The Study on Comprehensive Disaster Prevention around Mayon Volcano

SUPPORTING REPORT (2)

(Part II : Feasibility Study)

XV: Sabo Planning

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1. YAWA RIVER SYSTEM

1.1 Objective of Feasibility Study

(1) Objective rivers

The Master Plan study, completed prior to this feasibility study, assessed the priorities of the preliminary Sabo plans for the targeted 17 rivers in the Study Area to select a priority project as the objective of the feasibility study. The enumerated items are economic viability, number of beneficiaries, social impact and representativeness of each proposed project. The assessment concluded that the Yawa river system Sabo project has the highest economic internal rate of return and the largest number of beneficiaries. It might bring about a certain social impact. However, the conceivable impacts are to be solved by the supporting programs proposed in this report. It also revealed that the Yawa river system Sabo project could be a pilot project for other proposed Sabo projects from the administrative and technical points of view. In the light of this, the Master Plan Study proposed that the Yawa river Sabo project should be included for the feasibility study. The proposal was duly approved by both the JICA and the Steering Committee of the Study held on August 23, 1999 in Manila. The Committee concluded that a sand pocket is the basic option or the most appropriate facility to protect life and property of the people in conformity to the geomorphologic conditions of the Study Area

The selected Yawa river Sabo project comprises sand pockets and related structures for three tributaries: the Pawa- Burabod river, the Budiao river, and the Anoling river.

(2) Revision in Sabo plan from one proposed in the Master Plan

The Sabo plans for three tributaries proposed in the Master Plan were reviewed on the basis of the results of additional surveys conducted in this period and the elaboration of the obtained data. Such in depth study attested the appropriateness of the proposed plan in general. The magnitude of hazard or design mud and debris flow and the major features of proposed facility or the alignments, heights and materials of dam and dike for sand pocket are confirmed to be adopted in the feasibility study as proposed in the Master Plan.

The major revisions adopted in this study are as follows:

- The proposed open dike is revised to the continuous dike in order to avail the dike as a reliable road especially for the inspection and the maintenance of the Sabo facility.
- The proposed training dike at the right bank of downstream reach of the Pawa-Burabod sand pocket was deleted because the road provided along the river was confirmed to be functioning as a dike as well. The paddy fields of around 30ha which extend from the river is included in the existing protected area.
- A more in depth study was carried out for the maintenance works of the proposed sand pocket.
- A preliminary study on stage wise development was carried out for the period until the facility is provided.
- A preliminary study on the buffer zone was carried out.
- The more in depth study on the structural design was carried out as follows:
    - Stability of dams
    - Dimensions of slit in the proposed spillway

1.2 Composition of the Yawa river system

The Yawa river system is situated on the southeast slope of the Mt.Mayon. The Yawa river gathers three tributaries from the Mayon volcano slope side. Three tributaries, the Anoling river, the Budiao river and the pawa- Burabod river (Figure XV 1.1). River basin characters of these tributaries are shown below:

River Condition in Project Area for Sabo Works

River Condition	Pawa-Burabod River	Budiao River	Anoling River
Catchments Area (km^2)	7.4	1.0	9.6
River Length (m)	5.8	3.7	5.6
River Bed Slope Gradient in Gully	0.200	0.083	0.067
River Bed Slope Gradient in Fan	0.063	0.067	0.053
Mean Channel Width In Fan	50	30	22
Mean Channel Depth In Fan (m)	2.5	3.0	3.0
Mean Particle Size of River deposit (mm)	344	74	189

Sources: Topographic map prepared by the Study in 1999
Air photo shot in 1998 and the hazard map prepared in 1998 by the study
Interpretation of satellite image carried out by the Study
Surveyed results on riverbed material conducted by the Study

1.3 Land Use

Land use in the Yawa river system is shown below：

Land Use in the Yawa River System

Land Use	Pawa-Burabod (a.s.l.m)	Budiao (a.s.l.m)	Anoling (a.s.l.m)
Forest	350-	400-	400-
Coconut Field	110-350	150-400	150-400
Barangay	100-110	130-150	130-150
Water Spring	90-100	130	130
Paddy Field	15-90	30-130	30-130

The areas from El.400 are alluvial fan areas and most have been devastated by mud and debris flow at one time or another. There are some in the lower portion of the areas which were used intensively as agriculture land including barangay yards. But the upper portions are mostly used for extensive coconuts field.

(1) Administrative boundary and Community in the catchment area

The administrative boundary are drawn in the Yawa river system as drawn in Figure XV 1.1 and the barangays situated in the river basin are as follows:

Community in the Yawa River System

Community	Pawa-Burabod	Budiao	Anoling
Municipality	Daraga and Legazpi City	Daraga	Camaling and Daraga
Barangay	Bonga Mabinit Pawa	Bunadero Matanag Budiao Kilicao	Salvacion Budiao Malabog

2. PRESENT CONDITION AND PROBLEMS IN THE OBJECTIVE AREA

2.1 Geomorphology and Geology

(1) Geomorphological and Geological Feature of Mayon Volcano

Land from divide the mountain slope into four segments.

The features of each segment are summarized in the following table.

Landform Classification of Mountains Slope

Elcvation of Segment Amsl (meter)	Mean Slope Gradient	Landform	Geological Structure
From summit to 1000masl	1/1.6	Volcanic dome	Volcanic rock (mainly Andesite rock)
From 1000 masl to 500-300 masl	1/3.3-1/7.8	Pyroclastic, Debris and lava Plateau	- Primary on secondary pyroclastic and debris material - Primary
From 500-300 masl, to 100-20 masl	1/16.7-1/23	Alluvial fan	- Secondary or thirdly pyroclastic and debris material
From 100-20 masl to mountain	More than 1/100	Alluvial plan	Sand and silt

(2) Alluvial Fan Formation

In general, a mud and debris flow occurs in the slope with a gradient of more than 15° . In accordance with the descent the type of the flow shifts from mud and debris flow to hyperconcentrated flow and finally to traction flow with the concentration of mud and debris descending accordingly. A gradient of 1/20-1/30 is marginal between mud and debris flow and hyperconcentrated flow although a gradient varies depending on the debris, coefficient of roughness, and topography of the channel. Figure XV 2.2 and Figure XV 2.3 presents the case of the fan deposited along the Pawa-Burabod river. Mud and debris flow occurs in the upstream reach from barangay road. While hyperconcentrated flow occurs in the reach between barangay road and the confluence to the Yawa main river.

