been deposited at the middle and downstream parts of K. Woro. Embankments have long been used in such locations as disaster prevention countermeasures. As a result the large-scale sedimentation, the riverbed is higher than the land around it, which means that there is considerable danger of major flooding damage. The size of the particles of matter making up the riverbeds is the same as in the case of Type-I rivers.

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

The rivers in these areas have little sediment discharge and stable configurations. Upstream the valleys are deeply cut, but downstream of about elevation 450 m K. Kuning and K. Boyong have fan-like deposit terrains.

Because the heads of K. Kuning and K. Boyong consist of lava (which is not easily eroded) and the old Merapi blocks the downward flow of volcanic debris, there is little sediment production. Upstream, however, there remain unstable deposits in the riverbeds and on the riverbanks which could be discharged at the time of major flooding. Along the middle stretches of the rivers there is danger of localized flooding and bank collapse where past deposits have resulted in narrowing of the cross-sectional area of the river and where the river flow is unstable. In addition, there has been armoring of the sediment deposited in the riverbeds, and the particle size is large.

Unlike K. Kuning and K. Boyong, K. Pabelan was affected by eruptions in the 1950's. Because of its large flow capacity, however, the erosion progressed very rapidly, and the river is now relatively stable.

3) Features of Each River

The topographical features of each river are given in Table 6. Details regarding the characteristics of each of the tributaries are summarized in Table 7.

Table 6 The Dimensions of the Tributary Basins

	Name of Tributaries	River System	Catchment Area (Km^2)	Stream Length (km)	Mean Channel Slope (%)
Type-I	K. Blongkeng	K. Progo	44.6*	27	10.9
	K. Putih	"	26.6	27	10.9
	K. Batang	"	22.8	20	14.7
	K. Krasak	"	31.7	29	10.2
Type-II	K. Gendol	K. Opak	14.6	22	14.0
	K. Woro (and K. Simping)	K. Dengkeng	17.4	34	8.7
Type-III	K. Pabelan	K. Progo	103.2	46	6.4
	K. Boyong	K. Opak	76.0	37	8.0
	K. Kuning	"	47.7	38	7.8
	TOTAL	-	384.6	280	-

* not include the catchment area of K. Putih

Table 7 Characteristics of the Tributary Basins

Type	River \ Character of landform *	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Comment
Type I	K. Blongkeng	convergence	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	divergence	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	divergence	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	divergence	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 suppllied large quantities of debris from upper part of K. Batang.
	K. Krasak	divergence	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	convergence	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	divergence	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. Buyong	divergence	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	divergence	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	divergence	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.

2.3.3 Planning Policy

1) Background Situation and Basic Policies

a) Type-I Areas

The features of the Type-I area are as follows:

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

(2) River piracy is pronounced, with change in basin area and course of flow and sharp change in amount of flow and amount of sediment discharge very possible.

(3) For work safety considerations and such change in course of flow affected by nuée ardente, 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.

Considering the above features, the basic policy in the planning is as follows:

(1) Fixation of valley exits upstream.

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

(3) Improvement of the middle and lower river stretches so that flood waters can be carried down smoothly.

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

b) Type-II and -III Areas

The features of the Type-II and -III areas are as follows:

(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 sediments.

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

(4) K. Woro, which is a main river, has no sediment load capacity, and therefore at its middle and lower stretches the riverbed is rising year by year so that it has become higher than the surrounding land.

Considering these features, the basic policy in the planning is as follows:

(1) Reduction of sediment production and discharge.

(2) Improvement of middle and lower stretches 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.

2.3.4 Sediment Disposal Plan

1) Method of Sediment Disposal

The sediment disposal plan is basic to the planning of the sabo facilities.

The sediment disposal plan will rationally dispose of the harmful part of the sediment production and sediment discharge in the basins concerned by means of sabo facilities.

The equation to determine sediment disposal amounts is as follows:

$$F \leqq Q + A - B - C - D - E$$

where

Symbol	Sediment type	Function in river system
Q	Proposed discharge from upstream	Input
A	Proposed produced sediment	
C	Proposed controlled sediment in river channel	Naturally reduced amount
B	Proposed reduction of production	Amounts reduced by Sabo Works
D	Proposed reduction of discharge	
E	Proposed control of discharge	
F	Proposed allowable sediment discharge	Output balance

The following are other amounts of sediment used for planning purposes:

$G = A - C$ and $H = G - F$

where G : Proposed amount of discharged sediment
H : Proposed amount of excess sediment to be handled by the plan.

Notes: F : Proposed allowable amount of discharged sediment. This is the amount of sediment that can and must be sent downstream from the upper design basic point without doing any harm.

Q : Proposed amount of discharged sediment upstream of the design basic standard point.

A : Proposed amount of produced sediment. This is the amount of sediment that flows into river courses from volcanic debris deposits, riverbank collapse, etc. and that is produced by secondary erosion of riverbed deposits.

B : Proposed amount of sediment production to be reduced. This is the amount of sediment produced by riverbed and riverbank erosion and collapse, etc. to be reduced by means of check dams and other sabo facilities.

C : Proposed amount of controlled sediment in the river channel. This is the amount of produced sediment that is to be temporarily stored in the river course for control of the amount of sediment discharge.

