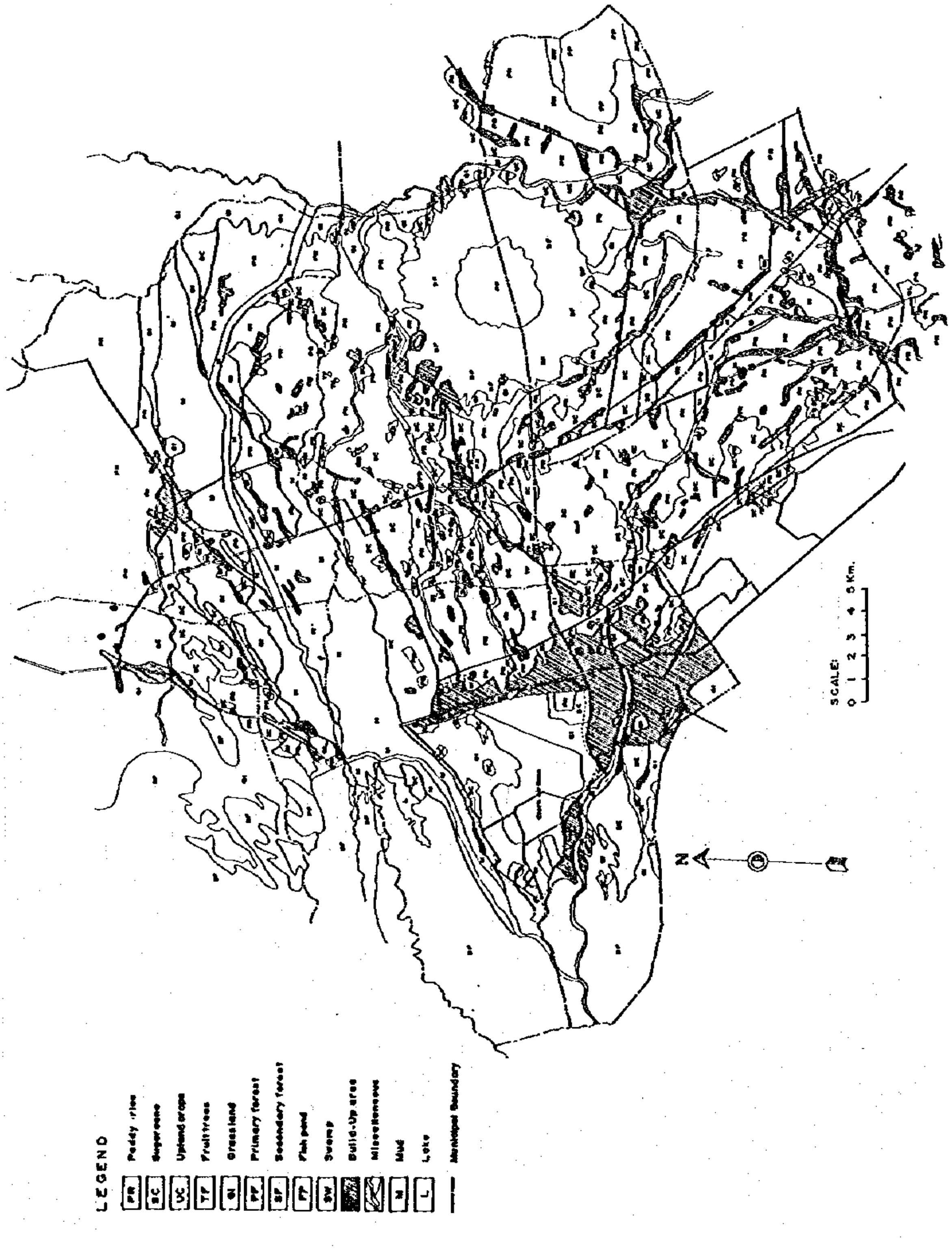

Figure E.2 Land Use Map in 1993 (Post-Eruption)

THE GOVERNMENT OF THE PHILIPPINES
THE DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS
THE STUDY ON FLOOD AND MUDFLOW CONTROL
FOR SACOBIA-BAMBAN/ABACAN RIVER
DRAINING FROM MT.PINATUBO
JAPAN INTERNATIONAL COOPERATION AGENCY

APPENDIX F

SEDIMENT BALANCE AND MONITORING

APPENDIX F

SEDIMENT BALANCE AND MONITORING

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PART I
SEDIMENT BALANCE IN SACOBIA-BAMBAN AND ABACAN RIVER SYSTEMS

F.1 INTRODUCTION

1.1 STUDY AREA

The target area of the study encompasses the two river basins of the Sacobia-Bamban River and the Abacan River, which drain from the eastern slopes of Mt. Pinatubo. Figure F.1 shows the basin boundary of the Sacobia-Bamban and Abacan river basins including the Pasig-Potrero river basin which is originating from the same pyroclastic flow field as the both rivers, and the existing dikes along those rivers. The following is a tabulation of the catchment areas of tributaries of these two rivers.

Sacobia-Bamban River			Abacan River	
Sacobia River	62.6 km^2	(38.5 km^2)	Sapang Bato River	19.2 km^2
Sapang Cauayan River	20.8 km^2		Taug River	14.1 km^2
Marimla River	64.6 km^2		Residual Basin	43.9 km^2
Sapang Balen River	41.6 km^2			
Residual Basin	35.9 km^2			
Total	225.5 km^2	(201.4 km^2)	Total	77.2 km^2

Note : The upstream reach of 24.1 km^2 of the Sacobia River was annexed to the Pasig River in October 1993. The catchment area of the Sacobia River was reduced to 38.5 km^2 in November 1994 as shown in parentheses.

1.2 METHODOLOGY

The 1991 eruption of Pinatubo Volcano deposited about 7 km^3 of pyroclastic flow materials on its slopes. These pyroclastic flow deposits provide the main source for lahar materials. About 3.5 km^3 of the materials, including the 1991 pyroclastic flow deposits and the pre-eruption sediments, are expected to be eroded and washed down the slopes as lahar in two decades (Ref. F.1 and F.2).

Regarding the study area, the expected sediment yield to be eroded in the next 15 years including those of the Pasig-Potrero River which drains from the same pyroclastic flow field (East Pinatubo Pyroclastic Flow Field: EPPFF) is estimated at about 160 to 310 million m^3. The projections on sediment budget, however, have some uncertainties due to lack of information that can be utilized as basic data such as hydrological data on rainfall and sediment discharge, forecasted occurrence of secondary explosions and secondary pyroclastic flows, and geomorphologic changes in the river systems. In particular, river piracy, which occurred between the Sacobia and Abacan rivers in April 1992 and between the Sacobia and Pasig rivers in October 1993, is the most important event to be considered.

The foregoing projections deal with the rates of annual accumulated lahar deposits from 1991 to 1993. Therefore, the projected volume shall be examined against actual sediment accumulation during the 1994 and 1995 rainy seasons. The sediment balance analysis executes and integrates the following studies and surveys: 1) topographic survey and monitoring to elaborate the geomorphologic changes in 1994 and 1995, 2) sediment yield forecast using the trend method of the rate of annual lahar deposits, and 3) sediment deposition forecast throughout the river system, especially in the downstream reaches.

F.2 SACOBIA-BAMBAN RIVER SYSTEM

2.1 SEDIMENT DELIVERY

Sediment control works in the volcanic hazard area are generally planned on the estimation of sediment discharge which is based on a monitoring to the chronological changes in geomorphology. These chronological changes gradually progress in accordance with the differences of sediment delivery rate among the following categorized zones: 1) the sediment source zone in the uppermost reach, 2) the sediment deposition/secondary erosion zone in the middle stream, and 3) the sediment conveyance zone in the downstream reach.

In the Sacobia-Bamban river basin draining from Mt. Pinatubo, a remarkable volume of ashfall and pyroclastic flow were deposited in the uppermost reach as a source material. Although the ashfall deposit was one of the sediment sources immediately after the eruption in 1991, the pyroclastic flow and secondary pyroclastic flow deposits triggered by secondary explosions (phreatic explosion) have been regarded as the major sources of sediment to the downstream areas since 1992.

Generally, sediment accumulates at the downstream end of mountainous areas and the shape of deposition is governed by the topographic condition. The intersection point, which could be defined as the crossing point of riverbed longitudinal profile and fan surface, generally begins to be formed in a stretch of the sediment deposition/secondary erosion zone when the excessive sediment delivery from the sediment source zone terminates and the riverbed degrades around the uppermost point of the sediment deposition/secondary erosion zone.

While a remarkable pyroclastic flow deposit is still remaining in the sediment source zone, sediment delivery rate shows a considerable quantity and the intersection point shifts broadly within a range of the sediment deposition/secondary erosion zone. After termination of the excessive sediment delivery from the sediment source zone, the intersection point gradually transfers downstream in accordance with the secondary erosion rate of stream-flow. In the sediment deposition/secondary erosion zone, the stream-flow forms a braided channel with a shallow water depth and widely spreads sediment material along the river course.

Figure F.2 illustrates the approximate segment of each sediment delivery zone in the Sacobia-Bamban river basin. The downstream reach of 9 km from the piracy point between the Sacobia and Pasig rivers is defined as the sediment source zone. The valley filled with pyroclastic deposit is not only being heavily eroded by flood runoff during monsoon rains, it also produces a massive movement of secondary pyroclastic flow triggered by secondary explosions and flood runoff.

Most of the sediment transported from the sediment source zone is deposited in the sediment deposition/secondary erosion zone from 2 km upstream of Mactan to the San Francisco bridge. The spindle-shaped valley from Mactan to Maskup had stored a remarkable volume of sediment and supplied sediment due to secondary erosion composed of bank erosion and channel incision to the downstream areas. The deposition and secondary erosion of sediment had occurred repeatedly in this zone. The sediment telescopically dispersed in the downstream reach of this transition zone.
The sediment in the sediment conveyance zone is gradually transported through the river channel to the Rio Chico River in proportion to the sediment transport rate of river flow.

2.2 CHARACTERISTICS OF LAHAR FLOW

In the Sacobia River, lahar flow began occurring soon after the major eruption on June 12, 1991. More lahar flows occurred in the weeks and months following the mid-June eruption, with the heaviest flow activity occurring from late July to early September during the 1991 monsoon season (Ref. F.3). The acoustic flow sensor at the Lower Sacobia Station, which is located at about 2.5 km upstream of the Mactan Watchpoint, recorded 88 lahar flows in 48 days between July 17 and September 4. Typical lahar flow were estimated to be 2 to 3 m deep, 20 to 50 m wide, and moving at 4 to 8 m/s with peak discharges in the range of about 200 to 1,200 m^3/s. Sediment concentrations of 0.55 to 0.70 by volume were reported in the August 20 lahar event (Ref. F.4).

Regarding the 1992 lahar events, large-scale lahar flows occurred on August 28 to 30 and September 3 to 5 (Ref. F.5). During those lahar events, large-scale secondary explosions, 9-15 km high, occurred accompanied with several small- and medium-scale secondary explosions. This means that those lahar flows were triggered by the secondary explosions. However, the available observation data on lahar flow are limited. According to the observation results at the Mactan Watchpoint, 24 lahar with mudflows occurred from July 1 to August 29. The observed discharges of mudflow ranged from 1 to 559 m^3/s (Ref. F.6).

From June 26 to October 7 in 1993, 11 lahar events with mudflow or hyperconcentrated flow occurred at the Mactan Watchpoint and Mabalacat (Ref. F.1). Most of those lahars deposited their transported sediment between Mabalacat and the Magalang-Concepcion road. As a result, the lahar flows transformed into muddy water before the Magalang-Concepcion road due to the gentle slope of the riverbed, while some large-scale lahar flows reached the road without transformation of their sediment transportation mechanisms (Ref. F.1).

The characteristics of the 1991-1993 lahars are given as follows (Ref. F.2):

- Surface flow velocity at Mactan : 2 - 15 m/s
- Surface flow velocity at Maskup : 1 - 5 m/s
- Peak discharge at Mactan : 10 - 2,000 m^3/s
- Peak discharge at Maskup : 1 - 400 m^3/s
- Sediment concentration : 40 - 70% by volume
- Wet sample bulk density : 1.5 - 2.1
- Temperature of hot lahars : 50 - 85°C

The occurrence of lahars in the Sacobia River dramatically diminished in 1994 due to reduction of the headwaters to about two-thirds by the river piracy. According to the field observations around Mabalacat, only a few lobes of mudflow deposition were observed during the 1994 rainy season. In accordance with the reduction of lahar occurrence the magnitude of lahar also decreased, so that lahars deposited a main part of their transported sediment around Mabalacat and could not travel to the lower reaches in the form of hyperconcentrated flow. The dominant transport process of sediment could be regarded as changing into normal raifall-runoff process so-called individual particle transportation in 1994. Thus, the occurrence of a highly concentrated sediment flow such as mudflow and hyperconcentrated flow is likely to diminish rapidly year by year in the Sacobia River.

In addition, the mudflow lobe was only once observed around Mabalacat during the heavy rainfall triggered by the passage of Typhoon Mameng on September 30 to October 1 in 1995. Before this event, the active channel gradually aggraded in a stretch of Mactan to Maskup due to sediment deposition for the period of June to September 1995. This channel was heavily scoured during this event and a main part of transported sediment was deposited around Mabalacat.

2.3 *SEDIMENT DEPOSITION*

2.3.1 Chronological Changes of Sediment Deposition

The Sacobia river course has been frequently changed in a stretch of Maskup to the Magalan-Concepcion road by floods and lahars in 1994. Lateral and vertical erosion of the river channel were mainly observed in the upstream reach from Mactan to Maskup. Figure F.3 shows the changes of the river course in the Sacobia-Bamban and Marimla rivers during the rainy season of 1994. The chronological changes of river course of the Sacobia River in 1994 and additional information of the 1995 changes are described below, based on PHIVOLCS observation data, information of DPWH and results of field survey by the JICA study team.

(1) Before the onset of rainy season in 1994

Lahar had occurred frequently in the Sacobia River until its uppermost reach was annexed to the Pasig River on October 5-6, 1993. The 1993 lahar mainly rushed eastward from Maskup as an outlet of the spindle-shaped valley. As lahar deposits accumulated on the river terrace along the Mabalacat dike, the Sacobia active channel shifted toward the north-east direction from Maskup following the topographic gradient.

(2) June 23, 1994

The river channel changed its direction eastward into the sand pocket during the relatively heavy rainfall of 76 mm recorded at the Sacobia rainfall gauge of PHIVOLCS on June 23, 1994.

(3) July 10, 1994

The closing dike in the sand pocket was partially damaged by flooding when the PI2 rainfall gauge of PHIVOLCS recorded 106 mm on July 10, 1994. On July 15, a small-scale lahar of 1 m deep was observed at Mabalacat and a portion of the repaired closing dike was washed out when daily rainfall of 88 mm was recorded at the Upper Sacobia rainfall gauge of PHIVOLCS.

(4) July 18, 1994

Daily rainfall of 222 mm was recorded at the Upper Sacobia gauge on July 18, 1994, it was the heaviest daily rainfall at this station in 1994. The moderate-scale lahar of 1.5 m deep was observed at Mabalacat. This lahar formed the 4 km long by 3-4 m high lobed deposition around Tabun Village which was buried by the 1992 lahars.
The flood flow completely washed out the upper portion of the left sandbag dike in the sand pocket. After this event, the main stream of the Sacobia River shifted its course along the Bamban-Parua river dike and the San Nicolas Balas dike inside of the sand pocket.

(5) July 23 to 25, 1994

Daily rainfall of 119 mm, 125 mm and 88 mm were recorded at the Upper Sacobia gauge for the three consecutive days from July 23 to 25, and the small-scale lahar of 1 m deep was observed at Mabalacat on July 25.

During this flood, a remarkable volume of sediment from the Sacobia River were deposited over a 2 km long stretch on the Bamban River through the breached portion of the Bamban right dike 3.5 km upstream of the San Francisco bridge. The volume of sediment deposit was estimated at 600,000 m^3.

