# 5. FLOOD/MUDFLOW INUNDATION ANALYSIS

## Formulation of Flood Inundation Scenario

Since the eruption of Mount Pinatubo in 1991, frequent lahar events have been observed in the study area resulting in severe damages from mudflow and flood. To contain floods within river channels, dike system has been constructed along each river. As a result, sediment deposition in the channel has become predominant and this has accelerated riverbed rising. Floods and mudflow have sometimes overflowed the dikes. Dike height was raised twice on the right side of the downstream in the Bucao River and three times on the left side of the middle reach of the Sto.Tomas River in the 10 years from 1991 to 2000.

All revetments of the right side dikes in the Bucao River were destroyed during the rainy season in 2002. In the downstream sections of the Bucao River, clearance between the riverbed and the dike crest is less than 2.0 m because the level of the riverbed has risen by 1.5 m. A breach of a part of the dike in the Maloma River was observed in 2001 and 2002 and it has not been repaired yet. In addition, water flow is restricted at the Maloma Bridge during floods, which causes overflow and floods on the right side of the river every year. Several hectares of agricultural land were inundated on the left side downstream of the Maculcol Bridge due to a breach of the dike in July 2002. Areas on the left side 3.5 km upstream of the Maculcol Bridge were also inundated in 2000. Characteristics of floods in July 2002 are summarized in Table 5.1. It is noted that the same section was again breached by small flood on 9 August 2003 and the land side areas were buried by sediment.


**Damaged Dike in the Bucao River**


**Agricultural Land Buried by Sediment due to Breach of Left Side Dike in the Downstream of the Sto. Tomas River in July 2002**

**Table 5.1 Summary of Floods in July 2002**

| | Unit | Rivers | | |
|---|---|---|---|---|
| | | Bucao | Maloma | Sto. Tomas |
| Maximum Daily Rainfall | mm/day | 404.4 (July 7, at Baquilan) | 369.1 (July 7, at Paete) | 385.3 (July 7, at Mapanuepe) |
| Return Period for Daily Rainfall | year | 5 to 10 | 5 to 10 | 5 to 10 |
| Maximum Observed Water Level | El.m | 7.8 (July 8) | 4.1 (July 8) | Top of girder of Maculcol Bridge |
| Discharge* | $m^3/s$ | 2,500 | 640 | 890 |
| Damages | | | | |
| (1) Flood from July 4 to July 8 | | ・2 people and 5 carabaos were flown (at Baquilan Bridge)<br>・15 ha of agricultural land were inundated (downstream of Bucao Bridge, right side) | ・90 houses and 120 ha of agricultural land were inundated (along National Highway No.7, right side) | ・no severe damages |
| (2) Flood from July 24 to July 26 | | ・no severe damages | ・no severe damages | ・25 houses and 2.5 ha of agricultural land were buried by sediment (downstream of Maculcol Bridge, left side) |

*Simulated by flood runoff model with recorded rainfall

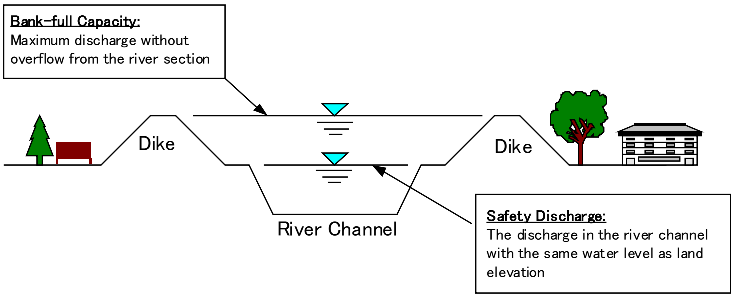
Based on the above, the conditions of inundation in the mudflow analysis for the study area were set as follows:

