APPENDIX-IV

Sediment Balance

THE STUDY ON SABO AND FLOOD CONTROL
FOR WESTERN RIVER BASINS OF MOUNT PINATUBO
IN THE REPUBLIC OF THE PHILIPPINES

FINAL REPORT

SUPPORTING REPORT

APPENDIX IV SEDIMENT BALANCE

Table of Contents

Page

List of Tables

List of Figures

CHAPTER 1 SEDIMENT YIELD

1.1 Mechanism of Sediment Balance

In view of sediment balance, the river basin area can be mainly divided into three areas, 1) sediment source zone, 2) sediment deposition / secondary erosion zone, and 3) sediment conveyance zone.

The above classification was made based on the existing condition of sediment deposition and river gradient in the study area, which are the main factors to determine the mechanism of sediment balance in the rivers.

The characteristics of the three different zones in the study area are given as follows:

(1) Sediment Source Zone

The basin from Mount Pinatubo down to the lower limit of pyroclastic deposit area on the mountain slope is defined as sediment source zone.

From immediate after the eruption of 1991 to 1995, secondary explosions frequently occurred in the sediment source zone, and the pyroclastic material flew down as hot lahar and deposited in the downstream stretch. Since 1995, the unstable pyroclastic deposit in the sediment source zone has been eroded by rainfall or largely collapsed due to scouring by flooding. The eroded or collapsed pyroclastic material is the source of sedimentation to the downstream.

(2) Sediment Deposition / Secondary Erosion Zone

The river stretch including river terrace from the downstream end of pyroclastic deposition area down to the sediment deposition area is defined as the sediment deposition/secondary erosion zone. Most of the sedimentation currently deposits within this zone. The sediment was widely spread in this area and secondary erosion has been frequently observed by the flooding. Although the sediment deposit level rose year by year, it is also observed that the secondary erosion of the sediment deposition started a few years ago mainly at the upper part of the sediment deposition / secondary erosion zone.

(3) Sediment Conveyance Zone

The river stretch including river terrace from the downstream end of the sediment deposition / secondary erosion zone down up to the river mouth is defined as the sediment conveyance zone. In this stretch, the sediment delivered from the upstream is deposited and partially transported down to the mouth by river flow. The sediment transportation capacity in this area is subject to the volume, depth and gradient of the river flow and properties of riverbed materials. This zone still tends to deposit sediment rather than transport it to the mouth as the volume of sediment delivery is beyond the capacity of sediment conveyance there.

Figure 1.1.1 and Figure 1.1.2 show the three zones in the Bucao and Sto.Tomas Rivers, respectively. They are classifies as follows based on the results of field investigation.

Classification by Sediment Characteristics in River Stretch

Classification	Bucao River		Sto.Tomas River	
	Upstream End	Downstream End	Upstream End	Downstream End
Sediment Source Zone	Summit of the Mount Pinatubo	End of pyroclastic deposit area	Summit of the Mount Pinatubo	End of pyroclastic deposit area
Sediment Deposition / Secondary Erosion Zone	End of pyroclastic deposit area	Malomboy	End of pyroclastic deposit area	Vega Hill
Sediment Conveyance Zone	Malomboy	River Mouth	Vega Hill	River Mouth

For the Maloma River, there is no significant area of sediment deposition. The pyroclastic flow after the eruption of Mount Pinatubo did not reach the Maloma River. The main source of sediment in the Maloma River consisted of direct fall of the pyroclastic material deposited on the mountain slope of the Maloma River basin. Almost all the pyroclastic fall material flew down to the downstream within one year after the eruption. The current main sediment source is therefore the old pyroclastic material deposited during the pre-eruption period on the mountain slope. The volume of erosion is not considerable as the source of sedimentation.

1.2 Sediment Yield

In this section, future sediment yield from the sediment source zone was estimated for plan formulation of the sabo control structural measures in the master plan.

1.2.1 Sediment Source

Over 11 years from Mount Pinatubo eruption, the vegetation has started to encroach on some of the pyroclastic-flow deposits with the tolerance to erosion. However, some other areas still remain unstable where serious gully erosion and cliff collapses occur. From these areas, a large amount of sediment is released into the river as a sediment source.

Future sediment yield in the basin was estimated in the following manners:

1) Actual sediment yield in 2001 was estimated through aero-photo reading,
2) Actual sediment yield in 2002 was estimated through river cross sectional survey conducted before and after the flood of July 2002, and
3) Future sediment yield in the basin was calculated through regression analysis of the observation data from 1994 to 1997 by PHIVOLCS and 2001 and 2002 by the study team.

The results are described as follows:

1.2.2 Sediment Yield in 2001

In this study, the sediment yield from the mountain slopes during 2001 was estimated using aerial photographs taken in May 2002.

The chatchment area of the three rivers was initially classified into three categories based on the condition of stability of the slope and the recovery condition of the slope vegetation. The followings are the initial classification:

i) Normal slopes: where no gully erosion is developed, and the herbaceous plants are observed on the slope,
ii) Moderately unstable slopes: where unstable gully erosions are developed but some herbaceous plants are also observed on the slope, and
iii) Unstable slope: where unstable gully erosions are developed, and no herbaceous plants are observed on the slope.

The area classification is shown in Figure 1.2.1 and summarized as follows:

Initial Area Classification of Mountain Slope by Reading of Aerial-Photo 2002

Slope Classification	Bucao		Maloma		Sto.Tomas		TOTAL	
	km^2	Ratio	km^2	Ratio	km^2	Ratio	km^2	Ratio
Normal Slope	599	91.5%	151	99.5%	250	95.5%	1,000	93.5%
Moderately Unstable Slope	46	7.0%	1	0.5%	8	3.0%	55	5.0%
Unstable slope	10	1.5%	0	0.0%	4	1.5%	14	1.5%
TOTAL	655	100.0%	152	100.0%	262	100.0%	1,069	100.0%

(1) Sediment Yield from Normal Slope Area in 2001

As shown above, 93.5% of the three basins were classified as normal slopes, or stable slopes, where no gullies are developed and natural vegetation such as trees, shrubs and grasses are observed on the slope. The sediment yield in the normal slope was calculated based on the standard collapse area ratio, depth and denudation rate per flood on each kind of geology as shown in Table 1.2.1 through Table 1.2.3. Those parameters were derived from the Japanese Technical Standard to estimate sediment yield. As all sediment source area in the study area is classified into pyroclastic deposit area, the sediment yield in the normal slope area was calculated as follows:

Average collapse area ratio: 0.22%
Average collapse depth: 2 to 3 m
Average denudation depth: 0.006 m/km^2
$V1 = A1 \times 0.006$ m/km^2
where,
V1: Sediment yield volume in normal slope area,
A1: Area of normal slope

(2) Sediment Yield from Moderately Unstable and Unstable Area in 2001

The rest 6.5% of the basin was classified as moderately unstable or unstable area, from which the majority of sediment may be delivered. For the estimation of the sediment yield, actual collapse area ratio was measured from the aero photographs taken in May 2002.

In the process, however, the actual collapse area ratio was found to be much different between the areas along the unstable slope area and the river bank. The difference was rather remarkable than the one between moderately unstable and unstable areas. The areas were therefore re-classified into two, unstable slope area, and river bank erosion area through inspection of aero-photographs. The area re-classification and actual collapse area ratio were then described as follows:

Re-classification of Moderately Unstable and Unstable Slope Area

Re-classification	Re-classified Unstable Slope Area (km^2)				Average Collapse Area Ratio
	Bucao	Maloma	Sto.Tomas	Total	
Unstable Slope Area	53.9	1.2	11.1	66.2	3%
River Bank Erosion Area	1.8	0.0	0.7	2.5	25%
Total Unstable Area	55.7	1.2	11.8	68.7	

The average width and length of erosion in the collapsed area was determined to be 20 m from the horizontal aero-photo reading, which should be converted into the actual area taking into account the actual average slope angle of 60 degrees. The average depth of erosion in the collapsed area was measured at site as approximately 4 m.

Based on the above observation results, the sediment yield from unstable area and river bank erosion area are calculated as follows:

(a) Sediment Yield from Unstable Slope Area in 2001

V2 = V2u + V2s
where,
V2: sediment yield from unstable slope (m^3/yr)
V2u : sediment yield from collapsed area of unstable slope (m^3/yr)
V2s: sediment yield from un-collapsed area of unstable slope, (m^3/yr)

In the estimation of V2u, the horizontal collapsed area, which was assumed to be 3% of unstable area, should be converted to the actual area considering the actual average slope of 60 degrees as follows:

V2u = A2 x 0.03 / cos (60deg.) x H
where,
A2: collapse area in unstable slope
H: average actual depth of collapse (H = 4 m)

On the other hand, sediment yield from the un-collapsed area of unstable slope area (97% of unstable area) is calculated by the same procedures as those of the normal slope area:

V2s = A2 x 0.97 x 0.006

Finally, the sediment yield from the unstable slope area is calculated as follows:

V2 = V2u + V2s = A2 x 0.03 / cos (60deg.) x 4 + A2 x 0.97 x 0.006

(b) Sediment Yield from River Bank Erosion Area in 2001:

Sediment yield from the river bank erosion area can be estimated in the same manner as the unstable slope area. The collapsed area ratio is to be 25% instead of 3%:

V3 = A3 x 0.25 / cos (60deg.) x 4 + A3 x 0.75 x 0.006
where,
A3: River bank erosion area

(3) Total Sediment Yield

Total sediment yield (V) is as follows:

V = V1 + V2 + V3

The results of estimation of sediment yield in 2001 for the three river basins are shown in Table 1.2.4 and summarized as follows:

Estimated Sediment Yield in 2001

River Basin	Total Catchment Area	Normal Slope Area (A1)	Unstable Slope Area (A2)	River Bank Erosion Area (A3)	Sediment Yield from A1 (V1)	Sediment Yield from A2 (V2)	Sediment Yield from A3 (V3)	Total Sediment Yield (V)
	km^2	km^2	km^2	km^2	10^6 m^3/yr	10^6 m^3/yr	10^6 m^3/yr	10^6 m^3/yr
Bucao	655	599	53.9	1.8	3.6	13.3	3.6	20.5
Maloma	152	151	1.2	0.0	0.9	0.3	0.0	1.2
Sto.Tomas	262	251	11.1	0.7	1.5	2.7	1.4	5.6
TOTAL	1,069	1,001	66.2	2.5	6.0	16.3	5.0	27.3

Based on the aero-photo reading, which was taken in May 2002, the sediment yield in 2001 was estimated at 20.5 million m3 in the Bucao River basin and 5.6 million m3 in the Sto. Tomas River basin. These values are nearly same as the predicted values by PHIVOLCS in 1998, 18 million m3 and 5 million m3, respectively (Refer to Figure 1.2.2).

1.2.3 Sediment Delivery in 2002

(1) Sto. Tomas River Basin

a) Upstream Stretch (Marella River)

Sediment deposition volume in the Marella River due to the flood at the beginning of July 2002 was estimated based on the field investigation conducted before and after July 2002.

For the upstream stretch, no river cross sectional survey was conducted before and after the flood of July 2002. The sediment deposit volume was then presumed based on the visual observation at the check points. There are two check points, where the study team visited and marked the riverbed elevation before and after the event. The condition of sediment deposition is described in Figure 1.2.3 and summarized as follows:

(i) Check Point No.1 : Mt. Bagang

Around the Mt. Bagang, the river terrace was developed with sedimentation for the whole river area. The deposition depth caused by the flood in July 2002 was approximately 0.5 m, which was estimated by the height of tree on lahar deposition area compared before and after the flood (See Photo-1 and Photo-2 of Figure 1.2.3).

(ii) Check Point No.2: Right Bank Nose (6 km upstream from Mt. Bagang)

At the check point No.2, 6 km upstream from the Mt. Bagang, the river terrace was developed with sedimentation for the whole river area. In May 2002, the natural channel was formed by erosion of riverbed with the depth of 4 m from sediment terrace. In September 2002, the channel was completely buried.

The deposition depth of the entire sediment terrace was approximately 0.5 m, which was estimated by the field investigation conducted before and after the flood (See Photo-3 and Photo-4 of Figure 1.2.3).

Based on the above investigation results, the sediment deposit volume in the upstream part of the Sto. Tomas River (the Marella River) was estimated as follows:

Volume of Sediment Deposition in the Marella River during Flood in July 2002

Sub-section	Sediment on River Terrace			Sediment on River Channel			Total Sediment Deposition
	Riverbed Change	Sediment Area	Sediment Volume	Riverbed Change	Sediment Area	Sediment Volume	
	m	10^6 m^2	10^6 m^3	m	10^6 m^2	10^6 m^3	10^6 m^3
Check Point No.1~No.2 (downstream)	0.5	7.0	3.5	4.0	0.0	0.0	3.5
Check Point No.2~upstream (upstream)	0.5	3.5	1.8	4.0	0.6	2.4	4.2
Total			5.3			2.4	7.7

b) Downstream Stretch (Sto. Tomas River)

In order to estimate the sediment deposit volume at the lower stretch of the Sto. Tomas River (River Mouth ~ Mt. Bagang) by the July 2002 flood, the river cross sections before and after the flood were compared as shown in Figure 1.2.4. The sediment deposit volume in the Sto. Tomas River by the flood was estimated at approximately 8.1 million m^3 as described below:

Volume of Sediment Deposit in the Sto. Tomas River by July 2002 Flood

Line No.	Distance from River Mouth (m)	Average Riverbed Rise H: (m)	River Width B: (m)	Sediment Deposition Area A=H x B: (m^2)	Sediment Deposition Volume V: (m^3)	Remarks
Line-1	0	0.400	551	221		*Estimated from Line-08
Line-8	1,535	0.401	363	146	280,956	
Line-16	4,801	0.018	775	14	260,923	
Line-25	7,801	0.241	625	151	247,159	
Line-27	8,394	0.531	745	396	162,032	
Line-35	11,444	0.550	1,371	754	1,752,456	
Line-45	16,444	0.256	1,738	445	2,997,389	
Line-56	21,981	0.250	1,738	434	2,435,654	*Estimated from Line-56
TOTAL					8,136,569	

Note : Sediment Deposit volume from River mouth to Confluence of Marella River and Mapanuepe Lake

c) Sediment Delivery in the Sto. Tomas River in 2002

Accordingly, total sediment delivery in the Sto. Tomas River is as follows:

River Mouth – Mt. Bagang	: 8.1 million m^3
Marella River	: 7.7 million m^3
Total	: 15.8 million m^3

(2) Bucao River Basin

In order to estimate the sediment deposit volume by the July 2002 flood in the Bucao River, the field investigations and interviews for local people were undertaken. Figure 1.2.5 shows the presumed sediment deposition in the river course due to the flood. There are five check points to assess the sediment deposition along the Bucao River. The observation results are summarized as follows:

(i) Check Point No.1: Bucao Bridge

The river cross sectional survey was conducted at the Bucao Bridge for discharge measurement before and after the flood. Figure-2 in Figure 1.2.5 indicates that the average riverbed rose approximately 1 m after the flood. From the survey results above, the riverbed aggradation at the Bucao Bridge was estimated at 1 m.

(ii) Check Point No.2: Culvert Outlet at Barangay San Juan

The culvert outlet exists on the right dike of the Bucao River at approximately 3km upstream from the Bucao Bridge. The outlet structure was visible before the flood, but it was completely buried by the sediment deposition after the flood as compared in Photo-2 and Photo-3 in Figure 1.2.5.

(iii) Check Point No.3: Baquilan Bridge

Photos 3 and 4 compare the view of the Baquilan Bridge located approximately 6 km upstream from the Bucao Bridge. It was found that the river terrace elevation after the flood was higher than before with approximately 2 m at the point.

(iv) Check Point No.4: Barangay Malomboy

There is a sediment measurement gauge established by PHIVOLCS at barangay Malomboy, which is located approximately 9 km upstream from the Bucao Bridge. It was reported that the sediment deposition due to the flood was 4 m based on the gauge reading by PHIVOLCS.

(v) Check Point No.5: Bucao / Balin Baquero Confluence

The confluence of the Bucao and the Balin Baquero Rivers is located in approximately 13 km upstream from the Bucao Bridge, which was the upper most accessible area during the rainy season. The study team undertook the interviews for local people after the flood at the point. The local people reported that the visible height of coconuts tree on the sediment deposition area shown in Photo-5 of Figure 1.2.5 decreased by approximately 4 m, which was basis for the estimation of riverbed aggradation at Check Point No.5.

For the upstream of the confluence, the interviews for local people from the upstream barangays were also conducted at Check Point No.5. According to them, the riverbed aggradation due to the flood was also approximately 4 m. The sediment deposit volume in the Bucao River by the flood was then estimated at approximately 65 million m^3 as summarized below:

Sediment Deposit Volume in the Bucao River by July 2002 Flood

Area No.	Stretch	Sediment Area (mil.m^2)	Sediment deposit Depth (m)	Sediment deposit Volume (mil.m^3)
1	Mouth ~ Bucao Bridge (CP-1)	0.91	1.0	0.9
2	Bucao Bridge ~ Baquilan (CP-3)	4.65	2.0	9.3
3	Baquilan ~ Malomboy (CP-4)	2.41	4.0	9.6
4	Malomboy ~ Upstream	11.35	4.0	45.4
TOTAL				65.3

1.2.4 Future Sediment Yield

Future sediment yield was estimated by regression line between the past data. A regression line by PHIVOLCS used the sediment delivery until 1997. A regression line by the study team applied the same data from 1994 to 1997 and the data obtained in this study for 2001 and 2002. Data for 2002 for the Bucao River basin was excluded because the one of the major flooding was caused by the overflowing of water from the lake after the breaching of the Crater Lake at Maraunot Notch in July 2002. It was judged as an extreme event.

The annual measured and estimated sediment delivery by PHIVOLCS and this study are compared in Figure 1.2.2. The regression line by the study team shows slightly higher values than those by PHIVOLCS. However, the differences were assumed to be negligibly small.

CHAPTER 2 SEDIMENT TRANSPORT CAPACITY

2.1 Riverbed Material

Riverbed material sampling was conducted in 2002 by the study team to obtain data on sediment properties in the study area, which is inevitable for sediment hydraulic analysis. The location map for the sampling of the riverbed material in the three rives is shown in Figure 2.1.1. The total number of the samples was 24, eight locations multiplied by three points, right, center and left side in each river cross-section.

The test results of specific gravity and grain size are tabulated in Table 2.1.1 and Table 2.1.2. The average value for the specific gravity in the three rives is Gs = 2.58, which is slightly lower than the default value of 2.65 in Japan. The average grain sizes for the sampling locations are illustrated in Figure 2.1.2. The lower reaches of the river have smaller grain size (D = 0.35 mm), while upper reaches have larger grain size (D = 0.7 mm). The average value for the representative grain size (60% passable) is D60 = 0.54 mm, which is classified as coarse sand, which is defined as D = 0.5 to 1.0 mm. The grain size in this study area is smaller compared to that in the eastern area, as shown in Figure 2.1.3.

2.2 Sediment Balance Analysis

The flow chart of calculation of sediment discharge is illustrated in Figure 2.2.1. The annual daily flow duration curve was approximated as a step graph as shown in Figure 2.2.2. Annual sediment transport volume was calculated by multiplying the sediment discharge and the duration time, and summing up the products over 365 days.

2.2.1 Sediment Balance Model and Conditions

(1) Sediment Transport Formula

Brown's formula was adopted for calculation of the sediment discharge in accordance with the previous JICA study for the eastern basins of Mount Pinatubo. This formula is simple and has the advantage that it is possible to estimate the total sediment load including bed load and suspended load.

Sediment discharge (Qb) is calculated with the tractive force (U_*^2), specific gravity of a grain (S), grain size (D) and flow width (B) in the Brown's formula.

$$Qb = 10 * (U*2 / (g*(S-1)*D))^{2.5} * (g*(S-1)*D)^{0.5} * D * B$$

Tractive force (U_*^2) was calculated with the flow depth (H) and bed slope (I). The critical tractive force (U_{*c}^2) was calculated from the grain size (D), using Iwagaki's Formula.

$U*^2 = g * H * I$ (g = gravity acceleration = 9.8 m/s^2)

$U*c^2 = 8.41 * D^{11/32}$ (for 0.0065 cm < D < 0.0565 cm)

$U*c^2 = 55.0 * D$ (for 0.0565 cm < D < 0.118 cm)

If the tractive force of the flow is larger than the critical tractive force of a sediment grain, the grain is moved.

A regime formula was applied to estimate the flow width (B) with the flow discharge (Q). Flow depth (H) was calculated with the roughness coefficient (n), flow discharge (Q), flow width (B) and bed slope (I), using Manning's Formula assuming uniform flow.

$$B = 7 * Q^{0.5}$$

$H = (n*Q / B / I^{0.5})^{0.6}$

Sediment discharge (Qb) is subject to flow discharge (Q), bed slope (I) and grain size (D) according to the Brown's Formula. Based on the calculation formulae mentioned above, the following relationship were found.

Qb is proportional to $Q^{1.25}$
Qb is proportional to $I^{1.75}$
Qb is inversely proportional to D

(2) Reference Point

Sediment discharge in the three river basins was calculated at the upstream and downstream ends of river reaches, where the sediment inflow from tributaries assumed to be negligible. Five points in the Bucao River, three in the Maloma River and four in the Sto.Tomas River were selected as reference points. They correspond to the downstream ends of boundaries of sub-basins in the river basins shown in Figure 2.2.3.

(3) Flow Diagram

The sediment discharge at a reference point was calculated from the daily flow duration curve mentioned with the catchment area ratio. Applied flow duration curve was developed based on the data before the eruption of Mount Pinatubo.

However, flow discharge after the eruption of Mount Pinatubo was assumed to be lower than that in 1980s due to the seepage into the sediment depositions especially in the Bucao and Sto.Tomas Rivers. Therefore, the daily flow was adjusted to fit the actual sediment balance as of year 2001 for the calibration of the sediment balance model.

In addition, it was observed that there was no surface water in the downstream reaches of the Sto. Tomas River during the dry season in 2002 and 2003. Accordingly, the discharge on the flow duration curve within 120 days, which is equal to the number of annual rainy days at San Marcelino from 1991 to 2000 was considered in the Sto. Tomas River.

2.2.2 Calibration of Sediment Balance in the Sto. Tomas River

The sediment discharge calculation formula can be applied to diluted stream flow, but are not applicable to mudflow or hyper-concentrated flow. In the actual mudflow, the sediment concentration is assumed at 70 to 80%, and the flow volume increased three to five times as much as clean water volume. However, after the sediment deposition has occurred along the river course, the mudflow was diluted by the time it reaches the river mouth. With the following procedure, a sediment balance simulation including mudflow can be attempted with an interval of a year.

As for the inflowing sediment concentration at the most upstream end (Upper Marella, A=54 km^2), the values of sediment delivery measured by PHIVOLCS from 1991 to 1997, and the estimated values by the study team from 1998 to 2001 (S4) instead of the values by Brown's Formula (Q4).