(6) July 29 to 30, 1994

Relatively heavy daily rainfall of 34 mm and 72 mm were recorded at the Upper Sacobia gauge on July 29 and 30, respectively. During this storm, the Sacobia river course shifted down south and the flood water flowed along the Mabalacat-Magalang dike into the sand pocket area. The flood water washed out the lateral embankment at Mabalacat, which was constructed as a temporary transportation route to connect Mabalacat with Bamban, and formed the 1 km long by 2-3 m high lobed deposition along the Mabalacat-Magalang dike.

After this event, the Sacobia River was flowing down along the dike to the sand pocket until October 22.

(7) August 3, 1994

Daily rainfall of 67 mm was recorded at the Upper Sacobia gauge and the small-scale lahar of 1 m deep was also observed at Mabalacat on August 3. The confluence of the Marimla and Sapang Cauayan rivers was shifted northward, and the Bamban River followed down on its pre-eruption channel around Bamban town. At the same time, the Bailey bridge and the old Bamban river channel were completely buried with sediment.

(8) October 22, 1994

After the preceding events, no major morphological change of the river channel occurred until October 22. The Malonzo-San Pedro Hill diversion dike (separation dike) was constructed in October to prevent the heavy sediment inflow from the Sacobia River to the Bamban River and to store the sediment in the sand pocket.

Based on the field interview survey, Navaling, which is located at 1.5 km downstream from the sand pocket, was affected by siltation from September to October due to the dike breach of the Sapang Balen River. The volume of sediment deposited was estimated at 900,000 m^3. Paddy fields in the affected area were covered with sand and pumice and thoroughly damaged.

On October 22, the Sacobia River changed its direction again to the north-east. Several river channels were created from Maskup up to the downstream end of the sand pocket. Based on the field observation in the 1994 rainy season, the river course had shifted frequently at many points after choking its old channel and flowed down on the another old channel.

(9) Chronological Changes in 1995

Figure F.4 illustrates changes of the Sacobia river course based on the field investigation during the 1995 rainy season. From Mactan to Maskup, the river course did not significantly change except for river bed aggradation. Before Typhoon Mameng on October 1, 1995, the river bed had been gradually rising inside of the active channel from the beginning of the 1995 rainy season. Then flood runoff triggered by the passage of the Typhoon Mameng heavily scoured the active riverbed by 3 to 4 m deep. Regarding the downstream reach of Maskup as far downstream as the outlet of the sand pocket, the river course followed the micro topography flowing from Mabalacat toward the downstream end of the separation dike and along the San Nicolas Balas ring dike.

2.3.2 Sediment Deposits in 1994 and 1995

(1) Sediment Deposit Survey

As described in the preceding subsections, the sediment transport mechanism of the Sacobia River dramatically changed with river piracy occurred in October 1993 as a turning point. Quantitative survey of the actual sediment deposition and secondary erosion caused by lahar transported from the sediment source zone is indispensable in order to project the future sediment delivery with more accuracy. Thus, a simple cross-section survey and leveling were executed in the area from Mactan to the Magalang-Concepcion road(Route 329), where sediment deposition and secondary erosion mainly took place, to quantify the sediment delivery in 1994.

In the sediment accumulation area from Mactan to Maskup, a simple cross-section survey was carried out immediately after the 1994 rainy season in a 1 km longitudinal interval following the alignment plotted on the latest topographic map with a 1:10,000 scale which was compiled using aerophotos taken in March 1994. Figure F.5 shows the cross-sectional changes, and the volume of secondary erosion in the 1994 rainy season is estimated at 3.1 million m^3. This result indicates that the area from Mactan to Maskup, the spindle-shaped valley, turned from a sediment accumulation area into a sediment supply source by secondary erosion in 1994.

On the other hand, a simple leveling was executed also immediately after the 1994 rainy season in the sand pocket area in order to clarify the volume of sediment deposition/erosion. The survey results are compiled as an isopach map in Figure F.6. The volumes of the quarry and the embankment were estimated according to the data collected from the quarry checkpoint at Mabalacat and the DPWH, respectively. The depth and area of sediment accumulation in the downstream from Route 329 was based on the interview to the residents.

The results of survey show that a remarkable sediment volume of 10 million m^3 was stored in the sand pocket structure. This structure was effective in protecting farmlands such as sugarcane and paddy from dispersion and accumulation of sediment. Also, the residents, especially in San Nicolas Balas, contributed to realize these effects through their flood-fighting activities to protect the San Nicolas Balas ring dike.

(2) Sediment Deposits in 1994 and 1995

The sediment deposit survey shows a sediment volume of 11 million m^3 had accumulated in the area downstream of Maskup as shown in Figure F.6, while 3 million m^3 had been eroded in the area between Mactan and Maskup as shown in Figure F.5. In comparison with those two figures, sediment of 8 million m^3 in volume was estimated as sediment yield in the sediment source zone in 1994. Compared with the sediment yield of 65 million m^3 in 1993, the sediment yield drastically diminished to one-eighth in 1994.

In addition, the sediment deposition of 4 million m^3 was estimated for the 1995 delivery based on the field observation to the deposit, as shown in Figure F.7, by lahar during Typhoon Mameng on October 1, 1995. This lahar was the only one event which formed the sediment material as a lobed deposit along the Sacobia River during the 1995 rainy season.

2.4 SEDIMENT BALANCE AFTER ERUPTION

2.4.1 Sediment Source Zone

The catchment area of the sediment source zone has changed as presented in Table F.1. The remaining pyroclastic deposits in EPPFF have been reduced to 55% in volume by the end of the 1994 rainy season. Although pyroclastic flow deposits of 295 million m^3 still remain in the Sacobia river headwaters, lahar deposits have been observed only a few times around Mabalacat in 1994. This may be due to the following reasons:

1) River piracy in October 1993 reduced the catchment area of the Sacobia headwaters to one-half, and sediment yield and transportation rate were also reduced in proportion to the reduction of flood runoff.

2) In 1994, only a few small-scale secondary explosions were observed in the upstream reach of the Sacobia River and, accordingly, most of the sediment source materials in this area did not become loose.

3) The pyroclastic flow deposits in the Sacobia River have already been deeply eroded, and a series of narrow gorges which function to retard the sediment discharge and flood flow were formed in the upper reach from Mactan.

2.4.2 Sediment Deposition/Secondary Erosion Zone

The volumes of sediment deposition in the sediment deposition/secondary erosion zone are given in Table F.2. Lahar deposits of 80 million m^3 had filled the valley between Mactan and Maskup after the 1991 eruption, while sediment of 174 million m^3 had dispersed from Maskup and deposited on the alluvial fan in the same period.

This zone is divided into three areas: 1) the spindle-shaped valley from Mactan to Maskup, 2) the Sapang Cauayan and Marimla-Bamban River Channel, and 3) the sand pocket. Of these areas, the spindle-shaped valley is regarded as the major source of sediment in the succeeding rainy seasons. The changes of cross-sectional area are shown in Figure F.8, and the longitudinal profile of sediment deposition which was estimated by GIS is illustrated in Figure F.9.

Before the eruption, the Sacobia River formed a 50 m wide river course in the middle reach of this spindle-shaped valley. The flood channel along the river course was utilized for paddy, sugarcane and root crops cultivation, and fishponds by installation of temporary intake facilities. The riverbed was organized into boulders, gravel and sand.

As shown in Figure F.8 the riverbed aggraded by around 15 m for the period from 1991 to 1993. In 1994 the secondary erosion occurred because of rapid reduction of sediment supply from the Sacobia headwaters, as shown in Figure F.5.

In the 1994 rainy season, secondary erosion was observed with lateral erosion of the riverbank, down-cutting of the riverbed and shifting or short-cutting of the meandering channel. Flood flows form a flat riverbed with some antidunes. This phenomenon could be anticipated to continue in this zone in the succeeding rainy seasons.

2.4.3 Sediment Conveyance Zone

The sediment conveyance zone transports sediment through the river channel of Bamban (Parua) River to the Rio Chico River in proportion to the rate of stream flow. In the lower reach of the Bamban River, there is no additional inflow from the area along the river channel due to topography. Since the riverbed materials have not been sorted yet, sediment transport rate in the lower reach of the Bamban River is mainly governed by the riverbed gradient.

Table F.3 and Figure F.10 show the freeboard and cross-sectional changes at the San Francisco bridge which was surveyed by DPWH in 1994 to 1995. The San Francisco bridge is located at the uppermost point of the sediment conveyance zone. The riverbed has slightly aggraded in the 1994 rainy season, because of the secondary erosion of deposited sediment in the upstream channel. The riverbed in the sediment conveyance zone tends to gradually aggrade.

Before the onset of the 1995 rainy season DPWH conducted dredging work with 1.5 m deep and 100 m wide around the San Francisco bridge. Figure F.10 indicates that the effect of this dredging had been lasting until the middle of September. Since the Bamban river channel was separated from the Sacobia River by the diversion dike and sediment transportability of the Bamban River might be close to normal level, those dredging works may become one of the appropriate measures in the Bamban river system.

2.4.4 Sediment Transport to Downstream Reach

(1) River Systems in the Downstream Reach

On the low-lying area, the Bamban River has braided characteristics as it traverses portions of Concepcion in Tarlac. As it approaches the Rio Chico River to the east, the Bamban River before the eruption split into several smaller waterways that empty their surface water into the Matuladtan Swamp. Surface water received by the Matuladtan Swamp are drained off the Rio Chico River, one of the tributaries of the extensive Pampanga River. The confluence of the Rio Chico and Pampanga rivers is located at 16.5 km downstream from the confluence between the Bamban and Rio Chico rivers. The catchment area at the confluence point is 3,020 km^2 for the Rio Chico River and 3,512 km^2 for the Pampanga River.

The San Antonio Swamp has an elevation of 10-45 MASL. It serves as a depositional basin for silt and sediment as well as natural retention basin which holds rainy season overflow from the Bamban River as well as the Rio Chico River.
Southward, downstream of the San Antonio Swamp is a bigger wetland, the Candaba Swamp. The Candaba Swamp located adjacent to the Pampanga River acts as a natural flood retention basin of the rainy season overflow of numerous rivers draining into the Pampanga River. Its natural retention capacity is estimated to be approximately 1.5 billion m^3.

In the downstream reach from the confluence, the Pampanga River flows southward for another 72 km and merges with the complex drainage system of the Manila Bay estuary.

(2) Riverbed fluctuation after the eruption

Cross section surveys were carried out in 1988, 1992 and 1993 by the NIA. The location map of survey sections and the cross-sectional data are shown in Figure F.11. The longitudinal profile of the lowest riverbed elevation is also shown in Figure F.12.

The data show that the lowest riverbed elevation especially at the Rio Chico River aggraded by about 3 to 4 m in 1991. However, the lowest riverbed elevation is diminishing gradually over the years. Although riverbed aggradation was identified at some sections in 1993, it was caused by the filling of sediment materials in local scouring portions before the eruption, and the Rio Chico River in December 1993 forms a rather smooth riverbed profile compare with that before the eruption. This deposition in local scouring portions does not raise the flood water level along the Rio Chico River. Therefore, from the viewpoint of hydraulic engineering, the river channel in 1993 was restored to its pre-eruption hydraulic condition.

In the main channel of the Pampanga River, the pre-eruption local scouring portion was also buried with sediment from the Rio Chico River. However, local scouring is developing at the same pre-eruption portion. The scale of the local scouring in 1993 is almost equal to that of the pre-eruption.

On the other hand, in the lower reach (from estuary to 4 km upstream point) of the Pampanga River, a cross section survey was carried out in December 1993 to clarify the increased amount of dredging volume after eruption for the on-going Pampanga Delta Development Project (Flood Control Component). The data in December 1993 is compared with the data in July 1988, as shown in Table F.4.

The table shows that the incremental sediment volume estimated at 55,000 m^3 is only 1.7% of the total dredging volume before the 1991 eruption. The sediment deposit volume in the lower reach of the Pampanga River is estimated at 13.7 m^3/m which is equivalent to a riverbed aggradation of 6.9 cm assuming that the average river channel width is 200 m in the Lower Pampanga River.

(3) Riverbed material

Grain size analyses were carried out in March 1992, March 1993 and December 1993 by the NIA. The results at the Rio Chico River and at the confluence with the Pampanga River are shown in Figure F.13.

The riverbed in the Rio Chico River in March 1992 (one year after eruption) and March 1993 (two years after eruption) has a lot of fine particles with a diameter of less than 0.074 mm, especially at RC-2 which is located immediately upstream from the confluence point between the Rio Chico and Pampanga rivers. However, the riverbed materials of the Rio Chico River have changed remarkably from fine particles to bigger particles. This maybe due to the following conditions:

1) Immediately after the 1991 eruption, the sediment from the Bamban River was organized into fine particles of ashfall deposit.

2) The river channel of the Rio Chico River aggraded at a range of 2 to 4 m by the excessive sediment from the Bamban River in 1991.

3) As to the diminution of supply of fine particles from the Bamban River, the fine particles deposited in the Rio Chico River were washed out in the two rainy seasons of 1992 and 1993.

4) Sediment with relatively bigger size remained in the local scouring portion of the Rio Chico River. As a result, the lowest riverbed profile of the Rio Chico River in 1993 is rather smooth and stable until a local scouring occurred during a large-scale flooding.

(4) Water quality

The water quality of the Rio Chico and Pampanga rivers was slightly affected by the 1991 eruption, but it satisfies the criteria adopted in crop production by the Philippines and Japan (Ref. F.7). The data in 1993 is shown in Table F.5.

2.5 *SEDIMENT YIELD AND TRANSPORTATION ANALYSIS*

2.5.1 Sediment Yield Projection from Sediment Source Zone

The Sacobia River used to share pyroclastic flow deposits with the Pasig-Potrero River. The following surveys were carried out to estimate the total volume of sediment delivery rate from EPPFF:

1) Sediment deposition survey through interview to residents immediately after the lahar events on September 22 and October 22 mainly outside of the dike system, and

2) Sediment deposition survey through interpretation of aerophotos and field measurements in the upstream area of Watchpoint Delta 5.

The results are compiled in Table F.6 and in Figures F.14 and F.15. Historical changes of sediment source in EPPFF, erosion and lahar deposition are summarized in Figure F.16, based on the sediment deposition survey in the Pasig-Potrero River and the Sacobia-Bamban River.

Regarding the sediment deposition in the Pasig-Potrero River in 1995, the detail is described in the Part II, Sediment Monitoring.

In the first half of the 1994 rainy season, a remarkable volume of pyroclastic flow deposits in EPPFF shifted downwards overflowing across the ridge between the Pasig River and its tributary, the Timbu Creek. As a result, the valley of the Timbu Creek was filled up with sediment, 50-100 m deep.

The normalized sediment yields adopted as indices in the PHIVOLCS-USGS forecast were estimated for the Sacobia and Pasig rivers (Ref. F.2). Figure F.17 shows that no distinctive decay rate is identified in the total volume of lahar deposition in the Sacobia-Bamban and Pasig rivers, while the Sacobia River is marked with a regression line for the period from 1991 to 1995.

The volume of sediment yield for 1996 to 2000 is forecasted on the assumption that annual rainfall is 2,300 mm on an average and the catchment area is constant as of 1994, while the erosion rate of 50 mm/year on the pyroclastic flow deposits is applied to the estimation after 1998.

The monitored and forecast sediment yields in the Sacobia River are as tabulated below.

Monitored and Forecast Sediment Yield in the Sacobia River

(Unit: million m^3)

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Volume	150.0	80.0	65.0	8.0	4.0	2.0	0.9	0.4	0.4	0.4

The surplus sediment due to the 1991 eruption will terminate in the rainy season in 1997, and the sediment condition after 1998 will be restored to the pre-eruption condition.

In the above estimation, the recapture of headwaters by the Sacobia River is not expected in the near future in view of the following reasons:

1) Large to medium scale secondary explosions frequently occurred in the Sacobia river basin from 1991 to 1993, but none were observed in 1994.