**Setting Inundation Block :** Inundation block was determined considering the topographic conditions as follows:

- Bucao River: Inundation block is located only on the right side of the downstream reach including agricultural lands and Botolan Municipality.
- Maloma River: One inundation block was set in the downstream reach on both the right and left sides of the downstream of the confluence of the Maloma River and the Gorongoro River.
- Sto. Tomas River: Because various large flood plains occur in the middle and downstream reaches, and their characteristics are different from one another, inundation blocks are divided into three as follows:
  - ➢ Block 1: Agricultural land and residential area on the left side of the upstream of Vega Hill.
  - ➢ Block 2: Agricultural land and residential area on the left side of the downstream of Vega Hill.
  - ➢ Block 3: Agricultural land and residential area on the right side of the downstream of Paete Hill.

**Estimation of Safety Discharge and Bank-full Capacity :**

It is necessary to estimate safety discharge and bank-full capacity of rivers for inundation analysis. General definition of safety discharge and bank-full capacity of rivers is illustrated in Figure 5.1.




Source: "Manual on Economic Evaluation for Flood Control Project" Ministry of Land, Infrastructure and Transport, May 2002

**Figure 5.1 General Definition of Safety Discharge and Bank-full Capacity**

Safety discharge is defined as the discharge with the same water level as the land elevation. Under floods within the safety discharge, there is no possibility of flooding to the land area as the water level is lower than the land elevation.

Bank-full capacity is defined as the maximum discharge of the river channel, which depends on the dike height. The land area will not be flooded within the maximum discharge as far as the dike is in function, but there would be possible that the flood may occur if the dike breaches by scouring or seepage.

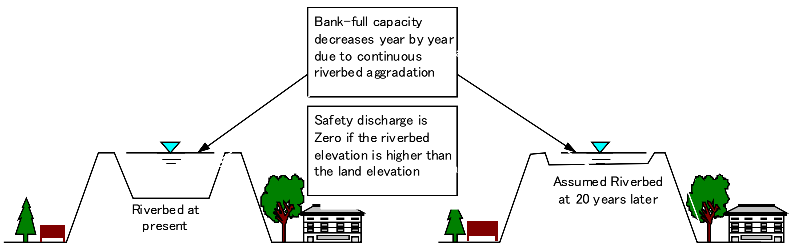



**Figure 5.2 Change in Bank-full Capacity**

For the Bucao and Sto.Tomas Rivers, the safety discharge is defined as zero as the riverbed elevation is higher than the land elevation. The inundation damage is generally considered for the discharge exceeding the safety discharge in flood control plan formulation, if the dike is not strong enough against the scouring and seepage.

The bank-full capacity will be decreased year by year for the Bucao and Sto.Tomas River as the riverbed aggradation would continue for the next 20 years as shown in Figure 5.2. The bank-full capacity for the Bucao, Maloma and Sto.Tomas are calculated by non-uniform flow analysis as summarized in Tables 5.2 to 5.4, respectively.

At present, the bank-full capacity of the Bucao River is equivalent to 2-5 year probable flood at the upstream stretch from the Baquilan River, but it will be zero after 20 years due to continuous riverbed aggradation. The bank-full capacity was estimated at 60 $m^3/s$ for the Maloma River from the Maloma Bridge to the confluence with the Gorongoro River. For the Sto.Tomas River, the bank-full capacity would be zero after 20 years as well as the Bucao River.

Considering the above, the safety discharge and bank-full discharge for inundation damage analysis are defined as zero in the flood / mudflow control plan formulation for the Bucao and Sto.Tomas Rivers, and 60 $m^3/s$ for the Maloma River.