S4 is considerably larger than Q4 for several years after the eruption. The amplification coefficient (C) was set for the calculation of the sediment discharge at the downstream portion as follows:

$$C = (S4/Q4) - 1$$

Sediment discharge calculated from Brown's Formula (Q3 and Q2) at Mt.Bagang (A=91 km^2) and Vega Hill (A=253 km^2) are modified using amplification coefficient (C) and catchment area ratios. Modified sediment discharges at Mt.Bagang (S3) and Vega Hill (S2) were calculated as follows:

$$S3 = Q3 * (1 + C*54/91)$$

$$S2 = Q2 * (1 + C*54/253)$$

Sediment discharge calculated from Brown's formula (Q1) at the Maculcol Bridge (A=262 km^2) near the river mouth was not amplified considering the dilution of mudflow (S1=Q1).

The change of sediment deposit volume in a river section was calculated as the balance between inflow and outflow of sediment.

(Marella River)	Deposit V3=S4-S3
(Mt.Bagang to Vega Hill)	Deposit V2=S3-S2
(Vega Hill to Maculcol Bridge)	Deposit V1=S2-S1

The accumulated V1, V2 and V3 as of 2001 were checked with the actual deposit volume in the river channel in 2001 obtained by GIS. The values of Q1 through Q4 were then adjusted to fit the calculated V values to the actual V value for several times.

Table 2.2.1 summarizes the calibration results of sediment transport from 1991 to 2001 in the Sto. Tomas River. Gradient of riverbed slope in 1977 obtained from the topographic map made by NAMRIA was used in the calibration. In sediment transport volume, 40% of porosity was taken into account.

The total sediment deposition with the sediment balance model was almost same value as the actual volume with only 2% of the difference. It was concluded that the simulated results indicate the actual tendency of sediment deposition, although some discrepancies between the simulated and actual values of V were found particularly on the lower reach of the Sto. Tomas River from Vega Hill to the Maculcol Bridge

2.2.3 Calibration of Sediment Balance in the Bucao River

The Bucao River joins the Balin Baquero River and the Upper Bucao River at Malomboy with many tributaries containing sediment from pyroclastic flow deposit areas. This condition makes the sediment balance in the Bucao River more complicated.

The sediment balance simulation for the Bucao River is attempted in a similar way as the Sto.Tomas River. The sediment delivery volume after the eruption from the mountain area was allocated to the Upper Bucao River by 30% and the Balin Baquero River by 70% based on the ratio of catchment area.

In the calibration, it was found that the Upper Bucao reach would not contribute to sedimentation in the lower reaches from 1991 to 2001. The actual sediment deposition as of 2001 was measures as 324 million m^3 in the Upper Bucao River. However, the sediment transportation capacity in the stretch was estimated as much bigger than the sediment inflow and no sediment deposition was accumulated under the condition with the riverbed slope in 1977. Therefore, the sediment transport from the Upper Bucao River was set at zero over the past 11 years. It was considered that the phenomenon was caused by the dammed up action at the end of the Upper Bucao River due to the sediment deposition by the Balin Baquero stretch.

Table 2.2.2 summarizes the calibration results of sediment transport from 1991 to 2001 in the Bucao River. Gradient of riverbed slope in 1977 obtained from the topographic map made by NAMRIA was used in the calibration. In sediment transport volume, 40% of porosity was taken into account.

The estimated value of sediment deposition was almost same as the actual sediment deposition in all the stretch with the difference volume less than 5%. Estimated total sediment deposit volume was also same as the actual sediment deposition volume as of 2001. Accordingly, it was concluded that the sediment balance model was applicable for estimation of annual sediment transport capacity in the Bucao River.

2.3 Annual Sediment Transport

2.3.1 Annual Sediment Transport Capacity in 2002

To estimate annual sediment transport capacity in 2002, gradient of riverbed slope in 2002 obtained from the cross section survey conducted during the study. Porosity of 40% was considered in the estimation of sediment transport. The other parameters were same as those in the calibration. The details of the calculations of annual sediment transport in the three river basins as of 2002 are given in Table 2.3.1 to Table 2.3.12. The conditions and results of the estimation are summarized in the following table.

Annual Sediment Transport Capacity in the Study Area

River and Site	Catchment Area A (km^2)	Grain Size D (mm)	For Calibration (as of 1991)		For Estimation (as of 2002)	
			Bed Slope I	Sediment Qb (10^6m^3/yr)	Bed Slope I	Sediment Qb (10^6m^3/yr)
Bucao River						
Bucao Bridge	655	0.35	1/300	24.0	1/250	33.0
Middle Bucao	309	0.40	1/150	21.5	1/120	31.8
Upper Bucao	97	0.70	1/60	22.1	1/80	13.3
Lower Baquero	216	0.40	1/150	13.9	1/100	28.4
Upper Baquero	151	0.70	1/80	23.5	1/90	19.1
Maloma River						
Maloma Bridge	152	0.60	1/720	0.92	1/700	0.97
Middle Maloma	99	0.60	1/500	1.01	1/500	1.01
Gorongoro River	42	0.60	1/550	0.30	1/550	0.30
Sto.Tomas River						
Maculcol Bridge	262	0.35	1/580	1.3	1/300	3.5
Vega Hill	253	0.70	1/130	6.9	1/150	5.4
Mt. Bagang	91	0.70	1/60	21.1	1/70	16.1
Upper Marella	54	0.80	1/40	25.2	1/40	25.2

2.3.2 Change in Volume of Sediment Deposit

The change in sediment deposit volume in each reach of the three rivers was calculated as the balance between the inflow and outflow of sediment. Results are illustrated in Figure 2.3.1 to Figure 2.3.3. The average change of the deposits in the Maloma and Sto. Tomas Rivers has a tendency to increase by 0.10 to 0.50 m/year. In addition, the depth of sediment deposition in the lower reach of the Bucao River would increase by more than 1.0 m/year based on the estimated annual sediment transport capacity. The result also shows that the depth of the deposition in the upstream of the Bucao River would annually decrease.

However, the model used in the sediment balance analysis has some limitation. For example, it does not include the dynamic change of riverbed slope between different time steps when calculating river flow and sediment transport or the influence of the river width change along the longitudinal profile. Therefore, detailed one-dimensional and two-dimensional sediment transport analyses were conducted to predict future riverbed movement. The results are described in the following chapter.

CHAPTER 3 RIVERBED MOVEMENT ANALYSIS

3.1 General

Riverbed movement in future was analyzed to reflect results of the prediction in the design of proposed structural measures for the Bucao and Sto. Tomas Rivers. For example, predicted riverbed movement was taken into account in computation of design high water level which is inevitable for the design of river structures.

Riverbed movement was simulated for two different events. Short term riverbed movement analysis was conducted with two-dimensional mudflow model for a lahar event with duration of two days or 48 hours. In addition, long term riverbed movement was simulated with one-dimensional sediment transport model for long term runoff with duration of 20 years.

Design riverbed elevation should be determined as stable slope to formulate master plan for sabo and flood control. However, riverbeds in the study area tend to fluctuate due to movement of huge amount of sediment deposition with floods and it seemed to be impossible to determine permanently stable riverbed slope. However, it was assumed that the riverbed slope after 20 years would be the most naturally stable within the target period of the master plan.

3.2 Short Term Riverbed Movement Analysis

3.2.1 Two-Dimensional Mudflow Model

In order to assess the short term riverbed movement with the existing and proposed structures in the Bucao and Sto. Tomas Rivers, a hyper-concentrated flow during a single lahar event was analyzed using a two-dimensional flow and a sediment transport model.

The simulation was conducted based on the hydrographs of probable floods obtained in the appendix III, Meteorology and Hydrology. The numerical simulation applied the two-dimensional mudflow model, which was developed by the Public Works Research Institute and the Sabo and Landslide Technical Center of Japan and improved by Nippon Koei Co., Ltd.

The whole study area is divided into meshes with a proper size. The finite difference forms of the above flow and sediment transport equations were derived from the staggered mesh system and are solved explicitly using the Leap-Frog scheme. The calculation procedure is shown in Figure 3.2.1. All parameters used in the two-dimensional model are summarized in Table 3.2.1.

(1) Methodology

In the two-dimensional mudflow model, water depth for the average flow was calculated applying the two-dimensional shallow water flow equation, while the riverbed fluctuation was calculated using the continuity equation for bed load transport.

(a) Momentum and Continuity Equations for Water Flow

The two-dimensional momentum equations for water flow, can be described as follows:

In the x-direction:

$$\frac{\partial q_x}{\partial t} + \beta_x \frac{\partial u q_x}{\partial x} + \beta_y \frac{\partial v q_x}{\partial y} = -gh\frac{\partial H}{\partial x} - \frac{\tau_x}{\rho}$$

In the y-direction:

$$\frac{\partial q_y}{\partial t} + \beta_x \frac{\partial u q_y}{\partial x} + \beta_y \frac{\partial v q_y}{\partial y} = -gh\frac{\partial H}{\partial y} - \frac{\tau_y}{\rho}$$

where,

qx , qy:	x and y components of discharge per unit width
βx, βy:	x, y components of momentum adjustment factor (=1.0)
u, v :	x and y components of the depth-averaged flow velocities
h:	water depth
H:	water level (= riverbed elevation + water depth)
τx ,τy:	x, y components of shear stress
ρ:	density of water

Assuming that the bed shear stresses (τ_x and τ_y) are described with the local depth-averaged flow velocities, the bed shear stresses in the momentum equation can be written using Manning's mean velocity equations as follows:

$$\frac{\tau_x}{\rho} = \frac{gn^2 u\sqrt{u^2 + v^2}}{h^{1/3}} \qquad \frac{\tau_y}{\rho} = \frac{gn^2 v\sqrt{u^2 + v^2}}{h^{1/3}}$$

where,

g :	gravitational acceleration (=9.8 m/s2)
n :	Manning's roughness coefficient.

A continuity equation for flow can be described as:

$$\frac{\partial h}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = 0$$

where,

t :	time

(b) Sediment Transport Equation

The continuity equation for sediment transport can be described as:

$$c_* \frac{\partial z_b}{\partial t} + \frac{\partial q_{Bx}}{\partial x} + \frac{\partial q_{By}}{\partial y} = 0$$

where,

c* :	sediment concentration of bed load
qBx, qBy:	x and y components of bed load transport rate per unit width
zb:	change in riverbed elevation

$$q_B = \Phi_B \sqrt{sgd^3}$$

where,

ΦB:	dimensionless sediment discharge

qB: sediment discharge per unit width
s: specific gravity of sediment in water (=σ/ρ-1, σ/ρ=specific gravity of sediment = 2.60)

Because the flow contains a large volume of suspended sediment, Brown's formula was adopted to calculate the dimensionless sediment discharge, Φ_B.

$$\Phi_B = 10 * \tau^{*2.5}$$

where,
τ*: dimensionless bottom shear stress (=u* /sgd, u*=friction velocity)

The transport rate of the suspended sediment (q_{ss}) was estimated using the same formula.

(2) Topographic Data

Topographic data was produced from a DTM (Digital Topographic Map of 1:10,000 scale) in 2002 using a GIS (Geographical Information System). The model domain was divided into a 40 m square grid of data segments. Basically, the elevation at the center point of the mesh was selected as the representative value. Where the river channel or a dike was located in the grid segment, the elevation of those features were selected as the representative.

(3) Stream Flow Generation

A single 3-day hydrograph from the scale of 2-year to 100-year probable flood determined in the chapter of meteorology and hydrology was input as stream flow in the model.

(4) Sediment Inflow

A sediment volume of 16 million m^3 (defined as bed sediment and suspended sediment) was defined as the inflow sediment volume for a 20-year probable event, considering a bed-deposition concentration (C_b) of 0.6.

Figure 3.2.2 shows the input of hydrograph and sediment discharge in the model of the Bucao and Sto. Tomas Rivers to simulate riverbed change by a mudflow event. Total flood volume and peak discharge and sediment volume are described as follows:

Volume and Peak Discharge of 20-Year Probable Flood and Sediment Volume for Simulation

Rivers		Flood		Sediment
		Total Volume	Peak Discharge	Total Volume
		(million m^3)	(m^3/sec)	(million m^3)
Bucao	Bucao	245	2,930	60
	Baquilan	76	920	4
Sto.Tomas	Marella	45	680	12
	Mapanuepe 1 (without Storage Effect)	43	1,020	0
	Mapanuepe 2 (with Storage Effect)	27	220	0

(5) Sediment Hydraulic Parameters

The sediment hydraulic parameters for the simulation are summarized as follows:

Density of water: ρ = 1.0 (normal flood) and 1.4 (in lahar event) g/cm^3
Specific gravity of sediment: σ_s = 2.60 g/cm^3
Mean grain sizes of sediment:d_{60} = 0.30 mm (for the Bucao River)

d_{60} = 0.50 mm (for the Sto. Tomas River)
Manning's roughness coefficient: n = 0.03 (average value for natural rivers)
Max erosion depth: max_e = 5.0 m

The specific gravity (σ_s) and the grain size distribution curve were obtained from the laboratory test results of the sediment sampling for the Bucao and Sto. Tomas Rivers performed in 2002 by the study team. The mean grain size of the sediment (d_{60}) was used assuming uniform sediment. The density of water (ρ) is estimated at 1.0 g/cm^3 for usual flood flow and more than 1.0 g/cm^3 up to 1.4 g/cm^3 for the hyper-concentrated flow.

3.2.2 Calibration of Two-Dimensional Mudflow Model

To calibrate model parameters, the actual flood in July 2002 was applied to the Bucao River model. A couple of flood discharge peaks were observed in July 2002. One was due to the heavy rain on July 08 and the other was due to the collapse of the Maraunot Notch on July 10. The water volume for the latter was estimated at 46 million m^3 with the volume of the re-mobilized sediment of 44 million m^3. The depth of sediment deposition was observed to be 1-2 m along the existing dike and 5-6 m at Malomboy.

Figure 3.2.3 shows calibration results for the two dimensional mudflow model. The results show that the river channel with relatively lower riverbed elevation was buried with sediment during the former flood and the remobilized lahar deposit was spread over the whole width of river channel from the Baquilan River to Malomboy during the latter flood.

In addition, Figure 3.2.4 shows the longitudinal profile of changes in riverbed elevation before and after the flood in July 2002. It is indicated that the trend of simulated sediment deposition is similar to the observed value though the simulated values are slightly less.

3.2.3 Short Term Riverbed Movement in the Bucao River

The Bucao River model for short term riverbed movement analysis consists of two rivers, the Bucao River as a main river and the Baquilan River as a tributary. The downstream end was set at the river mouth and the upstream end near Malomboy.

The simulation for the Bucao River was conducted based on the three structural alternatives shown in the following table.

Structural Alternatives for Two-Dimensional Mudflow Analysis in the Bucao River

Alternative	Structural Measure
1	Heightening of the Existing Dike
2	Alternative 1 + Consolidation Dam at Malomboy
3	Alternative 2 + Sand Pockets at the Downstream of Malomboy

In the alternative-2 and -3, the analysis was conducted on the condition that the riverbed in sections where the proposed structures were located was fixed at the present elevation.

The simulation results for the three alternatives in the Bucao River are shown in Figure 3.2.5 in terms of the maximum deposit during the occurrence of a 20-year probable flood.

(1) Alternative-1: Heightening of the Existing Dike

The maximum sediment deposition at the lower stretch was estimated at approximately 1 m along the existing dike of the Bucao River on the right side. On the left side, the maximum deposit would be approximately 2 m. The depth of the sedimentation would increase gradually toward the upstream. If there is another flood event after the simulated mudflow, the deposited sediment would be remobilized toward the downstream resulting in deeper sedimentation along the dike.

(2) Alternative-2: Alternative-1 + Consolidation Dam at Malomboy

The results show that the trend of sediment deposition is similar to the alternative-1 although a huge volume of sediment would be trapped in the upstream of the consolidation dam at Malomboy.

(3) Alternative-3: Alternative-2 + Sand Pocket at the Downstream of Malomboy

The sand pocket structures, two rows of lateral dike and one separation dike, are significantly effective in trapping the sediment with a depth of more than 6 m. However, the maximum deposition along the existing dike is similar to the alternative-1 to alternatives-2 with approximately 1 m.

The openings of the lateral dikes and separation dike are provided adequately to fix the river flow at mountainous side or left side in the alternative-3. As a result, the maximum deposit on the left side is the smallest among the three alternatives.

(4) Comparison among Three Alternatives

All riverbeds would rise by a mudflow with 20-year probable peak discharge in any alternatives. The riverbed aggradation ranges from less than 1 m along the existing dike to 6 m near Malomboy.

The above three alternatives are to be compared in terms of effectiveness as sediment retention structures. As for the effect, it is possible that both alternative-2 and alternative-3 would mitigate the riverbed aggradation near the confluence of the Baquilan River. However, there would be no predominant difference to mitigate the riverbed aggradation near the Bucao Bridge and along the existing dike among the three. Therefore, the adequate scale of structural measures is to be determined based on the economic analysis with cost and benefit of each structure.

3.2.4 Short Term Riverbed Movement in the Sto. Tomas River

The Sto. Tomas River model for short term riverbed movement analysis is composed of two rivers, the Marella River with a huge amount of lahar deposits drains from Mount Pinatubo and the Mapanuepe River flowing from the Mapanuepe Lake basin. The downstream end was set at the river mouth and the upstream end was set at 5 km upstream of the Mt. Bagang.

The simulation for the Sto. Tomas River was conducted based on the three structural alternatives in the following table.

Structural Alternatives for Two-Dimensional Mudflow Analysis in the Sto. Tomas River

Alternative	Structural Measure
1	Heightening and Strengthening of the Existing Dike
2	Alternative 1 + Consolidation Dam and Training Channel in the Marella River
3	Alternative 1 + Sand Pocket Structure and Consolidation Dam in the Marella River

In the alternative-2 and alternative-3, the analysis was conducted on the condition that the riverbed where the proposed structures were located was fixed at the present elevation.

The simulation results for the three alternatives in the Sto. Tomas River are shown in Figure 3.2.6 in terms of the maximum deposit during the occurrence of a 20-year probable flood.

(1) Alternative-1: Heightening and Strengthening of the Existing Dike

The result shows that sediment from the Marella River is transported smoothly to the downstream stretch with the maximum deposit of approximately 1 m at the downstream and 2 m at the middle reach from Vega Hill to Mt. Bagang. There would be overflow of sediment into the Mapanuepe Lake from the Marella River with maximum deposit of 1 m.

(2) Alternative-2: Alternative-1 + Consolidation Dam and Training Channels in the Marella River

The purpose of the structures proposed in the alternative-2 is to fix the river channel at the existing level. On the other hand, the disadvantage for this alternative is that remarkably high construction cost is necessary.

In spite of huge amount of trap of sediment in the Marella River along the training channel, there would be still riverbed aggradation in the downstream and middle stream with similar maximum deposit to the alternative-1.

(3) Alternative-3: Alternative-1 + Sand Pocket and Consolidation Dam in the Marella River

The sand pocket structures, three rows of lateral dike and ring dike, are significantly effective resulting in trapping the sediment with a depth of more than 6 m. It results in reducing sediment inflow to the Mapanuepe Lake. However, the maximum deposit in the lower reach is similar to the alternative-1.

(4) Comparison among Three Alternatives

The riverbed would be aggradated by less than 1 m averagely along the reach from the river mouth up to Mt. Bagang in all alternatives. The riverbed would greatly rise by approximately 6 m in the Marella River in any alternatives.

As for the effect of the structural measures, there would be no predominant effects to prevent riverbed aggradation in the downstream and mid-stream of the Sto. Tomas River by the alternative-2 and alternative-3, although larger amount of sediment would be deposited in the Marella River. Therefore, as well as the Bucao River case, the adequate scale of structural measures is to be determined based on the economic analysis with cost and benefit of each structure.

3.3 Long Term Riverbed Movement

3.3.1 One-Dimensional Sediment Transport Model

The long term riverbed movement in the Bucao and Sto. Tomas Rivers was analyzed for 20 years with the one-dimensional sediment transport model using the HEC-6 Version 4.1 program, Scour and Deposition in Rivers and Reservoirs.

(a) Bucao River Model

Figure 3.3.1 shows the longitudinal profile and riverbed width of the Bucao River model. In the model, the downstream end was set at the river mouth (Sta. -2.4 km) and the upstream end was set at the upstream of the Balin Baquero River (Sta. 23.0 km). The Balin Baquero River was regarded as a main reach in the model and the Upper Bucao River was considered as a tributary because it was assumed that sediment yield in the Balin Baquero River basin would be greater than that in the Upper Bucao River basin. The Upper Bucao River ends at 19.0 km upstream from the Bucao Bridge. The Baquilan River flows into the main reach at Sta. 5.5 km and the Balintawak River joins the Upper Bucao River at Sta. 13.0 km. It is noted that the riverbed width becomes extremely narrow at the portion of the Bucao

Bridge in comparison with the width from Sta. 2.0 km to Sta. 5.0 km.

(b) Sto. Tomas River Model

Figure 3.3.2 shows the longitudinal profile and riverbed width of the Sto. Tomas River model. In the Sto. Tomas River model, the downstream end was set at the river mouth (Sta. -1.5 km) as well as the Bucao River model. The upstream of the reach in the Marella River ends at 30.0 km upstream from the Maculcol Bridge. There are two tributaries flowing into the main reach: the Mapanuepe River at Sta. 21.0 km and the Santa Fe River at Sta. 11.5 km. The riverbed is extremely wide with maximum 2.0 km at the mid-stream portion where a large amount of lahar deposits remains.

(c) Conditions for Simulation

Conditions for the one-dimensional sediment transport simulation are summarized in Table 3.3.1. Annual inflowing sediment volume was set as constant for 20 year simulation. Estimated sediment yield in 2007 was assumed as representative to be applied for both Bucao and Sto. Tomas Rivers. Inflowing sediment in each time step was computed as a function of discharge at the upstream end in the model.

Because of lack of daily runoff data in the study area, hydrograph pattern was designed based on the flow duration curve and runoff pattern in 1963 and 1984 in the Bucao River basin, which are only reliable runoff data as discussed in the appendix III, Meteorology and Hydrology. The annual hydrograph pattern for the one-dimensional sediment transport analysis is shown in Figure 3.3.3. It was applied for both Bucao and Sto. Tomas River models.

Sediment load was calculated with Yang's Formula (1973), which was developed for total-load transport capacity with an approach based on the excess of stream power over a critical value. It is said that the formula can be applied for small or medium size river with sand-bed.

The simulation was conducted for the following three hydrological cases to include the effect of a 20-year probable flood in the long term riverbed movement:

1) Case 1: No flood occurs in 20 years

Annual hydrograph pattern in normal year without floods was repeatedly computed twenty times in the model.

2) Case 2: 20-year probable flood occurs in 5th year

Annual hydrograph pattern in flood year with maximum discharge of 20-year probable flood was input in 5th year instead of the normal pattern.

3) Case 3: 20-year probable flood occurs in 15th year

Annual hydrograph pattern in the flood year was input in 15th year instead of the normal pattern.

Reliable record on long-term riverbed movement was unavailable for the purpose of calibration of the established one-dimensional sediment transport model. Therefore, the model was only compared with the sediment balance analysis presented in the section 2.3 to examine its reliability. The results of the one-dimensional sediment transport analysis would be reasonable as shown in the following table.