D : Proposed amount of sediment discharge to be reduced. This is the amount of sediment, the discharge of which is to be reduced by means of storage at check dams, sand pockets, and other facilities.

E : Proposed amount of sediment discharge to be controlled. This is the amount of sediment to be stored at check dams, sand sand pockets, and elsewhere at times of flooding to be gradually released downstream afterwards so as to adjust the amount of sediment discharge.

G : Proposed amount of discharged sediment (A - C). This is that part of the proposed amount of produced sediment that will be discharged at the design basic points after being carried by lahar, sweep flood force, and other means.

In other words, it is the proposed amount of produced sediment minus the proposed amount of controlled sediment in river channel.

E : Proposed amount of excess sediment to be handled by the plan (G - F). This is the amount of sediment that is most basic to the sediment disposal plan. It is the proposed amount of discharged sediment minus the proposed allowable amount of discharged sediment.

2) Design Basic Points

The Design basic points are the points that will serve as standards for the sediment disposal plan. Each river will have two such basic points as follows:

(1) First Design Basic Point

This point is to be at the boundary between the flooding erosion area and the depositing area. The amount of discharged sediment between it and the second Design basic point will be considered.

(2) Second Design Basic Point

These are the points where the tributaries flow into K. Progo, K. Opak, and K. Dengkeng. In the case of K. Lamat however, the point is the confluence with K. Blongkeng. They will be used to consider the amount of sediment discharged into these rivers.

3) Setting of Proposed Basic Amounts of Sediment

a) Basic Policy for each Type of Tributaries.

The different types of area have different characteristics with respect to sediment discharge. Fig. 10 depicts the time series with respect to amount of sediment discharge for each type which is described below:

i) Type-I Areas

There is major sediment discharge immediately after eruption, followed by a gradual decrease thereafter. The peak amount of sediment discharge is greater than in the case of the other two types of areas. Furthermore, the amount of sediment discharged in average years is also considerable. In these areas the major sediment discharged immediately after an eruption is the main cause of disaster damage. If this harmful sediment discharge can be taken care of, the rest should not be much of a problem since there is relatively good capacity for the flow conveyance of the amount of sediment discharged in normal years.

It is assumed that the direct effect of eruptions will continue to be restricted, at least for the time being, to Type-I areas. The proposed basic amounts of sediment are the same scale as that of 1969 eruption. As for the amount of sediment discharge in normal years, it is assumed that it will be carried down smoothly into the main rivers.

ii) Type-II Areas

At the time of major flooding there is major sediment discharge. Although less than in the case of Type-I areas, there is still considerable sediment discharged in normal years. In the case of K. Woro the discharged sediment in normal years is deposited in the river course since there is no capacity for conveying it to K. Dengkeng.

The proposed basic amounts of sediment are the amounts that occur in years of major flooding. In the case of K. Woro, consideration will also be given to the amount of sediment discharge in normal years.

iii) Type-III Areas

Although there is considerable sediment discharged when there is major flooding, in normal years there is hardly any at all.

The proposed basic amounts of sediment are the amounts in years of major flooding.

(Note: The K. Lamat, a tributary of K. Blongkeng, is to be treated one river.)

b) Policy for Calculation of the Basic Amounts of Sediment

The method of calculation of the basic amounts of sediment must be suited to the way in which the sediment moves. Normally sediment movement in the area covered by the plan is by bed load or suspended load, but at times of major flooding there is mass movement (called lahar) upstream and tractive-mass movement type downstream because of the small particle size of the riverbed matter.

Furthermore, at times of major flooding, the sediment load particle diameter can be expected to be considerably smaller than that of the matter presently deposited in the riverbeds since there will be a large admixture of volcanic ash and other materials from erosion upstream.

There are many possible ways of calculating the sediment load for bed load and for suspended load. For mass movement, however, there is no suitable method of calculation of the sediment load since a lot has still to be learned about it, including the type of area in which it occurs. Accordingly, in this case it is necessary to calculate the amount of sediment discharged at times of major flooding on the basis of the riverbed fluctuation method or observation of the amount of sediment load. At normal water levels, however, it should be possible to get a rough idea of the amounts of conveyance on the basis of the method for calculating the amount of sediment load.

The method for calculating the basic amounts of sediment will be based on the following:

i) Proposed amount of produced sediment and the proposed amount of controlled sediment on the river channel are to be determined on the basis of topographical surveying and field investigations as well as study of riverbed variation.

ii) Proposed allowable amount of discharged sediment is to be determined on the basis of calculation of the bed load in normal years. Brown's formula is to be used since there is a high percentage of suspended load sediment in the sediment load in the area covered by the plan and this formula covers both bed load and suspended load. In this case the same particle size will be used for the sediment as that of the present riverbed matter.

c) Proposed Amount of Produced Sediment

i) Type-I Areas

(General calculation policy for all rivers)

(1) Most of the produced sediment in Type-I areas at the time of major flooding is due to lateral and downward erosion of valleys by lahar.

(2) The smaller the valley, the greater the expansion. During the period 1969 - 1976 the cross-sectional area of K. Bebeng, (a tributary of K. Krasak) increased 17-fold on the average, and that of K. Putih increased 2.5-fold on the average.