(3) Process of fan development

The following figure shows the distribution of debris flow lobes on an alluvial fan on the foot of the Yake-dake, which is one of active volcanoes in Japan. Flow route are shown by arrows (Figure XV 2.1) (Suwa et al., 1985).

The deposition process usually occurs at the exit from a gorge. The material brought down by successive mudflows forms a cone-shaped deposit as the transported material spreads out on emerging from the gorge. A series of debris lobes can have an appearance similar to the fork of tree. If the topographical condition is just like volcanic slope, a mudflow may take a course lateral to an existing alluvial fan, which broadens as a result (Figure XV 2.4). Most of debris flow stop to leave the deposits on the fan. Running direction of debris flows is effectively controlled by the shape and orientation of the fan-head trench, which changes significantly every several years. Debris flows bury the fan surface in relatively low area. This process however does not smooth the fan at all, but make a new relief of same degree as before.

(4) River Bed Fluctuation

A mud and debris flow traveled along steep sloped channel begins to deposit debris at the section where the slope gradient become smaller than the marginal gradient. The section is called as an intersection point. Successive deposition of the debris move the intersection point to upstream reach. On the contrary, if flow swallows the bed material it degrades the bed and the intersection point moves to downstream reach. The riverbed aggravation due to the deposition reduces the carrying capacity of the river which entails overtopping from the channel. In an extreme case, the riverbed may even become higher than the neighboring terrain (UN, 1996).

The series of longitudinal and cross sectional surveys for the Pawa- Burabod river carried out in 1985, 1986, and 1989 indicates the variability of the river channel after the eruption in 1984. The intersection point fall on the boundary of the plateau formed by the deposit of pyroclastic flow and fan. Figure XV 2.5, Figure XV 2.6, and Figure XV.2.7 illustrates the time series variation of the river channel. The figure shows the results of surveys conducted in 1999 by this Study as well. It should be noted that the results of the latest surveys reflect the effect of eruption that occurred in 1993.

The elevation of the intersection is around 340m above mean sea level or section B where the riverbed elevations increase and the differences in the elevations between the banks and beds or depths show sudden decrease due to the deposition of mud and debris. The points which was seen at around 340m downstream reach from section A in 1985 and 1986 moved downward by around 190m in 1988 and 1989.

The width of the channel become narrow if the depth of the channel become deeper. Such tendency can be seen in all the graphs except for the graphs for 1999 which do not afford such analysis because of the longer interval of the surveyed section.

(5) River Condition in the Yawa River System

a) Anoling river

The Anoling river drains the water from three tributaries in its upstream reach. Tentatively the tributaries are named as, the Anoling (A), (B), (C) rivers dissect deeply on the pyroclastic plateau in the upper reach. The channels of the Anoling (A), (B), (C) river have rather straight courses on the alluvial fan area. The Anoling (A), (B) rivers meander slightly at the elevation of 160m (the Anoling (A) river) and 240m (the Anoling (B) river). The Anoling (C) river absorbed the most part of the catchment area (4.1km^2) of the Budiao river. Therefore volume of sediment materials had increased since the piracy event. There is no evidence of large scale debris movement so far in the Anoling tributaries. Scouring of riverbed occurred in the Anoling (A) river channel in the fan area on the 1998 typhoon Loleng. But the landform change was small.

b) Budiao river

Catchment area of the Budiao river was pillaged by the Anoling (C) river at the elevation of 600m between 1990 and 1994. As a result, catchment area of the Budiao river reduced 10Km^2 from 5.1Km^2. There is no occurrence of debris flow movement since.

c) Pawa-Burabod river

Pyroclastic flow, which was ejected by the eruption in 1984, widely covered the drainage area of the middle reach of the Pawa Burabod river. New channel had formed along the west edge of a pyroclastic flow deposit area. Consequently, new channel had run with a large and smooth curve through the alluvial fan area. While the process of making a new channel, the Pawa Burabod river totally carried sediment material of 1,250,000m^3 to the lower reach after the 1984 eruption. When the 1993 eruption occurred, pyroclastic flow deposited on the same place again. After the 1993 eruption, the downstream area of the Pawa Burabod river has been devastated by several debris flows. However,remarkable debris flow has not occurred recently in the Pawa Burabod river since the last disaster which was caused by the 1996 Typhoon Akang.

(6) Geomorphological Map around Yawa River System

In 1999 the geomorphological map was already prepared to specify hazard area and so on. Then the result of analysis of the aerial photograph taken in February 1999 is traced out on the topographic map prepared in 1980. After that new topographic map based on the aerial photograph taken in February 1999 is prepared. River channels have changed geomorphologically during 20 years mainly due to the recent lahar deposits. So in this study the result of analysis of the new topographic is reflected on the geomorphological map. The developed new giomorphological map shows small landform in alluvial fan such as mound reflected.

Geomorphological Map around Yawa River System is shown in Figure XV 4.8.

2.2 Historical Mud and Debris Hazard and Disaster

Mayon volcano has erupted 4 times in the past 40 years in 1968, 1978, 1984 and 1993. Immediately after the 1984 eruption, mud and debris flow occurred all over the slopes of the volcano.

Following table shows the recent occurrences of mud and debris flow. The Pawa-Burabod river is the most frequent river in terms of the occurrence of mud and debris flow.

