

# 1. INTRODUCTION

## Study Background

The study area is the western river basins of Mount Pinatubo (Bucayo, Maloma, and Sto. Tomas Rivers) located in the mid-western part of Luzon Island with a catchment area of approximately 1,300 km<sup>2</sup>. In June 1991, Mount Pinatubo erupted and approximately 6.7 billion m<sup>3</sup> of pyroclastic material was deposited around the mountain slopes. It is estimated that 70% of the total pyroclastic flow deposits, or 4.7 billion m<sup>3</sup>, were deposited in the study area.

Pyroclastic materials are transported to the downstream in the form of mudflow during the rainy season and deposited there. Although 12 years have passed since the Pinatubo eruption and the volcanic activity has ceased, the safety of the existing dike system is not enough because of the remarkable raising of the riverbed in the mid-stream and downstream. Moreover, it is anticipated that riverbed would still continue to rise due to erosion of the remaining pyroclastic materials on the mountain slope and remobilization of upstream sediment deposits. These conditions have worsened the difference in economic development between the eastern and western slopes of Mount Pinatubo since the 1991 disaster because there has been no investment in the vulnerable western areas and the local people suffer from insufficient income sources and no opportunities for employment.

Based on the above situation, a master plan for sabo (sediment control) and flood control is required for the three major rivers (Bucayo, Maloma and Sto. Tomas Rivers) of the western areas of Mount Pinatubo. It is also necessary to carry out a feasibility study for the main priority projects. The purpose of this study is to present comprehensive strategies to cope with the prevailing situation through i) analysis of the existing conditions of damages from flood and mudflow in the western river basins of Mount Pinatubo, ii) estimation of future damages, iii) examination of structural measures for sabo and flood control, and iv) study of non-structural mitigation measures such as early warning, evacuation and resettlement.

The Government of the Philippines officially requested assistance from the Government of Japan for the preparation of a master plan and feasibility study for sabo and flood control in March 1999. Accordingly, the Japan International Cooperation Agency (JICA) delegated a preparatory study team from November to December 2001. After agreement on the Implementing Arrangement, this study was conducted for 18 months from March 2002 to September 2003.

## Study Objectives

The objectives of the study are as follows:

- (i) To formulate a master plan for sabo and flood control in the major three rivers (Bucayo, Maloma and Sto. Tomas Rivers) and carry out a feasibility study for the main priority projects, however, excluding a study on internal drainage issues,
- (ii) To transfer technology that is used in the planning of sabo and flood control to the counterpart personnel during the study, and
- (iii) To assist with disaster rehabilitation and economic development in the study area as well as other river basins in the Philippines, by transferring planning technology that can be applied to mitigate regional economic differences and poverty levels and, therefore, improve and enhance the welfare of the regional inhabitants.

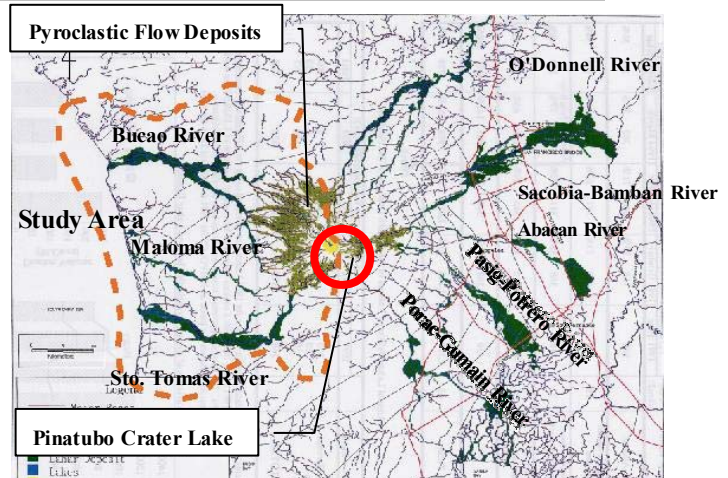


Figure 1.1 Eight Rivers around Mount Pinatubo

## 2. CHANGES IN NATURAL AND SOCIAL CONDITIONS AFTER THE ERUPTION

### Damages due to Mount Pinatubo Eruption and Mudflow

The Mount Pinatubo eruption is regarded as the largest volcanic eruption in the 20<sup>th</sup> century in the world. The damages from the eruption were valued at the end of 1991 at a total of 10.6 billion pesos in Region 3, which consists of six provinces including Zambales. Because of the eruption, 1,034 people were killed and 33,623 families evacuated in Region 3. In the study area, Zambales Province, it has been reported that 215 people were killed and 157 people were injured because of the eruption in 1991 and the following lahar events. A total of 19 barangays were forced to be resettled because they were buried by lahar or submerged by dammed-up lakes.

**Table 2.1 Damages from the Eruption of Mount Pinatubo (1991)**

Item	Unit	Region 3	Zambales
Regional Data			
Area	km <sup>2</sup>	18,231	3,611
Population (in 2000)	nos.	8,030,945	433,542
Damage from Mount Pinatubo Eruption			
Death Toll	person	1,034	215
Missing	person	30	8
Injured	person	196	157
Completely Destroyed Building	nos.	47,789	25,845
Half Destroyed	nos.	80,337	25,845
Household Resettled in Resettlement Center	HH.	33,623	4,127
Cost of Damage on Utilities	10 <sup>6</sup> Pesos	4,403	206

Source: NSO, NSCB, NEDA

Two-thirds of the houses in Zambales were totally or partially damaged in 1991 when the damage was most serious, and approximately 60% of the total provincial population evacuated to 70 evacuation centers in Zambales. In spite of such large scale disaster, the death toll in Zambales was relatively small because the prediction of the eruption, warning for evacuation, and monitoring and public relations after the eruption

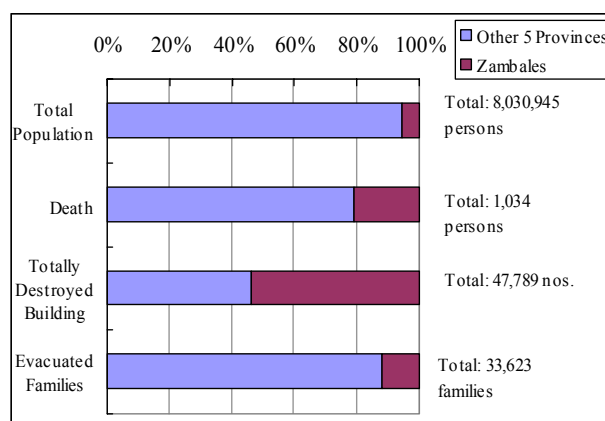
by the Philippine Institute of Volcanology and Seismology (PHIVOLCS) functioned well.