(3) The rivers course in these areas change direction, and the amount of produced sediment varies according to whether it flows in the expanded existing river channel or in a new course of flow, the amount being greater in the late case.

(4) The proposed amount of produced sediment will be based on the case of flow in a new course of flow.

(5) Considering the amount of valley expansion, it is assumed that the amount of produced sediment in 1969 in the cases of K. Bebeng and K. Putih (K. Jurang Jero) was based on flow in a new course of flow.

(6) The amount of produced sediment has also been calculated for the case in which the flow is in the existing river channel for use as a control amount of sediment for the sabo facilities. The sections for which the case of flow in the existing river channels will apply are downstream of the 7km point from the mountain top in the cases of K. Krasak and K. Batang and downstream of the 6km point from the mountain top in the cases of K. Putih and K. Blongkeng.

Upstream of these points, the flow in new courses will be based on the assumption that the valleys will be blocked there at at the time of major eruptions.

(7) It is assumed that the amount of produced sediment in the case of flow in the existing river channels will be one-half of that in the case of flow in new courses of flow. In the case of K. Krasak proper, however, this amount of produced sediment will be calculated on the basis of a study of the amount of unstable sediment since the cross-sectional area of the river is large.

(Calculation policy for individual rivers)

(1) K. Krasak

The proposed amount of produced sediment is to be the same as that in 1969 eruption so that the course of lahar flow from K. Bebeng will be the same as in the case of lahar flowing to the K. Krasak proper.

(2) K. Putih

Same as the amount produced in the 1969 eruption.

(3) K. Batang

Same as in the case of K. Krasak considering the topography and the past state of flooding.

(4) K. Blongkeng

Same magnitude as in the case of K. Putih for the same reasons as in the case of K. Batang.

As for K. Lamat, the amount of produced sediment will be set independently of K. Blongkeng proper in view of the fact that the direct effect of eruptions is small. The method of calculation is the same as for Types-II and -III.

ii) Type-II and -III Areas

(1) The proposed amount of produced sediment in these area will be determined as the basis of study of the amount of sediment that can be produced by major flooding from the unstable sediment presently on the riverbeds, riverbanks, and elsewhere.

(2) The places where existing land erosion and volcanic debris control facilities are checking sediment production are not to be taken into account in calculating the amount of produced sediment.

Table 9 gives the proposed amounts of produced sediment as based on the above policy.

d) Proposed Amount of Controlled Sediment in the River Channel

i) Type-I Areas

(1) The proposed amount of controlled sediment in the river channel is to be calculated for the part of the river upstream of the first design basic point, and for the riverbed downstream of that point, it is not to be raised above its present level.

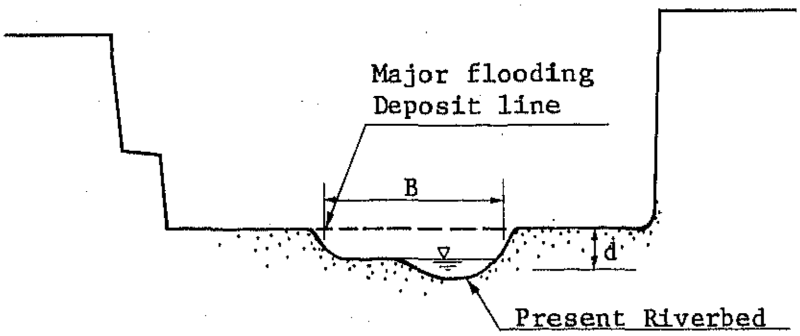
(2) It is to be the same as the amount of controlled sediment on the river channel in 1969, and it is to be the same for K. Batang as for K. Krasak and the same for K. Blongkeng as for K. Putih.

ii) Type-II and -III Areas

(1) It is to be calculated for the part of the river upstream of the 1st design basic point.

(2) The amount of controlled sediment is to be the difference between the deposit line at times of major flooding in the past and the present riverbed.

Table 10 gives the calculated proposed amounts of controlled sediment on the river channels as based on the above policy.



$V = B \times d$

where V : Proposed Amount of Controlled Sediemnt on River Course (m^3)
d : Different Height (m)
B : Minor Bed Area (m^2)

e) Allowable Amount of Discharged Sediment

The allowable amounts of discharged sediment are to satisfy the following conditions:

(1) An amount that can be allowed to be carried downstream of the Design basic points without any harm.

(2) The amount that is needed to maintain the river course below Design basic points.

i) First Design Basic Point (boundary between erosion area and deposit area)

The allowable amount of discharged sediment for this point is the amount that can pass between the first design basic point and the second design basic point with no trouble and that is not in excess of the planned allowable amount of discharged sediment for the second design basic point.

In the case of the eight rivers other than K. Boyong, the propose allowable amount of discharged sediment is the same for the first and second design basic points. In the case of K. Boyong the sediment load capacity for about 5 km downstream of the first design basic point is only about one-tenth of that at the second proposed standard point. Accordingly, the sediment load capacity at this bottleneck is to be used for the proposed allowable amount of discharged sediment at the first design basic point.

ii) Second Design Basic Point (where the tributary runs into the main river)

For 1 - 2 years after a major eruption, the riverbeds of K. Progo, K. Opak, and K. Dengkeng rise as a result of a large amount of sediment production, and this causes considerable trouble until the riverbed subsequently gradually get lower (except at the mouth and a few other places) and approaches the level prior to the eruption. Accordingly, it should be alright to let the sediment loads of the tributaries flow into these main rivers in normal years, i.e. when there is no influence from major eruptions.