Recent Record of Mud and Debris Flow

Disaster	The 1968 Eruption	The 1978 Eruption	The 1984 Eruption	The 1993 Eruption	The 1998 Typhoon Loleng
Yawa					
Pawa-Burabod			Mud Flow	Mud Flow	Debris Flow
Budiao	Mud Flow		Mud Flow		
Anoling	Mud Flow				
Quirangay	Mud Flow	Mud Flow	Mud Flow		Scouring of Riverbed
Tumpa	Mud Flow	Mud Flow			
Maninila	Mud Flow	Mud Flow			
Masarawag	Mud Flow	Mud Flow	Mud Flow		Down cutting of Riverbed
Ogsong		Mud Flow			
Nasisi		Mud Flow			
Buang			Mud Flow		
Quinali (B)					
San Vicente			Mud Flow		
Arimbay			Mud Flow	Mud Flow	
Padang			Mud Flow	Mud Flow	Debris Flow
Basud			Mud Flow		Debris Flow
Bulawan			Mud Flow		Debris Flow

2.3 Delineation of Danger Zone

(1) Permanent Danger Zone (PDZ)

“Operation Mayon” provides a framework and systematic guidelines for smooth and effective disaster management in the event that Mayon Volcano erupts.

"Operation Mayon" classified the hazards by the volcano into the following four-types: Lava flows, Pyroclastic flows, Lahars, Ashfall.

The Permanent Danger Zone (PDZ) of Mt. Mayon defined by PHIVOLCS in "Operation Mayon" is the area within 6km radius from the crater of the volcano. The interpretation study on aerial photo confirmed that most of the pyroclastic debris could be found within 6km radius.

(2) Danger Zone for Mud and Debris flow

Mud and debris flows accompanying floods are expected to constitute immediate hazard as well as long-term major hazards for downstream areas located in the area between two circles with radius of 6km and 8km. In these situation PDMO set up the High Danger Zone (HDZ), which is the area between 6km and 12.5km from the volcano's crater.

Mud and debris flow accompanied a volcanic eruption has largest magnitude and ones occurred after eruption should be focused to formulate disaster prevention plan.

Since the magnitude was the largest among those recently occurred and records are rather satisfactory, the mud and debris flows occurred in 1984 and 1993 were highlighted in the Study.

The Hazard map prepared reflects the date of the mud and debris flow that occurred in 1984 and 1993.

2.4 Economic and Social Condition

(1) Population and Number of Houses

The population of the protected area is 14,282 and the number of households is 2,621 in 1999. This area includes Legazpi City, two municipalities of Daraga and Camalig. Legazpi City has 64.9% of total population in the protected area followed by Daraga municipality, (31.8%) and Camalig (3.2%). But, the area of Legazpi City is only 36.1% of total protected area, 2,318ha. This is reflected in the population density of Legazpi City which includes highly populated barangays such as Dita (491/ha.), Arimbay (32/ha.) and San Joaquin (33/ha). These household population is major beneficiaries by protection from mud flow.

(2) Family Income and Poverty Level

According to the People's Intention Survey carried out by the JICA Study Team in September-October 1999, the average income levels of the households of resettlers and candidates resettlers living around Mayon Volcano was estimated as 42,075 pesos per year or 3,506 pesos per month. Family income and poverty level, the protected area of this Study is not completely considered with the one of this survey. These figures can explain approximately the present situation for income level of the protected area. The level of monthly average income is far below that of Bicol Region at 6,425 pesos.

(3) Present Land Use

The area of the Yawa River System Sabo Project (the Yawa Project Area, 2,658.55ha) and surroundings show clear classification along its slope over the skirt of Mayon volcano. The area from the peak of the Mayon Volcano to the 6km radius line, Permanent Danger Zone (PDZ), is mostly covered by lava, volcanic sand, bush and coconut, where is the upper edge of the Yawa Project Area. The Project area has 96.28ha of PDZ. The area from this PDZ toward 10km area is indebted to the volcano and grown fertile for the agricultural activity. The area leads farther down to urban center, City of Legazpi. The Project Area is adjacent to the center of city over Yawa River.

(4) Circulation

The main barangay road running horizontally in the middle of the area between Salvacion, Daraga, and Padang, Legazpi, is the core for residents in this area. Yawa River dividing the Yawa Project Area and the city proper. Also there is the National road running from Salvacion into the center of the city of Legazpi. To commute from the Project Area to the center of Legazpi City there are only two ways, the one from Matanog through Alcara and over Yawa River by the spillway to Binitayan, and another from Bonga through Dirta to Rawis. The new bridge from Pawa to Bogtong over the Yawa River was constructed in February 2000.

(5) Agriculture

The Yawa project Area has about 70% of the share of agricultural use. The major crop in this area is coconut and paddy. The main barangay road mentioned above is running between these two major crop area and appears to divide them into an upper area and lower area. Upper area is mostly occupied by coconut and intercropping. Vegetable area can be seen along the barangay road of Mi-isi.

Vegetables are also harvested on the paddy area along the barangay road as semiannual crops with rice in the lower area.

(6) Bush and Forestry

Some bush area show their share in the upper part of the Project Area toward into the PDZ. Forestry, mostly "agoho", has its share along the gully and among the sand and gravel area.

(7) Vacant Area- Sand and Gravel Area

The pyrocrastic materials deposited at the upper portions due to the eruption of Mayon Volcano. These materials were carried down during flash floods along gullies to tributary rivers like Budiao, Banadero, Mabinit, Matanag and Pawa-Brabod down to the main Yawa River. The quarrying activity can be seen along these rivers.

(8) Residential

Twenty barangays are in this Yawa Project Area. Most of the settlements are along the barangay road and in the paddy field. Not many settlements can be seen in upper area except Anoling.

3. BASIC SABO PLANNING

3.1 Background of the Plan

As reterated several times, Mayon Volcano is an active strata volcano which ejects voluminous ashfall, lava and pyroclastic flow with debris and thereby changes the land form of its slopes still now. Ejecta, once parched on the steep slope with a gradient less than 1/10 tends to move downward by the traction force of water which is sustained by torrential rainfall with a high intensity. The average volume of ejecta is estimated to be 20 million cubic meters per eruption. The estimated average annual precipitation is assumable more or less 4,000mm on the slope with a high altitude and 3,000mm on the flat low land. The estimated average annual rainy day in Legazpi City is 210 days out of 365 days a year.