2) At the piracy point, PHIVOLCS had observed that the difference between the riverbed elevations of the Pasig River and the Sacobia River was 50 m.

2.5.2 Sediment Transportation in Sacobia-Bamban River System

The volume of sediment transportation is estimated as follows:

(1) Sediment concentration

Sediment transportation rate has been estimated using the Brown formula because of high adaptability for transportation mechanism from bed load transport (individual particle transportation) to immature debris flow (Ref. F.8). Table F.7 shows the average sediment concentration estimated at several reference points. These values of concentration rate can be regarded as relatively small amounts compared with the observed data for the period 1991 to 1993. Based on the 1994 observation, however, the frequency of mudflow and hyperconcentrated flow events has drastically diminished. Furthermore, the annual sediment balance computed using the Brown formula could show a good resemblance to the 1994 situation of sediment deposition.

(2) Annual Sediment Transportation Volume

The annual rainfall amount at the Upper Sacobia gauge in 1994 is almost equivalent to the annual average rainfall value for the period of 5 years from 1991 to 1995, as shown in Figure F.17. Through regression analysis on the daily basis between the point rainfall of Upper Sacobia and areal rainfall over the Sacobia basin estimated in Appendix D, Meteo-Hydrology, areal average rainfall on daily basis is computed as shown in Figure F.18.

According to the observation data by PHIVOLCS for the occurrence of small and moderate-scale lahars in 1994, daily rainfall of 20 mm is likely to be the threshold of those events as shown in Figure F.19. The flood volume is estimated by multiplying the runoff coefficient of 0.85 to the total volume of daily rainfall over 20 mm as shown in Figure F.18.

The annual rainfall amount of 1,570 mm is likely to contribute the sediment transport volume in the Sacobia River. The volume of annual sediment transport is regarded as a deposition volume considering porosity of 40%. Those volumes are tabulated for the reference points by each condition in Table F.7.

(3) Sediment Balance Forecast

Figure F.20 shows the future sediment balance from 1995 to 2000 in the case of no-action in the future. The balance shows that secondary erosion will be the major sediment source in the future. The results of sediment balance are summarized as follows:

1) Sediment delivery from the sediment source zone is still considerable in a few years, and deposits will flow down the sand pocket area with incremental sediment yield due to secondary erosion in the reach from Mactan to Maskup.

2) The downstream area from Route 329 will receive sediment discharge out of the sand pocket. Siltation and flooding with much sediment will continue every year.

3) Since a remarkable volume of sediment is still deposited in the upstream channel of the Bamban River, the downstream channel will gradually

aggrade and the San Francisco bridge will confront the serious problem of insufficient freeboard.

In order to provide information on sediment balance for the comparative study in the flood and mudflow control plan, sediment balance is computed for the following alternatives:

1) Preliminary screening among the alternatives proposed in the USACE study (Ref. F.9)

Case 1: Immediate diversion of the Sacobia to the Bamban upstream of Malonzo (Figure F.21), or downstream of Malonzo (Figure F.22)

Case 2: Permanent sand pocket with control structure (Figure F.23)
The immediate diversion alternative needs continuous excavation work ranging from 3 to 8 million m^3 of annual rate. Regarding the design confluence point of both rivers, the upstream point from Malonzo is preferable judging from sediment balance. The permanent sand pocket alternative also requires maintenance excavation work of 0.9 million m^3 annually, as well as the prudent investigation for structural design of the control structure.

2) Comparative study among the stepwise alternatives

No. 1: Permanent use of sand pocket (Figure F.24)

No. 2: Provisional use of sand pocket and Maskup and Route 3 consolidation dams (Figure F.25)

No. 3: Provisional use of sand pocket and series of consolidation dams from Maskup to Mactan (Figure F.26)

No. 4: Provisional use of sand pocket, Maskup and Route 3 consolidation dams, and Upper-Bamban groundsills (Figure F.27)

Alternatives among No. 1, No. 2 and No. 3 require maintenance excavation work of almost 1.5 million m^3 per year, while No. 4 requires that of 1.0 million m^3 per year, since thick erodible sand has accumulated in the river channels of the Bamban River and the Sacobia River. Even if sediment control structures are planned in the upper reaches of the Sacobia River to firmly consolidate the riverbed, the diluted floodwater could cause much erosion in the lower reaches of both rivers in proportion to the sediment transport rate.

According to the simulation results of sediment transport forecast in Appendix G, the erodible riverbed of the upper-Bamban River will become stable 10 years later as the result of moderating slope of riverbed due to channel degradation. Thus channel excavation of 1.0 to 1.5 million m^3 could be assumed to continue until the year of 2004.

The forecasted sediment volumes still have some uncertainty and error because of insufficient basic information on sediment transport mechanism, therefore continuous monitoring to clarify the sediment movement is essential for appropriately constructing the proposed structural measures.

F.3 ABACAN RIVER SYSTEM

3.1 LAHAR EVENTS AND ABACAN GAP

The first major lahar in the Abacan River occurred on June 15, 1991, mainly rolling ashfall deposits along the Sapang Bato River. Lahars in the 1991 monsoon season, more than 40 in all, spilled mudflow deposits onto Clark Air Base, destroyed or damaged all of the bridges across the Abacan River upstream of Mexico, including the Capaya Expressway bridge, and caused bank collapse that has destroyed hundreds of buildings in Angeles City.

Immediately after the eruption, the pyroclastic flow reached the third narrow gorge at 1.9 km downstream of Abacan Gap, and then accumulated with a 1 m depth on the river terrace which was formed in the Buag Period that is the latest eruption about 500 years ago. A piracy between the Abacan and Sacobia rivers used to occur at Abacan Gap, which is located at the uppermost reaches of the Sapang Bato River (Ref. F.3).

A secondary explosion took place in the afternoon of 04 April 1992. Ashfall of 0.7 cm and 2.0 cm in thickness accumulated at the Mactan gate and in the vicinity of the Abacan Gap, respectively. The following morning, a secondary pyroclastic flow deposit was noted along the valleys of the Sacobia and Sapang Bato rivers. About 5 m of aggradation was observed in both channels, flattening the entire 3 km and 2.5 km stretches of the Sacobia and Sapang Bato rivers, respectively, from the Abacan Gap. The sabo dam No. 1 to No. 3 along the Sapang Bato River were completely buried, while the sabo dam No. 4 was partially buried (Ref. F.10).

A deep elongated escarpment was formed in the vicinity of the Abacan Gap during the event generating the secondary pyroclastic flow. This area was filled with about 30-40 m of primary pyroclastic flow deposits prior to the April 4 event. The secondary pyroclastic flow remained steaming hot for several days after deposition and warm for several months afterwards. After this event the riverbed of the Sacobia River had been down-cut in the vicinity of the Abacan Gap, and no lahar was observed in the Sapang Bato and Abacan rivers since 1992 (Ref. F.10).

In 1994, the river channel of Sacobia River formed a deep gorge with a height difference of about 40 m between the channel bed elevation of the Sacobia River and the Abacan Gap.

3.2 SEDIMENT SOURCE

Only a small volume of pyroclastic flow deposits remains at the reach from the site of the sabo dam No. 1 to No. 3 in the upper catchment of the Sapang Bato River, while ashfall deposits are stored by the sabo dams in the Taug River. These damsites are shown in Figure F.28.

The sediment source in the succeeding years could be divided into four categories; namely, 1) lahar deposits in the upper reach of the Sapang Bato River, 2) lahar and ashfall deposits in the river channels, 3) sediment deposits arrested by the sabo dams, and 4) soil erosion over the basin. The sediment source volume and annual sediment yield in the upstream area of the Friendship bridge is estimated referring to the field interview survey results and using the annual erosion rate, as follows:

1) Unstable sand
    - In-channel deposition : 2,200 x 103 m^3
    - Sabo dam : 1,500 x 103 m^3

2) Sediment yield
  - Surface and lateral erosion in the lahar deposits : 4 x 103 m^3/year (= 10 mm/year x 0.4 km^2)
  - Sheet and gully/rill erosion over the basin : 33 x 103 m^3/year (= 1 mm/year x 32.9 km^2)

Although around 40% of the total unstable sediment is stored in the sabo dams, four dams partially or completely collapsed due to deterioration of the materials fabricated and local scouring in front of their aprons during the rainy season in 1994. This collapse of the existing sabo dams caused some effects to the lower reaches. In particular, heavy lateral erosion and sediment deposition occurred in the lower reach of the Taug River due to the collapse of the sabo dam TL-1 on July 27, 1994. Therefore, restoration work for the existing sabo dams is required to be carried out continuously.

3.3 . SEDIMENT DELIVERY SYSTEM

Longitudinal profile and riverbed width in the upper reaches from the sabo dam No. 9 are shown in Figure F.29.

A series of natural constriction and wide riverbed have been formed along the Sapang Bato River, and these areas store the sediment during large-scale floods and release the stored sediment gradually downstream during small to moderate scale floods. In the lahar events in 1991 and early 1992, these areas also functioned to store some parts of the lahar materials. The riverbed elevation of the Sapang Bato River is, therefore, higher than the pre-eruption. In the Taug River, flash floods which contained a mass of ashfall flowed down in 1991. The lower reach of the Taug River was then heavily scoured at 1 to 2 m in depth.

In the middle reach of the Abacan River, the riverbed gradient became gentle, gradually downward to the point between San Jose Malino and San Juan which is located at 9 to 10 km upstream of the confluence with the San Fernando River. The riverbed slope decreased from 1/250 to 1/730 at that point where the Abacan River flows into the alluvial plain of the Pampanga Delta. Flood water level of the lower Abacan River is affected by backwater from the San Fernando River. Therefore, the lower Abacan River has a natural tendency of sediment accumulation.

Before the 1972 flood which is the biggest flood recorded in the Central Luzon area, there was no high dike system from the Capaya bridge to San Juan, and floodwaters dispersed to low-lying areas from the middle reach. As a result, heavy siltation did not occur in the lower reach of the Pampanga Delta. After the 1972 flood, construction of a high dike system was commenced to protect the surrounding areas from floods, and the system was completed after the 1991 and 1992 lahar events.

According to the field interview survey, lahar deposits of 3.5 million m^3 remain in the river channel of 10 km long from San Jose Malino to the confluence with the San Fernando River. Furthermore sediment accumulation is anticipated to continue in the succeeding years in this reach. Continuous excavation/dredging work is, therefore, necessary to mitigate flood damage and improve the drainage system in the low-lying areas.

3.4 SEDIMENT BALANCE

The volume of annual sediment transportation is estimated as follows:

1) Basin average annual rainfall of 1,470 mm/year, which is the total amount minus daily rainfall below 20 mm/day multiplied with the runoff coefficient of 0.85, will contribute to the sediment transport in the Abacan River as the effective annual rainfall (refer to Figure F.30).

2) Compared with the sediment transport process in the Sacobia River, a thinner sediment flow was frequently observed during the heavy rains in 1994. Bed load transport (individual particle transportation) could be regarded as the dominant transport process in the Abacan River. Brown formula is adopted for estimating the sediment concentration of the Abacan River because of high adaptability for the bed load transport process in the steep channel (Ref. F.8).

3) The volume of annual sediment transport is estimated using effective annual rainfall, sediment concentration, catchment area and porosity of 40%. The results are given in Table F.8.

According to the sediment balance among the annual sediment transport volume, the remaining unstable sediment volume and the annual sediment yield, the following prediction could be made for the Abacan River system:

1) If restoration work for the existing sabo dams is continuously carried out, the unstable sand in the upstream reach will be emptied in a few years.

2) The riverbed surface will be organized into gravel and boulders accompanying the sorting of riverbed materials. As a result, the riverbed of the upper reach from the sabo dam No. 9 will become stable, and floodwaters will convey a relatively small volume of fine sand of about 40 thousand m^3 which is mainly produced by surface erosion in the upper catchment.

3) In accordance with the reduction of sediment transport from the headwaters, the riverbed of the middle reach will gradually degrade and the low water channel inside of the present flat bed will be formed.

4) In the lower reach, excavation/dredging work is continuously required for the succeeding several years.

PART II
SEDIMENT MONITORING IN PASIG-POTRERO RIVER

F.1 GEOMORPHOLOGIC CHANGES AFTER ERUPTION

1.1 PRE-ERUPTION CONDITIONS

Before the 1991 eruption, the Pasig-Potrero headwaters covered an area of 21.3 km^2 originating on the eastern flank of Mt. Pinatubo, draining the southwestern section through a deeply incised reach. The headwaters were drained by four streams, Bucbuc, Yangca, Timbu, and Papatac creeks, which combined to form the Pasig-Potrero River as shown in Figure F.31. The pre-eruption channel had a layer of gravel less than 1 m thick overlying more than 20 m of coarse sand. Less than 2 million m^3 of annual sediment discharge through rainfall-runoff processes was estimated including monsoons and typhoons by the previous study done by JICA (Ref. F.11).

From the confluence of Timbu and Papatac creeks to about the Angeles-Porac road, the river is called Pasig. This was an area of sediment production, transport and deposition. This reach was incised into a gently sloping alluvial fan consisting primarily of pre-1991 lahar and alluvial deposits, which were composed of sand with silt fines and coarser sizes. From the Angeles-Porac road to about Highway 7, the river is called Potrero. This is an area where deposition has caused damage to farmlands and barangays. The Potrero River flows into the Guagua River, which empties into Pampanga Bay. This delta reach is flat and consists of silts and fine sand.

1.2 1991 ERUPTION

On June 15, 1991, pyroclastic avalanches flowed down the eastern slope from the exploding crater of Mt. Pinatubo, traveling at high speeds under the influence of gravity and following pre-eruption topography, and deposited 430 million m^3 of pyroclastic flow material in the upper basin. Most of the 430 million m^3 of pyroclastic material was deposited in the deep canyon along the north side of Mt. Dorst in the Bucbuc Creek drainage. Deposits in this drainage reached depth of up to 180 to 200 m. Outside of the canyon, the pyroclastic deposits typically had depths of only 10 to 20 m (Ref. F.12).

1.3 1991 LAHAR EVENTS

Although lahar in the Pasig-Potrero River started to occur during and shortly after the climatic eruption on June 15, the most destructive lahar in 1991 occurred on September 7.

The pre-eruption channel geometry at the confluence of Papatac and Yangca creeks favored rapid sediment accumulation due to a natural constriction and a reduction in slope. The rapid narrowing of the pre-eruption channel caused the pyroclastic flow to deposit approximately 5 million m^3 of material in this confluence area. The blockage measured 100 to over 400 m in width, functioned as a dam, and grew to an approximate volume of 10 million m^3 before its failure on September 7. The failure rapidly eroded the entire 10 million m^3 of sediment, causing it to cascade onto the alluvial-fan complex. An additional 10 to 15 million m^3 of material was eroded from the Pasig River as this flood moved downstream (Ref. F.9).

During this event, the channel of Papatac Creek was scoured to as much as 20 m below its pre-eruption riverbed, while the beds of Timbu Creek and the Pasig River were eroded 5 to 10 m as far downstream as Mancatian, Porac. This lahar buried parts of the town of Bacolor with 1 to 3 m of deposits (Ref. F.12).

1.4 1992 LAHAR EVENTS

A second blockage formed in early August 1992 as the result of a large secondary pyroclastic flow along Papatac Creek. This blockage was larger than the 1991 blockage, and more than 20 million m^3 of material filled the confluence area and Papatac Creek as far downstream as its confluence with Timbu Creek. During the tropical storm on August 29 to 30, the blockage was overtopped, but this time it eroded at a slower rate. The August 29 to 30 storm and another on September 3 to 4 acted together to deliver 10 million m^3 of sediment to the lower Pasig-Potrero river basin. Both of these events were mudflows and they deposited 7 to 10 km upstream of the 1991 event. Deposition filled the channel at Mancatian and 4 km downstream. Mudflow deposits in the overbanked areas were 1 to 2 m deep around Mitla, Porac and about 0.5 m near Balas, Bacolor (Ref. F.12 and F.13).