For this reason the average value of the bed load capacity at the design basic points in normal years is to be used for the allowable amount of discharged sediment. As for the river mouths and other places were there is a rise in the riverbed due to the sediment discharged in normal years, they will have to be handled by improving the river course since such a rise cannot be prevented by reducing sediment discharge.

iii) Table 11 gives the calculated proposed allowable amounts of discharged sediment.

f) Proposed Amount of Discharged Sediment

i) Proposed Amount of Discharged Sediment for Maximum Flood Years

This is the proposed amount of produced sediment minus the proposed amount of controlled sediment on the river channel.

ii) Amount of Discharged Sediment for Normal Years

In the case of K. Woro the amount of discharged sediment for normal years is to be obtained by calculating the amount of discharge at the check dam where sediment deposit is a problem in normal years.

g) Proposed Amount of Excess Sediment to be Handled by the Plan

The proposed amount of excess sediment can be obtained by subtracting the proposed allowable amount of discharged sediment from the proposed amount of discharged sediment.

Table 12 gives the proposed basic amounts of sediment on which the plan is based.

4) Plans for Handling the Sediment

a) Basic Policy

i) The following are three plans for coping with the proposed amount of excess sediment so that the proposed amount of discharged sediment is reduced to the proposed allowable amount of discharged sediment:

(1) Plan for reducing sediment production.

(2) Plan for controlling sediment discharge.

(3) Plan for reducing sediemnt discharge.

ii) The order of the planning will, as a rule, be as follows:

(1) Priority provision of facilities for reducing sediment production.

(2) Provision of facilities for controlling sediment discharge to the extent that the amount of reduction in sediment production is less than the proposed amount of excess sediment.

(3) Planning for reduction of sediment discharge, if the above facilities for reducing sediment production and facilities for controlling sediment discharge both still do not reduce the sediment discharge to the extent of the proposed excess sediment (ie, to the extent of the deficiency). Such facilities for reducing sediment discharge are to have a capacity of at least the amount of sediment that they are to handle, during the fifty years of their life.

iii) River course improvement is to be planned for places where it is not possible to carry flood waters and sediment down safely even if the proposed amount of excess sediment is handled by means of the above three plans because of the structure of the river course. For example, where the river course suddenly narrows considerably, at sharp curves, or at places where the riverbed is very wide and the course of flow is unstable. Furthermore, in cases where there is considerable danger and socio-economic importance, implementation of such planning for river course implementation of the plans for coping with sediment.

b) Plan 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 sabo 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.

i) Causes of Sediment Production and How to Handle It

The main cause of sediment production in the area in question is erosion of river valleys by lahar. Furthermore, the amount of erosion is doubled in Type-I areas by change in basins and courses of flow as a result of river channel piracy. The following is a discussion of how to handle such erosion.

(1) Reduction of Lahar

Lahar occurs above an elevation of about 1,000m and flows down to an elevation of about 400m, increasing in scale and energy by erosion of the sediment of the riverbed and the riverbanks along the way. Lahar occurs, however, in nuée ardente areas, where it would be difficult to provide sabo facilities. Accordingly check dams and consolidation dams for fixing riverbeds are to be provided in erosion ereas for sediment storage to raise riverbeds, widen river channels, and lower riverbed gradient so as to reduce the erosion and keep the lahar from gathering too much energy. In this way it will be possible to reduce the range of flow of the lahar.

If the check and consolidation dams and other such facilities prove, however, to be inadequate, sand pockets to reduce the range of lahar flow and embankments, bank protection works, etc. to prevent lahar flooding will be provided.

(2) Fixation of Courses of Flow

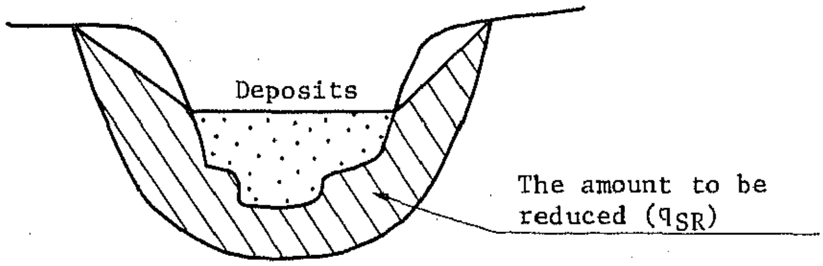
In the area in question nuée ardente and lahar block up valleys, erode riverbeds and banks, and overflow river channels, giving rise to the phenomenon of river channel piracy. This phenomenon drastically changes basin areas and the river course, causing great change in the configurations of downstream rivers and considerable disaster damage. This being the case, check and consolidation dams and training levees are to be provided to guide the unstable flow into a single channel and prevent the erosion of new valleys for greater stability of downstream river channels. These measures are to be taken in Type-I areas, where there is marked river channel piracy.