Comparison of Results of Estimated Sediment Transport in the Lower Reach

	Sediment balance analysis with Brown's Formula (x 10^6 m^3/year)	One-dimensional sediment transport analysis (x 10^6 m^3/year)
Bucao River	9.8 (1) (at the Bucao Bridge)	8.2 (Average from Sta. 0.0 km to 12.0 km)
Sto. Tomas River	3.5 (at the Maculcol Bridge)	3.5 (Average from Sta. 0.0 km to 10.5 km)

(1)Computed with riverbed gradient revised to 1/500 near the Bucao Bridge

3.3.2 Long Term Riverbed Movement in the Bucao River

Long term riverbed movement in the Bucao River was examined under the present condition only with heightening of the existing dike, in other words, alternative-1.

(1) Riverbed Movement after 20 Years

Figure 3.3.4 presents the results of riverbed movement simulation under the present condition after 20 years from the river mouth up to the Balin Baquero River. Riverbed change is defined as the difference between the simulated lowest riverbed elevation and original lowest riverbed elevation in 2002. As well, the simulated riverbed movement in the Upper Bucao River is shown in Figure 3.3.5. As a result, there is no significant difference in fluctuation trend among the three cases: Case 1 (no flood in 20 years), Case 2 (flood occurs in 5th year), and Case 3 (flood occurs in 15th year). The long term riverbed movement in the Bucao River is described for the downstream, mid-stream and upstream as follows:

1) Downstream: River Mouth – Bucao Bridge – Baquilan River (Sta. 5.5 km)

Under the present condition, it is estimated that the riverbed would rise from the downstream of the Bucao Bridge to the confluence of the Baquilan River after 20 years. The aggradation in 20 years is approximately 4.2 m at the immediate upstream of the Bucao Bridge. On the other hand, the riverbed at the upstream of the confluence with the Baquilan River would be stable or eroded because of the influence of the Baquilan River without serious sedimentation.

2) Mid-stream: Baquilan River – Malomboy – Confluence (Sta. 12.0 km)

The riverbed aggradation would be the most predominant near the confluence of the Balin Baquero and Upper Bucao Rivers with the aggradation by 4.8 m. It is recognized that the topographic feature near Malomboy, where the river width decreases suddenly as flowing downwards, would cause the serious riverbed aggradation at the portion.

3a) Upstream: Confluence – Balin Baquero River (Sta. 23.0 km)

The riverbed change would be stable with the balance between inflowing and transported sediment under the normal condition. On the other hand, the riverbed would be elevated by 2.1 m if a 20-year probable flood occurs in 20 years.

3b) Upstream: Confluence – Upper Bucao River (Sta. 19.0 km)

The simulation results show that riverbed degradation would be predominant at the upstream of the Upper Bucao River. The erosion would occur at the upstream end of the reach and propagate downwards. However, the confluence between the Balin Baquero and the Upper Bucao Rivers would not be affected by the erosion in 20 years.

(2) Chronological Riverbed Movement in Future

Figure 3.3.6 and Table 3.3.2 show chronological riverbed movement for 20 years in the Bucao River based on the three hydrological cases for the alternative-1. In all cases, the riverbed would continue to rise near the Bucao Bridge (Sta. 0.0 km – Sta. 4.0 km) and near the confluence of the Upper Bucao and Balin Baquero Rivers (Sta. 10.0 km – Sta. 13.0 km) without convergence within 20 years. This would be because of the condition of inflowing sediment in the model. It is assumed that the continuous riverbed aggradation is caused by constant inflowing sediment input, which is same as estimated sediment yield in 2007, at the upstream end every year for 20 years without declining the inflow rate.

However, actual future inflowing sediment into the reach would decrease as time passes. Long term continuous monitoring of riverbed movement and sediment balance is strongly recommended to calibrate the sediment transport model and predict future riverbed movement more accurately.

In addition to 20 year simulation, riverbed movement after 50 years was simulated as a reference beyond the planning scale on the following conditions. Initial year was set at 2022, or 20 years after 2002, and riverbed movement after more 30 years was analyzed. The presumed cross sections after 20 years as a result of case 1 were used as input cross sections. It was assumed that there would be no inflowing sediment at the upstream end of the Upper Bucao River and the Balin Baquero River after 2022. No flood was input for 30 years. The maximum erosion depth was determined assuming the riverbed would be potentially degradated down to the elevation of the riverbed in 1977 when the topographic map was made by NAMRIA. All the other conditions were same as the 20 year simulation with the initial year of 2002.

The results of riverbed movement analysis for 50 years in the Bucao - Balin Baquero Rivers and the Upper Bucao River are shown in Figure 3.3.7 and Figure 3.3.8, respectively. It is shown that riverbed elevation would not be changed for 30 years after 2022 at the downstream portion from the river mouth to Malomboy (Sta. 10.5 km) with balanced inflowing and transported sediment. Riverbed in the middle reach near the confluence of the Upper Bucao and Balin Baquero Rivers would be degradated to the elevation as of 2002. Riverbed in the upstream of the Upper Bucao River and the Balin Baquero River would be degradated down to the same elevation as in 1977.

The result indicates that there would be no serious riverbed aggradation due to secondary erosion of lahar deposits if the sediment yield on the mountain slope is negligible after 20 years.

3.3.3 Long Term Riverbed Movement in the Sto. Tomas River

Long term riverbed movement in the Sto. Tomas River was examined under the following conditions in terms of proposed structures.

a) Alternative-1: Heightening the Existing Dike
b) Alternative-2: Consolidation Dam + Training Channel from Sta. 21.5 km to Sta. 25.5 km
c) Alternative-3: Sand Pocket + Consolidation Dam at Sta. 21.5 km

The results of those three alternatives were compared to examine the effect of each structure. Additional simulation was conducted under the following conditions as references though these alternatives were not included in the proposed structural measures in the master plan.

d) Alternative-2*: Consolidation Dam + Training Channel from Sta. 21.5 km to Sta. 30.0 km
e) Alternative-3*: Large Scale Sand Pocket + Sabo Dam at Sta. 21.5 km

(1) Riverbed Movement after 20 Years

(a) Alternative-1: Heightening the Existing Dike

Figure 3.3.9 shows the simulated riverbed movement with alternative-1 in the Sto. Tomas River after 20 years. As well as the Bucao River, there is no significant difference in fluctuation trends among the three hydrological cases. The results in the downstream, mid-stream and upstream are described as follows:

1) Downstream: River Mouth – Maculcol Bridge – Vega Hill (Sta. 10.5 km)

The simulation shows that the riverbed in the downstream reach would rise after 20 years from the Maculcol Bridge up to Paete Hill (Sta. 7.25 km) with the maximum aggradation by 1.5 m.

2) Mid-Stream: Vega Hill – Mt. Bagang (Sta. 21.5 km)

The result shows that outstanding riverbed aggradation would not occur after 20 years in the mid-stream though the riverbed would rise by less than 1.0 m around Sta. 16.0 km where the riverbed width suddenly becomes wide.

3) Upstream: Mt. Bagang – Marella River (Sta. 30.0 km)

The riverbed would be degradated with erosion in the Marella River in all three cases. The maximum degradation near the Mapanuepe Lake is approximately 3.0 m, which is within safety range against break of the natural dike between the Mapanuepe Lake and the Marella River. The great erosion of riverbed in the upstream of the Marella River would be due to steep slope of the reach.

(b) Alternative-2: Training Channel from Sta. 21.5 km to Sta. 25.5 km

The riverbed elevation was fixed at the existing level in 2002 from Sta. 21.5 km to Sta. 25.5 km to analyze the riverbed movement with consolidation dam at Mt. Bagang and training channel in the Marella River.

Figure 3.3.10 shows that riverbed movement after 20 years with the alternative-2 would be similar to the result of alternative-1 with only difference in riverbed movement in the upstream. The riverbed in the downstream would tend to rise with maximum aggradation of 1.8 m near Paete Hill. There would be fluctuating trend of riverbed in the middle reach. The presumed training channel would prevent riverbed degradation in the Marella River.

(c) Alternative-3: Sand Pocket + Consolidation Dam at Sta. 21.5 km

The riverbed elevation was fixed at the existing level in 2002 at Sta. 21.5 km to simulate the riverbed movement with consolidation dam at Mt. Bagang.

Riverbed movement after 20 years with the alternative-3 would be similar to the result of alternative-1 as shown in Figure 3.3.11. The riverbed in the downstream would tend to rise with maximum aggradation of 1.5 m near Paete Hill. There would be fluctuating trend of riverbed in the middle reach. The maximum degradation near the Mapanuepe Lake is approximately 4.0 m, which is within safety range against break of the natural dike between the Mapanuepe Lake and the Marella River.

(d) Alternative-2*: Consolidation Dam + Training Channel from Sta. 21.5 km

To examine the effect of complete prevention of secondary erosion in the Marella River, simulation with the alternative-2* was conducted. Riverbed movement with the alternative-2* was analyzed on the condition that training channel was extended up to the end of the upstream of the Marella River.

Figure 3.3.12 shows the result of riverbed movement after 20 years with the alternative-2*. It indicated that extended training channel would prevent riverbed aggradation in the middle reach. However, the riverbed movement in the downstream is similar to alternative-1 with maximum aggradation of 1.4 m. It is assumed that secondary erosion in the middle reach would cause riverbed aggradation in the downstream portion.

(e) Alternative-3*: Large Scale Sand Pocket + Sabo Dam at Sta. 21.5 km

Riverbed movement was analyzed on the condition that total sediment load from the Marella River is completely stored at the immediate upstream of Mt. Bagang with large scale sand pocket and sabo dam at Sta. 21.5 km. The riverbed elevation of the upstream end was fixed at the existing level in 2002 at Sta. 21.5 km in the model. Maximum erosion depth at the immediate downstream of the structure was set at 15 m based on the riverbed elevation in 1977. In addition, it was assumed that there was no inflowing sediment at the upstream boundary.

Figure 3.3.13 shows the result of riverbed movement after 20 years with the alternative-3*. There would be serious riverbed scouring at the immediate downstream of Mt. Bagang with maximum erosion depth of 15.0 m. It is indicated that the riverbed would not rise at all sections even in the downstream if inflowing sediment into the Sto. Tomas River was negligible.

Riverbed profile after 20 years in the Sto. Tomas River is summarized in Table 3.3.3 for five alternatives.

(2) Chronological Riverbed Movement in Future

Figure 3.3.14 and Table 3.3.4 show chronological riverbed movement for 20 years in the Sto. Tomas River based on the three hydrological cases for the alternative-1. In all cases, the riverbed tends to rise from the Maculcol Bridge to Paete Hill (Sta. 0.0 km – Sta. 7.5 km). It is assumed that riverbed aggradation would converge in 20 years at the immediate upstream of the Maculcol Bridge resulting in stable riverbed gradient with balanced sediment load and transport. Riverbed degradation at the upstream of Vega Hill (Sta. 10.0 km – 14.0 km) and in the Marella River would converge after 5 years.

As well as the Bucao River, long term continuous monitoring of riverbed movement and sediment balance is strongly recommended to predict future riverbed movement more accurately with more reliable calibration of the model.

In addition to 20 year simulation, riverbed movement after 50 years was simulated as a reference beyond the planning scale on the same conditions as the 50 year simulation for the Bucao River.

The results of riverbed movement analysis for 50 years in the Sto. Tomas River are shown in Figure 3.3.15. It is shown that riverbed would rise by less than 1.0 m at all cross sections after 2022. Especially, riverbed aggradation would converge at the immediate upstream of the Maculcol Bridge. Riverbed in the Marella River would be degradated down to the elevation in 1977. The result indicates that there would be no serious riverbed aggradation due to secondary erosion of lahar deposits if the sediment yield on the mountain slope is negligible after 20 years.

3.4 Comparison of Short Term and Long Term Riverbed Movement Analysis

The following table compares the results of short term and long term riverbed movement for the Bucao and Sto. Tomas Rivers under the condition of the alternative-1.

Comparison of Results between Short Term and Long Term Riverbed Movement Analysis

	Short Term	Long Term
Model	Two-Dimensional Mudflow Model	One-Dimensional Sediment Transport Model
Duration of Input Hydrograph	48 Hours	20 Years
Bucao River		
Downstream (River Mouth – Baquilan River)	Aggradation (Max. +2.0 m)	Aggradation (Max. +4.2 m)
Mid-Stream (Baquilan River – Malomboy- Confluence)	Aggradation (Max. +6.0 m)	Aggradation (Max. +4.8 m)
Upstream (1) (Confluence – Balin Baquero River)	-	Aggradation (Max. +2.4 m)
Upstream (2) (Confluence– Upper Bucao River)	-	Degradation (Max. -15.0 m)
Sto. Tomas River		
Downstream (River Mouth – Vega Hill)	Aggradation (Max. +1.0 m)	Aggradation (Max. +1.5 m)
Mid Stream (Vega Hill – Mt. Bagang)	Aggradation (Max. +4.0 m)	Fluctuation (Max. +1.0 m)
Upstream (Mt. Bagang – Marella River)	Aggradation (Max. +4.0 m)	Degradation (Max. -3.0 m)

Note: "-" was not included in the simulation

It is characteristic of the short term riverbed movement that riverbeds in all sections tend to rise by a lahar event with a 20-year probable flood. On the other hand, in the long term some portion of riverbed, such as in the upstream of the Marella River, would be eroded resulting from the one-dimensional sediment transport analysis.

It is noted that the maximum riverbed aggradation in the long term is greater than that in the short term in the downstream of both the Bucao and Sto. Tomas River. This would be because of the following two reasons: difference in the total volume of inflowing sediment and the effect of secondary erosion in the middle and upstream. The total inflowing sediment volume in the long term, 112 million m^3 for 20 years in case-1 and 134 million m^3 in case-2 and case-3, is almost double of that in the short term, 64 million m^3 for one mudflow event.

The other reason is that the secondary erosion in the middle and upstream in the long term contributes to the more aggradation in the downstream as additional sediment delivery. On the other hand, 48 hours in the short term simulation would not be enough long to describe the secondary erosion effect in the upper reach as shown as more aggradation in the upper stretch.

3.5 High Water Level with Riverbed Movement

As final outputs in riverbed movement analysis, high water level for a 20-year probable flood, which is the design flood in the study area, was computed including the presumed riverbed change for 20 years. The computed high water level was applied for the design of selected structural measure in the feasibility study.

3.5.1 Selection of Alternatives for Structural Measures

(1) Bucao River

Three alternatives of structural measures are proposed for the Bucao River in the master plan. To select alternatives for the feasibility study, the effect of each structural measure was examined with riverbed movement analysis.

As a result of the short term riverbed movement analysis, it was concluded that there would be no predominant difference to mitigate the riverbed aggradation along the existing dike from the Bucao Bridge to the Baquilan River among the three alternatives. It would be impossible to prioritize alternatives in terms of the mitigation effect against sediment deposition. Therefore, economic assessment was introduced for the selection. Finally, the alternative-1 was prioritized for the feasibility study because it would be the most economically feasible as discussed in appendix XII.

(2) Sto. Tomas River

Three alternatives of structural measures are proposed for the Sto. Tomas River in the master plan. To select alternatives for the feasibility study, the effect of each structural measure was examined with riverbed movement analysis.

As a result of the short term and long term riverbed movement analysis, it was concluded that there would be no predominant difference to mitigate the riverbed aggradation from the Maculcol Bridge to Mt. Bagang among the three alternatives. As well as the Bucao River, economic assessment was introduced for the selection. Finally, the alternative-1 was prioritized for the feasibility study because it would be the most economically feasible and the most urgent countermeasure.

3.5.2 Computation of High Water Level

Based on the selected alternatives of structural measure, high water level was determined in the Bucao and Sto. Tomas River with non-uniform flow computation. Design discharge was set as same as the peak discharge of 20-year probable flood in each river.

Table 3.5.1 and Table 3.5.2 show the computation result of high water level for the Bucao and Sto. Tomas Rivers, respectively. The comparison between the water level with original riverbed in 2002 and with riverbed change after 20 years is shown in Figure 3.5.1.

In the Bucao River, the 20-year probable flood would overflow the existing dike only at the immediate upstream and downstream of the Bucao Bridge. Considering future riverbed change, water level would be above the existing dike crest in almost all sections. It indicates that the dike heightening is necessary for all the portion of the existing dike.

In the Sto. Tomas River, water level would rise after including the presumed riverbed change although the change of high water level is smaller than the case in the Bucao River. The 20-year probable flood may overflow the existing dike from Sta. 4.0 km up to Sta. 10.0 km near Vega Hill with future riverbed movement. However, heightening of the existing dike should not be necessary for the upstream from Vega Hill in future.

CHAPTER 4 MONITORING FOR RIVERBED MOVEMENT

4.1 Sediment Transport Analysis and Monitoring for Riverbed Movement

A great concern in the study area is whether the riverbed elevation would still have rising tendency or not. The proposed structural countermeasures fully depend on further riverbed movement. Two kinds of detailed riverbed movement analysis were conducted to predict future tendency of sediment balance in short term with one extreme lahar event and long term with 20 year normal stream flow. However, the models indicate the future trend with limited conditions. Results are subject to initial conditions, boundary conditions, and scenario of sediment transport. On the other hand, rivers in the study area are facing dynamic change of riverbed during rainy season due to movement of thick lahar deposition in the reach.

Therefore, continuous monitoring of further riverbed movement in the study area is strongly recommended especially in the Bucao and Sto. Tomas Rivers because more data obtained from monitoring will result in more reliable calibration of the models. Then it would be possible to simulate future riverbed change with more accurate sediment transport model prior to the implementation.

To measure the change of riverbed elevation, staff gauges were installed in the Bucao and Sto. Tomas Rivers at the begging of 2003 by the study team. Two gauges are located near right and left side banks in each section to obtain averaged riverbed fluctuation trend and to prevent scouring by the flow in the center river course.

Results of further monitoring for riverbed movement in future should be compared with simulation results by one-dimensional sediment transport analysis shown in Table 3.3.2 and Table 3.3.4 for the Bucao and Sto. Tomas Rivers, respectively. If there is significant difference between observed and simulated riverbed movement, the sediment transport model should be revised and improved with more accurate calibration. For example, it is desirable to review the model after 5 years or 10 years when detailed design is to be conducted.

4.2 Monitoring Activities in 2002 and 2003

4.2.1 Bucao River Basin

Seven cross sections in the Bucao River were selected to monitor riverbed change regularly as shown in Figure 4.2.1. Among the seven sections, five along the Lower Bucao and Balin Baquero Rivers were surveyed in July and August 2002 during the rainy season. In addition, other two sections along the Upper Bucao River were established for further monitoring works together with the other five sections in January 2003.

Figure 4.2.2 shows the comparison of cross sections in the Bucao River in July 2002 and January 2003. The river profile is presented in Figure 4.2.3. It was observed that almost all the riverbed would tend to rise except in the far upstream portion of the Balin Baquero River with tendency of scouring during the latest six months. As a result, sediment deposit volume along the Bucao River channel was increased by approximately 32 million m^3 from July 2002 to January 2003 as shown in Table 4.2.1.

However, effects of the breach of the Maraunot Notch which occurred in July 2002 were included in the change of cross section in the Lower Bucao River stretch. It is noted that the above value would not be applied for the estimation of annual sediment yield for the year 2002 because of abnormal event. The future monitoring for sediment deposit in the Bucao River should be compared with the results in

January 2003 as initial conditions.

4.2.2 Sto. Tomas River Basin

Seven cross sections to monitor riverbed movement were also established along the Sto.Tomas River from the Maculcol Bridge to 25.5 km upstream from the bridge in the Marella River. Location of the seven monitoring sections is shown in Figure 4.2.4.

In the case of the Sto.Tomas River, the comparative river cross section survey was conducted in July and August 2002. The two surveys were just before and after the flood at the begging of July 2002, which was assumed to be equivalent to a 10-year probable flood. The volume of sediment deposition due to the flood in the Sto.Tomas River stretch was estimated at 8.3 million m^3 as shown in Table 4.2.2.

The measured river cross sections on the seven monitoring stations are illustrated in Figure 4.2.5. The longitudinal profile is also shown in Figure 4.2.6. Future monitoring should be always traced on the same survey lines so that the simulated long-term riverbed movement for the next 20 years can be calibrated with more accuracy. As a result, effective design review is possible at a detailed design stage to enhance the reliability of proposed structures and to choose more economic design.