### Damage on Socio-economy

Figure 2.1 shows the ratio of damage in Zambales to that in Region 3 overall. The population in Zambales is 433,000 as of 2000, which is only 5.3% of the total population in Region 3. On the other hand, Zambales accounted for 20.8% of deaths, 54.0% of the totally destroyed buildings, and 12.3% of evacuated families. Therefore, it can be said that people in Zambales have been the most severely affected in Region 3.

In addition, the population growth rate in Zambales since the eruption has been very different from the national and Region 3

growth rates. Table 2.2 shows that the population growth rate in the Philippines and Region 3 between 1990 and 2000 was similar to those existing between 1980 and 1990. However, the post-eruption population growth rate in Zambales and the study area dropped drastically from the 1980s to 1990s. The decreased population



Source: NSO, NSCB, NEDA

**Figure 2.1 Damage in Zambales Province and Region 3**

**Table 2.2 Population Change in the Philippines, Region 3, Zambales Province and Study Area**

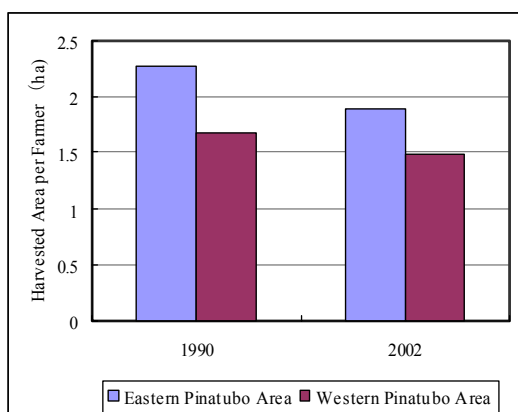
Region	Population			Growth Rate	
	1980	1990	2000	1980-90	90-2000
Philippines	48,098,460	60,703,206	76,503,333	2.35%	2.34%
Region 3	4,802,793	6,199,017	8,030,945	2.58%	2.62%
Zambales	287,607	369,665	433,542	2.54%	1.61%
Study Area	161,005	208,963	228,148	2.64%	0.88%

Source: Census of Population and Housing, NSO

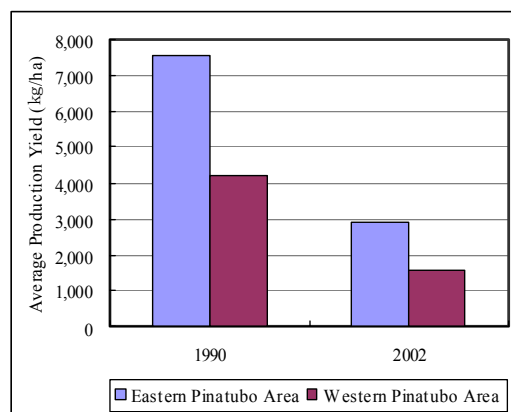
growth can be attributed to the disaster of Mount Pinatubo because the study area and Zambales Province were severely affected by the damage.

A similar trend to the decreased population growth is observed in the agricultural production. Interviews with affected farmers were conducted in the study area and also in the eastern part of Mount Pinatubo area. Figure 2.2 shows the change in the harvested area and Figure 2.3 shows the change in production yield of paddy from 1990 to 2002. Both figures indicate that the farming area and production efficiency have greatly decreased due to the eruption of Mount Pinatubo and there is still no effective recovery measures taken for the agriculture sector as of the year 2002.

As mentioned above, conditions of agricultural activities have not recovered even 10 years after the disaster. It is apparent that the living conditions of farmers accounting for 40% of the total population in the study area have not been regained yet. Recovery of agricultural land and rehabilitation of irrigation systems are urgently required.

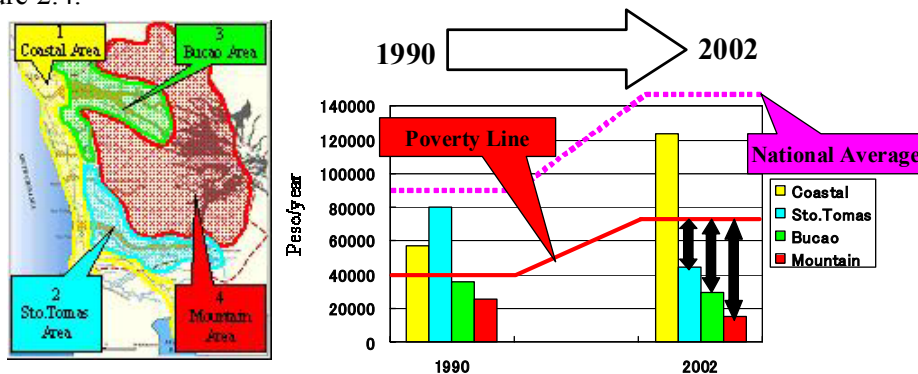


**Figure 2.2 Change in Harvested Area of Paddy per Farmer**



**Figure 2.3 Change in Production Yield of Paddy**

The change in average family income in the study area was investigated through interview survey as shown in Figure 2.4.