To ensure the passability of Highway 7 (Gapan-San Fernando-Olongapo Highway), the road was raised by several meters before the onset of the 1992 rainy season. The raised road virtually served as a sediment retention structure for lahars along the Pasig-Potrero River. The 1992 lahars were mostly confined upstream of Highway 7. Thus, while the net effect of the 1991 lahars was to deepen the channel at Mancatian by 10 m, the 1992 lahars completely filled it back, affecting areas adjacent to the river channel (Ref. F.1).

1.5 1993 LAHAR EVENTS

Typhoon Rubing on August 17, 1993, caused a mudflow and 3 to 5 million m^3 of deposition around Mancatian. The deposits filled the channel for about 1 km upstream of Mancatian and damaged the northern portion of the barangay. Flooding occurred in Santa Rita, where lahar flowed through an uncompleted portion of the levee. On October 4, 1993, typhoon Kadiang caused hyperconcentrated flows and mudflows that delivered another 20 to 25 million m^3 of material to the lower alluvial fan. Most of this sediment was deposited in the southern overbank from Mancatian, Porac to San Isidro, Santa Rita (Ref. F.1).

Typhoon Kadiang, furthermore, triggered the diversion of over 24 km^2 of the Sacobia headwaters into the Pasig-Potrero river basin due to a large-scale secondary pyroclastic flow. Figure F.31 explains the topographic changes of three river basins draining from the eastern flank of Mt. Pinatubo after this event.

1.6 1994 LAHAR EVENTS

From the beginning of the 1994 rainy season, the lahar activity of the Pasig-Potrero River had intensified, because the catchment area upstream of the confluence of Timbu and Papatac creeks increased from 24.5 km^2 at the end of the 1991 rainy season to 45.0 km^2 at the end of the 1994 rainy season. In addition to receiving more flood water due to increase of its catchment, the newly annexed headwaters also involved a remarkable volume of pyroclastic flow deposits.

At the beginning of the 1994 rainy season, a considerable volume of secondary pyroclastic flows had moved downwards, and again blocked the confluence of Papatac and Yangca creeks. Due to the blockage of Papatac Creek, secondary pyroclastic flows were diverted to the Timbu creek drainage flowing its pre-eruption thin ridge. As a result of the massive movement of secondary pyroclastic flows, the Timbu creek valley and the downstream reaches around Delta 5 had been fully buried with sediment of about 30 to 100 m deep, of which the accumulated sediment volume on the Timbu valley was estimated at about 37 million m^3.

Meanwhile, the dammed lake formed at the mouth of Yangca Creek grew to an approximate impounded water of 3 million m^3 until the end of August. The failure occurred on September 23 due to the passage of typhoon, rapidly eroded an enormous volume of clogged sediment involving impounded water. This lahar incised a wide and deep channel along the Pasig River, moved to the east around Manibaug Pasig, Porac, and breached the left secondary dike about 500 m downstream of the Angeles-Porac road. The main site of deposition for the 1994 lahars along the Pasig-Potrero River was generally concentrated in Bacolor but some lahar events also affected Manibaug Pasig, Calzadang Bayu and Mitla, Porac, San Isidro and San Matias, Santa Rita.

F.2 STRUCTURAL MEASURES

2.1 PRE-ERUPTION

River improvement works and sediment control measures had been undertaken by BPW, the predecessor of DPWH, before the 1991 eruption in the Pasig-Potrero River for the purposes of prevention of floods with much sediment overbanking the adjacent farmlands and barangays in Porac, Bacolor and Santa Rita along the river course, and protection of Highway 7. Major structures were dike with dry masonry in a stretch of about 4 km upstream of the Angeles-Porac road to the mouth on the right bank and about 2 km downstream of the road to the mouth on the left bank as shown in Figure F.32, and three sabo dams among which two dams were built on Papatac Creek and one was built on Timbu Creek (Ref. F.11).

2.2 AFTER 1991 ERUPTION

DPWH commenced to build the lahar retention dike in 1993. As for the year of 1991 and 1992, DPWH concentrated on rehabilitating the damaged primary dike which was 4 m high and desilting its channel in order to confine the lahar into this channel.

After the 1993 rainy season, the secondary dike system of 6 m high was completed partially expanding the inner area of the primary dike system. Since the riverbed from the confluence of Timbu and Papatac creeks to around Mancatian rapidly rose due to the enormous volume of lahar deposition until the middle of the 1994 rainy season, the left secondary dike was extended to the hillside of Delta 5 to prevent lahars from intrusion onto the Angeles City area. In addition, construction of the right tertiary dike was also commenced at the same time (Ref. F.14). During the 1994 rainy season the inner area between the secondary dikes were completely filled up in a stretch of 13 kilo-post near Maliwalu, Bacolor, to 21 kilo-post about 3 km upstream of the Angeles-Porac road. Furthermore, the September 23 lahar caused by lake breakout of Yangca Creek encroached and entered Gugu Creek far beyond the secondary dike.

After the 1994 rainy season DPWH commenced construction of the Gugu tertiary dike, the Maliwalu-Bulu dike and the secondary dike upstream of the Angeles-Porac road up to the hillside on the right bank. Although the tertiary dike system was almost completed before the onset of the 1995 rainy season, the first big-scale lahar on June 1 to 7 in 1995 easily breached the Gugu tertiary dike about 1 km downstream of the Angeles-Porac road near Calzadang Bayu, Porac because of no slope protection works. During the June to July lahar events, frequent dike breach occurred only around the Angeles-Porac road on the left bank, while the right tertiary dike was not damaged in 1995 because the right bank received only a few lahars.

After the dike breach about 300 m upstream of the downstream end of the Gugu tertiary dike on August 21, the situation in the whole stretch of the Pasig-Potrero River has drastically changed. The active channel deeply incised into not only the lahar deposits after the 1991 eruption but also pre-eruption alluvial deposits, and frequently meandered over the deposits. As the result, many portions of the Gugu tertiary dike were completely eroded or damaged in a stretch of about 2 km downstream of the Angeles-Porac road to its downstream end.

F.3 LAHAR MONITORING IN 1995

3.1 LAHAR EVENTS IN 1995

Immediately after the mobilization of the study team to the Philippines on June 1, 1995, preparation for lahar monitoring was commenced to establish stations at 45 sites inside of the tertiary dike using abandoned buildings, tree trunks and electric posts as shown in Figure F.33. After each lahar event, deposition depths and extents of deposit were verified by the spot measurement at each station, the interview survey with residents outside of the tertiary dike system, and reference to the related survey results done by PHIVOLCS and information from MPR-PMO, DPWH. Photograph F.1 explains the sediment deposition around the monitoring stations for the monitoring period of the 1995 rainy season.

3.1.1 June 1 to 7 Lahars

The lahars occurred by small-scale rainfall due to the passage of tropical storm Auring. The hourly rainfall intensity of 32 mm from 19.00 to 20.00 triggered the June 1 lahar as shown in Figure F.34 based on the data observed by PHIVOLCS. Around 20:30 on June 1, lahar flow of some 2 m deep was observed at Delta 5 and Mancatian. The locations of flow sensors and rainfall gauge are as shown in Figure F.31.

During this lahar event the left secondary dike was breached at the junction with the Angeles-Porac road, and the Gugu tertiary dike was also washed out near Calzadang Bayu, Porac, while lahar flow overtopped the right secondary dike on June 7 along the old channel formed by the October 22 lahar in 1994. The sediment deposition area is illustrated in Figure F.35. According to the PHIVOLCS observation, at least 0.5 to 1 m thick of material was deposited after the secondary dike breach, and in the area downstream of the Angeles-Porac road at least 0.75 m thick of deposition was found by spot check (Ref. F.15).

3.1.2 July 7 to 11 Lahars

The lahars were triggered by small-scale rain showers which occurred almost every evening from the beginning of July. Figure F.34 shows the typical hyetograph and lahar hydrograph on July 7 observed by the PHIVOLCS telemetry system. The frequent evening showers from the beginning of July may have saturated the subsurface of the Pasig-Potrero headwaters, and lahar occurred even by small-scale rainfall in the middle of July. A great amount of mudflow or hyperconcentrated flow continued for 0.5 to 1.5 hours with high sediment concentration of more than 50% by volume according to the PHIVOLCS data and the field sampling.

Lahar flow overtopped and washed away the left secondary dike about 2 km upstream of the Angeles-Porac road, and then breached two stretches of the Gugu tertiary dike downstream of the road. Figure F.36 also illustrates the sediment deposited area in this event. The estimated volume of sediment deposition was some 5 million m^3 on the basis of the interview and spot marking survey.

3.1.3 July 18 Lahar

The lahar was triggered by short-duration rainfall with moderate intensity of 60 mm from 17:30 to 18:30 on July 18 as shown in Figure F.34. At 18:50, lahar flow of 3.7 m deep was observed at Delta 5 by RDCC. Then at 19:40 lahar of 2.4 m deep flowed in the center channel at Mancatian, while another flow 1.2 m deep was observed toward the Gugu tertiary dike, as reported by DPWH.

Figure F.37 presents the sediment deposited area in this event. The estimated volume of sediment deposition was some 2 million m^3 on the inner area along the right tertiary dike, while there was no significant deposit on the upstream area of the Maliwalu-Bulu dike. After this event, the freeboard of Sta. Barbara bridge was reduced to about 0.4 m in the center.

3.1.4 July 27 to 30 Lahars

The destructive lahar on July 30 was triggered by the passage of Typhoon Karing. Figure F.34 shows the typical hyetograph and lahar hydrograph on July 30 observed by the PHIVOLCS telemetry system. The left secondary dike was breached at about 3 km upstream of the Angeles-Porac road. Then the Gugu tertiary dike was also breached over a 1 km stretch around the Angeles-Porac road. The lahar flowed down along the course of Gugu Creek and a part of lahar finally entered Palawe Creek. This lahar, for the first time, encroached the eastern areas beyond Gugu Creek that were previously unaffected. Another flow ran down along the Gugu tertiary dike and the Maliwalu-Bulu dike and deposited much material inside of the dike system (Ref. F.16). In the downstream reach the lahar overtopped the Santa Barbara bridge and the immediately upstream left dike. The area of sediment deposition in this event is shown in Figure F.38.

The July 27 to 30 lahar was the last lahar event that breached the tertiary dike around the Angeles-Porac road in 1995. During this event, significant channel incision started from the fan apex, around Delta 5, toward the downstream reaches. Furthermore, based on the ocular investigation, the sediment concentration of lahar may have become lower than the previous mudflows after this event so that the sediment transport mechanisms in the subsequent lahar events may be hyperconcentrated flow. The estimated volume of sediment deposition is about 15 million m^3 based on the interview and spot marking survey.

3.1.5 August 15 to 19 Lahars

The August 15 to 19 lahar event was not large, but it was the only case where lahar material was deposited on the right bank of the Pasig-Potrero River in 1995 as shown Figure F.39. On August 17, lahar flow buried and overtopped the Santa Barbara bridge of Highway 7 with 0.5 m thick deposits (Ref. F.17). Lahar material accumulated behind the dammed bridge, and finally a low portion of the right dike 200 m upstream of the bridge was breached. Subsequent lahars had followed through this breached portion and spread out over the low-lying areas. In addition, these lahars accumulated a maximum of 4 m thick inside the lower stretch of the Gugu tertiary dike.

3.1.6 August 28 to September 3 Lahars

After the August 15 to 19 lahar event, the lower part of the catch basin enclosed by the Gugu tertiary dike was filled up with lahar deposits, and serious lateral erosion was observed at some portions along the lower part of the dike. Finally, on August 21, the Gugu tertiary dike 300 m upstream from its downstream end was breached by flood water. The August 28 to September 3 lahars, which were triggered by Typhoon Gening and Helming, followed through this path to the downstream areas, and then completely buried Bacolor town proper. The lahars also buried or swept out Highway 7 over a stretch between the Santa Barbara bridge and a bridge of Gugu Creek.

Figure F.34 shows the typical hyetograph and lahar hydrograph on September 3 as observed by the PHIVOLCS telemetry system. The field survey could not be conducted until early October because of poor accessibility into the affected area. The area of sediment deposition in this event is presented in Figure F.40 on the basis of the field survey results on October 3 to 4.

During this event deep channel incision proceeded not only along the Pasig-Potrero River but also along Timbu Creek. The active channel after this event was found to be 100 m wide and 15 to 20 m deep from Delta 5 to the Angeles-Porac road, and 50 to 70 m wide and 6 to 12 m deep downstream of the Angeles-Porac road. On September 9 the Gugu tertiary dike about 1 km upstream of the August 21 breach point was newly breached by progressive bank erosion, and then flood water from the Pasig-Potrero River spread out through this path so that sediment deposition extended wider to the eastern areas near Gugu Creek. This effect is also reflected in Figure F.40.

3.1.7 September 30 to October 1 Lahars

The active channel incised deeply on the sediment deposit surface even by 4 to 6 m at the dike breach point. In order to prevent the expansion of flooding area, DPWH had tried to divert surface water back into the center channel about 3 km upstream of the Maliwalu-Bulu dike since the August 21 dike breach event. In late September the diversion was successfully completed to discharge surface water into the center channel.

Under these circumstances, the September 30 to October 1 lahars occurred due to the passage of Typhoon Mameng. the Upper Sacobia station of PHIVOLCS recorded the biggest amount of daily rainfall, 250 mm from 0:00 to 0:00 on October 1, 1995. Although rainfall observation at Upper Sacobia started in the middle of July 1994, daily rainfall of 250 mm could be evaluated as a 5- to 10-year storm by comparing with probable rainfall at the adjacent gauges.

The passage of Typhoon Mameng triggered five moderate to big scale lahars, as shown in Figure F.34, that affected the low-lying areas in Bacolor and San Fernando. The most severely affected area was Barangay Cabalantian, Bacolor where deposits are as much as 4 to 5 m thick. The affected areas expanded beyond Palawe Creek and the San Fernando River as shown in Figure F.41. The estimated volume of sediment deposition is about 22 million m^3 on the basis of the interview survey conducted on October 3 to 4.

During this event flood water heavily re-eroded lahar deposits, which were accumulated in the previous events, in lateral and vertical directions. The Pasig-Potrero river channel meandered with sharp bends inside of the dike system from Delta 5 to the downstream end of the Gugu tertiary dike. The flood runoff breached the Gugu tertiary dike near the September 9 breach point, and then traversed the Gugu creek dike toward San Fernando.

3.2 SEDIMENT DELIVERY RATE

3.2.1 Sediment Delivery in 1995

Based on the lahar monitoring survey results, the lahar disaster map was made overlaying the previous lahar deposited areas as shown in Figure F.42. The affected areas by year are as follows:

Year	Newly Affected Area
1991	37 km^2
1992	6 km^2
1993	5 km^2
1994	30 km^2
1995	19 km^2
Total	97 km^2

The areas newly affected by lahars tend to expand mainly southeastern-ward in the 1994 and 1995 rainy seasons after capturing the Sacobia headwaters.

Table F.9 summarizes the major lahar events in 1995 and 86 million m^3 of sediment deposition in 1995 was estimated. As mentioned in the lahar events in 1995, a remarkable amount of channel erosion occurred in a whole stretch during the 1995 rainy season. In order to estimate this volume, simple cross-sectional survey with an interval of 1 km was conducted in September and in mid-October. Table F.10 summarizes the survey results and 41 million m^3 of channel erosion volume was estimated. Comparing both figures, 45 million m^3 in volume was computed as a source material transported from the pyroclastic flow deposits.

According to PHIVOLCS, at least 35 to 60 million m^3 of lahar material was expected to be delivered mainly along the Pasig-Potrero river system (Ref. F.18). This may be an accurate prediction compared with the estimated deposition of 45 million m^3.