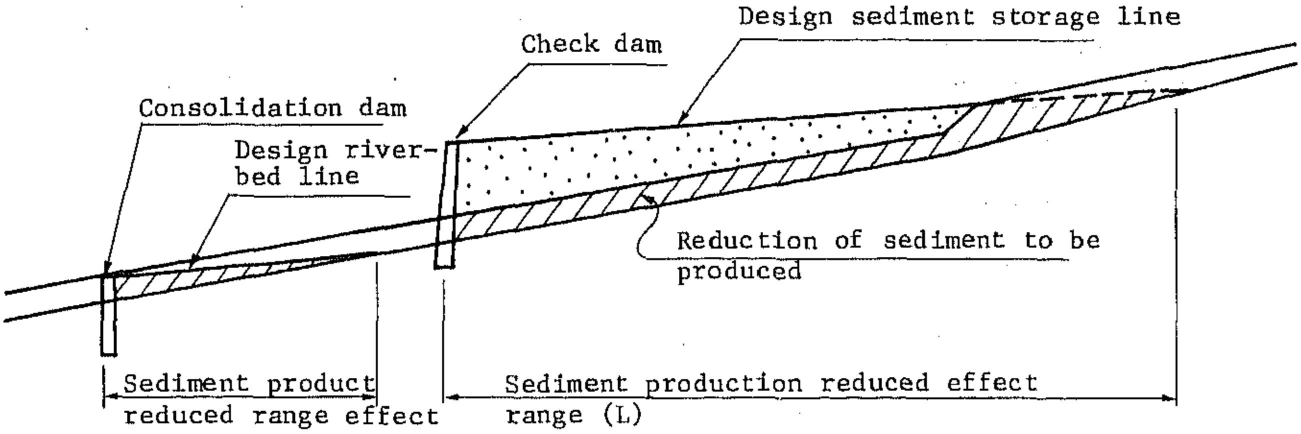
ii) Function of Facilities for Reducing Sediment Production

(1) Check and Consolidation Dams and Riverbed Fixation Works

These facilities will be able to reduce the amount of sediment produced by erosion of riverbeds and banks.

The effective range of such reduction of sediment production is to be up to the intersection of the design sediment storage line (design riverbed line) of the check and consolidation dams (riverbed fixation works) with the line of the unstable sediment that is subject to erosion.





(Proposed Amount of Sediment Production To Be Reduced)

The amount of sediment production to be reduced is to be calculated as follows:

$$Q_{SR} = L \times q_{SR}$$

$$q_{SR} = q_{SP} \times r$$

Where
- Q_{SR} : Amount of sediment production to be reduced (m^3).
- L : River course length of reduction of sediment production (m).
- q_{SR} : Unit amount of reduction of sediment production (per unit of river channel length) (m^3/m).
- q_{SP} : Unit amount of sediment production (per unit of river channel length) (m^3/m).
- r : Rate of reduction. This is the ratio of the amount of reduction in sediment production to the amount of sediment production, 1.0 meaning complete reduction (dams: 0.7 - 1.0; river channel fixation works: 0.35 ∿ 0.5

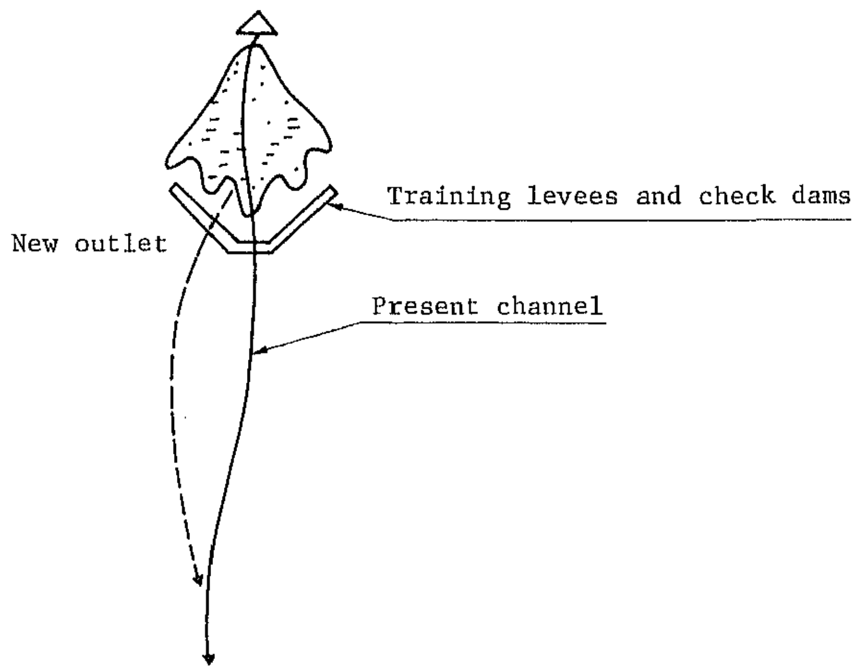
The unit amount of reduction of sediment production is to be calculated per kilometer of river course length.

(2) Valley Mouth Fixation Works

By fixing the valley mouth with training levees and check and consolidation dams so that the courses of flow will be guided into the present channel, it will be possible to prevent new valleys by erosion. Belts of protection forests will also be provided behind the training levees for reduction of sediment.