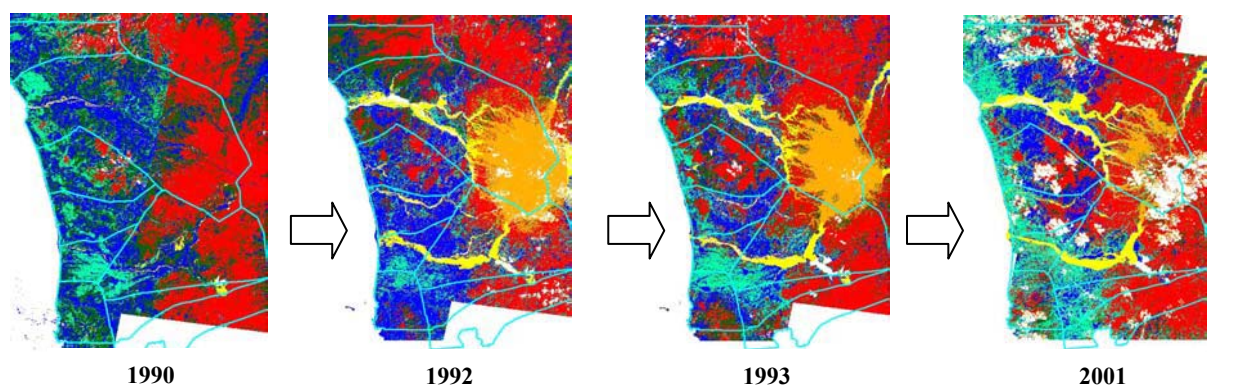
**Figure 2.4 Change in Family Income in Study Area**

It was found that family income in the coastal area along the national highway No.7 has been growing smoothly owing to production of cash crops such as mango and vegetables and tourism development of beach resorts and so on. On the other hand, the income of families living along the Bucao and Sto. Tomas Rivers and in mountain areas, where most of the Aeta people reside, has fallen greatly compared with that in 1990. The Sto. Tomas River basin served as a granary for Zambales Province before the eruption; three crops a year was typical because of an extensive irrigation network. However, the family income has drastically decreased because irrigation systems were damaged and agricultural land reduced due to mudflow. The present average family income in the area is below the poverty threshold. In addition, the average family income in the Bucao River basin and mountain

area is also below the poverty line and the difference is increasing. Countermeasures for poverty alleviation in the mid-stream and upstream are urgently needed.

### Change in River Basins

The eruption of Mount Pinatubo drastically changed the conditions of the eight rivers that drain the mountain. The western river basins where 70% of pyroclastic materials were deposited were predominantly affected.



**Figure 2.5 Land Use Change in Western River Basins of Mount Pinatubo**

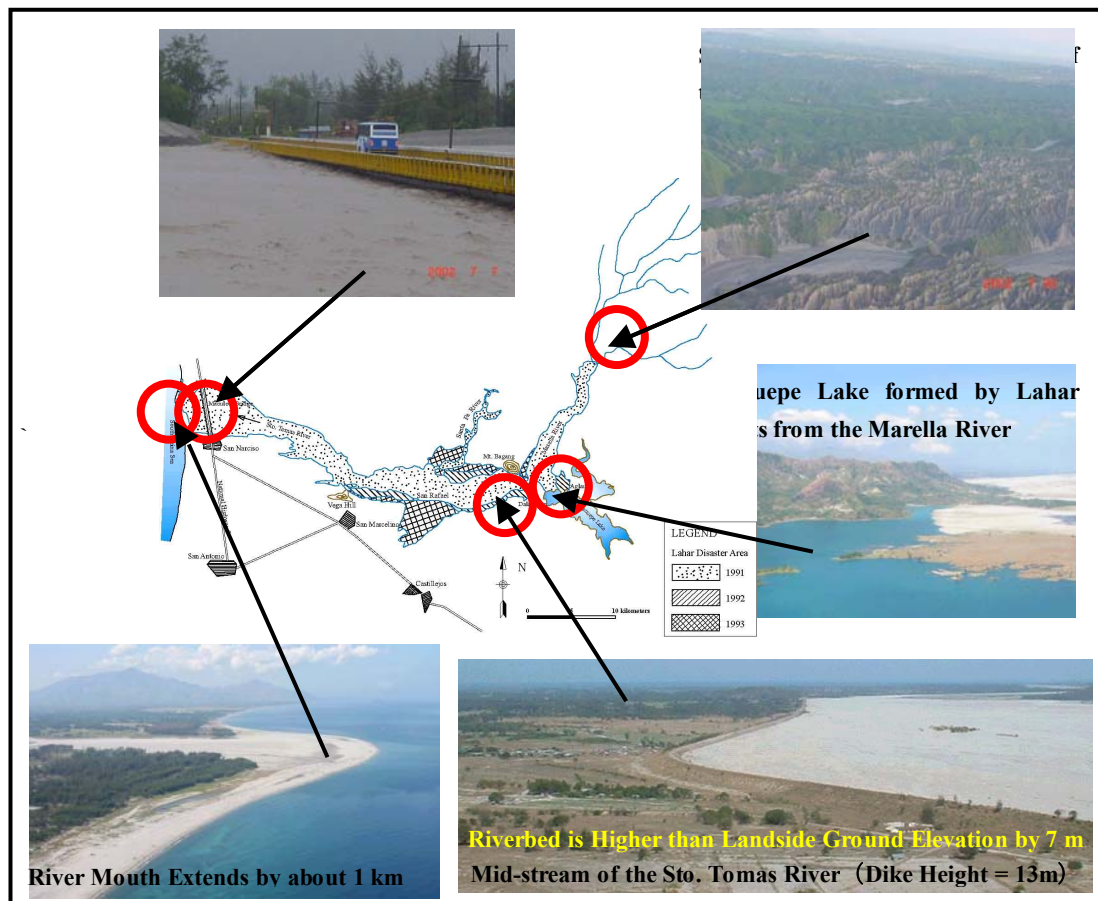
Landsat images in Figure 2.5 show the land use change in the study area. In 1992 immediately after the eruption, pyroclastic flow deposits could be observed all over Mount Pinatubo resulting in great loss in forest and cultivated areas and increase in bare land. However, the area buried by pyroclastic flow deposits has decreased greatly as time passed (2001). This is because pyroclastic flow deposits in the upstream have been transported to the downstream in the form of lahar and vegetation has recovered gradually since the 1991 eruption. It is estimated that the upstream area is going to be stabilized due to the resilience of nature.

In the mid-stream, lahar deposits are predominantly transported from the upstream as mudflow. The volume of lahar deposition in the Bucao and Sto. Tomas River channels is estimated at 843 million m<sup>3</sup> and 818 million m<sup>3</sup>, respectively. The area converted from riverside farmland into un-used area due to the spread of lahar flow along the river is 5,534 ha in the Bucao River and 3,797 ha in the Sto. Tomas River. Raising of the riverbed is outstanding in the both rivers. The riverbed in the middle and downstream of the Sto. Tomas River, in particular, is higher than the ground level by up to 7.0 m.