Regarding sediment transport capacity along the Pasig-Potrero River, sediment sampling and test were conducted at the three sampling points, Delta 5, Mancatian along the Angeles-Porac road, and the Santa Barbara bridge. The results are illustrated in Figure F.43. Sediment sampling observed two times of high sediment concentration flow with a longitudinal change. The results present a clear contrast of sediment transport mechanism as follows:

(1) The June 3 lahar with sediment concentration of 58% by volume reached the domain of mudflow at Delta 5 (2 to 3% in slope), but sediment concentration reduced to 27% when the flow traveled to Mancatian (about 1% in slope).

(2) Sediment concentration of the August 25 lahar became higher as the flow ran down to Mancatian; sediment concentration of 30% was observed even at the Santa Barbara bridge (0.2 to 0.3% in slope).

These characteristics of lahar may be due to the difference between mudflow and hyperconcentrated flow. The results indicate the following facts as often observed in the field:

(1) Mudflow can reach up to the Angeles-Porac road, then reduce its concentration with some deposition or overtop the dike and form a natural levee as a deposition if the lahar is big-scale.

(2) Hyperconcentrated flow can increase sediment concentration through entrainment of sediment supply by bank erosion on the riverbed of even 1% in slope.

(3) Hyperconcentrated flow can travel to the lower reaches of 0.2 to 0.3% in slope, if it flows down in the confined channel without shallow overbanking outflow.

Figure F.43 also shows the typical results of sediment material test in scale. The bulk density was estimated at 1.8 to 1.9 ton/m^3 of the June 3 lahar at Delta 5 and of the August 25 lahar at Mancatian, while it was estimated at 1.6 ton/m^3 of the August 25 lahar at the Santa Barbara bridge. The contents of transported material are summarized below.

Type of Material (Particle Size Range)	Delta 5 on June 3	Lahar Material Mancatian on Aug. 25	Sta. Barbara Br. on Aug. 25
Gravel (2 to 32 mm)	19 %	14 %	15 %
Sand (1/16 to 2 mm)	69 %	65 %	51 %
Silt (<1/16 mm)	12 %	21 %	34 %

3.2.2 Situation of Sediment Source Area

In the early 1994 rainy season, the river course of Bucbuc Creek was diverted from the clogged Papatac Creek into Timbu Creek, then secondary pyroclastic flow deposits of about 37 million m^3 accumulated in the Timbu valley. Timbu Creek has no natural narrow path along its valley except for its constricted outlet, while Papatac Creek has a long narrow path downstream of the confluence with Yangca Creek. In addition to increase of surface water by capture of the Sacobia headwaters, the diversion of Bucbuc Creek into Timbu Creek has intensified the lahar activity.

After this massive movement of secondary pyroclastic flows into Timbu Creek, lahars generated in the headwaters have been increasing in size by involving deposits along the Timbu valley. A field investigation was made on Timbu Creek on September 28 to clarify the situation of erosion, and an aerial survey was conducted on October 6, 1995 to verify the change caused by Typhoon Mameng. At the Timbu creek channel, it was observed that deep incision and wide lateral erosion had developed on the secondary pyroclastic flow deposits by 30 m deep and 200 m wide immediately upstream of the downmost constriction, and by 40 m deep and 100 m wide about 2.5 km upstream. Surface water of Timbu Creek flows down braiding on such wide and flat beds.

From the results of those surveys, it is estimated that about 20 million m^3 of secondary pyroclastic material was eroded and transported downstream during the 1995 rainy season. Based on this estimation, almost half of the 45 million m^3 source material was transported from the Bucbuc Creek drainage and the former Sacobia headwaters, while the remaining half was re-mobilized from the secondary pyroclastic deposit on Timbu Creek. As a result of heavy erosion during the 1995 rainy season, the secondary pyroclastic flow deposits on Timbu Creek were reduced by half.

Regarding the possibility of re-capture of the headwaters by the Sacobia River, it was found by the aerial survey that the difference of elevation between both river courses around the piracy point became bigger, extending more than 100 m. This indicates that there is only a little likelihood of re-capture for the time being.

3.3 RIVERBED FLUCTUATION

After the 1991 eruption, as described in the chapter F.1, the Pasig-Potrero River channel frequently and rapidly fluctuated under the influence of the big-scale lahar events that occurred in the headwaters such as secondary pyroclastic flow, blockage and lake failure, and river piracy. Figure F.44 presents changes of the Pasig-Potrero riverbed from pre-eruption as a longitudinal profile. The riverbed around Delta 5 aggraded 20 m higher in 5 months from March to August 1994, while the riverbed around the Angeles-Porac road was raised by only 2 to 4 m for the same period. The figure indicates that there are clear hinge points, at which channel slope increases, about

2 km upstream of the Santa Barbara bridge, near Dolores in Bacolor, and near the Angeles-Porac road. Around those points there is a tendency of frequent occurrence of overtopping and dike breach because decrease of sediment transport capacity causes sediment deposition and channel aggradation around the hinge point due to change of riverbed gradient.

After the July 28 to 30 lahar event, the river channel development process around Delta 5 apparently changed to erosion of deepening and widening. Figure F.45 illustrates chronological changes of cross-section, which are made through the simple photo-interpretation, at Delta 5 during the 1995 rainy season. This process has rapidly influenced the whole stretch of the Pasig-Potrero River since the downstream end of the Gugu tertiary was breached on August 21. During the passage of Typhoon Mameng on October 1, the river course heavily meandered with many sharp bends, and incised pre-eruption deposits, and was widened by headward and lateral erosion as shown in Figure F.46. The Pasig-Potrero river channel was incised by 15 to 30 m in the stretch of Delta 5 up to the Angeles-Porac road for the period from July to October 1995 as shown in Figure F.44. Those river-morphologic changes may be a sign of rapid decrease of sediment supply from the source areas of EPPFF.

F.4 FUTURE PROSPECT

4.1 FUTURE PROSPECT OF SEDIMENT DELIVERY

4.1.1 Annual Sediment Delivery from Source Material

Regression analysis was made using the actual sediment deposition data combining each deposit among the Sacobia, Abacan and Pasig basins as shown in Figure F.47. This figure indicates the following facts:

(1) Direct prediction using the actual sediment delivery of the Pasig-Potrero basin is still difficult because only two samples are available after the piracy.

(2) Combination of the actual sediment delivery from the Sacobia Pyroclastic Flow Field is most suitable for future prediction as of now.

(3) The result of regression analysis using all actual data is likely to be an overestimate due to the influence of the 1994 data.

(4) The result of regression analysis eliminating the 1994 data as an extraordinary value shows a good fit to the actual data.

Sediment delivery in 1996 was statistically estimated at 34 million m^3 from EPPFF. As for sediment delivery to the Sacobia River, its volume in 1996 may be negligible taking into account the actual lahar deposit of about 4 million m^3 in 1995 by comparison. Thus, 34 million m^3 of lahar material is expected to be delivered mainly along the Pasig-Potrero River system in the 1996 rainy season.
The factors to be simultaneously considered in relation to the sediment delivery are geomorphologic situations in the headwaters and predominant sediment transport mechanisms from the headwaters.

Before the onset of the 1995 rainy season, the remaining pyroclastic flow deposits were estimated at 475 million m^3 as shown in Table F1. Out of this amount of material, 37 million m^3 of material was already re-mobilized onto Timbu Creek by secondary pyroclastic flows in the early 1994 rainy season as shown in Figure F.15. During the 1995 rainy season, 25 million m^3 of lahar material was transported from the former

Bucbuc and Upper Sacobia drainage, while 20 million m^3 of lahar material was eroded from the deposits accumulated on Timbu Creek. Thus, the remaining potential sources to be delivered in the future are 413 million m^3 in the upper drainage and 17 million m^3 on Timbu Creek. If the attenuation rate of 0.46, which was figured out dividing 17 million m^3 by 37 million m^3, could be adopted only to the deposited material on Timbu Creek, 9 million m^3 of secondary pyroclastic material may be eroded in 1996.

Mudflows are generally formed by the collapse of high, hot pyroclastic banks into rapidly moving storm runoff in confined channels. The secondary explosions also contribute to the formation of mudflows by the sudden supply of enormous loosened material into the storm runoff. Based on the aerial survey of the headwaters, the predominant processes of channel development had been deepening and widening, and the previously confined deep channels had become wider so that chances of mudflow formation might have rapidly reduced. Table F.11 and Figure F.48 summarize the events of lahar and secondary explosion observed by PHIVOLCS. This figure indicates the occurrence of big-scale lahar in 1995 has rapidly diminished in comparison to the 1994 situation. Furthermore, a number of big-scale secondary explosions has also reduced by one fourth in 1995 compared with the 1994 events as shown in Table F.11, and massive movement of secondary pyroclastic flows was not found through the aerial surveys during the 1995 rainy season.

These facts indicate that the source material has become gradually stable and chances of mudflow formation also may have been drastically reduced. Thus, the predominant sediment transport processes could be forecasted as hyperconcentrated flow and muddy water in the 1996 rainy season. In accordance with the change of predominant sediment transport processes, material transported from the upper drainage areas may decrease by half based on the difference of sediment transport concentrations between mudflow and hyperconcentrated flow. Thus, 13 million m^3 of pyroclastic material is predicted to be delivered from the upper drainage areas.

Based on the field investigation and the comparative consideration of the actual sediment delivery in 1995, 22 million m^3 of source material is estimated to be delivered in 1996. On the other hand, sediment delivery in 1996 is statistically estimated at about 34 million m^3. Combining both results, 22 to 34 million m^3 of source material will be transported from the headwaters in 1995.

4.1.2 Annual Sediment Delivery over a Stretch in 1996

As shown in Figure F.46, once big-scale hyperconcentrated flow or storm runoff occurs, frequent and sharp meandering will develop through heavy lateral and headward erosion along the river course. According to the field survey results, almost half of the sediment deposits in 1995 has been supplied from these processes. Since chances of mudflow formation has been drastically reduced in the headwaters, the existing deep and wide channels on the alluvial fan are unlikely to be filled up again by massive mudflow in the 1996 rainy season. Therefore, widening and down-cutting channel development may continue in 1996. Although the magnitude of channel erosion will gradually subside and become stable in the future, heavy erosion and meandering is expected to continue for the time being.

The volume of channel erosion apparently depends on the frequency of new river course development and intensity of meandering. Up to the present, the actual sediment transport capacity in the Pasig-Potrero River shows a big difference from the hydraulic estimate using bed load and suspended load transport equations. Assuming that the maximum volume is produced by the same processes as 1995, newly forming incised channel and meandering, 41 million m^3 of channel erosion is estimated, the same amount as in 1995. Assuming that a minimum volume is produced by a half wavelength progress of meandering and burying old channel by half which is a natural tendency of progressive meandering based on the field observation, 21 million m^3 of channel erosion is estimated, half of the 1995 erosion rate.

As summarized above, sediment delivery of 22 to 34 million m^3 from the source material and 21 to 41 million m^3 by channel erosion are predicted for the 1996 rainy season. In total, 43 to 75 million m^3 of sediment will be transported to the downstream reaches and bury the low-lying areas if proper countermeasures are not taken. These predictions are based on average conditions, so that weather disturbances may cause some deviations from the predictions.

4.2 FUTURE PROSPECT OF DISASTER MITIGATION MEASURES

4.2.1 Encountered Problems and Comments

Presented below are the problems encountered along the Pasig-Potrero River during the monitoring activities in 1995 as illustrated in Figure F.49.

Lahar Avulsion into the Taug River

In June and early July 1995, the riverbed near Delta 5 aggraded by 2 to 3 m, then lahar avulsion into the Taug River was anticipated to extend the damage to Angeles City. During the 1995 rainy season channel down-cutting and widening proceeded in the whole stretch of the Pasig-Potrero River. As the active channel incised deeper, the natural ridge between the Pasig and Taug rivers became wider. This means that the width to be eroded also became wider. Thus, these channel development processes make avulsion beyond this ridge or lateral erosion to break through it less unlikely.

Lahar Avulsion into the Porac River

Lahar avulsion into the Porac River has been anticipated since the beginning of the 1991 eruption. The possibility of lahar overtopping in the right bank into the Porac River becomes smaller because of the progressing channel incision. Although there is still some possibility of lahar intrusion into the Porac River by progressive meandering to break through the deposits and the terrace, the distance from the active channel to the Porac River is more than 2 km as of now. The necessary measure to be taken in the 1996 rainy season is close monitoring regarding this matter.

Lahar Overtopping around the Angeles-Porac Road

Most of the big-scale mudflows that reached to the Angeles-Porac road overtopped the left bank due to change of riverbed gradient. At present the prevailing active channel is more than 100 m wide and 20 m deep, and the flow capacity could be evaluated as corresponding to more than a 500-year flood if the riverbank was stable against flood runoff. In accordance with the reduction of frequency of mudflow occurrence, lahar overtopping in the left bank becomes more unlikely. On the other hand, the incised meander is progressing in the whole stretch, and there is some possibility of breaking the dike and overbanking onto the area in Porac and Bacolor. The necessary measure to be taken in the 1996 rainy season is also close monitoring regarding this matter.

Dike Breach and Overbanking Floods along the Gugu Tertiary Dike

The major issue along the downstream reach of the Gugu tertiary dike is also dike breaching and overbanking floods caused by progressive incised meandering. Once flood water completely scours the base of the dike and reaches the low ground, it starts to rush toward the lower areas with new channeling and widely spreading out transported sediment as created in Bacolor from August to October 1995. Several critical portions were found along the old channel formed in August 1995. In order to prevent this type of flooding, construction of a protective structure with firm foundation is required at the diversion point and proper monitoring is necessary from the Angeles-Porac road to the diversion point.

Dike Breach along the Right Tertiary Dike

If the diversion channel shifts toward the catch basin of the right tertiary dike, a disaster similar to the August-October 1995 events will likely happen to Santa Rita and Guagua. In order to prevent dike breaching and flooding with severe sediment deposition in Santa Rita and Guagua, the possible countermeasures are (1) construction of river training structure from the diversion point to the downstream end of the tertiary dike along the active channel, (2) construction of protective open levee with slope protection outside of the existing tertiary dike, and (3) continuous dredging and excavation in the center channel from the diversion point to the downstream end of the tertiary dike.

Combination of the protective open levee and channel excavation is deemed to be the most applicable countermeasure among the alternatives taking necessary maintenance and reliability of structures against anticipated riverbed fluctuation and meandering into consideration. It is required to connect the open levee to the right primary dike upstream of the Santa Barbara bridge for discharging overtopped flood water back to the Pasig-Potrero River, so as to prevent extending floods to the downstream areas.

Flooding and Sediment Deposition along the Active Channel

Flooding and sediment deposition along the active channel on the lower reaches is the most serious and urgent problem in the whole stretch of the Pasig-Potrero River. The lower reaches have to receive muddy water even in a small amount of rain, and then transported sediment gradually accumulates over the ponding areas. The possible countermeasures are (1) construction of new channel and embankment along the active channel, (2) closing the active channel, and channel excavation along the primary dike between the diversion point and the confluence with the Guagua River, (3) construction of the protective ring dike with slope protection along the left bank of Palawe Creek connecting to the right dike of the San Fernando River, and (4) construction of the protective open levee with slope protection traversing from Dolores to Santa Barbara across the affected area.

Combination of the protective open levee and channel excavation is also deemed to be the most applicable countermeasure taking necessary land acquisition and necessary maintenance into consideration. It is required to connect the open levee to the left primary dike near the Santa Barbara bridge for discharging flood water back to the Pasig-Potrero main channel.

4.2.2 Basic Concept of Required Activities

During the 1995 rainy season, the Pasig-Potrero River incised deeply on the pre-eruption alluvial deposit as well as the lahar deposit after the 1991 eruption, and the frequent and sharp meandering progressed in the whole stretch like a river course on the alluvial plain. The progress of meandering was observed to be very rapid because bank material of lahar deposit has a non-cohesive nature due to lack of clay particles. If this type of meander, incised and free meander, is planned to be controlled, bank protection work with deep foundation has to be made over the whole stretch because of the rapid progress of meandering. This type of measure is extremely costly, so that meandering which is now progressing on the Pasig-Potrero River could be regarded as uncontrollable. Thus, continuous monitoring activity will play an important role to prevent serious flooding and sediment deposition, in particular, along the upper and middle reaches.