The moved mud and debris mostly deposit on the slopes with heights of 400m to 100m above mean sea level because the gradient of the slopes decrease to around 1/20. Mud and debris spread wide at this area of the slope and form an alluvial fan. A mud and debris flow from the upstream reaches from the alluvial fan spreads wide and leave behind mud and debris during it passes a fan. Small scale mud and debris flow deposit at the upper portion of a fan. While a large scale flow is strong enough to pass through the fan and deposits at the lower slope from the existing fan. Thus, the fan extends its lower portion incidentally. More than some thousand years, alluvial fan has played the role of a saucer for the volcanic ejecta. Consequently, to trap a mud and debris flow in a fan is the unique method adaptable to the overwhelming natural hazard and is to be adopted to mitigate the hazard around Mayon volcano. In the light of this, the Steering Committee meeting concluded to adopt the plan, which proposes the development of sand pocket in the Master Plan.

As stated in the Interim Report, the alternative study carried out by the Study concluded that a 20-year probable mud and debris flow should be adopted as the design value for the feasibility study. The Steering Committee meeting accepted the conclusion as well.

3.2 Design Debris Flow

(1) Probable rainfall and design rainfall

The crater of the volcano is open to the southwest exposing the dome to this direction. Accordingly, the possibility that lava flow and pyroclastic flow take this direction is high once the volcano erupts. Further, the recent geomorphologic activities have developed prominent gullies on the slopes of southeast, south and southwest. They are Basud gully on the southeast slope, Bonga gully on the south slope and Anoling gully on the southwest. These ruptures are liable to induce lava flow and pyrcolastic flow. In fact, lava frow and pyroclastic flow went down along Bonga gully at the eruption occurred in 1993. The photograph shot at the explosion in June 22, 1999 shows a trace of a kind of pyroclastic flow along Bonga gully. All these were contemplated to select the priority project from among several candidates at the Steering Committee meeting held on August 23, 1999 in Manila as mentioned before. The meeting accepted the Yawa river Sabo project as the priority project as proposed in the Interim Report.

Mud and debris flow is triggered by flood caused by a torrential rainfall with a high intensity as discussed before. Accordingly, the probable rainfall is imperative to designate the probable design mud and debris flow.

PAGASA has been recording daily rainfall at 5 gauging stations in the Study Area and made the data available since 1980. They are Legazpi City,Sto. Domingo, Tabaco, Buang and Guinobatan. Hydrogic study estimated the probable daily rainfalls for each river basin relating gauging station to the corresponding river basin. Below is a listing of the estimated probable daily rainfall for each river basin.

Table of Estimated Probable Daily Rainfalls

Basin	Whole Area	Eroding Area of Whole Area	Bed Slope of Whole Area	Pyroclastic Area in Eroding Area	Bed Slope of Pyroclastic Area	Design Rainfall (mm/day)						
	(km^2)	(km^2)	(1/n)	(km^2)	(1/n)	Station	2year	5year	10year	20year	50year	100year
Yawa River System												
Pawa-Burabod	20.835	7.257	1/14.0	5.098	1/10.6	Legazpi	229	326	394	463	554	626
Budiao	10.475	2.985	1/15.1	1.613	1/7.5	Legazpi	229	327	394	463	554	626
Anoling A	10.251	5.433	1/18.9	4.313	1/15.7	Legazpi	227	323	390	458	548	619
Anoling B	4.317	3.358	1/14.1	2.876	1/13.1	Legazpi	227	323	390	458	548	619
Anoling C	6.438	3.150	1/15.0	3.055	1/14.9	Legazpi	227	323	390	458	548	619
Quinali A River System												
Quirangay	11.844	5.081	1/12.0	3.641	1/9.1	Ligao	209	296	353	407	474	524
Tumpa	6.890	0.948	1/12.9	0.000		Ligao	213	303	361	416	485	536
Maninira	12.687	5.389	1/17.9	3.812	1/14.6	Ligao	215	305	363	419	488	540
Masarrawag	24.868	6.504	1/16.4	4.702	1/10.5	Ligao	207	294	351	404	471	521
Ogsong	9.820	3.785	1/15.4	3.179	1/12.7	Ligao	191	271	322	372	433	479
Nasisi	16.630	6.731	1/14.0	8.640	1/19.0	Buang	177	252	300	346	403	445
Quinali B River System												
Buang	28.602	11.446	1/17.1	19.645	1/16.1	Buang	172	297	400	515	696	865
San Vicente	52.382	11.348	1/14.3	15.089	1/16.2	Buang	141	213	267	324	406	474
Arimbay	5.778	0.676	1/12.7			St.Doming	236	308	356	403	467	514
Padang	17.258	9.501	1/16.0	5.996	1/8.5	St.Doming	226	295	341	386	447	493
Basud	22.862	11.3288	1/17.9	5.366	1/11.7	Tabaco	219	286	330	374	433	477
Bulawan	22.579	13.214	1/14.7	15.771	1/20.0	Tabaco	218	284	328	372	431	475

Note: Pyroclastic Area distributes in eroding area of whole catchment basin.

The consequent 20-year probable rainfalls of the target river basins to be adopted as design rainfalls are as follows:

Pawa – Burabod River 463mm

Budiao River 463mm

Anoling River 458mm

(2) The probable runoff and design runoff of mud and debris flow

<u>The probable runoff volume formula as the estimation model</u> (Technical Standard for the Measures against Debris Flow (Draft), 1988, Ministry of Construction)

The quantitative relationship between rainfall and the magnitude of mud and debris flow is not available in the Study Area since no measurement of mud and debris flow had been conducted.

The empirical probable runoff volume formula is applicable to estimate the magnitude of mud and debris flow on the basis of a rainfall depth.