Natural rivers usually function as drainage channels in lowland areas. However, the rivers of the study area have lost their drainage function. Therefore, the river channel network has changed in the middle and downstream reaches and there are a number of areas from which water cannot drain properly. In particular, natural dammed-up lakes have formed at the confluences of tributaries and the main channel in the Bucao and Sto. Tomas rivers, where the flow from tributaries is blocked by the sediment in the main channel. A total of 24 dammed-up lakes has been observed and the largest is the Mapanuepe Lake at the confluence of the Marella River, a tributary of the Sto. Tomas River, and the Mapanuepe River; this lake has a surface area of 6.8 km<sup>2</sup>.

The existing conditions in the Sto. Tomas and Bucao Rivers are shown in Figures 2.6 and 2.7.





### **3. BASIC CONCEPT OF MASTER PLAN**

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#### **Main Issues on Sabo and Flood Control**

Sediment yield has been decreasing in the western river basins of Mount Pinatubo because most of the unstable pyroclastic flow deposits remaining in the upstream have been transported down to the middle and downstream reaches and vegetation has recovered greatly. However, it is estimated that re-mobilization of the sediment deposited in the upper reaches would still continue resulting in more sediment deposition in the downstream reaches. If the riverbed continues to rise in the middle and downstream of the Bucao and Sto. Tomas Rivers, where the existing riverbed is already higher than the surrounding ground level, the potential risk of inundation in the downstream area will also increase. Sediment control/management is urgently required for further disaster prevention/mitigation in the downstream residential and agricultural areas.

Only one arterial route, national highway No.7 runs along the western coastline and crosses the Bucao, Maloma and Sto. Tomas Rivers. This road is recognized as a lifeline for the 434,000 people of Zambales Province. To improve reliability and security of national highway No.7 is essential for sustainable economic growth of Zambales. Reconstruction of the bridges should be examined to enable floods and mudflow to pass within the channel safely. Furthermore, local roads on the skirts of Mount Pinatubo have been buried by lahars since the eruption. Reconstruction of the local roads is desired to recover the livelihood of people residing in the mountainous area.

Another issue to be solved in the western river basins other than sabo and flood control in the downstream is to secure livelihoods for the people in the middle and upstream reaches, including the Aeta people. A number of farmlands including riverside areas and community roads in the river basins were destroyed and irrigation systems damaged due to the eruption and mudflow. Most of the evacuees in the resettlement centers tended to return to the original barangays permanently or seasonally because there was no livelihood after they moved into the resettlement centers. Even though they returned to the original barangays, they have been forced to live far below the living standards existing before the eruption.

The Government of the Philippines (GOP) and Non-Government Organizations (NGOs), with technical and financial support from donor countries and funding institutions, have taken various actions such as implementation of structural measures, including construction of dikes, to secure the residential and agricultural areas in the downstream, introduction of warning and evacuation systems for flood and mudflow as non-structural measures, establishment of resettlement centers, and support for livelihood projects. However, the issues detailed above remain unsolved. Therefore, a basin-wide comprehensive plan for sabo and flood control is required to solve these issues.

#### **Basic Concept of Master Plan**

Figure 3.1 illustrates the basic concept of master plan formulated in the study.

First of all, basin-wide comprehensive sediment control should be included in the master plan for sabo and flood control. The control measures must be based on predicted future sediment yield from upstream and analysis of sediment transport and riverbed movement along the river course in both the short and long terms.

The master plan should cover both lowland and upland areas and aim not only to mitigate flood/mudflow damages in the lowlands, but also to recover people's livelihood in the mountainous area. Creation of livelihood would increase people's living standard in which in turn gives people an incentive to be more concerned about disaster prevention. Hence, the goal of the master plan, that is

regional economic development and poverty alleviation, can be achieved by an integrated approach to both lowland and upland.

To cope with the issues mentioned above, a combination of structural measures to control floods/mudflows, non-structural measures to reduce vulnerability to damages, and community-based disaster prevention plans to improve the living standard of the damaged communities is to be incorporated into the master plan.

The formulated master plan should be harmonized with the strategy for economic development of the Philippine and local governments. Presently, the National Economic and Development Authority (NEDA) Region 3 considers tourism and agriculture as the major economic sectors of Zambales. To support their development, protection of lowland areas from floods/mudflows and security of the road networks in the Province are vital. Therefore, the master plan for sabo and flood control links to development in the sectors of agriculture, tourism and the road network.

The target year of the master plan is set at 2002, which is 20 years after 2003.