The Study on Sabo and Flood Control for Western River Basins of Mount Pinatubo
in the Republic of the Philippines
Final Report
Supporting Report

Tables

Table 1.2.1 Ratio of New Collapse on Each Geology (Watershed Under 100 km^2)

Geology		Average (Collapsed area/Watershed area)	Geology		Average (Collapsed area/Watershed area)
Igneous Rocks	Granite	0.50 %	Sedimentary Rocks	Sediment	1.70 %
	Diorite	0.06		Pyrocrastic deposit	0.22
	Gabblo,Serpentinite	0.04		Tuff	0.23
	Quartz porphyly	0.10		Tuff breccia	0.19
	Porphyrite	1.08		Volcanic lithosol	0.39
	Diorite	0.46		Conglomerate	0.10
	Qaurtz trachyte	0.26		Breccia	0.45
	Quartz ansesite	0.53		Sandstone	0.21
	Andesite	0.22		Quartzite	2.04
	Andesitic lava	0.29		Mudstone	0.36
	Basalt	0.11		Shale	0.10
	Porphyry diorite	0.13		Slate	0.07
Metamorphic Rocks	Schist	0.34		Sandy shale	0.14
	Hornfeis	0.07		Sandy slate	0.09
Sedimentary Rocks	Paleozoic Formation	0.50		Siliceous sandstone	0.25
	Mesozoic Formation	0.05		Tufferceous shale	1.01
	Tertiary Formation	0.25		Limestone	0.27
	Diluvium Deposit	0.19		Chert	0.16
	Aluvium Deposit	0.04		Siliceous tuff	0.73

Unstable	10.00

Table 1.2.2 Depth of Collapse on Each Geology

Geology		Depth of collapse (m)	Geology		Depth of collapse (m)
Igneous Rocks	Granite	2～3	Sedimentary Rocks	Sediment	1～2
	Diorite	5		Pyrocrastic deposit	2～3
	Gabblo,Serpentinite	2～3		Tuff	2～3
	Quartz porphyly	3～4		Tuff breccia	2～3
	Porphyrite	5		Volcanic lithosol	5
	Diorite	2～3		Conglomerate	1～2
	Qaurtz trachyte	5			
	Quartz ansesite	0～1		Sandstone	1～2
	Andesite	4～5		Quartzite	5
	Andesitic lava	3～4		Mudstone	2～3
				Shale	1～2
	Porphyry diorite	0～1		Slate	2～3
Metamorphic Rocks	Schist	2～3		Sandy shale	2～3
	Hornfeis	1～2		Sandy slate	1～2
Sedimentary Rocks	Paleozoic Formation	2～3		Siliceous sandstone	2～3
	Mesozoic Formation	2～3		Tufferceous shale	1～2
	Tertiary Formation	3～4		Limestone	2～3
	Diluvium Deposit	3～4		Chert	2～3
	Aluvium Deposit	4～5			

Unstable	4

Table 1.2.3 Average Depth of Erosion of Each Geology

Geology		Average depth (m)	Geology		Average depth (m)
Igneous Rocks	Granite	0.013	Sedimentary Rocks	Sediment	0.026
	Diorite	0.003		Pyrocrastic deposit	0.006
	Gabblo,Serpentinite	0.001		Tuff	0.006
	Quartz porphyly	0.004		Tuff breccia	0.005
	Porphyrite	0.054		Volcanic lithosol	0.020
	Diorite	0.012		Conglomerate	0.002
	Qaurtz trachyte	0.013			
	Quartz ansesite	0.003		Sandstone	0.003
	Andesite	0.010		Quartzite	0.102
	Andesitic lava	0.010		Mudstone	0.009
	Basalt			Shale	0.002
	Porphyry diorite	0.001		Slate	0.003
Metamorphic Rocks	Schist	0.003		Sandy shale	0.002
	Hornfeis	0.005		Sandy slate	0.002
Sedimentary Rocks	Paleozoic Formation	0.002		Siliceous sandstone	0.002
	Mesozoic Formation	0.013		Tufferceous shale	0.004
	Tertiary Formation	0.002		Limestone	0.025
	Diluvium Deposit	0.009		Chert	0.007
	Aluvium Deposit	0.009			

Unstable	0.400

Table 1.2.4 Estimation of Annual Sediment Yield in 2001

River	Watershed	Area				Sediment Yield			
		Catchment Area : A (km^2)	Normal Slope Area : A1 (km^2)	Unstable Slope Area : A2 (km^2)	River Bank Erosion Area : A3 (km^2)	Yield from A1 : V1 (10^6 m^3/yr)	Yield from A2 : V2 (10^6 m^3/yr)	Yield from A3 : V3 (10^6 m^3/yr)	Total Sediment : V (10^6 m^3/yr)
Bucao River	B1	68.4	58.9	9.2	0.3	0.35	2.26	0.60	3.22
	B2	20.0	20.0	0.0	0.0	0.12	0.00	0.00	0.12
	B3	50.5	37.1	13.0	0.4	0.22	3.20	0.80	4.22
	B4	12.0	6.6	5.1	0.3	0.04	1.25	0.60	1.90
	B5	142.1	114.7	26.6	0.8	0.69	6.54	1.60	8.84
	B6	154.0	154.0	0.0	0.0	0.92	0.00	0.00	0.92
	B7	64.9	64.9	0.0	0.0	0.39	0.00	0.00	0.39
	B8	13.0	13.0	0.0	0.0	0.08	0.00	0.00	0.08
	B9	35.1	35.1	0.0	0.0	0.21	0.00	0.00	0.21
	B10	60.9	60.9	0.0	0.0	0.37	0.00	0.00	0.37
	B11	33.9	33.9	0.0	0.0	0.20	0.00	0.00	0.20
	Total	654.8	599.1	53.9	1.8	3.59	13.26	3.61	20.46
	%	100.0%	91.5%	8.2%	0.3%	17.6%	64.8%	17.6%	100.0%
Maloma River	M1	42.6	41.4	1.2	0.0	0.25	0.30	0.00	0.54
	M2	39.4	39.4	0.0	0.0	0.24	0.00	0.00	0.24
	M3	17.4	17.4	0.0	0.0	0.10	0.00	0.00	0.10
	M4	42.0	42.0	0.0	0.0	0.25	0.00	0.00	0.25
	M5	10.4	10.4	0.0	0.0	0.06	0.00	0.00	0.06
	Total	151.8	150.6	1.2	0.0	0.90	0.30	0.00	1.20
	%	100.0%	99.2%	0.8%	0.0%	75.4%	24.6%	0.0%	100.0%
Santo Tomas River	S1	54.4	43.7	10.0	0.7	0.26	2.46	1.40	4.13
	S2	22.2	22.2	0.0	0.0	0.13	0.00	0.00	0.13
	S3	13.9	13.7	0.2	0.0	0.08	0.05	0.00	0.13
	S4	18.8	18.8	0.0	0.0	0.11	0.00	0.00	0.11
	S5	39.0	39	0.0	0.0	0.23	0.00	0.00	0.23
	S6	42.1	41.2	0.9	0.0	0.25	0.22	0.00	0.47
	S7	29.1	29.1	0.0	0.0	0.17	0.00	0.00	0.17
	S8	6.8	6.8	0.0	0.0	0.04	0.00	0.00	0.04
	S9	6.1	6.1	0.0	0.0	0.04	0.00	0.00	0.04
	S10	9.3	9.3	0.0	0.0	0.06	0.00	0.00	0.06
	S11	20.7	20.7	0.0	0.0	0.12	0.00	0.00	0.12
	Total	262.4	250.6	11.1	0.7	1.50	2.73	1.40	5.64
	%	100.0%	95.5%	4.2%	0.3%	26.7%	48.4%	24.9%	100.0%

Table 2.1.1 Grain Size and Specific Gravity of Riverbed Material

Sampling Location	Sample Number	River System	Distance from River-mouth	Portion in Riverbed	Specific Gravity (t/m^3)	Grain Size (mm)			Ratio
						D_{60}	D_{84}	D_{16}	D_{84} / D_{16}
No.1	No.1-R	Bucao	4 km	Right Side	2.56	0.50	0.90	0.18	5.0
	No.1-M			Middle Side	2.44	0.28	0.70	0.15	4.7
	No.1-L			Left Side	2.58	0.27	0.60	0.13	4.6
	Average				2.53	0.35			4.8
No.2	No.2-R	Bucao	12 km	Right Side	2.51	0.48	0.90	0.10	9.0
	No.2-M			Middle Side	2.65	0.28	0.70	0.16	4.4
	No.2-L			Left Side	2.77	0.29	0.40	0.18	2.2
	Average				2.64	0.35			5.2
No.3	No.3-R	Bucao	19 km	Right Side	2.67	0.55	1.30	0.19	6.8
	No.3-M			Middle Side	2.39	0.60	0.90	0.24	3.8
	No.3-L			Left Side	2.63	0.85	2.10	0.30	7.0
	Average				2.56	0.67			5.9
No.4	No.4-R	Maloma	3 km	Right Side	2.65	0.54	0.85	0.27	3.1
	No.4-M			Middle Side	2.48	0.67	1.30	0.34	3.8
	No.4-L			Left Side	2.58	0.59	1.00	0.28	3.6
	Average				2.57	0.60			3.5
No.5	No.5-R	Maloma	13 km	Right Side	2.53	0.54	0.85	0.27	3.1
	No.5-M			Middle Side	2.64	0.66	1.30	0.34	3.8
	No.5-L			Left Side	2.58	0.58	1.00	0.28	3.6
	Average				2.58	0.59			3.5
No.6	No.6-R	Sto.Tomas	3 km	Right Side	2.73	0.23	0.30	0.13	2.3
	No.6-M			Middle Side	2.36	0.55	2.60	0.18	14.4
	No.6-L			Left Side	2.52	0.28	0.60	0.14	4.3
	Average				2.54	0.35			7.0
No.7	No.7-R	Sto.Tomas	13 km	Right Side	2.31	1.60	4.00	0.35	11.4
	No.7-M			Middle Side	2.70	0.26	0.39	0.14	2.8
	No.7-L			Left Side	2.68	0.28	0.43	0.16	2.7
	Average				2.56	0.71			5.6
No.8	No.8-R	Sto.Tomas	23 km	Right Side	2.65	0.90	2.10	0.30	7.0
	No.8-M			Middle Side	2.72	0.70	1.40	0.30	4.7
	No.8-L			Left Side	2.65	0.55	0.80	0.20	4.0
	Average				2.67	0.72			5.2
Average of All Data					**2.58**	**0.54**			**5.1**

Note : D_{60} expresses the particle size with 60 % passing by weight
D_{60} = representative particle size = mean value of particle size (approximately)
D_{84}/D_{16} expresses mix degree of prticle size
A riverbed material with $D_{84}/D_{16} \leq 5$ can be assumed a uniform material in sediment hydraulics.

Table 2.1.2 Grain Size Distribution of Riverbed Material

River	Location	Site	Cumulative Passing (%) for Grain Size									
			19.0 mm	12.5 mm	9.5 mm	4.75 mm	2.06 mm	0.85 mm	0.425 mm	0.3 mm	0.15 mm	0.075mm
Bucao	No.1	Right		100.0	99.4	98.8	96.2	82.5	52.3	37.2	9.4	1.7
		Middle	100.0	99.6	99.0	96.9	93.3	86.9	76.4	64.8	17.4	1.8
		Left	100.0	99.3	98.9	97.1	94.2	89.2	79.6	69.2	21.4	4.6
	No.2	Right		100.0	99.0	98.6	96.5	83.7	55.7	41.1	35.6	1.5
		Middle	100.0	99.6	99.0	96.9	93.3	86.9	76.4	64.8	17.4	1.8
		Left				100.0	99.9	97.9	87.3	62.8	9.4	1.6
	No.3	Right		100.0	99.1	95.5	89.8	77.0	47.7	30.2	9.6	3.3
		Middle		100.0	99.2	98.1	94.6	83.8	27.8	20.0	8.0	1.8
		Left			100.0	97.9	84.7	60.2	30.6	15.7	3.0	1.2
Maloma	No.4	Right		100.0	99.5	98.4	95.7	84.5	44.3	19.4	3.5	1.2
		Middle	100.0	98.9	97.9	96.5	91.9	73.8	29.3	11.5	1.3	0.5
		Left	100.0	99.4	98.9	97.8	95.5	81.1	38.5	16.9	1.5	0.6
	No.5	Right		100.0	99.5	98.4	95.7	84.5	44.3	19.4	3.5	1.2
		Middle	100.0	98.9	97.9	96.5	91.9	73.8	29.3	11.5	1.3	0.5
		Left	100.0	99.4	98.9	97.8	95.5	81.1	38.5	16.9	1.5	0.6
Sto.Tomas	No.6	Right		100.0	99.7	99.7	99.3	98.8	88.6	85.4	20.4	3.0
		Middle	100.0	99.1	98.5	94.8	80.4	66.7	54.8	38.8	8.9	1.3
		Left			100.0	98.7	96.4	89.4	77.7	63.8	18.3	4.1
	No.7	Right	100.0	99.7	97.9	88.5	67.2	42.7	29.0	7.1	1.4	0.0
		Middle				100.0	99.9	98.2	87.8	72.0	19.2	3.6
		Left			100.0	99.9	99.1	95.2	84.7	65.8	13.8	1.4
	No.8	Right	100.0	98.6	98.0	94.3	84.1	53.7	26.2	17.5	6.3	3.0
		Middle			100.0	99.8	96.7	73.6	33.7	17.2	3.1	0.5
		Left				100.0	99.3	82.0	45.0	29.6	12.1	6.6
Average			100.0	99.6	99.1	97.5	93.0	80.3	53.6	37.5	10.3	2.0

Table 2.2.1 Calibration of Sediment Delivery in the Sto.Tomas River after Eruption (1991-2001)

Item	Symbol	Equation	Unit	Year						
				1991	1992	1993	1994	1995	1996	1997
Sediment Transport-1 (Upstream)	S4	Actual Lahar Volume	10^6m^3	185.0	195.0	125.0	60.0	40.0	55.0	25.0
Coefficient for Modification	C	C=S4/Q4-1 (C>0)		6.34	6.74	3.96	1.38	0.59	1.18	0.00
Deposit Volume (Marella River)	V3	V3=S4-S3	10^6m^3	84.5	89.5	54.3	21.6	11.5	19.1	3.9
Sediment Transport-2 (Mt.Bagang)	S3	S3=Q3*(1+C*(54/91km^2)	10^6m^3	100.5	105.5	70.7	38.4	28.5	35.9	21.1
Deposit Volume (Middle Reaches)	V2	V2=S3-S2	10^6m^3	84.3	88.7	58.0	29.5	20.7	27.3	14.2
Sediment Transport-3 (Vega Hill)	S2	S2=Q2*(1+C*(54/253km^2)	10^6m^3	16.2	16.8	12.7	8.9	7.8	8.6	6.9
Deposit Volume (Downstream)	V1	V1=S2-S1	10^6m^3	14.9	15.5	11.4	7.6	6.5	7.3	5.6
Sediment Transport-4 (Maculcol Bridge)	S1	S1=Q1=3.0	10^6m^3	1.3	1.3	1.3	1.3	1.3	1.3	1.3

Item	Symbol	Equation	Unit	Year					Deposit in 2001		Difference
				1998	1999	2000	2001		Actual	Simulated	
Sediment Transport-1 (Upstream)	S1	Actual Lahar Volume	10^6m^3	23.0	18.0	14.0	5.7				
Coefficient for Modification	C	C=S4/Q4-1 (C>0)		0.00	0.00	0.00	0.00				
Deposit Volume (Marella River)	V3	V3=S4-S3	10^6m^3	1.9	-3.1	-7.1	-15.4		260	261	1 (0%)
Sediment Transport-2 (Mt.Bagang)	S3	S3=Q3*(1+C*(54/91km^2)	10^6m^3	21.1	21.1	21.1	21.1				
Deposit Volume (Middle Reaches)	V2	V2=S3-S2	10^6m^3	14.2	14.2	14.2	14.2		390	380	-10 (-3%)
Sediment Transport-3 (Vega Hill)	S2	S2=Q2*(1+C*(54/253km^2)	10^6m^3	6.9	6.9	6.9	6.9				
Deposit Volume (Downstream)	V1	V1=S2-S1	10^6m^3	5.6	5.6	5.6	5.6		98	91	-7 (-7%)
Sediment Transport-4 (Maculcol Bridge)	S1	S1=Q1=3.0	10^6m^3	1.3	1.3	1.3	1.3				
								Total	748	731	-17 (-2%)

Sediment Transport Volume by Brown's Formula (Muddy Water) $Qb = 10*((U*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$

Site	Catchment Area	Bed Slope	Grain Size	Transport Volume by Brown's Formula			Adjustment Factor
Upstream	54 km^2	1/40	0.80 mm	Q4=	25.2	* 10^6 m^3 /yr	0.85
Mt.Bagang	91 km^2	1/60	0.70 mm	Q3=	21.1	* 10^6 m^3 /yr	0.70
Vega Hill	253 km^2	1/130	0.70 mm	Q2=	6.9	* 10^6 m^3 /yr	0.35
Maculcol Bridge	262 km^2	1/580	0.35 mm	Q1=	1.3	* 10^6 m^3 /yr	0.40

Table 2.2.2 Calibration of Sediment Delivery in the Bucao River after Eruption (1991-2001)

Item	Symbol	Equation	Unit	Year						
				1991	1992	1993	1994	1995	1996	1997
Sediment Delivery in Bucao River System	St	Actual Lahar Volume	10^6m^3	250.0	230.0	250.0	95.0	65.0	70.0	50.0
Sediment Transport (Upper Bucao)	S3	S3 = St * 0.3	10^6m^3	75.0	69.0	75.0	28.5	19.5	21.0	15.0
Coefficient for Modification	C1	C1=S3/Q3-1 (C>0)		2.39	2.12	2.39	0.29	0.00	0.00	0.00
Deposit Volume (Bucao Middle Reaches)	V2	V2=S3-S2	10^6m^3	75.0	69.0	75.0	28.5	19.5	21.0	15.0
Sediment Transport (Middle Bucao)	S2	S2=Q2*(1+C1*(97/309km^2)	10^6m^3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sediment Transport (Upper Balin Buquero)	S5	S5 = St * 0.7	10^6m^3	175.0	161.0	175.0	66.5	45.5	49.0	35.0
Coefficient for Modification	C2	C2=S5/Q5-1 (C>0)		6.45	5.85	6.45	1.83	0.94	1.09	0.49
Deposit Volume (Balin Buquero River)	V3	V3=S5-S4	10^6m^3	98.4	90.3	98.4	34.8	22.5	24.5	16.3
Sediment Transport (Lower Balin Buquero)	S4	S4=Q4*(1+C2*(151/216km^2)	10^6m^3	76.6	70.7	76.6	31.7	23.0	24.5	18.7
Deposit Volume (Downstream)	V1	V1=S2+S4-S1	10^6m^3	52.6	46.7	52.6	7.7	-1.0	0.5	-5.3
Sediment Transport (Bucao Bridge)	S1	S1=Q1=20.6	10^6m^3	24.0	24.0	24.0	24.0	24.0	24.0	24.0

Item	Symbol	Equation	Unit	Year					Deposit in 2001		Difference
				1998	1999	2000	2001		Actual	Simulated	
Sediment Delivery in Bucao River System	St	Actual Lahar Volume	10^6m^3	39.0	32.0	26.0	20.0				
Sediment Transport (Upper Bucao)	S3	S3 = St * 0.3	10^6m^3	11.7	9.6	7.8	6.0				
Coefficient for Modification	C1	C1=S3/Q3-1 (C>0)		0.00	0.00	0.00	0.00				
Deposit Volume (Bucao Middle Reaches)	V2	V2=S3-S2	10^6m^3	11.7	9.6	7.8	6.0		324	338	14 (+4%)
Sediment Transport (Middle Bucao)	S2	S2=Q2*(1+C1*(97/309km^2)	10^6m^3	0.0	0.0	0.0	0.0				
Sediment Transport (Upper Balin Buquero)	S5	S5 = St * 0.7	10^6m^3	27.3	22.4	18.2	14.0				
Coefficient for Modification	C2	C2=S5/Q5-1 (C>0)		0.16	0.00	0.00	0.00				
Deposit Volume (Balin Buquero River)	V3	V3=S5-S4	10^6m^3	11.8	8.5	4.3	0.1		400	410	10 (+2%)
Sediment Transport (Lower Balin Buquero)	S4	S4=Q4*(1+C2*(151/216km^2)	10^6m^3	15.5	13.9	13.9	13.9				
Deposit Volume (Downstream)	V1	V1=S2+S4-S1	10^6m^3	-8.5	-10.1	-10.1	-10.1		118	115	-3 (-3%)
Sediment Transport (Bucao Bridge)	S1	S1=Q1=20.6	10^6m^3	24.0	24.0	24.0	24.0				
								Total	842	863	-2 (-0.2%)

Sediment Transport Volume by Brown's Formula (Muddy Water) $Qb = 10*((U^*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$

Bucao Bridge(655 km^2)	Middle Bucao(309 km^2)	Upper Bucao(97 km^2)	Lower Balin Buquero(216 km^2)	Upper Balin Buquero(151 km^2)
Q1= 24.0 *10^6	Q2= 27.1 *10^6	Q3= 22.1 *10^6	Q4= 13.9 *10^6 m^3/yr	Q5= 23.5 *10^6 m^3/yr
I=1/300 m^3/yr	I=1/150 m^3/yr	I=1/60 m^3/yr	I=1/150	I=1/80
Adjustment factor 0.60	0.60	0.70	0.50	0.70

Table 2.3.1 Sediment Transport Calculation for the Bucao River (Bucao Bridge)

River = Bucao   Point = Bucao Bridge   Catchment Area = 655 km^2

Item	Symbol	Unit	Duration Days / Year										Total / Year
			1	10	20	30	50	100	150	200	250	365	
Flow Discharge	Q	m^3/s	518	302	186	121	72	42	28	11	7	6	
Grain Size of Riverbed	D	cm	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	
Critical Tractive Force	$(U_{*c})^2$	m^2/s^2	0.00027	0.00027	0.00027	0.00027	0.00027	0.00027	0.00027	0.00027	0.00027	0.00027	
Constant	g*s*d	m^2/s^2	0.00549	0.00549	0.00549	0.00549	0.00549	0.00549	0.00549	0.00549	0.00549	0.00549	
River Width	Bo	m	300	300	300	300	300	300	300	300	300	300	
Bed Slope	I	(1/250)	0.00400	0.00400	0.00400	0.00400	0.00400	0.00400	0.00400	0.00400	0.00400	0.00400	
Flow Width	B	m	159	122	95	77	59	45	37	23	19	17	
Flow Depth	H	m	1.297	1.103	0.954	0.838	0.717	0.610	0.540	0.408	0.357	0.340	
Flow Velocity	v	m/s	2.507	2.251	2.043	1.874	1.690	1.517	1.399	1.160	1.060	1.028	
Tractive Force	$(U_*)^2$	m^2/s^2	0.05084	0.04324	0.03739	0.03286	0.02812	0.02393	0.02119	0.01601	0.01398	0.01335	
Sediment Discharge	Qb	m^3/s	10.788	5.496	2.999	1.752	0.916	0.467	0.281	0.087	0.050	0.041	
Sediment Concentration	Cb=Qb/Q	%	2.08	1.82	1.61	1.45	1.27	1.11	1.00	0.80	0.71	0.68	
Days to represent	N	days	2	13	10	15	35	50	50	50	50	90	365
Sediment Volume	Vo	$1000\ m^3$	3,107	10,288	4,318	3,785	4,615	3,360	2,025	630	358	532	33,018

Note : Brown's Formula $Qb = 10*((U_*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$ (if $U_* < U_{*c}$ then Qb=0)

Critical Tractive Force $(U_{*c})^2 = 8.41D^{11/32} /10{,}000$ for $0.0065cm < D < 0.0565cm$

$(U_{*c})^2 = 55.0*D/10{,}000$ for $0.0565cm < D < 0.118cm$

Specific Gravity of Grain S = 2.6, s = S - 1 = 1.6

Gravity Acceleration $g = 9.8\ m/sec^2$

Roughness n = 0.030

Grain Size d = D/100 (unit : m)

Flow Width $B = 7 * Q^{0.5}$ (if B>Bo then B=Bo)

$H = (n*Q/B/I^{0.5})^{0.6}$

$v = H^{2/3}*I^{0.5} / n$

$(U_*)^2 = 9.8*H*I$

Vo = Qb * N * 86.4

Porosity = 0.40

Adjustment Factor= 0.60

Table 2.3.2 Sediment Transport Calculation for the Bucao River (Middle Bucao)

River = Bucao Point = Middle Bucao Catchment Area = 309 km^2

Item	Symbol	Unit	Duration Days / Year										Total / Year
			1	10	20	30	50	100	150	200	250	365	
Flow Discharge	Q	m^3/s	201	117	72	47	28	16	11	4	3	2	
Grain Size of Riverbed	D	cm	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	
Critical Tractive Force	$(U_{*c})^2$	m^2/s^2	0.00028	0.00028	0.00028	0.00028	0.00028	0.00028	0.00028	0.00028	0.00028	0.00028	
Constant	g*s*d	m^2/s^2	0.00627	0.00627	0.00627	0.00627	0.00627	0.00627	0.00627	0.00627	0.00627	0.00627	
River Width	Bo	m	300	300	300	300	300	300	300	300	300	300	
Bed Slope	I	(1/120)	0.00833	0.00833	0.00833	0.00833	0.00833	0.00833	0.00833	0.00833	0.00833	0.00833	
Flow Width	B	m	99	76	59	48	37	28	23	14	12	10	
Flow Depth	H	m	0.783	0.666	0.576	0.507	0.434	0.367	0.328	0.242	0.222	0.196	
Flow Velocity	v	m/s	2.586	2.320	2.106	1.934	1.743	1.559	1.446	1.181	1.115	1.028	
Tractive Force	$(U_*)^2$	m^2/s^2	0.06397	0.05438	0.04701	0.04137	0.03541	0.02994	0.02676	0.01975	0.01812	0.01604	
Sediment Discharge	Qb	m^3/s	10.444	5.310	2.894	1.698	0.889	0.442	0.276	0.078	0.054	0.033	
Sediment Concentration	Cb=Qb/Q	%	5.20	4.54	4.02	3.61	3.17	2.76	2.51	1.95	1.82	1.64	
Days to represent	N	days	2	13	10	15	35	50	50	50	50	90	365
Sediment Volume	Vo=Qb*N	1000 m^3	3,008	9,940	4,168	3,668	4,480	3,180	1,990	562	392	425	31,813