After every moderate-scale lahars and heavy rain shower, monitoring along the active channel should be conducted from Delta 5 to the downstream end of the tertiary dike. The major purposes of monitoring is inspecting the location and situation of the active river channel, clarifying the critical portions and their levels, and selecting the appropriate remedial measures if possible to execute.

4.3 BASIC CONSIDERATION FOR THE DPWH DIKE SYSTEM

4.3.1 Background

During the 1995 rainy season, the lahar situation of the Pasig-Potrero River changed dramatically, i.e., change of main sediment transport mechanism from mudflow to hyperconcentrated flow or muddy water through rainfall/runoff processes, progress of deep channel incision and sharp meander in the whole stretch, and concentration of lahar deposition into the downstream areas of the tertiary dike system. The 1995 lahar deposit of 86 million m^3 was estimated based on the lahar monitoring executed by the JICA study team. Out of this figure, 41 million m^3 was re-mobilized by channel erosion in the mouth of Timbu Creek as far as the end of the tertiary dike system downstream.

Based on the statistical analysis and the field investigation, sediment of 22 to 34 million m^3 from the source and 21 to 41 million m^3 by channel erosion were estimated to be delivered for the 1996 rainy season. In total, 43 to 75 million m^3 of sediment will be transported to the lower reaches and deposited on the low-lying areas unless appropriate countermeasures are taken. In accordance with the results of the monitoring activities in 1995, the following issues are proposed to be resolved before the onset of the 1996 rainy season:

(1) The 43 to 75 million m^3 of sediment that was predicted to be transported and deposited in the downstream areas in 1996.

(2) The frequent and sharp meandering over the whole stretch of the Pasig-Potrero River, the shift of the main channel toward any downstream direction in the middle and lower reaches, and the discharge of flood waters with highly concentrated sediment into the downstream areas as flood runoff progresses.

(3) The acceleration of pondage flooding in San Fernando and the adjacent areas by flood waters from Gugu Creek, because the channel was completely buried during the 1995 lahar events.

(4) The poor transportability of both flood water and sediment at the whole stretch of 21 km of the Guagua-Pasac River from the confluence with the Pasig-Potrero River to the river mouth, because the Guagua-Pasac River is already silted up and the waterway is receiving flood waters with highly concentrated sediment from the Pasig-Potrero River.

4.3.2. Basic Consideration for Structural Measures to Be Taken in 1996

<u>Middle and Upper Reaches</u>

The progress of meandering was observed to be very rapid because the lahar deposits at the bank has a non-cohesive nature due to lack of clay particles. If this type of incised and free meander is planned to be controlled, bank protection works with deep foundation has to be done over the whole stretch. This type of countermeasure is extremely costly, so that the meander which is now progressing on the Pasig-Potrero River could be regarded as uncontrollable. Thus, continuous monitoring activity will play an important role to prevent serious flooding and sediment deposition, in particular, along the upper and middle reaches.

Middle and Lower Reaches

The following functions are indispensable for the countermeasures to be taken: (1) sediment retention capacity of at least 43 to 75 million m^3 anticipated in 1996, (2) flood control to prevent expansion of the flooding areas, and if possible, and (3) bank protection to control the progressing meander and to reduce sediment entrainment by bank erosion.

The possible countermeasures are (1) sediment retention structures (sabo dams) in the headwaters, (2) groundsills and river training structures in the upper and middle reaches, (3) channeling with excavation in the middle reach, (4) sediment retention structures in the middle and lower reaches, and (5) desilting in the lower reaches.
It is clear that the application of only one of the countermeasures could not attain the objectives mentioned above. Furthermore, construction of structural measures in the headwaters and the upper reaches might be premature because of the rapid progress of geomorphologic changes at present. Thus, the comprehensive plan to be established should concentrate on the middle and lower reaches.

4.3.3. Comments on the Proposed DPWH Dike System

DPWH had proposed the Pasig-Potrero outer dike system, as shown in Figure F.50, to prevent any disastrous lahar avalanche in the 1996 and subsequent rainy seasons. Preliminary consideration for the proposed outer dike system was made as follows:

Flood Control Measures for Gugu Creek

The flood water originating from the Gugu Creek basin is one of the causes of pondage flooding in San Fernando and its surrounding areas. Implementing flood control measures for Gugu Creek in parallel with the outer dike system is crucial to resolving this problem.

There are two alternatives; namely, (1) separation of the Gugu Creek catchment, and (2) annexation of the Gugu Creek catchment within the outer dike system. In the former case, the new Gugu Creek channel has to be built with excavation and embankment as far downstream as the confluence with the San Fernando River to prevent pondage flooding in and around San Fernando. In the latter case, the alternative of annexation of Gugu Creek outlet is deemed viable to train flood waters and to protect the unaffected areas against flooding which cause heavy sediment deposition. Furthermore, the increase of flood water might contribute to the increase of sediment transport capacity in the lower reach of the Pasig-Potrero River as well as the Guagua-Pasac Waterway so that rapid riverbed aggradation in this reach is avoided.

Control Structure

The control structures are planned at both outlets of the Pasig-Potrero River and Gugu Creek in the DPWH outer dike system. In this case, control structures and river channels of the same scale have to be constructed at both outlets and their lower reaches, because the river courses would be uncontrollable inside of the catch basin. Thus, the control structure should be planned only at the outlet of the Pasig-Potrero River.

The location of the control structure is planned to be 0.5 km upstream of the Santa Barbara bridge, because the turbulent flow released from the control structure is expected to be stilled in this stretch of 0.5 km up to the Santa Barbara bridge. The spillway shall be designed with enough flow capacity to safely release flood waters both from the Pasig-Potrero River and Gugu Creek.

A drainage structure shall be considered at the control structure or along the lowest portion of the outer dike to avoid deep and lasting ponding and over-trapping of small silty materials during small-scale floods.

Outer Dike

The proposed outer dike shall be armoured at least with slope and toe protection, and a drainage ditch shall be installed along the land side of the dike as a countermeasure against seepage.

Regarding the proposed alignment, the acquisition of right-of-way will be a problem on the lowest right bank at the Santa Rita side because the alignment will traverse the slightly affected area. Even if the alignment is modified to encompass the heavily affected area with a curved form, this modification would be regarded as negligible because of easy and immediate construction of the dike system, although the storage capacity will be slightly reduced.

The alignment has to follow the fan-ridge line and not to stride over the stream valleys so as to avoid a dike breach caused by serious headward erosion due to rush of the main stream of flood runoff toward the dike. The proposed alignment strides over Gugu Creek on the left bank and Sapang Maragul Creek on the right bank. The dike construction on these portions is scheduled in and after the 1996/1997 dry season. Thus, the appropriate alignment should be examined after the detailed field investigation of the topography and the active channel conditions.

Effects of Sediment Retention

If the outer dike and the control structure function well and the sediment accumulates on the catch basin, the riverbed of the Pasig-Potrero active channel will be raised by more than 10 m from the elevation of the present riverbed. This channel aggradation would cause the active channel to easily shift toward any downstream direction in the upstream stretch of the catch basin, and then the possibility of overtopping by flood runoff would increase in the upstream bank of the outer dike. Thus, close monitoring is essential to clarify the effects of sediment retention to the active incised channel.

Retention Dams

A series of retention dams is designed as a transversal dike across the thick deposits of sediment contained in the area between the tertiary dike system. The difference of height between inside and outside areas already reached around 5 m. The construction of retention dams without removal of deposited sediment is unlikely to create the proper catch basin. If 15 to 20 million m^3 of deposited material could be excavated for the construction of the retention ponds, the removal work of deposited material to create the proper catch basin is recommended before building the retention dams instead of the retention pond construction.

Channel Excavation

The outer dike system is an effective structural measure, but this system will fully fail its functions if the active channel shifts toward the outer area of the existing dike in the upstream of the upper end of the constructed outer dike. In order to train flood water without shifting outside of the deposited area and prevent severe bank erosion caused by heavy meandering, the active channel has to have enough width and enough gentle slope.

Riverbed gradient control by some lateral structures is deemed premature due to the rapid progress of geomorphologic changes at present. Regarding river width, the prevailing meander width in the middle reach is approximately 500 to 700 m. If the active channel is excavated to a width of 500 m wide and a depth of 10 m, the excavation volume will reach an unrealistic figure of approximately 40 million m^3.

The channel proposed by DPWH is 300 m wide and 5 m deep. On the assumption of a 7 km long channel, the excavation volume is estimated at 10.5 million m^3. This figure could be evaluated as a possible volume, considering the realistic number of heavy equipment and workable time. Since meandering could progress beyond the excavated bank, monitoring activities should be continued during the rainy seasons.

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TABLES

Table F.1 Geomorphologic Changes in Sacobia-Pasig Headwaters

Time	Sacobia		Pasig		Total	
	C.A. (km^2)	P.F.D. (million m^3)	C.A. (km^2)	P.F.D. (million m^3)	C.A. (km^2)	P.F.D. (million m^3)
Pre-eruption	40.0	-	21.3	-	61.3	-
(Mt. Pinatubo eruption in June 1991)						
After-eruption	35.3	968[1)]	24.5	430	59.8	1,398
(Sacobia captured Abacan headwaters in April 1992)						
October 1992	38.8	688	24.2	340	63.0	1,028
(Pasig captured Sacobia headwaters in October 1993)						
April 1994	18.5	303	44.5	605	63.0	908
October 1994	18.0	295	45.0	475	63.0	770

Note : C.A. : Catchment area, Sacobia; Upstream of Mactan, Pasig; Upstream of the confluence of Papatac and Timbu creeks

P.F.D. : Pyroclastic Flow Deposits

1) : Including P.F.D in Abacan headwaters

Table F.2 Sediment Deposits in Sediment Deposition/Secondary Erosion Zone and Sediment Conveyance Zone

unit : million m^3

Segment	1991 &1992 rainy seasons	1993 rainy season	1994 rainy season	1995 rainy season	Total
Mactan - Maskup	55	28	-3	-	80
Maskup - Route 329	125	40	10	4	174
Lower Reaches	45	2	1	-	48
Total	220	70	8	4	302

Table F.3 (1/4) Freeboard Measurement of San Francisco Bridge

unit : m

Distance from	Observed Date (Year-Month-Day)									
Left Bank	940815	940817	940819	940824	940829	940831	940902	940905	940907	940909
0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
20	0.94	1.04	1.03	1.10	1.10	1.20	1.12	1.06	1.05	0.95
25	0.91	0.95	0.97	1.12	1.12	1.15	1.06	1.03	0.94	0.95
30	0.90	1.00	0.97	1.13	1.13	1.12	1.10	1.05	0.93	0.99
35	1.03	1.15	1.12	1.18	1.18	1.14	0.90	0.90	1.02	1.12
40	0.87	1.10	0.94	1.10	1.10	1.14	0.97	0.97	1.03	0.93
45	0.92	1.05	0.91	1.10	1.11	1.10	0.94	0.95	0.89	0.96
50	0.86	0.98	0.95	0.90	0.90	0.90	0.94	0.96	0.94	0.89
55	0.95	1.06	0.98	1.01	1.02	1.00	1.02	1.02	0.92	0.85
60	0.94	1.00	1.01	1.03	1.03	1.02	0.95	0.96	0.91	0.89
65	1.00	0.96	1.01	1.04	1.04	1.02	0.97	0.98	0.93	0.94
70	1.02	0.96	0.98	0.94	0.94	0.98	0.95	0.95	0.95	0.94
75	0.99	0.93	0.94	1.10	1.10	0.96	0.91	1.00	0.93	0.88
80	1.00	1.00	1.10	1.10	1.10	1.12	0.90	1.10	0.95	0.85
85	0.96	1.03	1.04	1.05	1.05	1.04	0.73	0.92	0.96	0.86
90	1.03	1.08	1.02	1.04	1.04	1.04	0.74	0.90	0.95	0.84
95	1.00	1.02	1.04	1.06	1.06	1.02	0.73	0.78	0.92	0.93
100	0.99	1.04	1.12	1.14	1.14	1.10	0.75	0.75	0.78	0.92
105	0.98	1.01	1.05	1.10	1.10	1.05	0.73	0.78	0.79	0.92
110	1.02	1.05	1.10	1.12	1.12	1.10	0.76	0.80	0.80	0.96
115	0.99	1.07	1.03	1.05	1.05	1.03	0.88	0.87	0.91	0.96
120	1.07	1.08	1.08	1.08	1.08	1.08	0.78	0.80	0.86	0.83
125	1.11	1.02	1.07	1.07	1.07	1.07	0.88	0.88	0.82	0.79
130	1.04	1.10	1.03	1.05	1.05	1.03	0.75	0.81	0.80	0.78
135	1.05	1.05	1.13	1.10	1.10	1.10	0.81	0.83	0.80	0.79
140	1.03	1.08	1.08	1.08	1.08	1.08	0.81	0.83	0.82	0.89
145	1.08	1.18	1.16	1.16	1.16	1.14	0.80	0.83	0.87	0.96
150	1.07	1.08	1.20	1.18	1.18	1.16	0.81	0.85	0.94	0.89
155	1.10	1.04	1.11	1.13	1.14	1.12	0.85	0.96	0.95	0.99
160	1.15	1.06	1.10	1.12	1.10	1.08	0.83	0.92	0.93	0.97
165	1.11	1.17	1.10	1.12	1.10	1.10	0.95	0.98	0.95	0.95
170	1.10	1.11	1.11	1.13	1.12	1.10	1.01	1.02	0.99	0.93
175	1.09	1.09	1.09	1.11	1.10	1.08	1.05	1.05	0.95	0.95
180	1.11	1.08	1.08	1.09	1.10	1.08	1.07	1.05	1.05	0.92
185	1.15	1.03	1.03	1.03	1.05	1.03	0.99	1.00	1.10	0.93
190	1.11	1.05	1.05	1.05	1.05	1.03	1.20	0.98	1.05	0.90
195	1.08	1.15	1.13	1.15	1.12	1.12	1.15	1.00	1.00	0.95
200	1.10	1.09	1.08	1.10	1.12	1.10	0.99	1.03	1.00	1.00
205	1.14	1.06	1.15	1.15	1.15	1.15	0.99	1.01	1.07	0.96
210	1.11	1.07	1.07	1.07	1.07	1.07	0.95	0.93	1.00	0.95
215	1.11	1.12	1.13	1.15	1.14	1.14	0.93	0.88	0.96	0.93
220	1.08	1.10	1.10	1.12	1.12	1.12	0.97	1.00	0.80	0.96
225	1.14	1.07	1.08	1.10	1.10	1.08	0.98	1.00	1.00	0.99
230	1.16	1.10	1.10	1.10	1.10	1.10	0.95	0.87	0.90	0.98
235	1.16	1.15	1.14	1.15	1.15	1.13	1.00	0.90	0.90	1.06
240	1.11	1.17	1.17	1.19	1.15	1.15	0.86	0.87	0.90	0.89
245	1.19	1.15	1.17	1.19	1.10	1.10	0.88	0.89	0.95	1.11
250	0.98	1.03	1.02	1.05	0.95	0.96	0.89	0.90	1.10	1.14
255	0.96	1.06	1.08	1.05	0.98	0.98	1.08	1.03	1.04	1.08
260	0.98	1.08	1.09	1.10	1.14	1.16	1.09	1.08	1.13	1.09
265	1.02	1.10	1.10	1.12	1.15	1.16	1.20	1.18	1.13	1.15
270	1.05	1.20	1.12	1.15	1.30	1.32	1.18	1.10	1.08	1.20
275	1.04	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
280	0	0	0	0	0	0	0	0	0	0
285	0	0	0	0	0	0	0	0	0	0
290	0	0	0	0	0	0	0	0	0	0
295	0	0	0	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0	0	0	0
Average	1.04	1.07	1.07	1.09	1.09	1.08	0.94	0.95	0.95	0.95
Narrowest	0.86	0.93	0.91	0.90	0.90	0.90	0.73	0.75	0.78	0.78
Widest	1.19	1.20	1.20	1.19	1.30	1.32	1.20	1.18	1.13	1.20