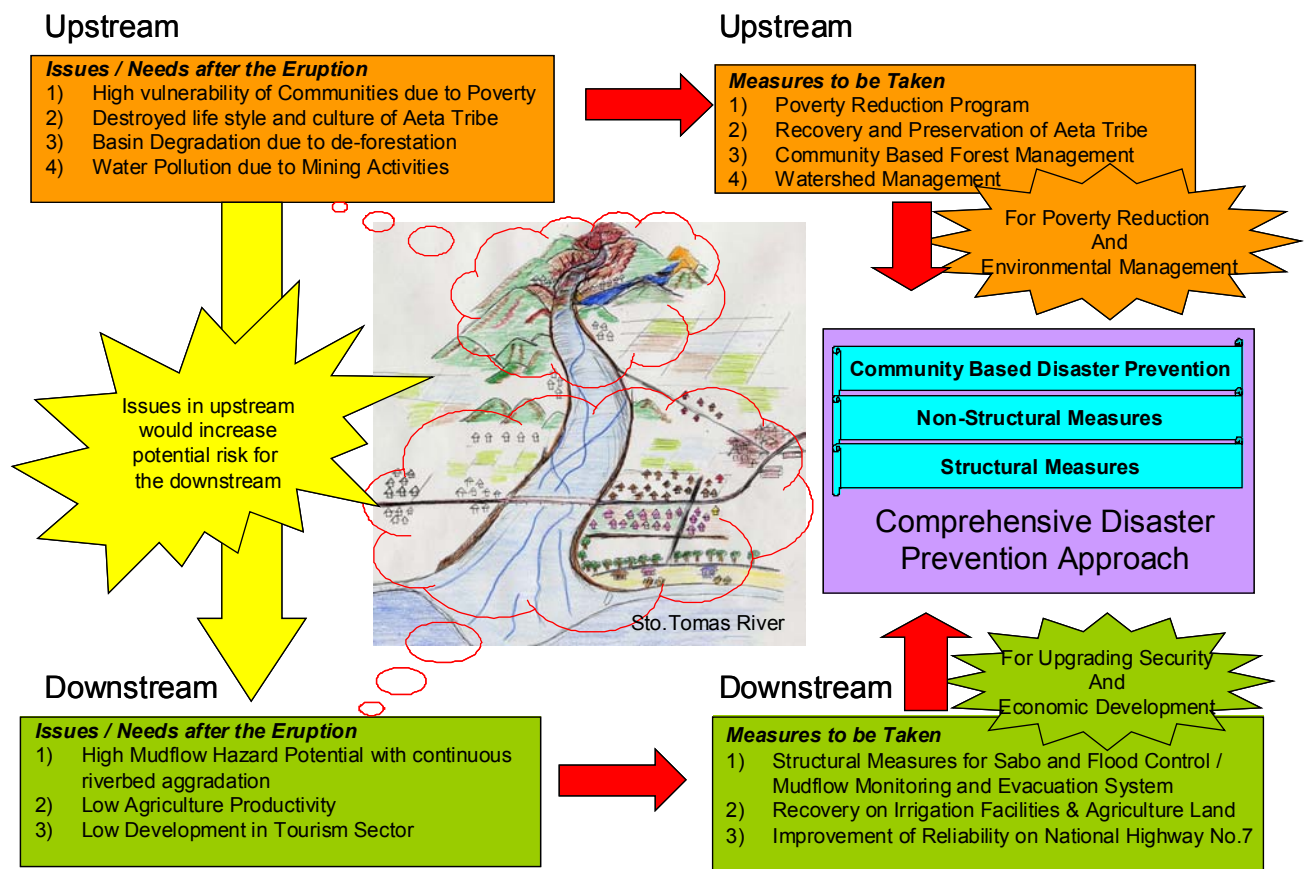


Figure 3.1 Basic Concept of Master Plan

## 4. HYDROLOGY/SEDIMENT YIELD/RIVERBED MOVEMENT ANALYSIS

### Hydrological Analysis

The study area is predominantly affected by southwest monsoon winds from South China Sea. Blocked by the Pinatubo mountainous area on the eastern side of Zambales Province, the southwest monsoon winds cause heavy rain in the study area. Average annual rainfall in the western river basins of Mount Pinatubo is approximately 3,600 mm, which is greater by 40% than that in the eastern river basins (approximately 2,500 mm) as shown in Figure 4.1. In addition, Figure 4.2 shows the recorded accumulated rainfall during a series of typhoons in July 2002, which indicates that rainfall in the western river basins is more than that in the eastern basins.

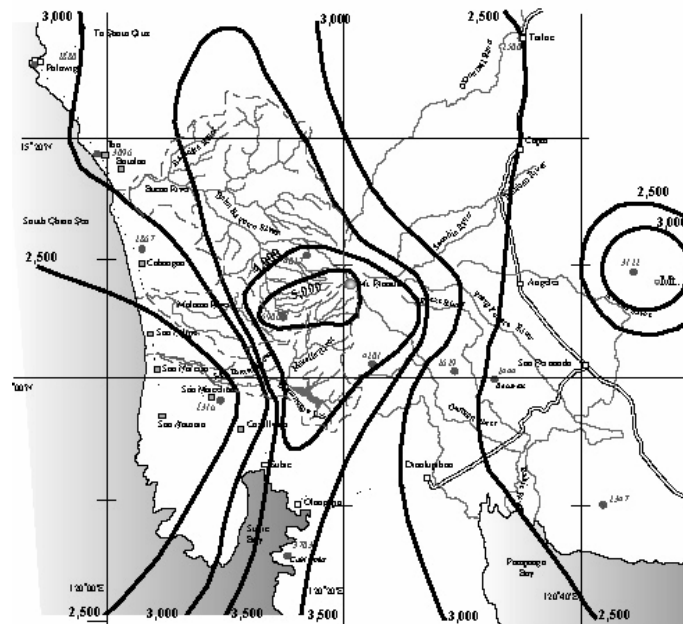


Figure 4.1 Isohyetal Map around Mount Pinatubo (1995)

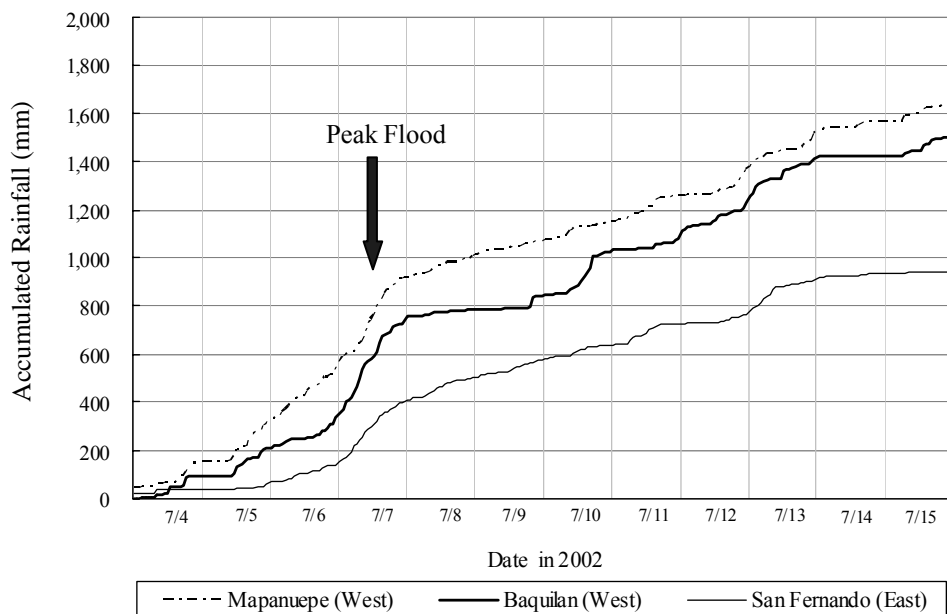


Figure 4.2 Comparison of Accumulated Rainfall between Eastern and Western Areas of Mount Pinatubo during Flood in July 2002