**Table 5.2 Bank-full Capacity for the Bucao River**

| Section | Bank-full Capacity | | | |
|---|---|---|---|---|
| | at present | | after 20 years | |
| | discharge ($m^3/s$) | return period | discharge ($m^3/s$) | return period |
| Mouth - Bucao Bridge | 200 | < 2year | 0 | None |
| Bucao Bridge | 5,200 | 50-100 year | 300 | < 2 year |
| Bucao Bridge - Baquilan | 1,900 | 2-5 year | 0 | None |

**Table 5.3 Bank-full Capacity for the Maloma River**

| Section | Bank-full Capacity | |
|---|---|---|
| | at present | |
| | discharge ($m^3/s$) | return period |
| Mouth - Maloma Bridge | 290 | <2 year |
| Maloma Bridge | 500 | 5-10 year |
| Maloma Bridge - Gorongoro River | 60 | <2 year |

**Table 5.4 Bank-full Capacity for the Sto. Tomas River**

| Section | Bank-full Capacity | | | |
|---|---|---|---|---|
| | at present | | after 20 years | |
| | discharge ($m^3/s$) | return period | discharge ($m^3/s$) | return period |
| Mouth - Maculcol Bridge | >2,000 | >100 year | 1,400 | 30 year |
| Maculcol Bridge | 1,100 | 10-20 year | 0 | None |
| Maculcol Bridge - Paete Hill | 700 | 5 year | 0 | None |
| Paete-Hill - Vega Hill | 600 | 2-5 year | 0 | None |
| Vega Hill - Mt. Bagang | >2,000 | >100 year | >2,000 | >100 year |

**Setting Dike Breach Points :** Breach points were determined to lead to the maximum damage in the respective inundation block. Based on the topographic conditions of the river reach and flood prone area, the upstream end of each inundation block was set as the breach point.

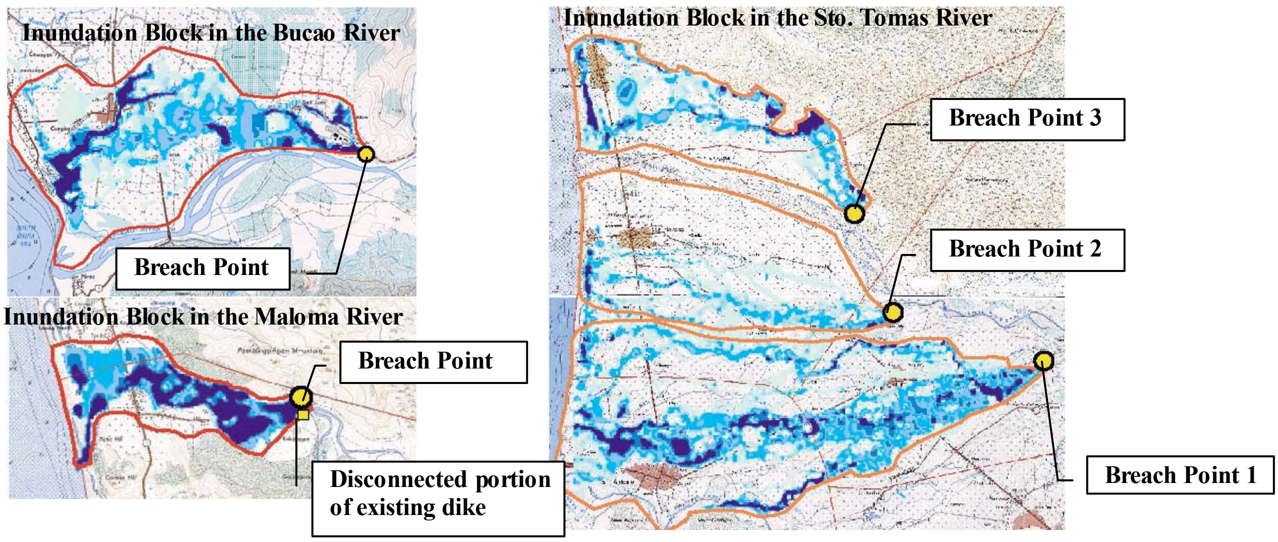



**Figure 5.3 Inundation Blocks and Breach Points of Dike for the Bucao, Maloma and Sto. Tomas Rivers**

## Two-Dimensional Flood/Mudflow Analysis

Two-dimensional mudflow analysis was conducted for probable floods of different return periods based on the conditions above. The whole inundation area was divided into a grid with 40 m x 40 m grid cells and data on topography, land use, the number of buildings, infrastructure, population, and so on were input for each grid in a GIS database. The GIS database and the results of inundation analysis were used to estimate damages due to the inundation of each return period. Table 5.5 shows the simulation results.