Note : Brown's Formula $Qb = 10*((U_*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$ (if $U_* < U_{*c}$ then Qb=0)

Critical Tractive Force $(U_{*c})^2 = 8.41D^{11/32} /10{,}000$ for $0.0065\text{cm} < D < 0.0565\text{cm}$

$(U_{*c})^2 = 55.0*D/10{,}000$ for $0.0565\text{cm} < D < 0.118\text{cm}$

Specific Gravity of Grain S = 2.6, s = S - 1 = 1.6

Gravity Acceleration $g = 9.8\ \text{m/sec}^2$

Roughness n = 0.030

Grain Size d = D/100 (unit : m)

Flow Width $B = 7 * Q^{0.5}$ (if B>Bo then B=Bo)

$H = (n*Q/B/I^{0.5})^{0.6}$

$v = H^{2/3}*I^{0.5} / n$

$(U_*)^2 = 9.8*H*I$

$Vo = Qb * N * 86.4$

Porosity = 0.40

Adjustment Factor= 0.50

Table 2.3.3 Sediment Transport Calculation for the Bucao River (Upper Bucao)

River = Bucao Point = Upper Bucao Catchment Area = 97 km^2

Item	Symbol	Unit	Duration Days / Year										Total / Year
			1	10	20	30	50	100	150	200	250	365	
Flow Discharge	Q	m^3/s	89	52	32	21	12	7	5	2	1	1	
Grain Size of Riverbed	D	cm	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	
Critical Tractive Force	$(U_{*c})^2$	m^2/s^2	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	
Constant	g*s*d	m^2/s^2	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	
River Width	Bo	m	300	300	300	300	300	300	300	300	300	300	
Bed Slope	I	(1/80)	0.01250	0.01250	0.01250	0.01250	0.01250	0.01250	0.01250	0.01250	0.01250	0.01250	
Flow Width	B	m	66	50	40	32	24	19	16	10	7	7	
Flow Depth	H	m	0.543	0.462	0.400	0.352	0.298	0.253	0.229	0.174	0.141	0.141	
Flow Velocity	v	m/s	2.481	2.228	2.022	1.859	1.662	1.492	1.395	1.161	1.011	1.011	
Tractive Force	$(U_*)^2$	m^2/s^2	0.06654	0.05663	0.04896	0.04315	0.03648	0.03103	0.02805	0.02131	0.01731	0.01731	
Sediment Discharge	Qb	m^3/s	4.383	2.239	1.220	0.721	0.358	0.183	0.120	0.038	0.016	0.016	
Sediment Concentration	Cb=Qb/Q	%	4.92	4.31	3.81	3.43	2.98	2.61	2.40	1.91	1.60	1.60	
Days to represent	N	days	2	13	10	15	35	50	50	50	50	90	365
Sediment Volume	Vo=Qb*N	1000 m^3	1,262	4,192	1,757	1,557	1,805	1,315	863	275	115	208	13,348

Note : Brown's Formula $Qb = 10*((U_*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$ (if $U_* < U_{*c}$ then Qb=0)

Critical Tractive Force $(U_{*c})^2 = 8.41D^{11/32} /10,000$ for $0.0065cm < D < 0.0565cm$

$(U_{*c})^2 = 55.0*D/10,000$ for $0.0565cm < D < 0.118cm$

Specific Gravity of Grain S = 2.6, s = S - 1 = 1.6

Gravity Acceleration g = 9.8 m/sec^2

Roughness n = 0.030

Grain Size d = D/100 (unit : m)

Flow Width $B = 7 * Q^{0.5}$ (if B>Bo then B=Bo)

$H = (n*Q/B/I^{0.5})^{0.6}$

$v = H^{2/3}*I^{0.5} / n$

$(U_*)^2 = 9.8*H*I$

Vo = Qb * N * 86.4

Porosity = 0.40

Adjustment Factor= 0.70

Table 2.3.4 Sediment Transport Calculation for the Bucao River (Lower Balin Baquero)

River = Bucao Point = Lower Balin Buquero Catchment Area = 216 km^2

Item	Symbol	Unit	Duration Days / Year										Total / Year
			1	10	20	30	50	100	150	200	250	365	
Flow Discharge	Q	m^3/s	140	82	50	33	20	11	8	3	2	2	
Grain Size of Riverbed	D	cm	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	
Critical Tractive Force	$(U_{*c})^2$	m^2/s^2	0.00028	0.00028	0.00028	0.00028	0.00028	0.00028	0.00028	0.00028	0.00028	0.00028	
Constant	g*s*d	m^2/s^2	0.00627	0.00627	0.00627	0.00627	0.00627	0.00627	0.00627	0.00627	0.00627	0.00627	
River Width	Bo	m	300	300	300	300	300	300	300	300	300	300	
Bed Slope	I	(1/100)	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	
Flow Width	B	m	83	63	49	40	31	23	20	12	10	10	
Flow Depth	H	m	0.665	0.567	0.489	0.431	0.371	0.310	0.282	0.210	0.186	0.186	
Flow Velocity	v	m/s	2.540	2.283	2.068	1.903	1.721	1.527	1.433	1.178	1.086	1.086	
Tractive Force	$(U_*)^2$	m^2/s^2	0.06520	0.05554	0.04788	0.04227	0.03637	0.03040	0.02763	0.02059	0.01823	0.01823	
Sediment Discharge	Qb	m^3/s	9.143	4.685	2.524	1.502	0.803	0.380	0.255	0.075	0.045	0.045	
Sediment Concentration	Cb=Qb/Q	%	6.53	5.71	5.05	4.55	4.02	3.46	3.19	2.50	2.26	2.26	
Days to represent	N	days	2	13	10	15	35	50	50	50	50	90	365
Sediment Volume	Vo=Qb*N	1000 m^3	2,633	8,770	3,635	3,243	4,047	2,738	1,840	540	325	585	28,357

Note : Brown's Formula $Qb = 10*((U_*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$ (if $U_* < U_{*c}$ then Qb=0)

Critical Tractive Force $(U_{*c})^2 = 8.41D^{11/32} /10{,}000$ for $0.0065cm < D < 0.0565cm$

$(U_{*c})^2 = 55.0*D/10{,}000$ for $0.0565cm < D < 0.118cm$

Specific Gravity of Grain S = 2.6, s = S - 1 = 1.6

Gravity Acceleration g = 9.8 m/sec^2

Roughness n = 0.030

Grain Size d = D/100 (unit : m)

Flow Width $B = 7 * Q^{0.5}$ (if B>Bo then B=Bo)

$H = (n*Q/B/I^{0.5})^{0.6}$

$v = H^{2/3}*I^{0.5} / n$

$(U_*)^2 = 9.8*H*I$

Vo = Qb * N * 86.4

Porosity = 0.40

Adjustment Factor= 0.50

Table 2.3.5 Sediment Transport Calculation for the Bucao River (Upper Balin Baquero)

River = Bucao   Point = Upper Balin Buquero   Catchment Area = 151 km^2

Item	Symbol	Unit	Duration Days / Year										Total / Year
			1	10	20	30	50	100	150	200	250	365	
Flow Discharge	Q	m^3/s	139	81	50	32	19	11	8	3	2	2	
Grain Size of Riverbed	D	cm	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	
Critical Tractive Force	$(U_{*c})^2$	m^2/s^2	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	
Constant	g*s*d	m^2/s^2	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	
River Width	Bo	m	300	300	300	300	300	300	300	300	300	300	
Bed Slope	I	(1/90)	0.01111	0.01111	0.01111	0.01111	0.01111	0.01111	0.01111	0.01111	0.01111	0.01111	
Flow Width	B	m	83	63	49	40	31	23	20	12	10	10	
Flow Depth	H	m	0.643	0.547	0.473	0.414	0.354	0.301	0.273	0.204	0.180	0.180	
Flow Velocity	v	m/s	2.618	2.350	2.134	1.952	1.759	1.576	1.479	1.216	1.121	1.121	
Tractive Force	$(U_*)^2$	m^2/s^2	0.07004	0.05957	0.05154	0.04508	0.03856	0.03273	0.02974	0.02216	0.01962	0.01962	
Sediment Discharge	Qb	m^3/s	6.227	3.170	1.735	0.993	0.518	0.261	0.176	0.052	0.031	0.031	
Sediment Concentration	Cb=Qb/Q	%	4.48	3.91	3.47	3.10	2.72	2.38	2.19	1.72	1.55	1.55	
Days to represent	N	days	2	13	10	15	35	50	50	50	50	90	365
Sediment Volume	Vo=Qb*N	1000 m^3	1,793	5,935	2,498	2,145	2,608	1,882	1,263	372	223	402	19,122

Note : Brown's Formula $Qb = 10*((U_*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$ (if $U_* < U_{*c}$ then Qb=0)

Critical Tractive Force $(U_{*c})^2 = 8.41D^{11/32} /10{,}000$ for $0.0065\text{cm} < D < 0.0565\text{cm}$

$(U_{*c})^2 = 55.0*D/10{,}000$ for $0.0565\text{cm} < D < 0.118\text{cm}$

Specific Gravity of Grain S = 2.6, s = S - 1 = 1.6

Gravity Acceleration g = 9.8 m/sec^2

Roughness n = 0.030

Grain Size d = D/100 (unit : m)

Flow Width $B = 7 * Q^{0.5}$ (if B>Bo then B=Bo)

$H = (n*Q/B/I^{0.5})^{0.6}$

$v = H^{2/3}*I^{0.5} / n$

$(U_*)^2 = 9.8*H*I$

Vo = Qb * N * 86.4

Porosity = 0.40

Adjustment Factor= 0.70

Table 2.3.6 Sediment Transport Calculation for the Maloma River (Maloma Bridge)

River = Maloma Point = Maloma Bridge Catchment Area = 152 km^2

Item	Symbol	Unit	Duration Days / Year										Total / Year
			1	10	20	30	50	100	150	200	250	365	
Flow Discharge	Q	m^3/s	199	116	72	46	28	16	11	4	3	2	
Grain Size of Riverbed	D	cm	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	
Critical Tractive Force	$(U_{*c})^2$	m^2/s^2	0.00033	0.00033	0.00033	0.00033	0.00033	0.00033	0.00033	0.00033	0.00033	0.00033	
Constant	g*s*d	m^2/s^2	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	
River Width	Bo	m	90	90	90	90	90	90	90	90	90	90	
Bed Slope	I	(1/700)	0.00143	0.00143	0.00143	0.00143	0.00143	0.00143	0.00143	0.00143	0.00143	0.00143	
Flow Width	B	m	90	75	59	47	37	28	23	14	12	10	
Flow Depth	H	m	1.401	1.127	0.977	0.854	0.736	0.622	0.556	0.411	0.377	0.333	
Flow Velocity	v	m/s	1.578	1.365	1.241	1.134	1.027	0.918	0.852	0.696	0.657	0.606	
Tractive Force	$(U_*)^2$	m^2/s^2	0.01962	0.01578	0.01368	0.01196	0.01030	0.00871	0.00779	0.00575	0.00527	0.00467	
Sediment Discharge	Qb	m^3/s	0.329	0.160	0.088	0.050	0.027	0.013	0.008	0.002	0.002	0.001	
Sediment Concentration	Cb=Qb/Q	%	0.17	0.14	0.12	0.11	0.10	0.08	0.08	0.06	0.06	0.05	
Days to represent	N	days	2	13	10	15	35	50	50	50	50	90	365
Sediment Volume	Vo	1000 m^3	95	300	127	108	137	97	60	17	12	13	965

Note : Brown's Formula $Qb = 10*((U_*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$ (if $U_* < U_{*c}$ then Qb=0)

Critical Tractive Force $(U_{*c})^2 = 8.41D^{11/32} /10,000$ for $0.0065cm < D < 0.0565cm$

$(U_{*c})^2 = 55.0*D/10,000$ for $0.0565cm < D < 0.118cm$

Specific Gravity of Grain S = 2.6, s = S - 1 = 1.6

Gravity Acceration $g = 9.8$ m/sec^2

Roughness n = 0.030

Grain Size d = D/100 (unit : m)

Flow Width $B = 7 * Q^{0.5}$ (if B>Bo then B=Bo)

$H = (n*Q/B/I^{0.5})^{0.6}$

$v = H^{2/3}*I^{0.5} / n$

$(U_*)^2 = 9.8*H*I$

Vo = Qb * N * 86.4

Porosity = 0.40

Table 2.3.7 Sediment Transport Calculation for the Maloma River (Middle Maloma)

River = Maloma Point = Middle Maloma Catchment Area = 99 km^2

Item	Symbol	Unit	Duration Days / Year										Total / Year
			1	10	20	30	50	100	150	200	250	365	
Flow Discharge	Q	m^3/s	130	76	47	30	18	10	7	3	2	1	
Grain Size of Riverbed	D	cm	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	
Critical Tractive Force	$(U_{*c})^2$	m^2/s^2	0.00032	0.00032	0.00032	0.00032	0.00032	0.00032	0.00032	0.00032	0.00032	0.00032	
Constant	g*s*d	m^2/s^2	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	
River Width	Bo	m	100	100	100	100	100	100	100	100	100	100	
Bed Slope	I	(1/500)	0.00200	0.00200	0.00200	0.00200	0.00200	0.00200	0.00200	0.00200	0.00200	0.00200	
Flow Width	B	m	80	61	48	38	30	22	19	12	10	7	
Flow Depth	H	m	1.055	0.898	0.777	0.679	0.583	0.489	0.439	0.340	0.301	0.245	
Flow Velocity	v	m/s	1.544	1.387	1.260	1.152	1.040	0.925	0.861	0.727	0.670	0.583	
Tractive Force	$(U_*)^2$	m^2/s^2	0.02067	0.01760	0.01523	0.01331	0.01142	0.00958	0.00860	0.00667	0.00591	0.00480	
Sediment Discharge	Qb	m^3/s	0.332	0.170	0.093	0.053	0.028	0.013	0.009	0.003	0.002	0.001	
Sediment Concentration	Cb=Qb/Q	%	0.26	0.22	0.20	0.18	0.16	0.13	0.12	0.10	0.09	0.08	
Days to represent	N	days	2	13	10	15	35	50	50	50	50	90	365
Sediment Volume	Vo	1000 m^3	95	318	133	115	142	97	62	22	13	10	1,007

Note : Brown's Formula $Qb = 10*((U_*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$ (if $U_* < U_{*c}$ then Qb=0)

Critical Tractive Force $(U_{*c})^2 = 8.41D^{11/32} /10,000$ for $0.0065cm < D < 0.0565cm$

$(U_{*c})^2 = 55.0*D/10,000$ for $0.0565cm < D < 0.118cm$

Specific Gravity of Grain S = 2.6, s = S - 1 = 1.6

Gravity Acceration $g = 9.8 m/sec^2$

Roughness n = 0.030

Grain Size d = D/100 (unit : m)

Flow Width $B = 7 * Q^{0.5}$ (if B>Bo then B=Bo)

$H = (n*Q/B/I^{0.5})^{0.6}$

$v = H^{2/3}*I^{0.5} / n$

$(U_*)^2 = 9.8*H*I$

$Vo = Qb * N * 86.4$

Porosity = 0.40

Table 2.3.8 Sediment Transport Calculation for the Maloma River (Gorongoro River)

River = Maloma Point = Gorongoro River Catchment Area = 42 km^2

Item	Symbol	Unit	Duration Days / Year										Total / Year
			1	10	20	30	50	100	150	200	250	365	
Flow Discharge	Q	m^3/s	55	32	20	13	8	4	3	1	1	1	
Grain Size of Riverbed	D	cm	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	
Critical Tractive Force	$(U_{*c})^2$	m^2/s^2	0.00032	0.00032	0.00032	0.00032	0.00032	0.00032	0.00032	0.00032	0.00032	0.00032	
Constant	g*s*d	m^2/s^2	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	0.00941	
River Width	Bo	m	100	100	100	100	100	100	100	100	100	100	
Bed Slope	I	(1/550)	0.00182	0.00182	0.00182	0.00182	0.00182	0.00182	0.00182	0.00182	0.00182	0.00182	
Flow Width	B	m	52	40	31	25	20	14	12	7	7	7	
Flow Depth	H	m	0.838	0.713	0.619	0.544	0.470	0.382	0.350	0.252	0.252	0.252	
Flow Velocity	v	m/s	1.264	1.134	1.032	0.947	0.859	0.748	0.706	0.567	0.567	0.567	
Tractive Force	$(U_*)^2$	m^2/s^2	0.01494	0.01270	0.01103	0.00969	0.00838	0.00680	0.00624	0.00449	0.00449	0.00449	
Sediment Discharge	Qb	m^3/s	0.096	0.049	0.027	0.016	0.009	0.004	0.003	0.001	0.001	0.001	
Sediment Concentration	Cb=Qb/Q	%	0.17	0.15	0.14	0.12	0.11	0.09	0.08	0.06	0.06	0.06	
Days to represent	N	days	2	13	10	15	35	50	50	50	50	90	365
Sediment Volume	Vo	1000 m^3	28	92	38	35	43	27	18	5	5	8	300

Note : Brown's Formula $Qb = 10*((U_*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$ (if $U_* < U_{*c}$ then Qb=0)

Critical Tractive Force $(U_{*c})^2 = 8.41D^{11/32} /10,000$ for $0.0065cm < D < 0.0565cm$

$(U_{*c})^2 = 55.0*D/10,000$ for $0.0565cm < D < 0.118cm$

Specific Gravity of Grain S = 2.6, s = S - 1 = 1.6

Gravity Acceration $g = 9.8\ m/sec^2$

Roughness n = 0.030

Grain Size d = D/100 (unit : m)

Flow Width $B = 7 * Q^{0.5}$ (if B>Bo then B=Bo)

$H = (n*Q/B/I^{0.5})^{0.6}$

$v = H^{2/3}*I^{0.5} / n$

$(U_*)^2 = 9.8*H*I$

$Vo = Qb * N * 86.4$

Porosity = 0.40

Table 2.3.9 Sediment Transport Calculation for the Sto.Tomas River (Maculcol Bridge)

River = Sto.Tomas Point = Maculcol Bridge Catchment Area = 262 km^2

Item	Symbol	Unit	Duration Days / Year										Total / Year
			1	10	20	30	50	100	120	200	250	365	
Adjusted Flow Discharge	Qt'	m^3/s	139	81	50	32	19	11	10				
Grain Size of Riverbed	D	cm	0.035	0.035	0.035	0.035	0.035	0.035					
Critical Tractive Force	$(U_{*c})^2$	m^2/s^2	0.00027	0.00027	0.00027	0.00027	0.00027	0.00027					
Constant	g*s*d	m^2/s^2	0.00549	0.00549	0.00549	0.00549	0.00549	0.00549					
River Width	Bo	m	400	400	400	400	400	400					
Bed Slope	I	(1/320)	0.00313	0.00313	0.00313	0.00313	0.00313	0.00313					
Flow Width	B	m	83	63	49	40	31	23					
Flow Depth	H	m	0.941	0.800	0.693	0.606	0.518	0.440					
Flow Velocity	v	m/s	1.790	1.606	1.459	1.334	1.202	1.078					
Tractive Force	$(U_*)^2$	m^2/s^2	0.02882	0.02451	0.02121	0.01855	0.01587	0.01347					
Sediment Discharge	Qb	m^3/s	1.353	0.689	0.377	0.216	0.112	0.057	0.000				
Sediment Concentration	Cb=Qb/Qt'	%	0.97	0.85	0.75	0.67	0.59	0.52					
Days to represent	N	days	2	13	10	15	35	35	10				120
Sediment Volume	Vo	1000 m3	390	1,290	543	467	567	287	0				3,543

Note : Brown's Formula $Qb = 10*((U_*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$ (if $U_* < U_{*c}$ then Qb=0)

Critical Tractive Force $(U_{*c})^2 = 8.41D^{11/32} /10{,}000$ for $0.0065cm < D < 0.0565cm$

$(U_{*c})^2 = 55.0*D/10{,}000$ for $0.0565cm < D < 0.118cm$

Specific Gravity of Grain S = 2.6, s = S - 1 = 1.6

Gravity Acceration $g = 9.8\ m/sec^2$

Roughness n = 0.030 Grain Size d = D/100 (unit : m)

Flow Width $B = 7 * Q^{0.5}$ (if B>Bo then B=Bo)

$H = (n*Q/B/I^{0.5})^{0.6}$ $v = H^{2/3}*I^{0.5} / n$ $(U_*)^2 = 9.8*H*I$

Vo = Qb * N * 86.4

Seepage Discharge = (Discharge at duration of 120 days)

120 days = Rainy days in a year at San Marcelino (average of 1991 to 2000)

Porosity = 0.40 Adjustment Factor= 0.40

Table 2.3.10 Sediment Transport Calculation for the Sto.Tomas River (Vega Hill)

River = Sto.Tomas Point = Vega Hill Catchment Area = 253 km^2

Item	Symbol	Unit	Duration Days / Year										Total / Year
			1	10	20	30	50	100	120	200	250	365	
Adjusted Flow Discharge	Qt'	m^3/s	117	68	42	27	16	9	8				
Grain Size of Riverbed	D	cm	0.070	0.070	0.070	0.070	0.070	0.070					
Critical Tractive Force	$(U_{*c})^2$	m^2/s^2	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039					
Constant	g*s*d	m^2/s^2	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098					
River Width	Bo	m	1,000	1,000	1,000	1,000	1,000	1,000					
Bed Slope	I	(1/150)	0.00667	0.00667	0.00667	0.00667	0.00667	0.00667					
Flow Width	B	m	76	58	45	36	28	21					
Flow Depth	H	m	0.712	0.605	0.524	0.459	0.392	0.330					
Flow Velocity	v	m/s	2.170	1.947	1.768	1.619	1.458	1.299					
Tractive Force	$(U_*)^2$	m^2/s^2	0.04652	0.03953	0.03421	0.02996	0.02561	0.02155					
Sediment Discharge	Qb	m^3/s	2.053	1.042	0.571	0.328	0.171	0.083	0.000				
Sediment Concentration	Cb=Qb/Q	%	1.76	1.53	1.36	1.22	1.07	0.92					
Days to represent	N	days	2	13	10	15	35	35	10				120
Sediment Volume	Vo	1000 m^3	592	1,950	822	710	860	420	0				5,353

Note : Brown's Formula $Qb = 10*((U_*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$ (if $U_* < U_{*c}$ then Qb=0)