Note : Facing Downstream

Data Source : MPR-PMO, DPWH

Table F.3 (2/4) Freeboard Measurement of San Francisco Bridge

unit : m

Distance from Left Bank	Observed Date (Year-Month-Day)									
	940914	940916	940919	940923	940926	940928	940930	941003	941005	941007
0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
20	1.20	1.04	0.93	0.85	0.95	0.98	0.90	0.75	0.74	0.75
25	0.98	1.00	0.90	0.85	0.85	0.86	0.85	0.75	0.75	0.75
30	0.90	0.94	0.80	0.82	0.85	0.85	0.85	0.75	0.75	0.75
35	0.90	0.93	0.79	0.82	0.85	0.86	0.85	0.80	0.80	0.80
40	0.97	0.94	0.80	0.90	0.75	0.75	0.80	0.77	0.80	0.75
45	0.96	0.93	0.79	0.90	0.75	0.75	0.80	0.85	0.85	0.80
50	0.90	0.90	0.75	0.85	0.85	0.85	0.85	0.70	0.70	0.75
55	1.05	1.00	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
60	0.95	0.94	0.80	0.85	0.85	0.85	0.85	0.85	0.85	0.85
65	0.97	0.95	0.82	0.80	0.85	0.85	0.85	0.77	0.80	0.75
70	1.00	0.99	0.90	0.92	0.85	0.85	0.85	0.80	0.82	0.80
75	0.85	0.87	0.85	0.82	0.80	0.82	0.83	0.90	0.85	0.85
80	0.95	0.90	0.80	0.82	0.80	0.82	0.84	0.85	0.84	0.82
85	0.85	0.80	0.81	0.85	0.88	0.86	0.89	0.85	0.90	0.85
90	0.91	0.87	0.85	0.82	0.88	0.88	0.90	0.90	0.90	0.90
95	0.85	0.85	0.87	0.90	0.93	0.93	0.95	1.00	0.95	0.95
100	0.85	0.85	0.87	0.92	0.93	0.93	0.94	0.90	0.95	0.92
105	0.94	0.92	1.03	1.00	0.90	0.92	0.90	0.95	0.95	0.90
110	0.90	0.90	1.03	1.15	0.85	0.86	0.85	1.00	1.05	1.03
115	0.90	0.90	1.05	1.10	0.88	0.86	0.87	0.95	0.90	0.87
120	0.86	0.90	1.05	0.95	0.95	0.95	0.95	0.92	0.90	0.95
125	0.97	0.95	1.07	0.95	1.00	0.97	1.00	0.95	0.95	0.98
130	0.92	0.97	1.08	0.90	1.25	1.20	1.25	0.95	0.95	0.95
135	1.05	1.08	1.10	1.00	1.10	1.05	1.08	0.95	0.95	0.95
140	1.10	1.12	1.10	1.03	1.00	1.02	1.00	0.90	0.95	0.90
145	1.00	1.03	1.02	1.03	1.03	1.03	1.03	1.00	1.00	1.03
150	0.98	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.95
155	1.00	1.00	0.98	1.05	0.95	0.95	0.95	0.90	0.95	0.95
160	0.90	0.92	0.95	1.05	0.96	0.95	0.95	0.95	0.95	0.95
165	0.92	0.94	0.95	0.88	1.05	1.05	1.05	0.95	1.00	0.95
170	0.92	0.95	0.94	0.86	0.95	0.95	0.95	0.93	0.95	0.95
175	0.93	0.95	0.92	0.86	0.90	0.90	0.90	0.95	0.95	0.95
180	0.95	0.98	0.90	0.95	0.95	0.95	0.95	1.00	1.00	0.95
185	1.00	1.02	1.03	1.00	0.96	0.95	0.95	1.15	1.10	1.05
190	0.93	1.02	1.05	0.90	0.90	0.90	0.90	1.00	1.05	1.00
195	0.88	1.00	1.05	1.00	1.05	1.05	1.05	1.05	1.05	1.05
200	0.90	1.05	1.07	0.90	0.90	0.90	0.90	1.30	1.25	1.15
205	0.93	0.94	1.00	0.90	0.95	0.95	0.95	0.97	1.00	0.95
210	1.00	0.90	1.02	0.95	0.95	0.95	0.95	1.00	0.95	0.95
215	0.99	0.90	1.05	1.00	1.05	1.05	1.10	0.95	0.95	0.95
220	0.95	0.90	1.02	1.08	1.03	1.02	1.05	1.00	1.00	1.00
225	0.99	1.00	0.97	1.05	0.95	0.95	1.00	0.95	1.00	0.95
230	1.00	1.00	0.95	1.01	0.98	1.00	1.05	1.00	1.05	1.00
235	1.02	1.02	0.95	1.00	1.22	1.20	1.20	0.95	0.95	0.95
240	0.97	1.00	1.00	1.00	1.09	1.10	1.12	0.95	0.95	0.95
245	0.95	0.96	0.98	1.02	1.06	1.05	1.05	1.05	1.00	1.00
250	1.00	0.98	1.00	1.05	1.10	1.10	1.10	1.10	1.05	1.05
255	1.05	1.04	1.00	1.00	1.05	1.06	1.05	1.10	1.10	1.05
260	1.05	1.06	1.10	1.03	1.00	1.00	1.00	1.10	1.10	1.10
265	1.30	1.24	1.13	1.03	1.05	1.06	1.10	1.05	1.05	1.00
270	1.22	1.18	1.21	1.23	1.10	1.12	1.18	1.10	1.05	1.00
275	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
280	0	0	0	0	0	0	0	0	0	0
285	0	0	0	0	0	0	0	0	0	0
290	0	0	0	0	0	0	0	0	0	0
295	0	0	0	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0	0	0	0
Average	0.97	0.97	0.96	0.95	0.95	0.95	0.96	0.94	0.94	0.93
Narrowest	0.85	0.80	0.75	0.80	0.75	0.75	0.80	0.70	0.70	0.75
Widest	1.30	1.24	1.21	1.23	1.25	1.20	1.25	1.30	1.25	1.15

Note : Facing Downstream

Data Source : MPR-PMO, DPWH

Table F.3 (3/4) Freeboard Measurement of San Francisco Bridge unit : m

Distance from Left Bank	Observed Date (Year-Month-Day) 941010	941012	941014	941017	941019	941024	941026	941102	941119	941209
0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
20	0.75	0.75	0.75	0.90	0.90	0.85	0.75	0.80	0.90	0.79
25	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.69
30	0.75	0.75	0.75	0.75	0.75	0.75	0.85	0.75	0.75	0.72
35	0.75	0.75	0.75	0.80	0.80	0.90	0.75	0.80	0.80	0.83
40	0.80	0.80	0.80	0.80	0.80	0.75	0.85	0.75	0.80	0.69
45	0.70	0.70	0.70	0.80	0.80	0.85	0.85	0.80	0.80	0.75
50	0.80	0.75	0.80	0.80	0.80	0.85	0.85	0.80	0.80	0.78
55	0.85	0.85	0.85	0.75	0.75	0.85	0.85	0.85	0.75	0.85
60	0.85	0.85	0.85	0.75	0.75	0.85	0.85	0.85	0.75	0.88
65	0.75	0.75	0.75	0.80	0.80	0.85	0.85	0.85	0.80	0.86
70	0.80	0.80	0.80	0.80	0.80	0.85	0.85	0.85	0.80	0.88
75	0.90	0.85	0.90	0.85	0.80	0.85	0.85	0.85	0.80	0.86
80	0.85	0.85	0.85	0.95	0.90	0.85	0.85	0.85	0.90	0.89
85	0.85	0.85	0.85	0.90	0.90	0.85	0.85	0.85	0.90	0.85
90	0.85	0.85	0.85	0.85	0.80	0.85	0.85	0.85	0.80	0.83
95	0.85	0.85	0.85	0.90	0.85	0.80	0.85	0.85	0.85	0.83
100	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.85	0.90	0.83
105	0.90	0.90	0.95	0.90	0.90	0.95	0.90	0.90	0.90	0.97
110	1.00	1.00	1.00	0.85	0.85	0.85	0.85	0.90	0.85	0.93
115	0.90	0.90	0.95	0.95	0.95	1.00	0.95	0.95	0.95	0.89
120	0.95	0.90	0.95	0.95	0.95	0.90	0.95	0.90	0.95	0.92
125	0.95	0.95	0.95	0.95	0.95	1.00	0.95	0.95	0.95	0.92
130	0.95	0.95	0.95	0.85	0.85	1.00	0.95	0.95	0.85	0.96
135	0.97	0.95	1.00	1.00	0.95	0.85	0.90	0.90	0.95	0.99
140	0.90	0.90	0.90	0.90	0.85	0.90	0.90	0.90	0.85	0.97
145	0.95	0.95	0.95	1.05	1.00	0.80	0.85	0.80	1.00	0.95
150	0.88	0.90	0.95	0.85	0.85	0.80	0.80	0.80	0.85	0.99
155	0.90	0.90	0.90	0.85	0.85	0.85	0.85	0.85	0.85	0.85
160	0.90	0.90	0.90	0.90	0.85	0.85	0.85	0.85	0.85	0.88
165	0.95	0.95	0.95	0.80	0.80	0.85	0.85	0.85	0.80	0.90
170	0.92	0.90	0.95	0.95	0.90	0.85	0.85	0.85	0.90	0.92
175	0.90	0.90	0.90	0.95	0.90	1.00	0.95	0.95	0.90	1.03
180	1.00	1.00	1.00	0.95	0.90	1.00	1.00	1.00	0.90	1.07
185	1.03	1.02	1.05	0.95	0.95	1.00	1.00	1.00	0.95	1.08
190	1.05	1.05	1.05	1.05	1.05	0.90	0.90	0.90	1.05	0.96
195	1.05	1.05	1.05	1.00	0.95	0.95	0.95	0.95	0.95	1.00
200	1.15	1.15	1.15	0.95	0.95	0.95	0.95	0.95	0.95	1.01
205	0.97	0.97	0.97	0.90	0.90	1.05	1.00	1.00	0.90	1.04
210	1.00	1.00	0.95	1.00	1.00	0.90	0.95	0.90	1.00	0.95
215	0.95	0.95	0.95	0.95	0.95	0.90	0.90	0.90	0.95	1.00
220	0.95	0.95	0.95	1.00	0.95	0.90	0.90	0.90	0.95	0.99
225	1.00	1.00	1.00	1.05	1.00	0.95	0.95	0.95	1.00	1.00
230	1.00	1.00	1.00	1.10	1.05	1.00	0.95	0.95	1.05	1.06
235	0.95	0.95	0.95	1.05	1.05	0.95	0.95	0.95	1.05	1.05
240	0.95	0.95	0.95	1.05	1.05	1.00	1.00	1.00	1.05	1.10
245	1.05	1.05	1.05	1.10	1.10	1.05	1.05	1.00	1.10	1.14
250	1.15	1.15	1.15	1.10	1.00	1.05	1.05	1.00	1.00	0.96
255	1.08	1.08	1.05	1.05	1.00	1.05	1.00	1.00	1.00	1.03
260	1.05	1.05	1.05	0.95	0.9	1.10	1.05	1.05	0.90	1.00
265	1.05	1.05	1.05	1.15	1.15	1.15	1.10	1.10	1.15	1.02
270	1.10	1.10	1.10	1.20	1.15	1.35	1.20	1.15	1.15	1.02
275	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.80
280	0	0	0	0	0	0	0	0	0	0
285	0	0	0	0	0	0	0	0	0	0
290	0	0	0	0	0	0	0	0	0	0
295	0	0	0	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0	0	0	0
Average	0.93	0.92	0.93	0.93	0.91	0.92	0.91	0.90	0.91	0.93
Narrowest	0.70	0.70	0.70	0.75	0.75	0.75	0.75	0.75	0.75	0.69
Widest	1.15	1.15	1.15	1.20	1.15	1.35	1.20	1.15	1.15	1.14

Note : Facing Downstream

Data Source : MPR-PMO, DPWH

Table F.3 (4/4) Freeboard Measurement of San Francisco Bridge

unit : m

Distance from	Observed Date (Year-Month-Day)									
Left Bank	941226	950401	950601	950724	950801	950808	950821	950914	950927	951013
0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
20	0.79	0.79	0.30	0	0.00	0.00	0.00	0.69	0.60	0.64
25	0.69	0.69	0.53	0.14	0.14	0.14	0.14	0.70	0.60	0.62
30	0.72	0.72	0.70	0.32	0.32	0.32	0.32	0.59	0.65	0.60
35	0.83	0.83	0.81	0.55	0.55	0.55	0.55	0.68	0.58	0.60
40	0.69	0.69	0.68	0.76	0.75	0.74	0.84	0.61	0.57	0.60
45	0.75	0.75	0.72	0.85	0.80	0.82	0.89	0.65	0.51	0.60
50	0.78	0.78	0.75	0.89	0.86	0.87	0.87	0.69	0.59	0.61
55	0.85	0.85	0.80	0.94	0.93	0.99	0.89	0.72	0.70	0.62
60	0.88	0.88	0.82	0.94	0.93	0.94	0.94	0.67	0.63	0.63
65	0.86	0.86	0.81	0.86	1.03	1.00	0.96	0.73	0.71	0.65
70	0.88	0.88	0.82	0.85	0.96	1.03	0.88	0.93	0.71	0.68
75	0.86	0.86	0.85	0.96	1.13	1.16	1.07	1.18	0.79	0.67
80	0.89	0.89	0.89	1.01	1.08	1.15	1.02	1.20	0.79	0.68
85	0.85	0.85	0.85	1.01	1.08	1.18	0.98	1.19	0.89	0.93
90	0.83	0.83	1.31	1.02	1.09	1.18	1.05	1.19	0.81	0.81
95	0.83	0.83	1.29	1.09	1.12	1.22	1.04	1.00	0.86	0.72
100	0.83	0.83	1.28	0.98	1.12	1.18	1.03	1.00	0.89	0.86
105	0.97	0.97	1.32	0.98	1.26	1.17	0.99	0.92	0.91	0.69
110	0.93	2.40	1.40	1.53	1.24	1.24	1.03	0.91	0.94	0.77
115	0.89	2.40	1.33	1.29	1.32	1.25	1.09	0.92	0.98	0.81
120	0.92	2.65	1.37	1.25	1.28	1.18	1.27	1.00	0.92	0.78
125	0.92	2.65	1.38	1.27	1.32	1.23	1.25	0.94	0.88	0.70
130	0.96	2.60	1.46	1.25	1.25	1.22	1.14	0.90	1.01	0.84
135	0.99	2.60	1.35	1.12	1.44	1.27	1.22	0.90	0.96	0.69
140	0.97	2.50	1.37	1.12	1.30	1.35	1.07	0.93	0.96	0.80
145	0.95	2.60	1.45	1.14	1.36	1.25	1.14	0.92	1.00	0.70
150	0.99	2.55	1.43	1.14	1.31	1.31	1.11	0.95	1.10	0.67
155	0.85	2.50	1.47	1.15	1.31	1.29	1.06	0.90	0.95	0.69
160	0.88	2.50	1.51	1.15	1.23	1.35	1.17	0.96	0.95	0.75
165	0.90	2.55	1.41	1.13	1.21	1.32	1.19	1.06	1.00	0.70
170	0.92	2.65	1.42	1.14	1.24	1.33	1.23	1.00	1.03	0.71
175	1.03	2.55	1.48	1.12	1.53	1.28	1.22	1.20	0.94	0.72
180	1.07	2.65	1.50	1.21	1.17	1.32	1.43	1.11	0.96	0.70
185	1.08	2.40	1.57	1.08	1.13	1.14	1.44	1.06	0.95	0.70
190	0.96	1.80	1.41	1.01	1.13	1.27	1.27	0.95	0.97	0.70
195	1.00	2.45	1.45	1.16	1.14	1.29	1.37	0.99	1.00	0.69
200	1.01	2.53	1.44	1.20	1.25	1.21	1.17	0.96	1.20	0.72
205	1.04	2.55	1.47	1.15	1.07	1.24	1.15	1.01	0.95	0.74
210	0.95	1.75	1.52	1.08	1.10	1.27	1.10	0.98	0.89	0.69
215	1.00	1.30	1.50	1.11	1.23	1.14	1.12	0.99	0.89	0.67
220	0.99	0.86	1.52	1.07	1.13	1.14	1.18	0.95	0.89	0.72
225	1.00	1.00	1.10	1.07	1.19	1.15	1.13	1.12	0.99	0.53
230	1.06	1.06	0.71	1.13	1.16	1.16	1.22	0.95	0.88	0.50
235	1.05	1.05	0.63	1.12	1.07	1.12	1.08	0.97	0.94	0.53
240	1.10	1.10	1.11	1.10	1.05	1.05	1.06	1.00	0.94	0.67
245	1.14	1.14	1.02	1.39	1.08	1.12	1.11	1.00	0.88	0.59
250	0.96	0.96	0.97	0.93	0.93	0.93	0.93	0.80	0.99	0.63
255	1.03	1.03	1.00	0.89	0.89	0.89	0.89	0.89	0.96	0.46
260	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.75	0.86	0.49
265	1.02	1.02	0.00	0.00	0.00	0.00	0.00	0.84	1.00	0.52
270	1.02	1.02	0.00	0.00	0.00	0.00	0.00	0.80	0.79	0.53
275	0.80	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59
280	0	0	0	0	0	0	0	0	0	0
285	0	0	0	0	0	0	0	0	0	0
290	0	0	0	0	0	0	0	0	0	0
295	0	0	0	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0	0	0	0
Average	0.93	1.54	1.06	0.94	0.98	1.00	0.95	0.90	0.85	0.67
Narrowest	0.69	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46
Widest	1.14	2.65	1.57	1.53	1.53	1.35	1.44	1.20	1.20	0.93