The formula reflects the topographic and geologic conditions of the site and have yielded satisfactory results in Japan. The following explain the formula:

$Vec = (10^3 \times R \times A) / (1-\lambda) \times (Cd/(1-Cd)) \times fr$ .... (1)

Where;

Vec	:	Sediment Flow Volume (m^3)
Rt	:	Provable one day rainfall (mm)
A	:	Catchment area (km^2)
λ	:	Void ratio of unstable material
C*	:	Sediment concentration of stable sediment material (0.6)
Cd	:	Sediment concentration of flowing debris material In case of Cd>0.9 C*; Cd = 0.9 C* In case of Cd<0.3 C*; Cd = 0.3
fr	:	Calibration coefficient runoff $A<0.1km^2$; fr = 0.50 $1km^2 \quad A \times 10.0km^2$; fr = 0.05 (logA × 2.0) + 0.05 $A>10.0km^2$; fr =0.10

The concentration of following debris material is obtained by the following equation:

$Cd = (\rho \times \tan\theta) / \{(\sigma - \rho) \times (\tan\phi - \tan\theta)\}$ .... (2)

Where;

Cd	:	Sediment concentration of flowing debris material
σ	:	Density of gravel ($2.6t/m^3$)
ρ	:	density of water ($1.2t/m^3$)
ϕ	:	Angle of internal friction in sediment material (30°)
θ	:	Slope gradient (from base point to 200m upstream)

The probable runoff volume formula was adopted to estimate sediment runoff.

(3) Estimation of sediment runoff soon after eruption

The probable runoff volume formula was developed analysing the sediment runoff of volcanic material. Most of materials analyzed were ones ejected several years before and fresh debris of ejecta are very few. Fresh debris of ejecta is easy to flow because it is not consolidated and have a higher λ of formula (1) as compared with those old debris. Another reason of this might be the smaller cohesion as compared with an old debris. Void ratio of unstable material (λ) has decreased in accordance with the lapse of time after deposition of pyroclastic flow. Consequently, different λ should be applied in the formula (1) considering the time of deposition. In this connection a special consideration is necessary for the estimation of sediment runoff for the fresh debris because the Mayon Volcano have erupted with an interval of approximately 10 years.

The deposit of mud and debris flow at October 18, 1985 was 260,000m^3 according to the measurement carried out in the Pawa-Burabod river. The daily rainfall of this occasion was 59.8mm as recorded at the Buang rain gauge station on October 18, 1985. The rainfall corresponds to under the 2-year design rainfall. The estimated sediment runoff on the basis of the proposed model is 28,308m^3 assuming the following parameters:

Basin area	:	5.1km^2
River bed slope	:	1/10.6
Internal friction angle	:	30.0 degree
Specific gravity	:	2.60 (t/m^3)
C*	:	0.17
Cd	:	0.30
fr	:	0.13

This big difference between the measured and the estimated might be due to the difference in λ s because the deposition occurred one year before on October 6, 1984. In this accord, it is concluded that the multiplier of 9.19 against the figure obtained by the model is to be applied to the estimation of the sediment runoff within one year

(4) Expectation of sediment runoff within the design flow

The expectation of sediment runoff due to the probable (n) year rainfall in a year is obtained by the product of sediment run off be estimated and the probability density. Where the probability density for (n) year event is approximated by following formula:

Pd（n） = 1/(n-1)(n+1) .... (3)

Where :

Pd	:	Probability density for n-year event
n	:	Return period of exceedence in year

Meanwhile the probability of a year to fall on the period within 10 year is 0.1 because the eruption takes place once 10 years. On the contrary the probability not to fall on the critical period is 0.9 because 9 years out of 10 there is no eruption.

Pe = 0.1 for erupted year and 0.9 for not erupted year

Since the 20-year mud and debris flow was adopted as the design flow, the expectation of sediment run off not exceeding the design flow for a year is given by the following formula:

$$V = \sum_{n-1}^{20} (k.V(n).Pd(n).Pe)$$

Where :

V	:	Expectation of sediment runoff in m^3
(n)	:	Index for return period of exceedence
K	:	Amplifier, 9.19 for erupted year, 1.0 for not erupted year
V(n)	:	Sediment runoff corresponding to (n)-year rainfall obtained by formula (1)
Pd	:	Probability density, obtained by formula (2)
Pe	:	Probability density, obtained by formula (3)

The estimated sediment runoff for several return period are summed up and shown in the following table:

Probable Outwash Runoff with 20-Year Design Rainfall

	Area	Bed Slope	Internal friction Angle of deposit		Specific Gravity	Concentration of Debris flow		Calibration Coefficient	Design Rainfall	Outwash Runoff	Ratio after Eruption	After Eruption
						C	Cd	fr		Vecl		
	(km^2)	(1/n)	(degree)	(rad)	(t/m^3)				(mm/day)	(m^3)	Vec2/Vec1	Vec2
Yawa												
Pawa-Burabod	5.098	1/10.6	30.0	0.577	2.60	0.17	0.30	0.13	463.0	219,200	9.190	2,014,400
Budiao	1.613	1/7.5	30.0	0.577	2.60	0.26	0.30	0.21	463.0	112,000	9.190	1,029,300
Anoling A	4.313	1/15.7	30.0	0.577	2.60	0.11	0.30	0.14	458.0	197,500	9.190	1,815,000
Anoling B	2.876	1/13.1	30.0	0.577	2.60	0.13	0.30	0.17	458.0	159,900	9.190	1,469,500
Anoling C	3.055	1/14.9	30.0	0.557	2.60	0.11	0.30	0.16	458.0	159,900	9.190	1,469,500

Probable Outwash Runoff with 10-year Design Rainfall

	Area	Bed Slope	Internal friction Angle of deposit		Specific Gravity	Concentration of Debris flow		Calibration Coefficient	Design Rainfall	Outwash Runoff	Ratio after Eruption	After Eruption
						C	Cd	fr		Vecl		
	(km^2)	(1/n)	(degree)	(rad)	(t/m^3)				(mm/day)	(m^3)	Vec2/Vec1	Vec2
Yawa												
Pawa-Burabod	5.098	1/10.6	30.0	0.577	2.60	0.17	0.30	0.13	394.0	186,500	9.190	1,713,900
Budiao	1.613	1/7.5	30.0	0.577	2.60	0.26	0.30	0.21	394.0	93,300	9.190	875,800
Anoling A	4.313	1/15.7	30.0	0.577	2.60	0.11	0.30	0.14	390.0	168,200	9.190	1,545,800
Anoling B	2.876	1/13.1	30.0	0.577	2.60	0.13	0.30	0.17	390.0	136,200	9.190	1,251,700
Anoling C	3.055	1/14.9	30.0	0.557	2.60	0.11	0.30	0.16	390.0	136,200	9.190	1,251,700