(Proposed Amount of Reduction of Sediment Production)

Since the present channels have already been eroded and have large cross-sectional areas they will undergo relatively little erosion in the future, however, large amounts of sediment will be eroded if new valleys are made. Accordingly, the amount of reduction of sediment production is to be calculated as the difference between the amount of sediment that would be produced if the lahar were to flow in a new river channel and the amount that will be produced by the lahar flowing in the present channel. The amount of reduction of sediment production is assumed to be one-half of the amount of sediment production over the river channel length in question (4,197 x 10^3 m^3, or approximately one-third, in the case of flow in K. Krasak proper).



c) 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. Although the absolute amount of sediment that is discharged downstream will not change, the controlling function will be permanent.

i) Controlling Function

Sand pockets and check dams will temporarily store the sediment discharged during flooding for gradual release downstream later on after the waters have resided to the normal level, thus keeping the amount of discharge within manageable proportions at all times.

Sediment will be deposited so that the riverbed gradient is high during flooding (when sediment density is high) and gentle at times of normal water level (when sediment density is low). The sediment between the riverbed radient during flooding and the riverbed gradient at times of normal water level is the amount of sediment that will be controlled.

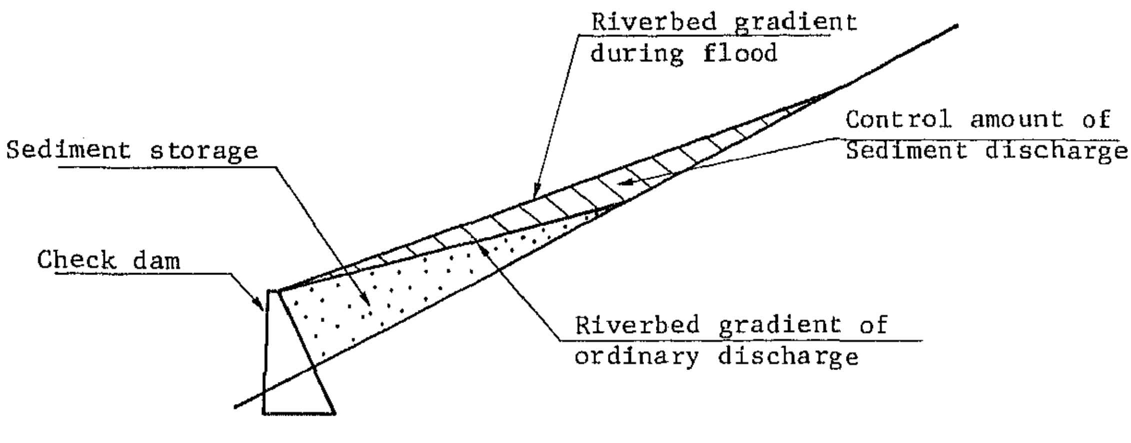


Fig. 11 gives the sediment storage gradients of existing check dams in the G. Merapi area. As can be seen, in the case of rivers in Types-I and -II areas, the sediment storage gradient is 2/3 - 3/4 of that of the riverbed before the dam was built and over 1/1 in the case of K. Krasak. In the case of rivers in Type-III areas it is 1/2 - 1/3. In order for the controlling function of the check dam to be adequate, it is necessary that there be a large difference between the sediment storage gradient during flood and the sediment strorage gradient at times of normal water level and that there be plenty of time for the sediment storage gradient during flooding to return to the gradient at times of normal water level.

ii) Proposed Amount of Sediment to Be Controlled

(1) In the case of Types-I and -II areas, the amount of control of sediment discharge is not to be used in the planning since the particle size of the discharged sediment is small and the amount is large.

(2) In the case of Type-III areas, the amount of control of sediment discharge is to be used in the planning since the controlling function will be more reliable. In this case the amount of sediment discharge to be controlled is the amount of sediment between 1/2 and 2/3 of the existing riverbed gradient.

(3) The amount of sediment discharge control by sand pockets is to be not counted in the plan.

d) 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 facilities and excavation, there is a limit to how effective it will be.

i) Amount of Sediment discharge to be Reduced

(1) Since the sediment storage pockets of the check dams will most probably be full at times of flooding, the amount of sediment discharge reduced by them is not to be taken into account in the planning.

(2) The amount of sediment stored in sand pockets, however, it to be used.

In this case it will be necessary to provide facilities to ensure that the sediment is evenly stored within the sand pockets and also to do maintenance and control work, including care of the riverbed.

(3) The amount of sediment discharge to be reduced is as follows.

(Amount of sediment discharge to be reduced) =
(Sand pocket area) x (Average height of stored sediment)

e) Plan for Improvement of River Courses

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

i) Countermeasures for Handling Insufficient Drainage Capacity

This plan will apply mainly to areas downstream of the design basic point. This is where sediment is conveyed and deposited and where there is pronounced flooding due to damage to embankments and bank protection 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 cases 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 cause results in a rapid increase in sediment load and in amount of flow.

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.

(1) Embankments

These will be provided at place where sediment tends to be deposited and this results in insufficient drainage capacity.

(2) Improvement of Sharp Bends and Bottlenecks in River Courses

At places where sharp bends in the river or extreme narrowing of the river at bridges, intakes, etc. impair drainage capacity improvements are to be made in the river course or the bridges or other structures involved.