Note : Facing Downstream

Data Source : MPR-PMO. DPWH

Table F.4 Comparison between Pre- and Post-Eruption Dredging Volume in Pampanga River

Reach	Dredging Volume (m^3) July 1988	Dredging Volume (m^3) December 1993	Balance (m^3)
P - 1	874,270	884,020	(+) 9,750
P - 2	773,110	832,000	(+) 58,890
P - 3	835,230	919,901	(+) 84,671
P - 4	818,460	720,054	(-) 98,406
Total	3,301,070	3,355,975	(+) 54,905

Note : Reach of the project area is 4.0 km long. The project area is divided into four packages for the contract.

Table F.5 Average Water Quality and Sediment Concentration of Irrigation Water (May to December 1993)

Location Site	pH	Ec x 10	Ca ppm	Mg ppm	Na ppm	K ppm	SO4 ppm	Cl ppm	SAR	Sediment
1. Pampanga River (P-2) Camba, Arayat Pampanga	7.81	290.10	29.26	11.73	10.40	0.63	21.01	5.75	0.375	831.78
2. Pampanga River (P-25) Bagong Buhay, Nueva Ecija	7.92	268.74	26.74	11.33	10.80	0.46	11.23	4.24	0.333	296.63
3. Sacobia Rio Chico (RC-9) San Antonio, N.E.	7.80	306.05	32.18	11.73	10.47	0.64	24.40	6.17	0.401	1,700.16
Average	7.84	288.30	29.39	11.60	10.56	0.58	18.88	5.39	0.370	942.86

Table F.6 Volume of Sediment Deposition in Inundated Areas of Pasig-Potrero River, 1994

Square No.	Sub-No.	Area (km^2)	Average Depth(m)	Volume (10^6m^3)	Square No.	Sub-No.	Area (km^2)	Average Depth(m)	Volume (10^6m^3)
1 -A		0.05	1.1	0.06	6 -H	1	0.53	4.0	2.12
1 -B		0.48	2.2	1.06		2	0.48	3.6	1.73
1 -C		0.50	2.1	1.05	6 -I		0.98	2.5	2.45
2 -B	1	0.10	2.3	0.23	6 -I*		0.20	0.6	0.12
	2	0.10	2.2	0.22	6 -J		0.23	1.1	0.25
2 -C	1	0.30	2.3	0.69	6 -J*	1	0.13	0.6	0.08
	2	0.60	2.1	1.26		2	0.08	1.0	0.08
2 -D		0.88	1.1	0.97	7 -D		0.08	0.6	0.05
2 -D*		0.08	0.6	0.05	7 -E		0.35	0.6	0.21
2 -E		0.53	0.8	0.42	7 -F*		0.80	0.5	0.40
2 -E*		0.10	0.6	0.06	7 -H		0.70	0.6	0.42
2 -F		0.06	0.8	0.05	7 -I	1	0.55	4.5	2.48
2 -F*		0.05	0.6	0.03		2	0.45	1.5	0.68
3 -A		0.15	2.1	0.32	7 -J		0.90	2.9	2.61
3 -B		0.30	2.0	0.60	7 -J*		0.13	1.0	0.13
3 -C		0.15	2.3	0.35	7 -K		0.05	1.5	0.08
3 -D	1	0.28	2.3	0.64	7 -K*		0.30	1.0	0.30
	2	0.45	2.1	0.95	8 -F		0.20	0.9	0.18
3 -D*		0.10	0.6	0.06	8 -I		0.50	1.8	0.90
3 -E		1.00	2.0	2.00	8 -J	1	0.80	2.0	1.60
3 -E*		0.35	0.6	0.21		2	0.20	1.8	0.36
3 -F		0.98	1.8	1.76	8 -K		0.78	1.5	1.17
3 -F*		0.73	0.6	0.44	8 -K*		0.20	1.0	0.20
3 -G		0.53	0.7	0.37	8 -L		0.15	1.5	0.23
3 -G*	1	0.53	0.6	0.32	8 -L*		0.05	0.6	0.03
	2	0.25	1.0	0.25	9 -F		0.30	0.9	0.27
3 -H		0.01	0.7	0.01	9 -J		0.83	1.2	1.00
3 -H*		0.15	1.0	0.15	9 -K	1	0.58	3.0	1.74
4 -B		0.53	2.0	1.06		2	0.42	2.1	0.88
4 -C		0.28	1.2	0.34	9 -L		0.73	3.0	2.19
4 -E	1	0.10	2.3	0.23	9 -L*		0.03	0.6	0.02
	2	0.35	1.6	0.56	9 -M*		0.08	0.6	0.05
4 -F		0.90	1.6	1.44	10-G		0.65	0.6	0.39
4 -G		1.00	2.0	2.00	10-H*		0.60	0.5	0.30
4 -G*		0.50	1.0	0.50	10-I*		0.80	0.5	0.40
4 -H		0.80	0.6	0.48	10-K		0.70	2.1	1.47
4 -H*	1	0.80	1.0	0.80	10-L	1	0.43	3.0	1.29
	2	0.05	0.6	0.03		2	0.57	1.5	0.86
4 -I		0.05	0.6	0.03	10-M		0.23	1.5	0.35
4 -I*		0.05	0.6	0.03	10-M*		0.23	0.6	0.14
5 -B		0.08	0.6	0.05	11-L		0.80	1.2	0.96
5 -C		0.85	0.9	0.77	11-M	1	0.23	1.5	0.35
5 -D		0.30	0.6	0.18		2	0.40	1.8	0.72
5 -F		0.30	3.0	0.90	11-M*		0.03	1.0	0.03
5 -G		1.00	3.3	3.30	12-L		0.40	2.1	0.84
5 -H		1.00	1.0	1.00	12-M	1	0.80	2.1	1.68
5 -H*		0.53	0.9	0.48		2	0.17	0.6	0.10
5 -I		0.58	0.5	0.29	12-N		0.13	0.6	0.08
5 -I*		0.68	0.6	0.41	13-L		0.50	1.2	0.60
6 -C		0.25	0.6	0.15	13-M		1.00	1.0	1.00
6 -D		0.38	0.6	0.23	13-N		0.60	0.7	0.42
6 -E		0.38	0.6	0.23	14-L		0.13	1.0	0.13
6 -E*		0.80	1.0	0.80	14-M		0.75	1.0	0.75
6 -F*		0.30	0.5	0.15	14-N		0.83	0.6	0.50
6 -G		0.63	3.6	2.27	14-O		0.53	0.6	0.32
					Total		47.56		71.88

Note * : Additional Survey Results to October 22 Lahar

Table F.7 Estimation of Annual Sediment Transport Volume in Sacobia-Bamban River

Reference Point	Catchment Area (km^2)	Channel Gradient	Sediment Concentration (%)	Annual Sediment Transport Volume (million m^3)
<u>Sacobia River</u>				
Maskup :				
- under present condition	38.5	1/90	3.5	3.5
- with Maskup consolidation dam	38.5	1/135	2.3	2.3
- with series of cosolidation dams	38.5	1/180	1.7	1.7
Sacobia Channel at the Junction with Bamban :				
- upstream from Malonzo	43.7	1/150	2.0	2.3
- downstream from Malonzo	50.2	1/210	1.4	1.8
Sand Pocket Outlet :				
- under present condition	61.4	1/210	1.4	2.2
- with series of groundsills	61.4	1/315	0.90	1.4
<u>Sapang Balen River</u>				
Confluence of Bamban :				
- with Joining Sacobia	103.0	1/625	0.43	1.2
<u>Bamban River</u>				
Malonzo :				
- under present condition	92.5	1/260	1.1	2.7
- with groundsills	92.5	1/390	0.72	1.7
San Francisco Br. :				
- under present condition	93 6	1/370	0.76	1.9
Confluence of Rio Chico :				
- under present condition	98.4	1/790	0.54	1.4

Table F.8 Estimation of Annual Sediment Transport Volume in Abacan River

Reference Point	Catchment Area (km^2)	Channel Gradient	Sediment Concentration (%)	Annual Sediment Transport Volume (million m^3)
Friendship Br.	33.3	1/150	0.65	0.53
San Jose Malino	77.2	1/250	0.35	0.66

Table F.9 Major Lahar Events in Pasig-Potrero River in 1995

Lahar Event	Daily Rainfall (mm)	Range of Deposition Depth (m)	Volume of Deposits (million m^3)	Remarks
June 1 to 7	40 (Jun. 01) 13 (Jun. 02) 62 (Jun. 03) 17 (Jun. 04) 20 (Jun. 06) 16 (Jun. 07)	1.0	1	Typhoon Auring
July 7 to 11	61 (Jul. 07) 24 (Jul. 09) 27 (Jul. 10) 7 (Jul. 11)	Inner Area : 0.5-3.0 Outer Area : 0.8	5	
July 18	65 (Jul. 18)	0.2-1.0	2	
July 27 to 30	6 (Jul. 27) 68 (Jul. 28) 36 (Jul. 29) 109 (Jul. 30)	Inner Area : 0.6-2.6 Outer Area : 0.2-3.0	15	Typhoon Karing
August 15 to 19	44 (Aug. 15) 13 (Aug. 17) 46 (Aug. 18) 38 (Aug. 19)	Inner Area : 0.5-4.0 Outer Area : 1.0-1.8	14	
August 28 to September 3	25 (Aug. 28) 80 (Aug. 29) 49 (Aug. 30) 12 (Sep. 02) 69 (Sep. 03)	Inner Area : 0.2-4.0 Outer Area : 1.0-2.8	27	Typhoon Gening and Helming
September 30 to October 1	32 (Sep. 30) 251 (Oct. 01)	1.4-4.2	22	Typhoon Mameng
Total			86	

Note : 1) Daily rainfall indicates the data of Upper Sacobia Gauge observed by PHIVOLCS.

2) Inner area means the area between the tertiary dike system, while outer area means the area outside this system.

3) Volume of deposits indicates the volume of sediment accumulated since the earlier event.

Table F.10 Estimate of Channel Erosion in 1995

Channel Segment	Average Eroded Area (m^2)	Active Channel Length (km)	Volume of Channel Erosion (million m^3)
Mouth of Timbu Creek - Delta 5	1,800	3.0	5.4
- Dike-Breach Point	2,400	6.4	15.4
- Diversion Point	1,500	6.2	9.3
- Downstream End of Dike System	570	18.6	10.6
Total			40.7

Note : Channel segment between diversion point and downstream end of dike system includes both the previously active and diversion channels.

Table F.11 Summary of Secondary Explosion and Lahar Events

in 1992

Month	Rainfall (mm)	Frequency of Secondary Explosion H : Column Height in km				Frequency of Lahar in Number of Days					
						Sacobia River			Pasig River		
		H<1	1≤H<3	3≤H<5	5≤H	Small	Moderate	Big	Small	Moderate	Big
Jan	0										
Feb	0										
Mar	0										
Apr	2		1								
May	98		2								
Jun	321	1	1								
Jul	527		5	1							
Aug	925	12	10	1	9						
Sep	171	20	16		4						
Oct	135	4	2		2						
Nov	36	1	1								
Dec	0										
Total	2215	38	38	2	15	-	-	-	-	-	-

Note : Monthly rainfall is referred to data observed at PI2
Lahar data is not compiled on the daily basis

in 1993

Month	Rainfall (mm)	Frequency of Secondary Explosion H : Column Height in km				Frequency of Lahar in Number of Days					
						Sacobia River			Pasig River		
		H<1	1≤H<3	3≤H<5	5≤H	Small	Moderate	Big	Small	Moderate	Big
Jan	0										
Feb	0	1									
Mar	0										
Apr	0										
May	0										
Jun	463	8	4			3	1			1	
Jul	349	10	9	1		2	3		2	1	
Aug	689	3	9	2	6	7	4		8	1	
Sep	449		5	6		14	2		6		
Oct	319	6	18	1		4	2	1	2	4	
Nov	171	2	2	1					1	2	
Dec	52		2								
Total	2492	30	49	11	6	30	12	1	19	9	0

Note : Monthly rainfall is referred to data observed at PI2

in 1994

Month	Rainfall (mm)	Frequency of Secondary Explosion H : Column Height in km				Frequency of Lahar in Number of Days					
						Sacobia River			Pasig River		
		H<1	1≤H<3	3≤H<5	5≤H	Small	Moderate	Big	Small	Moderate	Big
Jan	21				1					1	
Feb	59	1	4							1	1
Mar	29	6	3							2	
Apr	2	2	2		1				1	1	
May	28	14	5						6		
Jun	120	3	4			5	1		3	2	
Jul	1086	4	11	3		12	2		3	5	3
Aug	434	2	17	7	3	9	1		7	2	
Sep	289	3	8	2	3	15	1		16	2	5
Oct	188	4	6	1	5	1	1		7		1
Nov	0	1							3		
Dec	13										
Total	2269	40	60	13	13	42	6	0	46	16	10

Note : Monthly rainfall is referred to data observed at UPPER-SACOBIA

in 1995

Month	Rainfall (mm)	Frequency of Secondary Explosion H : Column Height in km				Frequency of Lahar in Number of Days					
						Sacobia River			Pasig River		
		H<1	1≤H<3	3≤H<5	5≤H	Small	Moderate	Big	Small	Moderate	Big
Jan	0										
Feb	0										
Mar	19								1	1	
Apr	0										
May	258		1			2			4	2	
Jun	211	2				2			2	3	1
Jul	508		2	1	2	4	1		5	6	3
Aug	501	3	2	2	1	1	2		4	4	1
Sep	484	3	5			2	2		4	4	
Oct	374	3	5	2			1		1	1	
Nov											
Dec											
Total	2355	11	15	5	3	11	6	0	21	21	5

Note Monthly rainfall is referred to data observed at UPPER-SACOBIA