Probable Outwash Runoff 5-year Design Rainfall

	Area	Bed Slope	Internal friction Angle of deposit		Specific Gravity	Concentration of Debris flow		Calibration Coefficient	Design Rainfall	Outwash Runoff	Ratio after Eruption	After Eruption
						C	Cd	fr		Vecl		
	(km^2)	(1/n)	(degree)	(rad)	(t/m^3)				(mm/day)	(m^3)	Vec2/Vec1	Vec2
Yawa												
Pawa-Burabod	5.098	1/10.6	30.0	0.577	2.60	0.17	0.30	0.13	326.0	154,300	9.190	1,418,000
Budiao	1.613	1/7.5	30.0	0.577	2.60	0.26	0.30	0.21	327.0	79,100	9.190	726,900
Anoling A	4.313	1/15.7	30.0	0.577	2.60	0.11	0.30	0.14	323.0	139,300	9.190	1,280,200
Anoling B	2.876	1/13.1	30.0	0.577	2.60	0.13	0.30	0.17	323.0	112,800	9.190	1,036,600
Anoling C	3.055	1/14.9	30.0	0.557	2.60	0.11	0.30	0.16	323.0	112,800	9.190	1,036,600

Probable Outwash Runoff 2-year Design Rainfall

	Area	Bed Slope	Internal friction Angle of deposit		Specific Gravity	Concentration of Debris flow		Calibration Coefficient	Design Rainfall	Outwash Runoff	Ratio after Eruption	After Eruption
						C	Cd	fr		Vecl		
	(km^2)	(1/n)	(degree)	(rad)	(t/m^3)				(mm/day)	(m^3)	Vec2/Vec1	Vec2
Yawa												
Pawa-Burabod	5.098	1/10.6	30.0	0.577	2.60	0.17	0.30	0.13	229.0	108,400	9.190	996,200
Budiao	1.613	1/7.5	30.0	0.577	2.60	0.26	0.30	0.21	229.0	55,400	9.190	509,100
Anoling A	4.313	1/15.7	30.0	0.577	2.60	0.11	0.30	0.14	227.0	97,900	9.190	899,700
Anoling B	2.876	1/13.1	30.0	0.577	2.60	0.13	0.30	0.17	227.0	79,300	9.190	728,800
Anoling C	3.055	1/14.9	30.0	0.557	2.60	0.11	0.30	0.16	227.0	79,300	9.190	728,800

The expectation of sediment volume for a year is the sum of the expectation to be obtained by the formula (4) for the erupted year and not erupted year because the year falls on one of either case. The estimated expectations for a year are summarized in the following table;

Probable Runoff Volume (m^3/year)

	(1/n)	(degree)	(rad)	(t/m^3)		After Eruption period runoff volume (m^3/year)					Total Annual Runoff vol
	V1= (vec1) /n×9/10					V2= (vec2) /n×1/10				$V2_{2,5,10,20}$	
	2year	5year	10year	20year	Total	2year	5year	10year	20year	Total	
Yawa											
Pawa-Burabod	48,780	27,770	16,790	9,860	103,200	49,810	38,360	17,140	10,070	105,380	208,580
Budiao	24,930	14,240	8,580	5,040	52,790	25,600	14,540	8,760	5,150	53,910	106,700
Anoling A	44,060	25,070	15,140	8,890	93,160	44,990	25,600	15,460	9,080	95,130	188,290
Anoling B	35,690	220,300	12,260	7,200	75,450	36,440	20,730	12,520	7,350	77,040	152,490
Anoling C	35,690	20,300	12,260	7,200	75,450	36,440	20,730	12,520	7,350	77,040	152,490
Anoling Total					296,850					303,120	599,970

The expectation of the total sediment volume within the assumed life period for the proposed disaster prevention facility of 30 years is simply 30 times the expectation for a year. Below is a listing up of the 30 year total sediment volume for each river.

Estimated Total Sediment Volume in 30 year

River	Volume of 30 years		
	Usually Period	After Eruption	**Total**
Yawa			
Pawa-Burabod	3,096,000	3,161,400	**6,257,400**
Budiao	1,583,700	1,617,300	**3,201,000**
Anoling A	2,794,800	2,853,900	**5,648,700**
Anoling B	2,263,500	2,311,200	**4,574,700**
Anoling C	2,263,500	2,311,200	**4,574,700**
Anoling Total	8,9005,500	9,093,600	**17,999,100**

3.3 Planning of sand pocket

(1) Basic Conditions for Planning

Basic conditions contemplated in sand pocket planning are as belows:

- Eruptive magnitude to be referred to is the one that occurred in 1984
- Existing structure and alignment of Sabo facility should be utilized in this planning after the availability thereof is confirmed
- Natural undulation on slope landform should be considered. For example, lava flow mound can be utilized as natural barrier like a large dike.
- Sabo planning should adapt to changeable river course, landform changes and increase of runoff volume by the future eruption.
- Changeable channel course will develop on fan surface.
- New channel will be formed from time to time by deposition of pyroclastic flow or lava flow In a gully portion

(2) Hazard area

Hazard area of mud and debris flow is identified on the basis of the assumptions as follows:

- mud and debris is to flow along the channel developed In a gully until it reach the intersection point which is situated at the rivet of a fan.
- the flow direction of mud and debris flow has possibility to fluctuate 25 degree to the left and 30 degree to the right at the intersection point according to the topographic conditions of the fan and the geomorphologic interpretation of the fan.
- the results of preliminary mud and debris flow analysis and interpretation of geography indicate that a mud and debris flow with a scale of 20-year return period flows down the fan to the area which has the slope gradient of less than 1/35

The identified hazard areas thus delineated for the Pawa-Burabod river and Anoling-Budiao rivers are shown in Figure XV 3.1 and Figure XV 3.2.