Critical Tractive Force $(U_{*c})^2 = 8.41D^{11/32} /10,000$ for 0.0065cm < D < 0.0565cm

$(U_{*c})^2 = 55.0*D/10,000$ for 0.0565cm < D < 0.118cm

Specific Gravity of Grain S = 2.6, s = S - 1 = 1.6

Gravity Acceration g = 9.8 m/sec^2

Roughness n = 0.030

Grain Size d = D/100 (unit : m)

Flow Width $B = 7 * Q^{0.5}$ (if B>Bo then B=Bo)

$H = (n*Q/B/I^{0.5})^{0.6}$

$v = H^{2/3}*I^{0.5} / n$

$(U_*)^2 = 9.8*H*I$

Vo = Qb * N * 86.4

Seepage Discharge = (Discharge at duration of 120 days)

120 days = Rainy days in a year at San Marcelino (average of 1991 to 2000)

Porosity = 0.40 Adjustment Factor= 0.35

Table 2.3.11 Sedimemt Transport Calculation for the Sto.Tomas River (Mt.Bagang)

River = Sto.Tomas Point = Mt.Bagang Catchment Area = 91 km^2 (After 1993)

Item	Symbol	Unit	Duration Days / Year										Total / Year
			1	10	20	30	50	100	150	200	250	365	
Flow Discharge	Q	m^3/s	84	49	30	20	12	7	5	2	1	1	
Grain Size of Riverbed	D	cm	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	
Critical Tractive Force	$(U_{*c})^2$	m^2/s^2	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	0.00039	
Constant	g*s*d	m^2/s^2	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	
River Width	Bo	m	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	
Bed Slope	I	(1/70)	0.01429	0.01429	0.01429	0.01429	0.01429	0.01429	0.01429	0.01429	0.01429	0.01429	
Flow Width	B	m	64	49	38	31	24	19	16	10	7	7	
Flow Depth	H	m	0.513	0.436	0.377	0.333	0.286	0.243	0.220	0.167	0.136	0.136	
Flow Velocity	v	m/s	2.553	2.292	2.078	1.916	1.730	1.553	1.452	1.209	1.052	1.052	
Tractive Force	$(U_*)^2$	m^2/s^2	0.07181	0.06108	0.05272	0.04669	0.04005	0.03407	0.03080	0.02340	0.01901	0.01901	
Sediment Discharge	Qb	m^3/s	5.150	2.626	1.422	0.857	0.452	0.231	0.151	0.048	0.020	0.020	
Sediment Concentration	Cb=Qb/Q	%	6.13	5.36	4.74	4.28	3.77	3.29	3.03	2.41	2.03	2.03	
Days to represent	N	days	2	13	10	15	35	50	50	50	50	90	365
Sediment Volume	Vo	1000 m^3	1,483	4,915	2,048	1,850	2,280	1,660	1,090	347	145	262	16,080

Note : Brown's Formula $Qb = 10*((U_*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$ (if $U_* < U_{*c}$ then Qb=0)

Critical Tractive Force $(U_{*c})^2 = 8.41D^{11/32} /10{,}000$ for $0.0065cm < D < 0.0565cm$

$(U_{*c})^2 = 55.0*D/10{,}000$ for $0.0565cm < D < 0.118cm$

Specific Gravity of Grain S = 2.6, s = S - 1 = 1.6

Gravity Acceration $g = 9.8$ m/sec^2

Roughness n = 0.030

Grain Size d = D/100 (unit : m)

Flow Width $B = 7 * Q^{0.5}$ (if B>Bo then B=Bo)

$H = (n*Q/B/I^{0.5})^{0.6}$

$v = H^{2/3}*I^{0.5} / n$

$(U_*)^2 = 9.8*H*I$

$Vo = Qb * N * 86.4$

Porosity = 0.40

Adjustment Factor= 0.70

Table 2.3.12 Sediment Transport Calculation for the Sto.Tomas River (Upper Marella)

River = Sto.Tomas Point = Upper Marella Catchment Area = 54 km^2

Item	Symbol	Unit	Duration Days / Year										Total / Year
			1	10	20	30	50	100	150	200	250	365	
Flow Discharge	Q	m^3/s	60	35	22	14	10	5	3	1	1	1	
Grain Size of Riverbed	D	cm	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	
Critical Tractive Force	$(U_{*c})^2$	m^2/s^2	0.00044	0.00044	0.00044	0.00044	0.00044	0.00044	0.00044	0.00044	0.00044	0.00044	
Constant	g*s*d	m^2/s^2	0.01254	0.01254	0.01254	0.01254	0.01254	0.01254	0.01254	0.01254	0.01254	0.01254	
River Width	Bo	m	600	600	600	600	600	600	600	600	600	600	
Bed Slope	I	(1/40)	0.02500	0.02500	0.02500	0.02500	0.02500	0.02500	0.02500	0.02500	0.02500	0.02500	
Flow Width	B	m	54	41	33	26	22	16	12	7	7	7	
Flow Depth	H	m	0.392	0.333	0.290	0.253	0.229	0.186	0.160	0.115	0.115	0.115	
Flow Velocity	v	m/s	2.823	2.534	2.310	2.110	1.973	1.717	1.551	1.245	1.245	1.245	
Tractive Force	$(U_*)^2$	m^2/s^2	0.09604	0.08170	0.07108	0.06206	0.05610	0.04557	0.03910	0.02812	0.02812	0.02812	
Sediment Discharge	Qb	m^3/s	7.880	4.017	2.248	1.278	0.839	0.353	0.186	0.047	0.047	0.047	
Sediment Concentration	Cb=Qb/Q	%	13.13	11.48	10.22	9.13	8.39	7.06	6.21	4.72	4.72	4.72	
Days to represent	N	days	2	13	10	15	35	50	50	50	50	90	365
Sediment Volume	Vo	1000 m^3	2,270	7,520	3,237	2,760	4,228	2,540	1,342	340	340	612	25,188

Note : Brown's Formula $Qb = 10*((U_*)^2/(g*s*d))^{2.5} *(g*s*d)^{0.5} *d*B$ (if $U_* < U_{*c}$ then Qb=0)

Critical Tractive Force $(U_{*c})^2 = 8.41D^{11/32} /10,000$ for $0.0065cm < D < 0.0565cm$

$(U_{*c})^2 = 55.0*D/10,000$ for $0.0565cm < D < 0.118cm$

Specific Gravity of Grain S = 2.6, s = S - 1 = 1.6

Gravity Acceration $g = 9.8$ m/sec^2

Roughness n = 0.030

Grain Size d = D/100 (unit : m)

Flow Width $B = 7 * Q^{0.5}$ (if B>Bo then B=Bo)

$H = (n*Q/B/I^{0.5})^{0.6}$

$v = H^{2/3}*I^{0.5} / n$

$(U_*)^2 = 9.8*H*I$

$Vo = Qb * N * 86.4$

Porosity = 0.40

Adjustment Factor= 0.85

Table 3.2.1 Conditions for Two-Dimensional Mudflow Analysis

Conditions	**Bucao River**	**Sto. Tomas River**	**Remarks**
River Conditions			
Simulated Area	6.08 km x 14.08 km (76 mesh x 176 mesh)	10.08 km x 28.08 km (126 mesh x 351 mesh)	
Unit Scale of Mesh (m)	80	80	Created from Digital Elevation Data (Scale 1:10,000)
Maximum Erosion Depth (m)	5.0	5.0	
Erosion Depth at Site of Structure (m)	0.0	0.0	
n: Roughness Coefficient	0.030	0.030	At All Meshes
Hydrograph			
Scale of Flood	20-Year Probable Flood	20-Year Probable Flood	
Duration of Hydrograph (Hour)	48	48	
Peak Discharge (m^3/s)	Bucao: 2,930 Baquilan: 920	Marella: 680 Mapanuepe Alt-1: 1,020 Mapanuepe Alt-2&3: 220	
Total Discharge (10^6 m^3)	Bucao: 245 Baquilan: 76	Marella: 43 Mapanuepe Alt-1: 43 Mapanuepe Alt-2&3: 27	
Density of Water (g/cm^3)	1.4	1.4	
Sediment Characteristics			
Specific Gravity of Sediment (g/cm^3)	2.60	2.60	
Mean Grain Size: D_{60} (mm)	0.30	0.50	
Sediment in Model	Uniform Sediment	Uniform Sediment	
Porosity of Deposited Sediment (%)	40	40	
Boundary Conditions			
Inflowig Sediment Volume (x 10^6 m^3)	Bucao: 60 Baquilan: 4	Marella: 12 Mapanuepe: 0	
Sediment Transport Formula	Brown's Formula	Brown's Formula	Total Load

Table 3.3.1 Conditions for One-Dimensional Sediment Transport Analysis

Conditions	Bucao River	Sto. Tomas River	Remarks
River Conditions			
n: Roughness Coefficient	0.035	0.035	At All Sections
Cross Sections	Survey Result in 2002	Survey Result in 2002	
Length of Reach in Model	25.4 km (Sta. -2.4 km to 23.0 km)	31.5 km (Sta. -1.5 km to 30.0 km)	
Maximum Erosion Depth (m)	30.0	30.0	
Sediment Characteristics			
Specific Gravity of Sediment (g/cm^3)	2.58	2.59	Laboratory Test (2002)
Mean Grain Size: D_{60} (mm)	0.35	0.35	Near Sta. 0.0 km
Sediment in Model	Mixed Gradation	Mixed Gradation	
Porosity of Deposited Sediment (%)	40	40	Laboratory Test (1994)
Hydrograph			
Annual Mean Discharge (m^3/s)	62.0	22.0	
Annual Runoff Coefficient (%)	68	67	
Peak Discharge in Normal Year (m^3/s)	743 (at Bucao Bridge)	264 (at Maculcol Bridge)	
Peak Discharge in Flood Year (m^3/s)	3,800 (at Bucao Bridge)	1,200 (at Maculcol Bridge)	20-Year Probable Flood
Flow Distribution for Tributaries	Balin Baquero: 0.47 Upper Bucao: 0.15 Balintawak: 0.25 Baquilan: 0.13	Marella: 0.66 Mapanuepe: 0.21 Santa Fe: 0.13	Total=1.00
Density of Water (g/cm^3)	1.0	1.0	
Boundary Conditions			
Upstream End			
Annual Inflowing Sediment Volume (x 10^6 m^3/year)	Balin Baquero: 4.0 Upper Bucao: 1.6	Marella: 2.8	Same as Estimated Sediment Yeild in 2007
Inflowing Sediment Volume during a Flood (x 10^6 m^3/day)	Balin Baquero: 17.0 Upper Bucao: 5.4	Marella: 4.7	10% of Sediment Concentration
Downstream End			
Water Depth	Critical Water Depth	Critical Water Depth	
Riverbed Elevation	Fixed at Original in 2002	Fixed at Original in 2002	
Sediment Transport Formula	Yang's Formula (1973)	Yang's Formula (1973)	Based on Unit Stream Power Theory, Total Load

Table 3.3.2 Lowest Riverbed Profile for 20 Years in the Bucao River under Present Condition (Alternative-1)

(Unit: El.m)

Station	Riverbed	Case 1				Case 2				Case 3			
km	in 2002	after 1 year	5 years	10 years	20 years	after 1 year	5 years	10 years	20 years	after 1 year	5 years	10 years	20 years
23.00	180.21	180.10	179.72	179.59	179.18	180.58	183.98	179.37	178.16	180.10	179.72	179.59	178.35
22.00	165.81	165.90	165.96	165.73	165.56	166.20	165.99	166.20	166.06	165.90	165.96	165.73	165.91
21.00	151.26	151.00	151.16	151.16	151.04	151.38	152.92	153.44	152.45	151.00	151.16	151.16	152.53
20.00	138.20	138.29	138.59	138.49	138.57	138.79	139.56	139.57	140.34	138.29	138.59	138.49	139.92
19.00	127.20	126.70	126.87	127.32	127.39	126.95	126.89	127.72	128.81	126.70	126.87	127.32	128.59
18.00	116.60	116.64	117.12	117.68	117.05	116.92	118.02	118.01	118.71	116.64	117.12	117.68	118.39
17.00	107.22	107.05	107.24	107.35	108.24	107.37	107.16	107.21	107.67	107.05	107.24	107.35	108.89
16.00	97.49	97.29	97.26	97.30	98.45	98.02	97.22	97.12	97.55	97.29	97.26	97.30	98.59
15.00	88.75	87.65	88.08	88.68	89.52	87.98	88.09	88.09	88.98	87.65	88.08	88.68	89.64
14.00	78.49	78.45	78.64	78.66	80.95	78.78	78.54	78.54	79.50	78.45	78.64	78.66	80.46
13.00	68.87	66.61	66.88	67.25	70.60	67.85	66.91	67.18	68.57	66.61	66.88	67.25	69.56
12.00	62.93	62.85	64.12	65.76	67.56	63.18	64.57	65.98	67.30	62.85	64.12	65.76	67.35
11.50	58.59	58.34	60.65	61.84	63.33	58.93	60.78	61.19	63.02	58.34	60.65	61.84	63.36
11.00	55.54	54.40	56.75	57.55	58.79	55.59	56.56	57.35	59.35	54.40	56.75	57.55	59.50
10.75	53.50	52.40	53.24	55.25	56.15	54.23	53.75	54.86	57.31	52.40	53.24	55.25	57.05
10.50	51.97	50.48	50.73	53.01	53.96	52.33	51.66	53.10	55.10	50.48	50.73	53.01	54.95
10.25	50.45	48.58	48.99	50.07	51.70	50.67	49.07	50.49	52.46	48.58	48.99	50.07	52.74
10.00	48.93	46.74	46.89	47.12	48.65	48.82	47.94	48.49	49.24	46.74	46.89	47.12	49.73
9.75	47.16	47.15	47.25	47.24	49.04	47.83	48.89	48.61	49.98	47.15	47.25	47.24	49.02
9.50	45.64	46.17	46.24	46.24	47.55	46.50	47.11	46.88	47.89	46.17	46.24	46.24	47.36
9.25	44.42	44.63	44.49	44.72	45.60	45.04	44.89	44.75	45.96	44.63	44.49	44.72	45.63
9.00	43.50	43.30	42.71	42.69	44.03	43.89	42.95	43.03	44.24	43.30	42.71	42.69	43.87
8.75	42.28	41.94	41.49	42.09	42.92	42.33	42.18	42.27	43.17	41.94	41.49	42.09	43.17
8.50	40.75	40.43	40.18	40.58	41.61	40.90	40.79	41.06	41.55	40.43	40.18	40.58	41.61
8.25	39.54	38.96	38.79	39.41	40.21	39.35	39.61	39.99	40.34	38.96	38.79	39.41	40.39
8.00	38.62	37.56	37.49	37.97	38.81	38.03	38.03	38.62	38.73	37.56	37.49	37.97	38.73
7.50	35.23	34.98	34.77	35.43	35.73	35.99	35.79	35.52	35.73	34.98	34.77	35.43	35.89
7.00	32.18	33.67	33.41	33.58	33.68	33.82	33.69	33.05	33.52	33.67	33.41	33.58	33.51
6.50	30.18	29.98	29.82	30.01	29.98	30.99	29.82	29.64	30.05	29.98	29.82	30.01	30.03
6.00	28.04	28.03	26.28	26.30	26.62	28.89	26.49	26.29	27.15	28.03	26.28	26.30	26.79
5.00	24.14	22.77	22.70	22.86	24.27	23.39	24.05	23.33	26.22	22.77	22.70	22.86	25.97
4.00	17.70	19.31	18.87	19.70	20.89	20.55	19.20	19.65	21.56	19.31	18.87	19.70	21.79
3.00	15.73	17.17	16.75	17.94	18.54	17.71	17.68	18.24	19.34	17.17	16.75	17.94	19.77
2.00	12.78	12.90	14.10	14.99	15.86	13.47	14.32	15.16	15.85	12.90	14.10	14.99	16.58
1.50	11.23	11.16	12.98	14.15	14.53	11.52	13.09	14.16	14.24	11.16	12.98	14.15	14.97
1.00	9.71	9.82	10.57	11.40	12.82	9.93	10.82	12.03	12.46	9.82	10.57	11.40	12.27
0.60	7.65	7.50	9.06	10.25	11.29	9.18	9.59	11.09	11.27	7.50	9.06	10.25	11.62
0.40	7.15	8.55	8.86	10.04	11.16	8.07	8.66	10.42	11.33	8.55	8.86	10.04	11.13
0.20	6.65	7.20	6.91	8.46	9.82	7.76	6.31	9.28	10.16	7.20	6.91	8.46	9.71
0.00	6.30	6.83	8.08	8.66	9.68	7.26	9.15	9.71	10.31	6.83	8.08	8.66	10.02
-0.20	5.97	6.42	7.00	8.48	8.89	6.86	7.11	8.43	8.84	6.42	7.00	8.48	8.95
-0.40	5.44	5.72	6.54	7.66	8.21	6.42	6.61	7.89	8.31	5.72	6.54	7.66	8.44
-0.70	4.91	4.93	5.75	6.92	7.24	5.45	5.81	6.89	7.20	4.93	5.75	6.92	7.37
-1.00	4.11	4.50	5.23	6.00	6.26	4.78	5.20	6.03	6.54	4.50	5.23	6.00	6.30
-1.50	2.77	3.15	3.79	4.09	4.69	3.38	3.64	4.38	4.54	3.15	3.79	4.09	4.51
-2.00	1.35	2.09	2.38	2.58	2.96	2.30	2.38	2.75	2.99	2.09	2.38	2.58	3.07
-2.40	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01

Table 3.3.3 Lowest Riverbed Profile for 20 Years in the Sto. Tomas River under Present Condition (Alternative-1)

(Unit: El.m)

Station	Riverbed	Case 1				Case 2				Case 3			
km	in 2002	after 1 year	5 years	10 years	20 years	after 1 year	5 years	10 years	20 years	after 1 year	5 years	10 years	20 years
30.00	292.00	286.33	280.36	275.82	273.97	286.33	279.36	276.50	273.20	286.33	280.36	275.82	273.08
29.50	278.00	275.54	270.49	267.22	266.04	275.54	269.48	269.14	265.50	275.54	270.49	267.22	266.03
29.00	262.00	261.71	259.11	255.79	255.66	261.71	259.35	258.81	254.13	261.71	259.11	255.79	255.64
28.50	248.00	247.88	244.53	244.21	243.94	247.88	247.05	244.71	244.46	247.88	244.53	244.21	243.94
28.00	235.00	234.98	233.11	232.82	232.35	234.98	233.17	232.82	232.35	234.98	233.11	232.82	232.36
27.50	226.00	224.90	223.66	222.56	221.93	224.90	223.81	222.62	221.88	224.90	223.66	222.56	221.91
27.00	214.00	213.58	213.50	213.47	213.44	213.58	213.56	213.51	213.46	213.58	213.50	213.47	213.45
26.50	206.00	206.33	206.33	206.10	205.95	206.33	206.30	206.02	205.90	206.33	206.33	206.10	205.98
26.00	200.07	199.11	198.95	198.61	198.14	199.11	198.99	198.30	197.99	199.11	198.95	198.61	198.29
25.50	191.23	191.20	191.19	191.08	190.98	191.20	191.20	191.12	190.94	191.20	191.19	191.08	190.94
25.00	185.29	185.03	184.70	184.71	184.62	185.03	184.87	184.78	184.71	185.03	184.70	184.71	184.65
24.50	178.83	177.98	177.48	177.40	177.24	177.98	177.39	177.35	177.24	177.98	177.48	177.40	177.23
24.00	172.12	170.02	170.00	169.97	169.44	170.02	170.08	170.02	169.48	170.02	170.00	169.97	169.05
23.50	162.09	161.66	161.13	160.86	160.50	161.66	161.09	161.08	160.48	161.66	161.13	160.86	160.34
23.00	152.92	152.24	152.23	152.16	152.01	152.24	152.22	152.15	152.02	152.24	152.23	152.16	152.05
22.50	144.02	142.91	142.66	142.64	142.55	142.91	142.66	142.64	142.55	142.91	142.66	142.64	142.54
22.00	134.39	132.66	132.65	132.58	132.44	132.66	132.65	132.56	132.45	132.66	132.65	132.58	132.43
21.50	124.96	124.21	124.18	124.07	123.94	124.21	124.17	124.05	123.96	124.21	124.18	124.07	123.98
21.00	113.53	113.01	113.15	113.20	113.11	113.01	113.21	113.20	113.24	113.01	113.15	113.20	113.77
20.50	107.75	108.30	108.17	108.29	108.27	108.30	108.19	108.40	108.40	108.30	108.17	108.29	108.66
20.00	104.14	103.77	103.92	103.96	103.88	103.77	103.96	104.17	104.06	103.77	103.92	103.96	103.79
19.50	100.89	100.45	99.74	99.75	99.72	100.45	99.77	99.69	99.71	100.45	99.74	99.75	99.34
19.00	97.20	97.32	96.45	96.51	96.53	97.32	96.48	96.52	96.54	97.32	96.45	96.51	96.54
18.50	93.84	91.74	91.70	91.77	91.80	91.74	91.71	91.83	91.88	91.74	91.70	91.77	91.88
18.00	87.68	87.52	87.53	87.77	87.57	87.52	87.54	87.65	87.62	87.52	87.53	87.77	87.49
17.50	84.28	84.39	84.38	84.41	84.55	84.39	84.37	84.44	84.52	84.39	84.38	84.41	84.51
17.00	79.71	79.35	78.95	79.04	79.05	79.35	78.96	79.01	79.05	79.35	78.95	79.04	79.00
16.50	75.04	74.69	74.90	74.98	75.34	74.69	74.84	75.09	75.41	74.69	74.90	74.98	75.23
16.00	71.38	71.91	71.69	71.87	71.96	71.91	71.71	72.00	71.94	71.91	71.69	71.87	72.09
15.50	68.33	69.48	68.63	68.57	69.03	69.48	68.60	68.64	68.95	69.48	68.63	68.57	69.02
15.00	65.81	66.01	65.06	65.09	65.15	66.01	65.17	65.16	65.05	66.01	65.06	65.09	65.12
14.50	62.42	62.29	61.93	61.90	62.08	62.29	61.90	61.91	62.08	62.29	61.93	61.90	62.00
14.00	59.13	59.78	58.43	58.68	58.63	59.78	58.49	58.59	58.44	59.78	58.43	58.68	58.52
13.50	56.11	55.80	55.26	55.14	54.85	55.80	55.23	54.91	54.92	55.80	55.26	55.14	54.91
13.00	52.93	52.61	52.53	52.18	52.14	52.61	52.67	52.08	52.04	52.61	52.53	52.18	52.05
12.50	50.23	50.62	49.55	49.41	49.52	50.62	49.63	49.20	49.54	50.62	49.55	49.41	49.72
12.00	47.63	47.09	46.56	46.69	46.93	47.09	46.67	46.61	46.83	47.09	46.56	46.69	46.73
11.50	44.62	44.36	43.85	43.97	44.10	44.36	43.81	44.14	44.59	44.36	43.85	43.97	44.34
11.00	42.00	42.06	41.61	41.76	41.69	42.06	41.76	41.64	41.52	42.06	41.61	41.76	41.66
10.50	40.34	39.92	39.72	39.67	39.76	39.92	39.88	39.63	39.83	39.92	39.72	39.67	40.01
10.00	37.54	37.77	37.66	37.64	37.60	37.77	37.78	37.49	37.90	37.77	37.66	37.64	37.80
9.50	35.54	34.90	35.09	35.21	35.66	34.90	35.11	35.07	35.34	34.90	35.09	35.21	35.57
9.00	33.41	33.88	33.42	33.17	33.59	33.88	33.30	32.89	33.57	33.88	33.42	33.17	33.72
8.50	31.56	31.56	31.96	31.65	31.86	31.56	31.97	31.64	31.98	31.56	31.96	31.65	32.27
8.00	30.10	29.95	30.82	30.47	30.75	29.95	30.78	30.22	30.83	29.95	30.82	30.47	31.18
7.70	28.41	28.51	29.20	29.19	29.40	28.51	29.07	29.38	29.40	28.51	29.20	29.19	29.86
7.50	27.58	28.39	28.38	27.96	28.37	28.39	28.15	28.52	28.64	28.39	28.38	27.96	28.86
7.25	26.90	27.05	27.03	26.97	28.12	27.05	27.16	27.57	28.07	27.05	27.03	26.97	27.78
7.00	26.06	25.96	25.81	25.87	26.89	25.96	26.01	26.34	26.74	25.96	25.81	25.87	26.81
6.80	25.26	25.49	25.46	25.41	26.16	25.49	25.57	25.99	26.38	25.49	25.46	25.41	26.18
6.50	24.17	24.34	24.15	24.38	24.88	24.34	24.23	24.47	24.95	24.34	24.15	24.38	24.94
6.25	23.71	23.86	23.25	23.22	24.15	23.86	23.42	23.94	24.16	23.86	23.25	23.22	24.12
6.00	22.85	22.01	22.90	22.75	23.30	22.01	22.73	23.03	23.25	22.01	22.90	22.75	23.43
5.75	22.13	22.85	20.66	21.04	21.97	22.85	21.03	21.44	22.12	22.85	20.66	21.04	22.01
5.50	21.45	20.76	21.32	20.85	21.85	20.76	21.02	21.28	21.62	20.76	21.32	20.85	21.89
5.25	20.96	20.47	20.24	20.63	21.34	20.47	20.50	20.39	20.73	20.47	20.24	20.63	21.09
5.00	19.55	19.67	19.70	19.55	20.55	19.67	19.82	19.90	19.89	19.67	19.70	19.55	20.56
4.50	18.05	18.01	18.17	18.38	19.01	18.01	18.18	18.73	19.00	18.01	18.17	18.38	19.00
4.00	16.71	16.40	16.86	17.31	17.60	16.40	16.94	17.70	17.68	16.40	16.86	17.31	17.63
3.50	15.15	15.94	15.75	16.01	16.46	15.94	15.81	16.04	16.49	15.94	15.75	16.01	16.57
3.00	14.20	13.80	13.88	14.28	14.47	13.80	14.00	14.55	14.36	13.80	13.88	14.28	14.40
2.50	12.58	12.31	12.69	12.81	12.92	12.31	12.81	12.94	12.79	12.31	12.69	12.81	12.88
2.00	11.30	10.83	11.37	11.91	11.45	10.83	11.60	11.97	11.44	10.83	11.37	11.91	11.57
1.50	9.86	9.95	10.52	10.48	10.53	9.95	10.63	10.42	10.87	9.95	10.52	10.48	10.66
1.00	8.46	8.88	9.33	9.79	9.25	8.88	9.57	9.81	9.49	8.88	9.33	9.79	9.34
0.50	7.23	7.94	8.16	8.00	8.18	7.94	8.37	8.03	8.70	7.94	8.16	8.00	8.22
0.33	6.85	7.44	7.70	8.35	7.81	7.44	7.69	8.50	8.10	7.44	7.70	8.35	7.85
0.13	6.45	6.36	6.72	7.15	7.15	6.36	6.64	7.07	7.54	6.36	6.72	7.15	7.25
0.00	6.27	6.52	7.03	7.09	6.89	6.52	6.98	6.50	7.11	6.52	7.03	7.09	6.96
-0.30	5.95	5.58	5.89	6.22	6.05	5.58	5.84	5.93	6.39	5.58	5.89	6.22	6.02
-0.50	5.50	5.02	5.34	5.52	5.36	5.02	5.30	5.67	5.61	5.02	5.34	5.52	5.39
-0.60	5.17	4.75	4.95	5.22	4.97	4.75	4.89	5.36	5.42	4.75	4.95	5.22	5.00
-0.85	4.02	3.86	3.95	4.12	4.01	3.86	3.96	4.16	4.33	3.86	3.95	4.12	4.04
-1.00	3.52	3.36	3.43	3.59	3.52	3.36	3.41	3.62	3.77	3.36	3.43	3.59	3.53
-1.25	2.89	2.73	2.79	2.91	2.93	2.73	2.78	2.92	3.01	2.73	2.79	2.91	2.94
-1.50	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19