(3) Lowering of Riverbeds by Increasing Sediment Load Capacity

At places where the riverbed gradient is gentle and the river is wide and therefore drainage capacity is small, sediment accumulates and the riverbed continues to rise, giving rise to danger of flooding. Accordingly, sediment load capacity is to be increased and the riverbed lowered at such places by means of embankments, reduction of river width by grains, and so on.

(4) Protection of Places Where There is Bank Collapse

River bank collapse is to be prevented by bank protection works and other means.

(5) Storage and Excavation of Deposited Sediment

Sediment deposits in river channels that cannot be handled by the means described above will be dealt with the storage using sand pockets and check dams, and by excavation.

Table 8 Location of Design Basic Points of Each Tributary

Type	Name of Tributaries	1st Design Basic Point	2nd Design Basic Point
Type-I	K. Blongkeng (K. Lamat)	Distance from the summit 9 km (13)	Confluence point to K. Progo Confluency point to K. Blongkeng
	K. Putih	9	Confluence point to K. Progo
	K. Batang	12	"
	K. Krasak	12	"
Type-II	K. Gendol	13	Confluence point to K. Opak
	K. Woro	10	Confluence point to K. Dengkeng
Type-III	K. Pabelan	14	Confluence point to K. Progo
	K. Boyong	13	Confluence point to K. Opak
	K. Kuning	13	"

Table 9 Proposed Amount of Produced Sediment (PAPS)

Unit: $10^3 m^3$/year

Type	River name	(1) Total river basin (km^2)	(2) River basin of sediment production Area (km^2)	(3) PAPS	(4) PAPS (through present river channel	(5)=(3)/(1) PAPS per unit river basin	(6)=(3)/(2) PAPS per unit river basin of sediment reduction area	Remarks
Type-I	K. Blongkeng	22.2	6.8	6,060	5,246	273	891	Blongkeng 22 km^2 at confluence point with K. Lama.
	(K. Lamat)	14.2	7.1	459	459	32	65	
	K. Putih	26.6	9.1	6,060	5,246	228	666	
	K. Batang	22.8	8.5	11,760	8,637	516	1,384	
	K. Krasak (Flow through K. Bebeng)	31.7	K. Bebeng 8.5	11,804	8.681	372	1,299	
	K. Krasak (Flow through upper K. Krasak)	(31.7)	(14.5)	(11,804)	(7,607)	(372)	(814)	
	Sub-total	117.5	40.0	36,143	28,269	308	904	
Type-II	K. Gendol	14.6	10.5	3,158	3,158	216	301	
	K. Woro	17.4	7.1	4,219	4,219	242	594	
	Sub-total	32.0	17.6	7,377	7,377	231	419	
Type-III	K. Pabelan	103.2	73.2	4,210	4,210	41	58	
	K. Boyong	76.0	10.3	1,437	1,437	19	140	
	K. Kuning	47.7	9.6	1,844	1,844	39	192	
	Sub-total	226.9	93.1	7,491	7,491	33	80	
	Total	376.4	150.7	51,011	43,137	136	338	

* year: Major Flooding Year

Table 10 Proposed Amount of Controlled Sediment on River Course (PACSRC)

	River name	Area of river channel $10^3 m^2$	Controlled height m	PACSRC $10^3 m^3$	Controlled ratio for PAPS	Remarks
Type-I	K. Blongkeng	-	-	3,630	0.599	from 1969 data
	(K. Lamat)	90	2.5	225	0.490	"
	K. Putih	-	-	3,630	0.599	"
	K. Batang	-	-	2,449	0.208	"
	K. Krasak	-	-	2,449	0.207	"
	Sub-total	90		12,383	0.343	
Type-II	K. Gendol	234	2.0	468	0.148	
	K. Woro	244	2.0	488	0.116	
	Sub-total	478		956	0.130	
Type-III	K. Pabelan	577	2.5	1,443	0.343	
	K. Boyong	209	2.5	523	0.364	
	K. Kuning	292	2.5	730	0.396	
	Sub-total	1,078		2,696	0.360	
Total		1,646		16,035	0.314	

$$\text{Control ratio for PAPS} = \frac{\text{Proposed Amount of Controlled Sediment on River Course}}{\text{Proposed Amount of Produced Sediment}}$$

Table 11 Proposed Allowable Amount of Discharged Sediment (PAADS)

Unit: $10^3 m^3$/year

	River name	PAADS at 1st and 2nd design basic points
Type-I	K. Blongkeng	310
	(K. Lamat)	170
	K. Putih	260
	K. Batang	280
	K. Krasak	900
	Sub-Total	1,920
Type-II	K. Gendol	210
	K. Woro	6
	Sub-Total	216
Type-III	K. Pabelan	340
	K. Boyong	90
	K. Kuning	40
	Sub-Total	470
Total		2,606

Note:

(1) The amount of PAADS is calculated as bedload.

(2) The average diameters of present riverbed material are used for the calculation.

(3) The average amount of discharged sediment for four years (1969, 1971, 1975 and 1976) are calculated.

(4) The calculation points are second design basic points except K. Boyong which is a first design point.

(5) The Brown formula has been used to calculate the amount of discharged sediment.