(3) Locations, alignment and height of the facilities

In the Master Plan Study, the locations of sand pockets for the Pawa-Burabod, Budiao and Anoling rivers are studied considering the followings:

- a sand pocket is provided in a fan area to trap mud debris
- a sand pocket is provided to protect area within the estimated hazard area as much as possible
- existing structures are availed to the maximum extent
- take advantage of natural topography to the maximum extent
- observe the existing land use and the area to be occupied by the proposed sand pocket should be the devastated land by the recent disaster
- angle of incidence of mud and debris flow to the proposed training dike of more than 30 degree is preferable
- the preliminary hydraulic analysis on the mud and debris flow concluded that the peak water levels of mud and debris flow of about 320m^3/s for the Pawa-Burabod river and 284m^3/s for Anoling-Budeao river with a return period of 20year are 2m at the site where the slope is 1to 15, 2.2m at 1to 20 and 3m at 1to 30
- The deposit caused by mud and debris in 1984 is 4m at the maximum

Consequently the height of 4m was adopted for the proposed training dike a part of which is provided at the site with a slope of less than 1 to 30.

Several alternative sites for a proposed dam were studied along each river. The contemplated heights of dam are 3, 4, and 5m in accordance with the incoming water levels of 320 and 284m^3 /s for the Pawa-Burabod and anoling-budiao rivers respectively. The results of the Study concluded that the dams with height of 4m are the optimum as the least costly alternative because the beneficial areas do not vary among the contemplated alternatives. Thus the proposed sites for dam axis corresponding to the height of 4m are adopted. The features of each sand pocket are described below.

(The Pawa-Burabod river)

The river diversified three branches at just upstream from the provincial road crossing. the training dikes are provided along the left bank of left branch and the right bank of right branch. The area extending both sides are well cultivated and populated in the downstream reach from the road and the dike is extended to protect these area down to the near the confluence with the Yawa River where a Sabo dam is proposed to trap debris before it flow into the Yawa River. The dam is so planned to trap the debris discharged from the neighboring river on the right bank.

(The Anoling-Budiao rivers)

The Anoling river consist of 3 tributatries at the crossing of the provincial road. The proposed sand pocket traps all the debris from these 4 rivers including the Budiao River. In order to protect barangay Budiao, the dams with a height of 4m are proposed at the upper reach of the rivers sacrificing the storage capacity. The existing dike on the left bank of the Budiao river is available and a training dike is proposed on the right bank of the Anoling river.

The proposed plans which considered geomorphological feature are shown on Figure XV 3.1, Figure XV 3.2, Figure XV 3.3, and Figure XV 3.4.

3.4 Stage Wise Development

There are several hurdle to clear to construct a sand pocket and it takes time and requires a considerable amount of investment. The development of a proposed sand pocket might take 5 years at shortest including detailed design of 1.5, contracting procedure of 1 year and construction of 2.5 years. The budget required for the construction of a sand pocket might be 1 to 2 billion pesos including indirect cost. It may take some time to prepare the budget. Staging of construction is one of the most realistic way to solve the budgetary constraint. In this case, the latter stages might be implemented more than 10 years from today.

In order to deal with the issue, provision of a temporary simple structure to protect the area that shall wait for certain period until the sand pocket is provided. Said structure should be easy to construct and cheap in its nature. It should be as cheap as to be afforded by the budget of communities.

In this conformity, a wooden beam structure, a concrete beam structure and CSG structure without concrete facing works were studied. However, preliminary study on the stability of these proposed structures concluded that such facilities are not effective because the hazard is overwhelming. there is a possibility that such temporary structures turn to be debris once it is broken by mud and debris flow.

Consequently it is recommended to construct only limited parts of the proposed training dike which is located at just upstream from residential areas If the budget afford. That part of the dike is to be constructed to save life of residents in emergency case as the partial implementation of the plans proposed in the Master plan. Evacuation is the substantial prevention measure of a disaster in this area.

3.5 Buffer Zone

The areas to be protected by proposed sand pocket should be developed to the maximum extent to enhance the regional economy and environment. A considerable amount of capital investment would be imposed for the development. Thus needs for protection increase in the areas. However, any structure has possibility of having defects which might hamper the structure to function well. Accordingly complimentary measures should be provided to secure higher security.

The proposed Sabo dam and training dike will protect the land side areas against the mud and debris flow with a return period less than 20-year. A mud and debris flow with a magnitude more than 20-year can overtop the dike and attack the land side areas although the hazard may be dissipated its energy to some extent when it overtop the provided dike. Accordingly any measure to mitigate the destructive energy is necessary.

In this connection, it is proposed to provide a buffer zone between the proposed dike and the areas to be developed in order to keep people away from the adjacent area to the proposed sand pocket not to live in. The width of the zone should be 150m at minimum. Cropping tree should be planted to use the zone as productive land. If trees are planted with an interval of 10m, 16 rows of trees is accommodated. A tree with a trunk diameter of 30cm might have some effect to raise the coefficient of roughness. No scientific study report is available to assess the resistance of tree against mud and debris flow so far. However, there are certain effect to mitigate the energy of mud and debris flow. There might be another possibility that the uprooted trees become a kind of screen to dehydrate mud and debris flow. Planning of buffer zone should take account of the fact that mud and debris mostly deposit at the slope with a gradient of less than 3°.

4. MAINTENANCE AND MONITORING WORKS

4.1 Present situation of maintenance works

DPWH region V has constructed various infrastructures and is mandated the maintenance thereof. It has conducted such mandated works with 6 divisions and

11 district engineering offices. The divisions are planning and design, quality control and hydrology, administration, maintenance, and construction. District engineering offices are provided to each province; Camarines Sur 4, Sorsogon 2, and one each for Camarines Norte, Albay, Catanduanes and Masbate. Further, Project Managers office and Regional Equipment Service (RES) are attached to the regional office.