Table 3.3.4 Lowest Riverbed Profile after 20 Years in the Sto. Tomas River

(Unit: El.m)

Station	Alternative-1			Alternative-2			Alternative-3			Alternative-2*			Alternative-3*		
km	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
30.00	273.97	273.20	273.08	275.39	274.29	274.05	275.31	277.08	274.23	292.00	292.03	292.03			
29.50	266.04	265.50	266.03	266.82	267.70	266.81	266.68	270.22	266.68	278.00	278.00	278.00			
29.00	255.66	254.13	255.64	255.66	258.68	255.63	255.27	258.67	255.25	262.00	262.00	262.00			
28.50	243.94	244.46	243.94	244.42	244.41	244.41	243.60	244.66	243.60	248.00	248.00	248.00			
28.00	232.35	232.35	232.36	231.57	231.44	231.57	232.39	232.29	232.39	235.00	235.00	235.00			
27.50	221.93	221.88	221.91	222.49	222.00	222.26	221.69	222.42	222.17	226.00	226.00	226.00			
27.00	213.44	213.46	213.45	213.91	213.89	213.94	213.65	213.70	213.67	214.00	214.00	214.00			
26.50	205.95	205.90	205.98	205.93	205.90	205.89	205.90	205.92	205.89	206.00	206.02	206.01			
26.00	198.14	197.99	198.29	198.42	198.38	198.36	197.97	198.11	197.85	200.07	200.07	200.07			
25.50	190.98	190.94	190.94	191.26	191.26	191.26	190.96	190.93	191.01	191.24	191.24	191.24			
25.00	184.62	184.71	184.65	185.35	185.27	185.36	184.87	184.90	184.81	185.30	185.30	185.30			
24.50	177.24	177.24	177.23	178.83	178.84	178.83	177.38	177.37	177.41	178.83	178.83	178.83			
24.00	169.44	169.48	169.05	172.13	172.13	172.13	167.79	167.94	167.91	172.12	172.12	172.12			
23.50	160.50	160.48	160.34	162.10	162.10	162.10	159.48	159.72	159.85	162.09	162.10	162.09			
23.00	152.01	152.02	152.05	152.92	152.92	152.93	151.95	152.21	151.96	152.92	152.92	152.92			
22.50	142.55	142.55	142.54	144.02	144.02	144.02	142.78	143.02	142.66	144.02	144.02	144.02			
22.00	132.44	132.45	132.43	134.39	134.39	134.39	133.37	133.47	133.39	134.39	134.39	134.39			
21.50	123.94	123.96	123.98	124.96	124.96	124.96	124.96	124.96	124.96	124.96	124.96	124.96	124.96	124.96	124.96
21.00	113.11	113.24	113.77	112.39	112.29	112.34	113.00	113.09	112.99	109.62	109.23	109.26	113.53	113.53	113.53
20.50	108.27	108.40	108.66	107.92	107.89	108.01	108.19	108.19	108.28	106.01	105.98	106.08	92.91	92.86	92.93
20.00	103.88	104.06	103.79	103.67	103.99	103.86	104.14	104.04	104.23	102.67	102.54	102.66	89.13	89.13	89.13
19.50	99.72	99.71	99.34	100.17	100.10	100.13	100.16	100.40	100.23	98.96	99.01	99.03	86.92	87.36	86.56
19.00	96.53	96.54	96.54	96.72	96.72	96.74	96.66	96.57	96.63	95.26	95.18	95.28	86.19	86.93	85.79
18.50	91.80	91.88	91.88	91.90	91.85	91.95	91.36	91.25	91.45	91.85	91.92	91.85	84.69	84.16	84.34
18.00	87.57	87.62	87.49	87.72	87.73	87.93	86.70	86.67	86.64	87.25	87.61	87.31	81.70	80.47	81.61
17.50	84.55	84.52	84.51	83.64	83.48	83.50	83.03	82.93	83.24	82.45	82.87	82.43	78.78	78.71	78.36
17.00	79.05	79.05	79.00	79.69	79.73	79.59	78.76	78.58	79.45	78.39	78.36	78.41	75.89	76.84	75.36
16.50	75.34	75.41	75.23	75.81	75.69	75.78	75.20	75.27	75.85	74.30	74.26	74.31	72.90	73.17	72.54
16.00	71.96	71.94	72.09	72.71	72.46	72.70	72.51	72.32	72.26	71.25	71.04	71.15	70.03	69.95	70.04
15.50	69.03	68.95	69.02	68.76	68.83	68.96	69.22	69.15	68.84	67.85	67.82	67.86	67.39	66.99	67.38
15.00	65.15	65.05	65.12	64.69	65.18	64.89	65.80	65.65	65.53	64.90	64.83	64.74	64.31	64.29	64.31
14.50	62.08	62.08	62.00	61.58	61.83	61.55	62.27	62.25	62.24	61.94	62.17	62.04	62.32	62.34	62.34
14.00	58.63	58.44	58.52	58.25	58.27	58.20	58.95	58.91	58.80	58.12	58.58	58.31	58.49	58.48	58.49
13.50	54.85	54.92	54.91	54.78	54.68	54.87	55.22	55.21	55.17	54.73	55.10	54.75	55.12	55.09	55.11
13.00	52.14	52.04	52.05	52.18	52.00	52.21	52.58	52.49	52.60	52.05	52.42	52.11	52.54	52.53	52.53
12.50	49.52	49.54	49.72	49.43	49.55	49.41	49.76	49.88	49.70	49.48	49.84	49.55	49.93	49.93	49.94
12.00	46.93	46.83	46.73	47.02	47.09	46.87	47.11	47.25	47.16	47.13	47.17	47.02	46.82	46.81	46.82
11.50	44.10	44.59	44.34	44.27	44.33	44.32	44.25	44.40	44.28	44.42	44.33	44.74	43.88	43.85	43.89
11.00	41.69	41.52	41.66	41.77	41.93	41.62	41.57	41.71	41.51	41.89	41.90	41.78	41.65	41.64	41.64
10.50	39.76	39.83	40.01	39.61	39.70	39.50	39.50	39.49	39.42	39.97	39.96	40.12	39.67	39.68	39.67
10.00	37.60	37.90	37.80	37.86	37.97	37.67	37.50	37.60	37.70	37.85	37.82	37.84	37.24	37.33	37.24
9.50	35.66	35.34	35.57	35.70	35.64	35.80	35.62	36.10	35.62	36.00	35.76	35.84	35.13	35.13	35.16
9.00	33.59	33.57	33.72	33.82	33.97	33.79	34.22	34.02	34.18	33.78	33.86	33.87	33.21	33.37	33.25
8.50	31.86	31.98	32.27	32.00	31.96	32.36	32.76	32.90	32.77	32.28	32.07	32.31	31.73	31.93	31.81
8.00	30.75	30.83	31.18	30.95	31.18	31.12	30.75	30.98	30.78	31.21	30.85	31.20	29.82	29.84	29.85
7.70	29.40	29.40	29.86	29.84	29.93	30.08	29.88	29.68	29.92	29.79	29.77	29.71	28.43	28.44	28.44
7.50	28.37	28.64	28.86	29.32	29.33	29.14	28.78	28.74	29.04	28.97	28.89	28.61	27.64	27.64	27.66
7.25	28.12	28.07	27.78	27.99	28.11	28.22	27.79	27.86	27.93	27.95	27.83	27.62	26.49	26.47	26.54
7.00	26.89	26.74	26.81	27.22	27.18	27.37	26.79	26.95	26.67	26.75	26.93	26.83	25.75	25.73	25.77
6.80	26.16	26.38	26.18	26.14	26.27	26.45	26.34	26.20	26.41	25.85	25.89	25.91	24.98	24.85	25.00
6.50	24.88	24.95	24.94	25.29	25.14	25.21	25.16	24.96	25.14	24.44	24.61	24.50	23.84	23.63	23.85
6.25	24.15	24.16	24.12	23.85	24.02	24.27	24.19	24.17	24.19	23.52	23.15	23.68	23.08	22.96	23.09
6.00	23.30	23.25	23.43	23.24	23.31	23.01	22.87	23.09	22.99	22.99	22.89	22.93	22.08	22.12	22.11
5.75	21.97	22.12	22.01	22.87	22.03	22.72	22.49	22.34	22.20	22.41	22.63	22.32	21.41	21.48	21.46
5.50	21.85	21.62	21.89	21.46	21.81	21.90	21.24	21.95	21.65	22.17	21.46	22.15	20.83	20.85	20.84
5.25	21.34	20.73	21.09	20.79	20.42	20.88	21.06	20.65	20.64	21.15	21.11	21.11	19.82	19.82	19.83
5.00	20.55	19.89	20.56	20.14	20.11	19.94	19.94	20.64	20.03	20.19	20.20	20.23	19.27	19.25	19.26
4.50	19.01	19.00	19.00	18.45	18.36	18.48	18.78	18.76	18.44	18.47	18.65	18.52	17.75	17.77	17.77
4.00	17.60	17.68	17.63	17.57	17.62	17.38	17.42	17.43	17.49	17.29	17.40	17.34	16.54	16.63	16.54
3.50	16.46	16.49	16.57	16.35	16.41	16.24	16.17	16.15	16.24	16.34	16.34	16.36	15.22	15.15	15.24
3.00	14.47	14.36	14.40	14.40	14.67	13.92	14.02	14.40	14.59	14.40	14.37	14.33	13.36	13.22	13.36
2.50	12.92	12.79	12.88	12.98	13.41	12.89	13.26	13.19	13.18	13.12	13.16	13.13	12.04	12.04	12.08
2.00	11.45	11.44	11.57	11.88	11.84	11.60	11.45	12.02	11.78	11.76	11.79	11.67	10.34	10.72	10.84
1.50	10.53	10.87	10.66	10.63	10.70	10.55	10.92	10.51	10.68	10.40	10.47	10.44	9.35	9.67	9.61
1.00	9.25	9.49	9.34	9.32	9.37	9.29	9.43	9.42	9.26	9.00	9.00	9.23	8.31	8.31	7.97
0.50	8.18	8.70	8.22	8.07	8.06	8.28	8.28	8.21	8.20	7.89	8.06	7.87	6.94	6.93	6.46
0.33	7.81	8.10	7.85	7.58	7.46	7.76	7.80	7.92	7.94	7.36	7.35	7.41	6.36	6.43	5.89
0.13	7.15	7.54	7.25	6.94	7.04	7.09	7.10	7.15	7.00	6.73	6.90	6.78	5.91	5.99	5.46
0.00	6.89	7.11	6.96	6.58	6.49	6.73	6.75	6.77	6.88	6.43	6.44	6.47	5.61	5.71	5.17
-0.30	6.05	6.39	6.02	5.70	5.80	5.85	5.84	5.87	5.88	5.58	5.64	5.61	4.86	4.97	4.45
-0.50	5.36	5.61	5.39	5.12	5.10	5.22	5.19	5.21	5.25	5.05	5.04	5.07	4.43	4.51	4.05
-0.60	4.97	5.42	5.00	4.76	4.80	4.84	4.87	4.86	4.89	4.69	4.71	4.69	4.18	4.24	3.83
-0.85	4.01	4.33	4.04	3.88	3.88	3.90	3.90	3.91	3.90	3.78	3.83	3.81	3.49	3.52	3.23
-1.00	3.52	3.77	3.53	3.37	3.42	3.45	3.40	3.39	3.40	3.30	3.35	3.32	3.13	3.12	2.96
-1.25	2.93	3.01	2.94	2.85	2.84	2.84	2.86	2.84	2.87	2.80	2.80	2.79	2.62	2.63	2.60
-1.50	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19

Table 3.5.1 Computation of High Water Level for a 20-Year Probable Flood in the Bucao River

Sta.	Ave.RB	River Width	Discharge	Computed Water Level	Average Velocity	Flow Area	Froude Number	Remarks
km	El.m	m	m^3/s	El.m	m/s	m^2		
-2.40	0.34	1,740	3,800	1.43	2.00	1,905	0.60	River Mouth (Sta. -2.4km)
-2.20	1.78	1,620	3,800	2.68	2.61	1,453	0.89	
-2.00	3.06	1,500	3,800	4.24	2.14	1,774	0.64	
-1.75	4.25	1,350	3,800	5.45	2.33	1,630	0.68	
-1.50	4.84	1,200	3,800	6.50	1.91	1,985	0.48	
-1.25	5.79	1,040	3,800	7.24	2.52	1,506	0.67	
-1.00	6.72	870	3,800	8.36	2.67	1,425	0.66	
-0.85	7.14	790	3,800	8.99	2.60	1,460	0.61	
-0.70	7.62	710	3,800	9.53	2.81	1,353	0.65	
-0.55	8.10	640	3,800	10.12	2.94	1,293	0.66	
-0.40	8.74	560	3,800	10.73	3.41	1,114	0.78	
-0.35	8.83	530	3,800	11.06	3.21	1,184	0.71	
-0.30	9.13	500	3,800	11.18	3.70	1,027	0.85	
-0.25	9.26	470	3,800	11.57	3.50	1,086	0.75	
-0.20	9.56	420	3,800	11.65	4.33	877	1.00	
-0.15	9.43	390	3,800	12.38	3.30	1,152	0.63	
-0.10	9.62	360	3,800	12.41	3.78	1,004	0.73	
-0.05	9.60	330	3,800	12.62	3.81	996	0.71	
0.00	9.90	310	3,800	12.54	4.66	816	0.89	Bucao Bridge (Sta. 0.0km)
0.05	10.21	360	3,800	13.29	3.43	1,107	0.61	
0.10	10.46	410	3,800	13.56	2.98	1,274	0.52	
0.20	11.03	470	3,800	13.84	2.88	1,321	0.55	
0.30	11.21	550	3,800	14.20	2.31	1,644	0.43	
0.40	11.69	620	3,800	14.37	2.28	1,663	0.45	
0.60	12.63	800	3,800	14.78	2.21	1,722	0.48	
1.00	14.02	1,250	3,800	15.69	1.81	2,095	0.45	
1.50	15.55	1,560	3,800	16.89	1.82	2,090	0.50	
2.00	17.66	2,030	3,800	18.65	1.88	2,022	0.60	
3.00	20.89	2,010	3,800	22.08	1.58	2,402	0.46	
4.00	24.64	1,960	3,800	25.62	1.97	1,932	0.63	
5.00	27.42	2,150	3,800	28.80	1.28	2,968	0.35	Baquilan River (Sta. 5.5km)
6.00	30.97	1,640	2,900	31.89	1.93	1,503	0.64	
6.50	32.96	1,400	2,900	34.08	1.85	1,564	0.56	
7.00	34.47	1,180	2,900	35.75	1.92	1,508	0.54	
7.50	37.39	1,060	2,900	38.40	2.73	1,062	0.84	
8.00	40.41	1,220	2,900	41.54	2.11	1,373	0.58	
8.25	41.49	1,160	2,900	42.61	2.24	1,297	0.66	
8.50	42.88	1,120	2,900	43.97	2.38	1,220	0.72	
8.75	44.24	1,100	2,900	45.40	2.27	1,275	0.67	
9.00	45.54	930	2,900	46.73	2.62	1,106	0.75	
9.25	47.19	840	2,900	48.38	2.91	997	0.83	
9.50	48.61	790	2,900	50.02	2.60	1,116	0.68	
9.75	50.17	740	2,900	51.46	3.05	950	0.84	
10.00	52.71	830	2,900	53.74	3.40	852	1.07	Malumboy (Sta. 10.0km)

Table 3.5.2 Computation of High Water Level for a 20-Year Probable Flood in the Sto. Tomas River

Sta.	Average Riverbed	River Width	Discharge	Computed Water Level	Average Velocity	Flow Area	Froude Number	Remarks
km	El.m	m	m^3/s	El.m	m/s	m^2		
-1.50	1.98	690	1,200	2.66	2.57	466	1.00	River Mouth (Sta. -1.5km)
-1.25	3.13	540	1,200	4.77	1.36	881	0.34	
-1.00	4.00	500	1,200	5.25	1.93	621	0.55	
-0.85	4.57	460	1,200	5.78	2.16	557	0.62	
-0.60	5.34	420	1,200	6.75	2.03	592	0.54	
-0.50	5.79	400	1,200	7.08	2.33	516	0.66	
-0.30	6.30	360	1,200	7.90	2.08	576	0.53	
0.00	7.25	330	1,200	8.82	2.31	520	0.59	Maculcol Bridge (Sta. 0.0km)
0.13	7.69	360	1,200	9.30	2.07	581	0.52	
0.33	8.37	430	1,200	9.87	1.86	647	0.48	
0.50	8.90	450	1,200	10.31	1.90	633	0.51	
1.00	10.05	510	1,200	11.52	1.60	751	0.42	
1.50	11.38	550	1,200	12.65	1.73	694	0.49	
2.00	12.76	610	1,200	13.97	1.63	738	0.47	
2.50	13.77	670	1,200	15.06	1.39	863	0.39	
3.00	15.15	730	1,200	16.19	1.58	759	0.50	
3.50	16.82	780	1,200	17.77	1.62	742	0.53	
4.00	18.62	760	1,200	19.56	1.67	718	0.55	
4.50	19.98	660	1,200	21.14	1.56	769	0.47	
5.00	21.17	550	1,200	22.43	1.73	693	0.50	
5.25	21.88	470	1,200	23.16	1.99	603	0.56	
5.50	22.36	410	1,200	23.92	1.87	640	0.48	
5.75	23.00	420	1,200	24.52	1.87	641	0.48	
6.00	23.58	480	1,200	25.11	1.63	735	0.42	
6.25	24.56	570	1,200	25.72	1.81	662	0.54	
6.50	25.49	640	1,200	26.56	1.74	688	0.54	
6.80	26.36	710	1,200	27.47	1.52	789	0.46	
7.00	27.19	750	1,200	28.10	1.75	684	0.58	
7.25	28.26	770	1,200	29.16	1.73	692	0.58	
7.50	29.40	760	1,200	30.28	1.81	662	0.62	Paete Hill (Sta. 7.5km)
7.70	29.93	770	1,200	31.04	1.41	854	0.43	
8.00	31.37	830	1,200	32.15	1.85	649	0.67	
8.50	33.25	820	1,200	34.28	1.42	842	0.45	
9.00	35.34	910	1,200	36.11	1.72	697	0.63	
9.50	36.71	1,000	1,200	37.80	1.10	1,095	0.33	
10.00	38.57	1,060	1,200	39.23	1.72	699	0.61	
10.50	40.89	1,110	1,200	41.59	1.54	782	0.58	Vega Hill (Sta. 10.5km)
11.00	43.54	1,160	1,200	44.18	1.62	741	0.65	
11.50	46.12	1,220	1,200	46.80	1.46	820	0.57	Santa Fe River (Sta. 11.5km)
12.00	48.01	1,210	860	48.65	1.12	768	0.44	
12.50	50.82	1,260	860	51.27	1.51	570	0.71	
13.00	53.75	1,250	860	54.31	1.24	693	0.53	
13.50	56.07	1,310	860	56.41	1.96	439	0.63	
14.00	59.37	1,580	860	59.67	1.81	474	0.75	
14.50	63.19	1,610	860	63.59	1.34	642	0.67	
15.00	66.49	1,720	860	66.90	1.24	694	0.61	
15.50	70.00	1,850	860	70.24	1.98	434	0.76	
16.00	73.91	2,110	860	74.12	1.89	456	0.74	
16.50	77.28	2,290	860	77.51	1.64	523	0.65	
17.00	80.55	2,330	860	80.75	1.87	461	0.73	
17.50	85.10	2,200	860	85.31	1.85	465	0.85	
18.00	90.04	2,110	860	90.22	2.23	385	0.82	
18.50	93.25	1,950	860	93.47	2.01	427	0.58	
19.00	97.11	1,760	860	97.32	2.34	368	0.92	
19.50	101.78	1,470	860	102.01	2.54	338	0.78	
20.00	106.13	1,200	860	106.32	3.70	232	1.00	
20.50	109.40	1,100	860	109.67	2.96	291	1.00	
21.00	114.53	1,010	860	114.83	2.88	298	1.00	Mapanuepe River (Sta. 21.0km)
21.50	126.94	1,110	680	127.12	3.32	205	1.00	Mt. Bagang (Sta. 21.5km)