Flood analysis was conducted for sub-basin models of the three river basins in the study area using unit hydrograph of the HEC-HMS model developed by the United States Army Corps of Engineers (USACE). The design hyetograph was based on one day rainfall for the following reasons:

- The catchment areas of the three rivers in the study area are relatively small ranging from 152 km<sup>2</sup> to 655 km<sup>2</sup> with short and steep river courses.
- Peak flood discharges have been caused by one day rainfall of typhoon based on the recorded floods over the latest 30 years. In addition, discharge measurements conducted



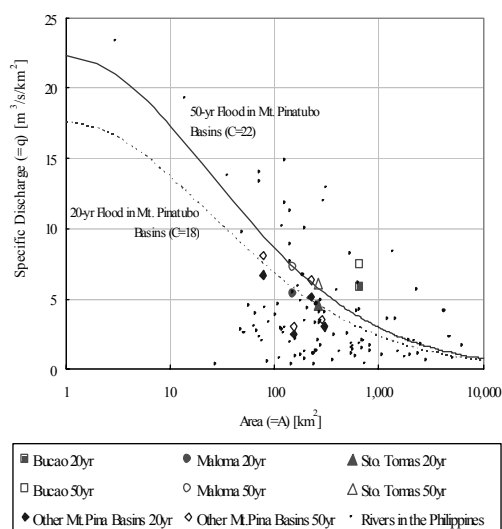
by the study team reveal that the peak discharge during floods is not due to long term monsoon rainfall but the peak one day rainfall associated with typhoons.

Probable peak discharges at the bridges in the downstream of the three rivers are shown in Table 4.1.

**Table 4.1 Probable Peak Discharge at Downstream End of the Three Rivers**

Bridges	Catchment Area km <sup>2</sup>	(Unit: m <sup>3</sup> /s)							
		Return Period (Year)							
		2	5	10	20	30	50	100	
Bucaao Bridge (Bucaao River)	655	1,600	2,500	3,100	3,800	4,300	4,900	5,800	
Maloma Bridge (Maloma River)	152	310	490	640	810	920	1,100	1,300	
Maculcol Bridge (Sto. Tomas River)	262	440	710	940	1,200	1,400	1,600	2,000	

Comparisons of the specific discharges for 20- and 50-year probable flood in the eight river basins of Mount Pinatubo are shown in Table 4.2 and Figure 4.3. The Creager's C-value for the Bucaao River is outstandingly high because the basin mean rainfall in the Bucaao River is much larger than the other basins. Although the mean rainfall of the Sto. Tomas River basin is also predominant, the specific discharge for the Sto. Tomas River is small because the retarding effect of the Mapanuepe Lake is considered in the model resulting in a similar Creager's C-value to those in the eastern river basins of Mount Pinatubo. The Maloma River basin has a similar Creager's C-value to the eastern basins because the upstream end of the river has an elevation of 400 m and receives little effect of the heavy rainfall on the slope of the Pinatubo Mountains.



**Figure 4.3 Specific Discharges in Pinatubo Basins**

**Table 4.2 Comparison of Specific Discharge and Creager's C-Value in Eight River Basins around Mount Pinatubo**

Basin	Area (km <sup>2</sup> )	Specific Discharge		Creager's C-Value	
		20-yr	50-yr	20-yr	50-yr
Sacobia-Bamban	225	5.2	6.3	19	23
Abacan	77	6.7	8.0	16	19
Porac-Gumain	302	3.0	-	12	-
Pasig-Potrero	154	2.5	3.0	8	9
O'Donnell	283	-	3.5	-	14
<b>Bucaao</b>	<b>655</b>	<b>5.8</b>	<b>7.5</b>	<b>35</b>	<b>45</b>
<b>Maloma</b>	<b>152</b>	<b>5.3</b>	<b>7.2</b>	<b>16</b>	<b>22</b>
<b>Sto. Tomas</b>	<b>262</b>	<b>4.6</b>	<b>6.1</b>	<b>18</b>	<b>24</b>
Average (around Mt. Pinatubo)	264	4.7	6.0	18	22

Source: The Study on Flood and Mudflow Control for Sacobia-Bamban/Abacan River Draining from Mt. Pinatubo, 1996  
Monitoring and Planning of Flood Control Works on the Pasac Delta (including Porac-Gumain River) and Third River Channel, 2002  
Pinatubo Hazard Urgent Mitigation Project Part III monitoring and Planning on Lahar/Mudflow Control Works in Pasig-Potrero River Basin, 1998  
The Detailed Engineering Design of the Urgent Rehabilitation and Improvement Works for Agno River Flood Control Project, 1994

## Sediment Yield Analysis

Sediment yield in the basins of Mount Pinatubo was estimated by PHIVOLCS from immediately after the eruption to 1997 by measuring the volume of sediment deposition in the river channel of the middle and downstream reaches. In this study, future sediment yield was estimated based on the assumed sediment yield in 2001 and 2002 as follows.

**Sediment Yield in 2001 :** The catchment area of the three rivers was initially classified into three categories, (1) normal slope, (2) moderately unstable slope, and (3) unstable slope, based on slope

stability and recovery of slope vegetation using aerial photographs taken in May 2002. The sediment yield from the normal slopes was calculated based on an average denudation depth of 6 mm/year, which was derived from the Japanese Technical Standard for pyroclastic flow deposit areas. For the estimation of sediment yield from the moderately unstable slope and unstable slopes, the actual collapse area ratio was measured from the aerial photographs and denudation depth was obtained from site investigation. The average collapse depth was assumed as 246 mm/year on moderately unstable slopes and 2,000 mm/year on unstable slopes (mainly river bank slopes). As a consequence, the estimated sediment yields of the three rivers in 2001 are as follows.