Maintenance division is the main responsible organization in charge of maintenance works together with the relevant district engineers office although direct and indirect cooperation from other divisions are indispensable such as planning and design or regional equipment service. A part of maintenance work has been conducted under force account basis. In these cases, heavy equipment kept by RES are availed. Force accounting system is effective for the emergency response because of is simple procedure. Recent highlight of maintenance works might be the dredging works conducted for the Pawa-Burabod river, Padang river, and Basud river.

The total number of employees is 2290 including casual and temporary. About 35% belong to the regional office and remaining to district engineering office. The number of staffs belong to maintenance division is 122 including casual. The number of permanent staff of RES is 133. One of the substantial resources of RES is heavy equipment for construction works as follows:

- Bulldozer
- Backhoe
- Shovel
- Pump
- Generator
- Others

The budget allocated to maintenance works in 1998 are as follows:

Budget Allocation in 1998

(unit: 1000 pesos)

Item	Amount
River structure	43,144
Road and bridge	245,066
Urban infrastructure	656
Total	288,866

*Source: DEPARTMENT PUBLIC WORK and HIGHWAYS 1998

The largest scale of maintenance works were conducted in 1990. The dredged volume was 84,000 cubic meter and the allocated budget was 3,291,000 pesos.

The monitoring works of infrastructure are carried out by planning and design division and relevant district engineering office. Once any defect are detected, the division formulate the rehabilitation plan. The plan is to released to maintenance division after the approval of the regional office.

There are the cases local people detect defects. The request to repair the defects is to be raised to the provincial governor. The provincial governor request district engineer to take action for repair.

4.2 OMR works related to the proposed Sabo works

(1) Maintenance of sand pocket

Mayon Volcano ejects debris when it erupts. The ejecta move downward and deposit on the fan. The proposed sand pocket in the fan will trap these ejecta in the pocket in a controlled manner. Sand pocket confines the area for mud and debris flow to deposit. If the provided sand pocket area cannot accommodate the debris for the life period of 30 years, removal of deposit by means of dredging is necessary to maintain space to secure the function during the life period. The limitation of area, on the other hand, results in the higher piling up of debris. This will entail the followings;

- The rivet of fan climb up the mountain slope to upstream reach and it will grant wider option of flow direction to the mud and debris flow. The mud and debris flow tend to flow to arbitrary directions other than to concentrate to the channel.
- The slope of the river channel become gentle in the fan area and it will deprive of the sufficient traction force of the flow to supply sand and gravel to maintain river channel in the down stream reach from the fan.

The DPWH should conduct maintenance works to avoid such situation through dredging works.

(2) Dredging works as maintenance works

There are two types of dredging works in view of the objectives discussed in the previous paragraph. The first one is to secure available storage of the proposed sand pocket. The other is to maintain a channel within the proposed sand pocket.

The balance of the debris inflow and storage capacity is summarized in the following table:

Balance of Sediment

Sand Pocket	A Sand pocket Capacity (m^3)	B Sediment Flow Deposit in 30 year (m^3)	(B-A) Total Excess Material Volume (m^3)	(B-A)/30Annual Dredged Material (m^3)
Pawa-Burabod	14,960,000	6,257,400	-8,702,600	-
Anoling Budiao	13,600,000	17,999,100	4,399,100	146,637
Total	28,560,000	24,256,500		

According to the balance, the estimated necessary dredging volume is 146,637m^3/y for the Anoling-Budiao sand pocket and none for the Pawa-Burabod sand pocket.

The removal of deposited materials in the original river channel is the second type of dredging works. The following figures designate the length of deposit of each river:

Deposit Gradient of Sabo Dam

Sand pocket	Deposit at dam (m)	Original gradient	After deposit gradient
Pawa-Burabod	4	1/20	1/40
Anoling-Budiao	4	1/18	1/36

The obtained lengths are 120m for both sand pockets. Applying the channel width of 55m for the Pawa-Burabod and 120m for the Anoling-Budiao channels, the required dredging volumes are estimated as follows:

Pawa-Burabod : 13,200m^3/y
Anoling-Budiao : 28,800m^3/y

However, the Type 1 dredging volume of Anoling-Budiao of 146,600m^3/y cover the Type 2 dredging and consequent dredging volumes are given below:

Pawa-Burabod : 13,200m^3/y
Anoling-Budiao : 146,600m^3/y

The dredged materials are suitable for aggregate of concrete and the river bed materials have been exploited by private enterprises. In this connection the dredged material should be stockpiled at appropriate places as the material for aggregate industry. The dredged materials are stockpiled with a height of 5m. and a sloe of 1:20. The areas required to deposit materials of one year dredging, are 0.5ha for the Pawa-Burabod and 3.5ha for Anoling. The distances between the dredging sites and spoil bank yards for the proposed Pawa-Burabod sand pocket and Anoling sand pockets are 1.800m and 800m, respectively. The typical screen dam as maintenance free facility in Japan is shown in Figure XV 4.1.

(3) Other maintenance and monitoring works

One of the most frequent damages to a structure is scouring of foundations. The traction force of mud and debris flow is overwhelming and loose soil are to be scoured easily. Back filling of scoured foundation and riprap works should be provided as maintenance works.

With this respect, monitoring and inspection will be one of the most significant tasks of DPWH region V. Monitoring and inspection are to be conducted in the following items:

- Surface of dike and revetment works of channel works
- Foundation of dike and revetment work of channel works
- Fluctuation of riverbed and riprap at the cutoff wall of apron
- Deposition on apron
- Abrasion on spillway surface
- Clogging of slit
- Deposition at immediately upstream from dam
- Surfaces of training dike of both rivers
- Riprap of spur dike
- Silting along the channel in the sand pocket
- Deposition in the sand pocket
- Channel upstream from the rivet of fan

(4) Implementation Schedule

Considering to the short of budget for construction of Sabo facility, priority order for the implementation schedule on Sabo works will be recommended as the Table XV 4.1 and Table XV 4.2 proposed plan are shown in the Figure XV 4.1 to 4.8.