Table 12 Basic Proposed Sediment Amount

Unit: x $10^3 m^3$

Type	River \ Amount of sediment	(1) Amount of produced sediment (A)	(2) Amount of controlled sediment amount on river course (C)	(3) Amount of discharged sediment (G)=(A)-(C)	(4) Allowable amount of discharged sediment (F)	(5) Amount of excess sediment (H)=(G)-(F)
Type-I	K. Blongkeng	6,060	3,630	2,430	310	2,120
	(K. Lamat)	459	225	234	170	64
	K. Putih	6,060	3,630	2,430	260	2,170
	K. Batang	11,760	2,449	9,311	280	9,031
	K. Krasak	11,804	2,449	9,355	900	8,455
	Sub-Total	36,143	12,383	23,760	1,920	21,840
Type-II	K. Gendol	3,158	468	2,690	210	2,480
	K. Woro*	4,219	488	3,731	6	3,725
	Sub-Total	7,377	956	6,421	216	6,205
Type-III	K. Pabelan	4,210	1,443	2,767	340	2,427
	K. Boyong	1,437	523	914	90	824
	K. Kuning	1,844	730	1,114	40	1,074
	Sub-Total	7,491	2,696	4,795	470	4,325
Total		51,011	16,035	34,976	2,606	32,370
*K. Woro normal years:			-	24	6	18

Fig. 10 Sediment Discharge Amount Time Series

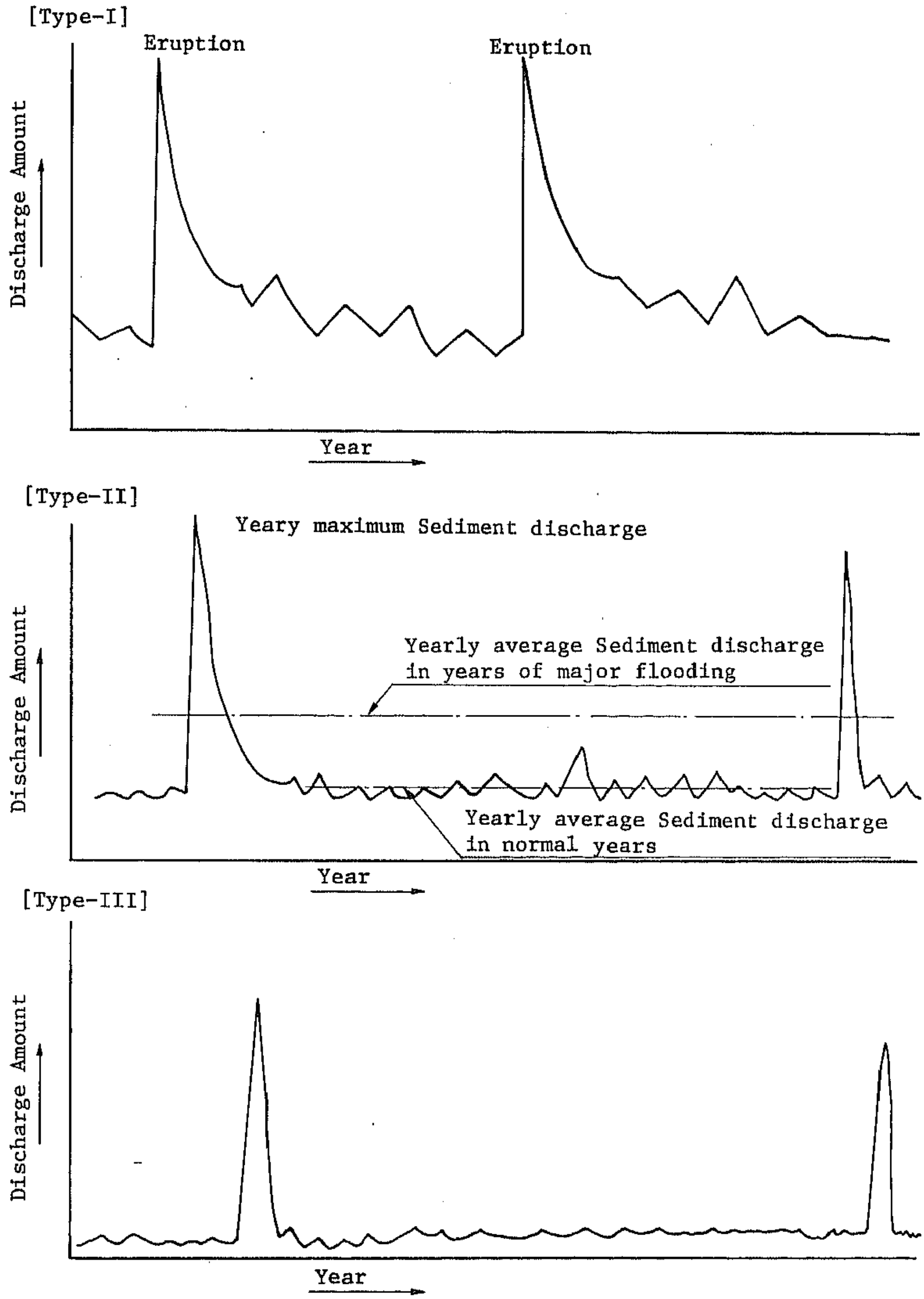


Fig. 11 Comparison between Original Slope of Riverbed and Present Accumulating Gradient at Site upper stream of Check Dams