**Table 4.3 Estimated Sediment Yield in 2001**

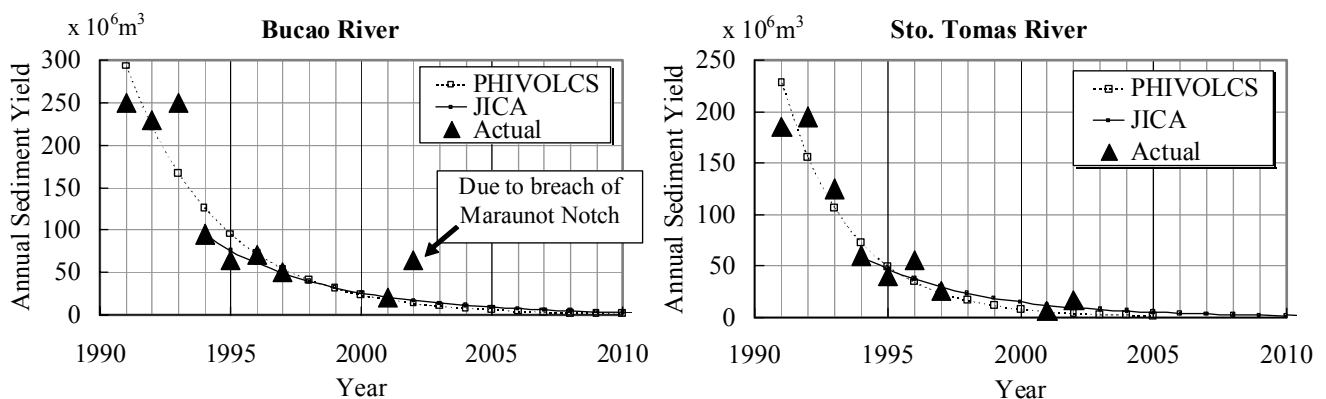
River Basin	Catchment Area (km <sup>2</sup> )	Slope Classification (km <sup>2</sup> )			Sediment Yield (million m <sup>3</sup> /year)				Average Depth of Collapse (mm/year)
		Normal	Moderately Unstable	Unstable	Normal	Moderately Unstable	Unstable	Total	
Bucaio	655	599	53.9	1.8	3.6	13.3	3.6	20.5	31.3
Maloma	152	151	1.2	0	0.9	0.3	0	1.2	7.9
Sto. Tomas	262	251	11.1	0.7	1.5	2.7	1.4	5.6	21.4

**Sediment Yield in 2002 :** To estimate sediment yield in 2002, it was assumed that the sediment yield was the same as the volume of sediment deposition in the river channel estimated by comparison of river cross sections in the sediment deposition area before and after the flood in July 2002. Sediment yield was not estimated for the Maloma River because the basin sediment transport has stabilized and the methodology above was not able to be applied. The methodology to estimate sediment yield with comparison of cross sections was the same as that used by PHIVOLCS until 1997. It was assumed that the scale of floods in July 2002 was the same as the 5-year probable flood in the Bucaio River and the 10-year probable flood in the Sto. Tomas River, resulting in larger sediment yields in 2002 than in 2001. Moreover, a breach of the Maraunot Notch in July 2002 released water from the Crater Lake causing flood and lahar in the Bucaio River; this contributed to increased sediment yield.

**Table 4.4 Estimated Sediment Yield in 2002**

River Basin	Catchment Area (km <sup>2</sup> )	Sediment Yield (million m <sup>3</sup> )	Average Depth of Collapse (mm/year)
Bucaio	655	65.3	99.7
Sto. Tomas	262	15.8	60.3

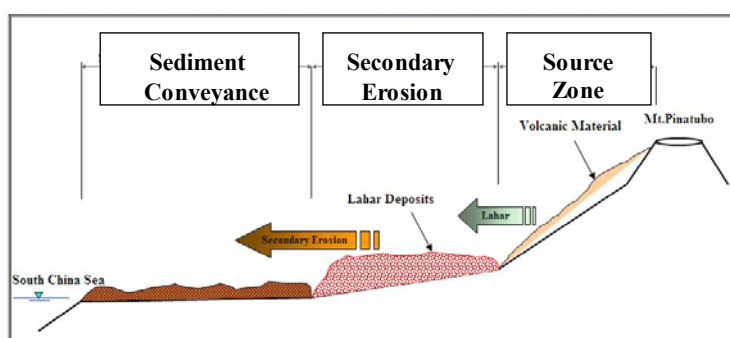
**Estimation of Future Sediment Yield :** Future sediment yield was estimated from regression relationships of annual sediment yield determined by PHIVOLCS until 1997 and by the study team for 2001 and 2002. Sediment yield would continue to decrease in future because most of the remaining unstable pyroclastic flow deposits in the basins have already been transported to the middle and downstream reaches and vegetation has recovered gradually in the upstream. In 20 years or so, it should be possible to control sediment yield by sabo technique and planting trees.



**Figure 4.4 Estimated Future Sediment Yield in the Bucaio and Sto. Tomas River Basins**

## Riverbed Movement Analysis

Although sediment source zone in the upstream is going to be stabilized, approximately 700 million m<sup>3</sup> and 300 million m<sup>3</sup> of sediment are deposited in the steep upstream area of the Bucao and Sto. Tomas Rivers, respectively. It was anticipated that deposited sediment would be easily eroded and transported to the downstream by normal stream flow because the grain size is very small at approximately 0.7 mm. To understand the mechanism of re-mobilization of deposited sediment in the river channel, one-dimensional sediment balance analysis was conducted with Brown's sediment transport formula using such parameters as annual runoff, riverbed slope, and grain size distribution of riverbed materials. The sediment balance analysis clarified that there is a tendency of erosion and remobilization of deposited sediment in the upstream zone. On the other hand, sediment will continue to be deposited in the downstream reach in both the Bucao and Sto. Tomas Rivers as shown in Figure 4.5.



**Figure 4.5 Mechanism of Sediment Transport Clarified by Sediment Balance Analysis**

The most important issue in the master plan for the study area is to control/manage riverbed aggradation in the middle and downstream reaches and to protect the areas prone to mudflow. Riverbed movement analysis aims at examining alternatives for how to prevent the riverbed from continuing to rise and how to accelerate riverbed degradation.

In this study, two-dimensional mudflow analysis was conducted to examine the characteristics of sediment transport during flood/mudflow and one-dimensional riverbed movement analysis was carried out to analyze the long term sediment transport in the river channel. Table 4.5 shows the summary of each analysis.