Table 4.2.1 Monitoring for Riverbed Movement in July 2002 and January 2003 in the Bucao River

Section Name/ (as of Jul. 2002)	Distance from Bucao Bridge. (km)	Riverbed Width (m)	Average Riverbed Elevation		Change in Riverbed El. (m)	Sediment Balance(*2) (10^6 m^3)	Locations
			Jul.2002(*1) (El.m)	Jan.2003 (El.m)			
Rivermouth/(L1)	-2.5						
						0.0	
B1/(L3)	-1.0	815	4.3	4.3	0.0		Bucao Downstream
						0.8	
B2 / (L9)	4.1	1,943	21.4	21.6	0.2		Barangay San Juan
						6.5	
B3 / (L14)	9.1	1,438	44.0	45.6	1.6		Malumboy
						21.1	
B4 / (L23)	18.3	916	120.7	123.2	2.5		Balin-Baquero River
						4.0	
B5 / (L28)	22.9	1,004	184.6	184.0	-0.6		Balin-Baquero / Maraunot
B6 / (None)	14.4	1,513		76.2			Upper Bucao/Balintawak River
B7 / (None)	19.0	1,163		118.1			Upper Bucao River
Total						32.3	

Notes: (*1) Survey was conducted after the lahar of 10 July 2002

(*2) Sediment balance for only Lower Bucao - Balin Baquero stretch (for 22.9km)

Table 4.2.2 Monitoring for Riverbed Movement in July and August 2002 in the Sto. Tomas River

Section Name/ (as of Jul. 2002)	Distance from Maculcol Bridge (km)	Riverbed Width (m)	Average Riverbed Elevation		Change in Riverbed Elevation (m)	Sediment Balance (10^6 m^3)	Locations
			Jul.2002(*1) (El.m)	Aug.2002 (*2) (El.m)			
Rivermouth / (L0)	-1.5						
						0.25	
S1 / (L8)	0.1	383	5.9	6.3	0.40		Upstream of Maculcol Bridge
						0.28	
None / (L16)	3.5	774	15.4	15.4	0.02		Downstream of Paete Hill
						0.25	
S2 / (L25)	6.5	626	24.7	24.9	0.24		Paete Hill Downstream
						0.14	
None / (L27)	7.0	745	26.2	26.8	0.53		Paete Hill Upstream
						0.97	
S3 / (L35)	10.0	1,564	38.4	38.6	0.16		Vega Hill Downstream
						0.35	
None / (L38)	11.5	1,376	None	45.1	0.16		Vega Hill Upstream
						1.17	
S4 / (L45)	15.0	1,762	66.4	66.6	0.26		Barangay San Rafael
						2.10	
S5 / (L52)	18.5	2,935	None	94.8	0.26		Upstream End of Left Dike
						1.60	
S6 / (L58)	21.5	1,255	None	130.3	0.26		Mt.Bagang
						1.20	
S7 / (None)	25.5	1,100	None	None	0.26		Marella River
Total						8.30	

Notes:
(*1) Survey was conducted before the flood of 10 July 2002
(*2) Survey was conducted after the flood of 10 July 2002
(*3) Riverbed change for S3, S5, S6, S7 was assumed.

The Study on Sabo and Flood Control for Western River Basins of Mount Pinatubo
in the Republic of the Philippines
Final Report
Supporting Report

Figures

THE GOVERNMENT OF THE PHILIPPINES
THE DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS

The Study on Sabo and Flood Control for Western River Basins of Mount Pinatubo in the Republic of the Philippines

JAPAN INTERNATIONAL COOPERATION AGENCY

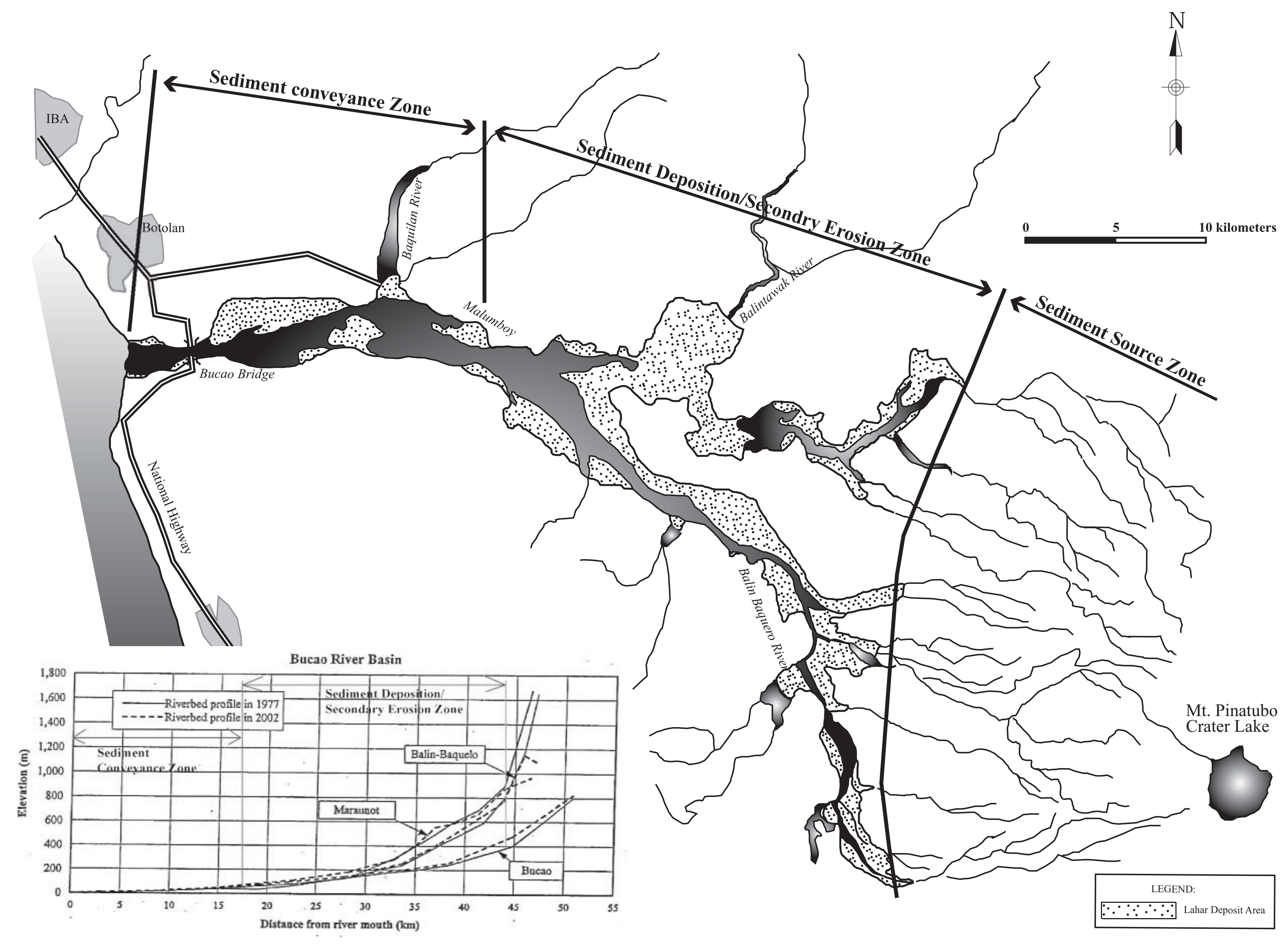


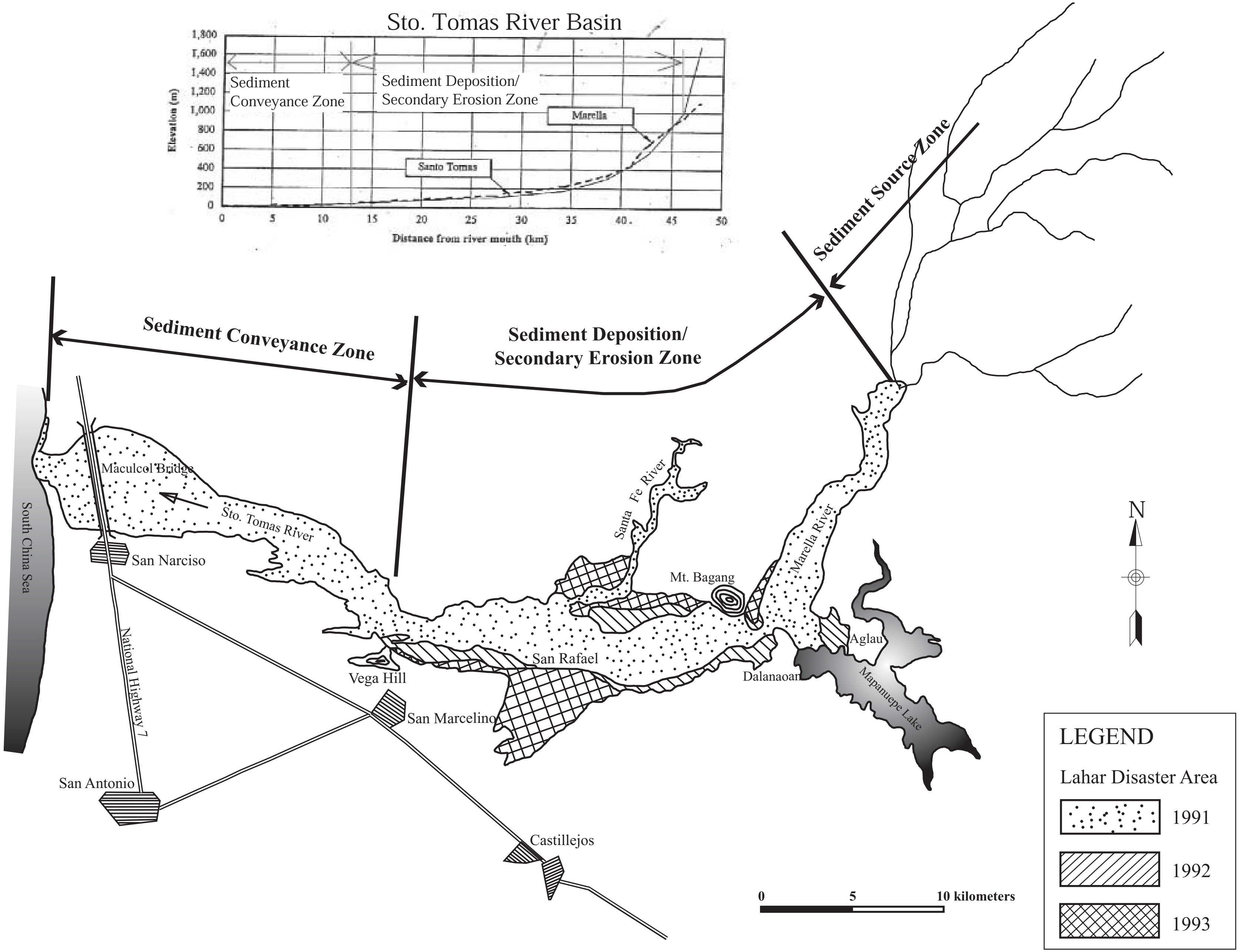
Figure 1.1.1
Classification of Sediment Balance in the Bucao River

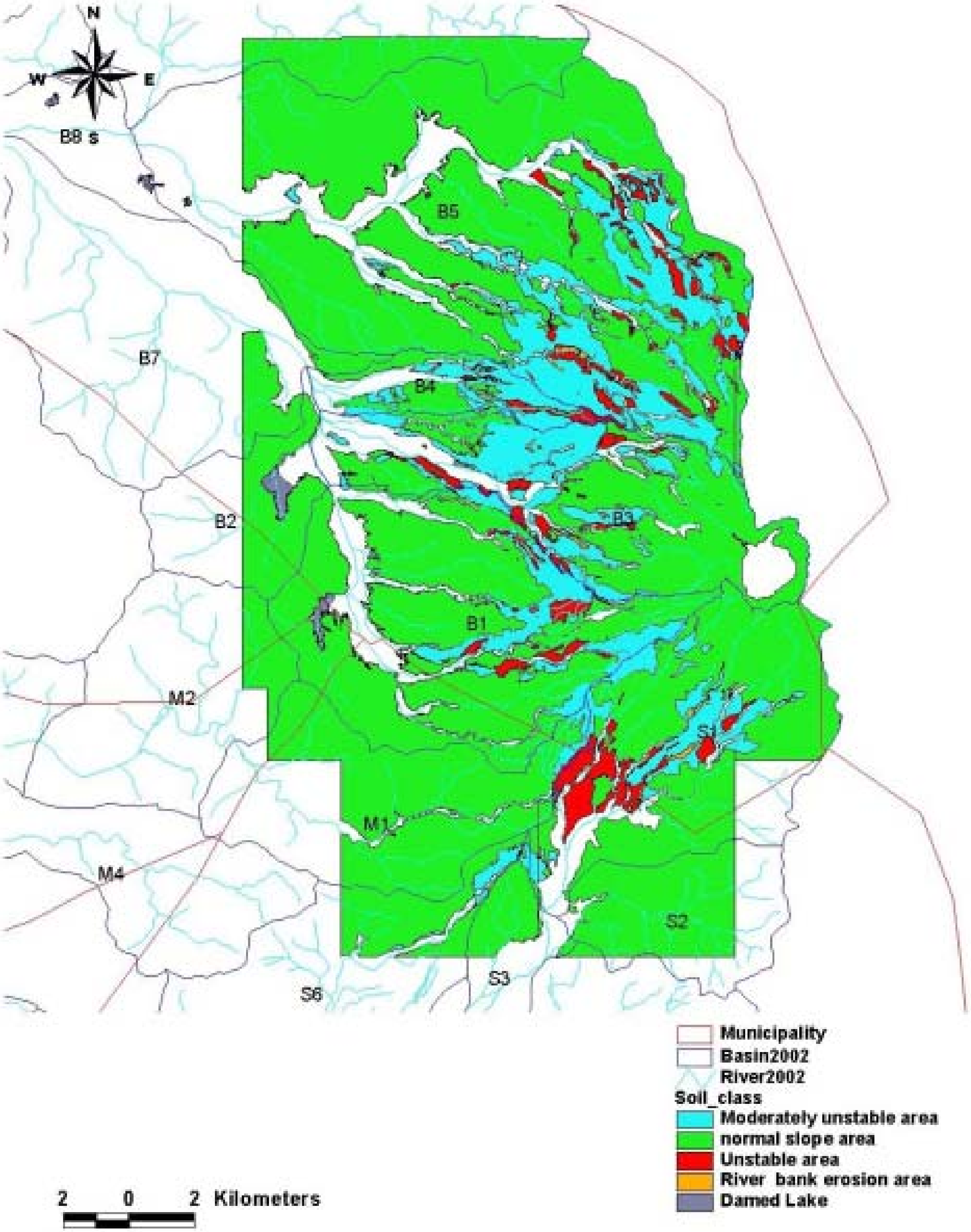
THE GOVERNMENT OF THE PHILIPPINES
THE DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS

The Study on Sabo and Flood Control for Western River Basins of Mount Pinatubo in the Republic of the Philippines

JAPAN INTERNATIONAL COOPERATION AGENCY

Figure 1.1.2
Classification of Sediment Balance in the Sto. Tomas River





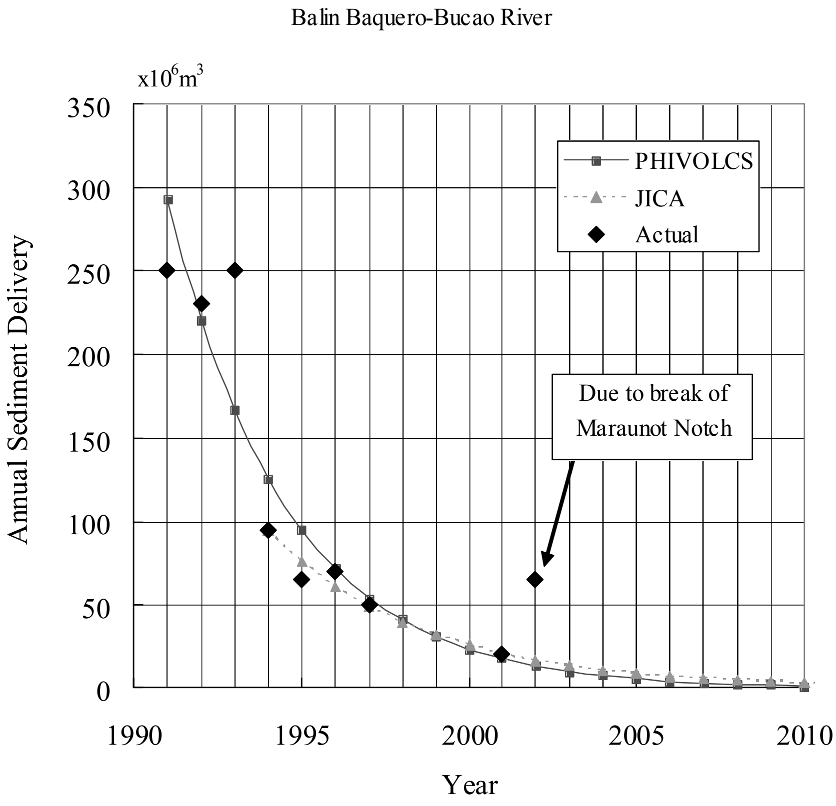
THE GOVERNMENT OF THE PHILIPPINES
THE DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS

The Study on Sabo and Flood Control for Western River Basins of Mount Pinatubo in the Republic of the Philippines

JAPAN INTERNATIONAL COOPERATION AGENCY

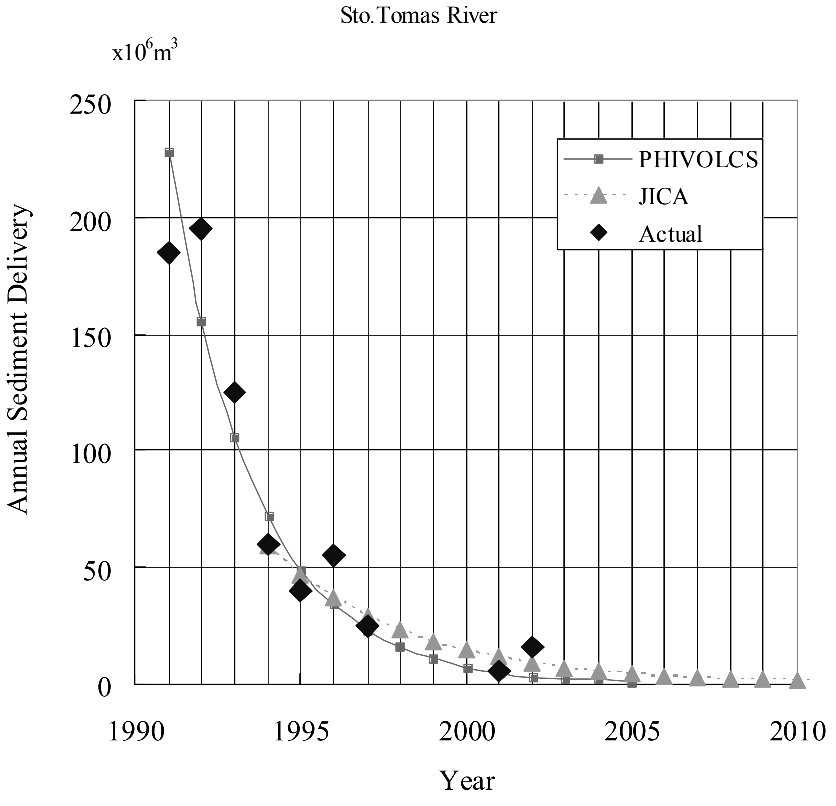
Figure 1.2.1

Classification of Slope Stability on Western Slope of Mount Pinatubo



Unit: $10^6 m^3$

Year	Actual	PHIVOLCS	JICA
1991	250	293	
1992	230	221	
1993	250	167	
1994	95	126	94
1995	65	95	75
1996	70	72	61
1997	50	54	49
1998		41	39
1999		31	32
2000		23	26
2001	20	18	21
2002	65	13	17
2003		10	13
2004		8	11
2005		6	8.7
2006		4	7.0
2007		3	5.6
2008		2	4.5
2009		2	3.6
2010		1	2.9



Unit: $10^6 m^3$

Year	Actual	PHIVOLCS	JICA
1991	185	228	
1992	195	155	
1993	125	106	
1994	60	72	59
1995	40	49	47
1996	55	34	37
1997	25	23	29
1998		16	23
1999		11	18
2000		7	14
2001	5.7	5	11
2002	16	3	9.0
2003		2	7.1
2004		2	5.6
2005		1	4.4
2006			3.5
2007			2.8
2008			2.2
2009			1.7
2010			1.4

THE GOVERNMENT OF THE PHILIPPINES
THE DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS

The Study on Sabo and Flood Control for Western River Basins of Mount Pinatubo in the Republic of the Philippines

JAPAN INTERNATIONAL COOPERATION AGENCY

Figure 1.2.2

Past and Future Sediment Delivery in the Bucao and Sto. Tomas Rivers