**Table 4.5 Summary of Mudflow and Riverbed Movement Analysis**

Analysis	Mudflow	Riverbed Movement
Event	Lahar (Mudflow)	Stream flow with flood
Duration	48 hours	20 years
Model	2-D mudflow <sup>(1)</sup>	1-D sediment transport <sup>(2)</sup>
Transport Formula	Brown	Yang (1973)
Sediment Concentration	Max. 40% (Lahar)	Max. 10% (20-year probable flood)
Calibration	Lahar in 2002	Balance for 1991-2002

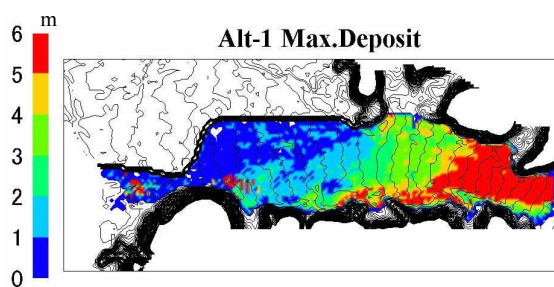
<sup>(1)</sup> Public Works Research Institute and the Sabo and Landslide Technical Center of Japan

<sup>(2)</sup> HEC-6 (Scour and Deposition in Rivers and Reservoirs), U.S. Army Corps of Engineers

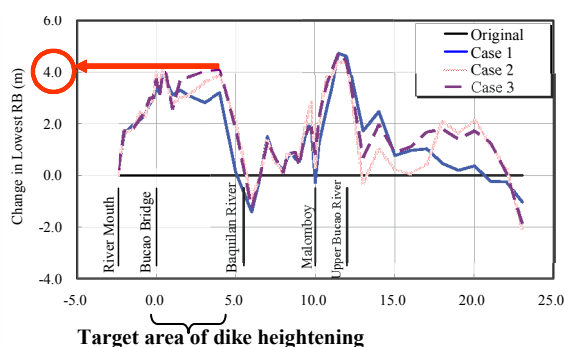
Figures 4.6 and 4.7 show the sediment transport simulation results. It was revealed that long term sediment transport would predominate over short term riverbed movement resulting in continuing riverbed rising in the downstream reach. It was estimated that riverbed would rise by approximately 4.0 m in the downstream and 5.0 m in the middle reaches of the Bucao River. In the Sto. Tomas River, the riverbed would rise by 1.5 m in the downstream and by 1.0 m in the middle reaches.

However, these results were obtained from limited data collected during the study term. It is desirable to monitor the riverbed movement continuously and review the results of analysis at the detailed design stage to improve the reliability of the simulation model; this could greatly affect the structural design and project cost.

Result of 2-D Mudflow Analysis in the Bucao River



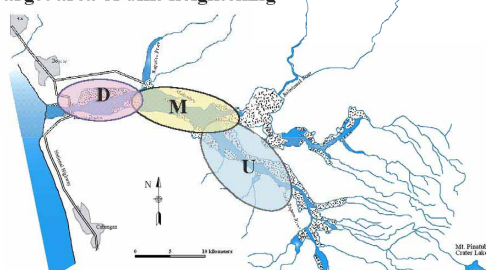
Result of 1-D Riverbed Movement Analysis in the Bucao River



Comparison of Results of Mudflow and Riverbed Movement Analysis in the Bucao River

Model	①Down River Mouth -	②Middle Baquilan -	③Up Malombo – Balin-Baquero
2-D Mudflow	↑ max.+2.0 m	↑ max.+6.0 m	NA
1-D Riverbed Movement	↑ max.+4.2 m	↑ max.+4.8 m	↑ max.+2.4 m

Target area of dike heightening

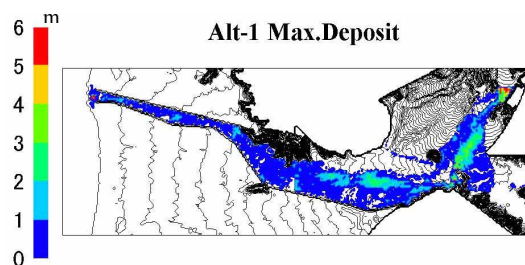


Note: Analysis was conducted based on three hydrological cases as follows:

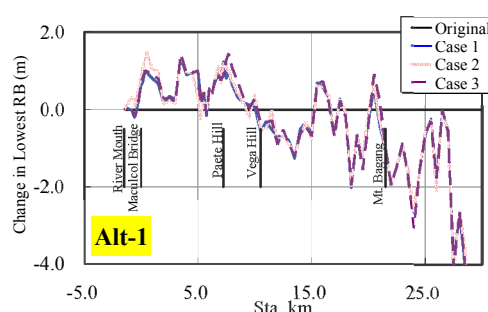
- Case 1: No flood occurs in 20 years
- Case 2: 20-year probable flood occurs in 5<sup>th</sup> year
- Case 3: 20-year probable flood occurs in 15<sup>th</sup> year

Figure 4.6 Results of 2-D Mudflow and 1-D Riverbed Movement Analysis in the Bucao River

Result of 2-D Mudflow Analysis in the Sto. Tomas River



Result of 1-D Riverbed Movement Analysis in the Sto. Tomas River



Comparison of Results of Mudflow and Riverbed Movement Analysis in the Sto. Tomas River

Model	①Down River Mouth -	②Middle Vega Hill -	③Up Mt. Bagang – Marella
2-D Mudflow	↑ max.+1.0 m	↑ max.+2.0 m	↑ max. +4.0 m
1-D Riverbed Movement	↑ max.+1.5 m	↑↓ max.+1.0 m	↓ min. - 3.0 m

Target area of dike heightening

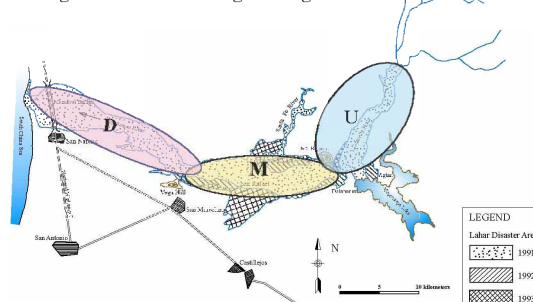


Figure 4.7 Results of 2-D Mudflow and 1-D Riverbed Movement Analysis in the Sto. Tomas River