**Table 5.5 Summary of Inundation Simulation**

| Return Period (Year) | Bucao River | | | Maloma River | | | Sto. Tomas River | | |
|---|---|---|---|---|---|---|---|---|---|
| | Inundated Area (ha) | Inundated Building (Nos) | Inundated Farmland (ha) | Inundated Area (ha) | Inundated Building (Nos) | Inundated Farmland (ha) | Inundated Area (ha) | Inundated Building (Nos) | Inundated Farmland (ha) |
| 2 | 767 | 1,276 | 330 | 480 | 128 | 207 | 3,985 | 3,782 | 2,387 |
| 5 | 869 | 1,460 | 378 | 514 | 144 | 226 | 4,849 | 5,045 | 2,862 |
| 10 | 956 | 1,591 | 417 | 529 | 150 | 234 | 5,395 | 5,762 | 3,175 |
| 20 | 1,112 | 1,908 | 508 | 545 | 154 | 242 | 5,894 | 6,444 | 3,465 |
| 30 | 1,185 | 2,040 | 547 | 555 | 161 | 248 | 6,220 | 6,832 | 3,656 |
| 50 | 1,292 | 2,191 | 609 | 571 | 253 | 255 | 6,589 | 7,296 | 3,868 |
| 100 | 1,443 | 2,406 | 670 | 586 | 292 | 261 | 7,140 | 8,079 | 4,168 |

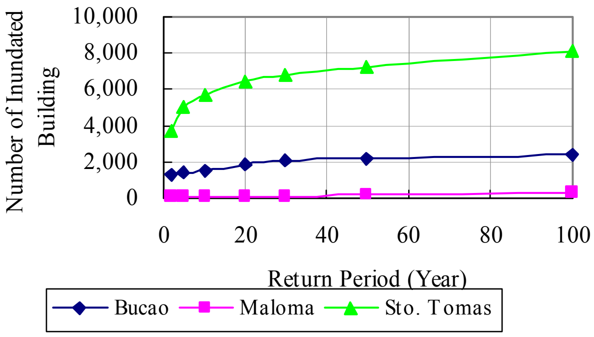



**Figure 5.4 Damage Curve for Building**

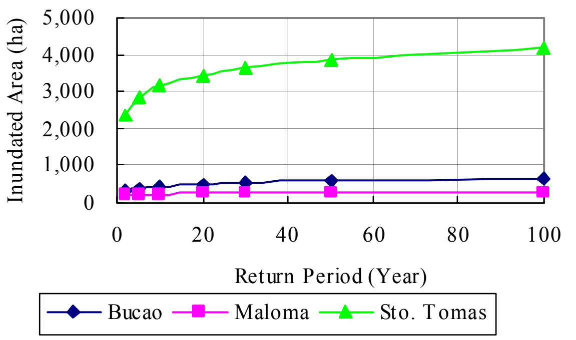



**Figure 5.5 Damage Curve for Farmland**

Figures 5.4 and 5.5 show the damage curve for buildings and farmland in each river basin. The inundation damage is the greatest in the Sto.Tomas River. The gradient of the damage curves show that the incremental damages are not significant beyond the 20-year return period for all three rivers. In addition, the planning scale for the other river basins of Mount Pinatubo is set at 20 years. Therefore, the design probable flood adopted for the study area to formulate the master plan was determined to be 20-year flood.

Hazard maps (inundation area under 100-year probable flood) in the subject river basins are shown in Figure 5.6 to Figure 5.8.

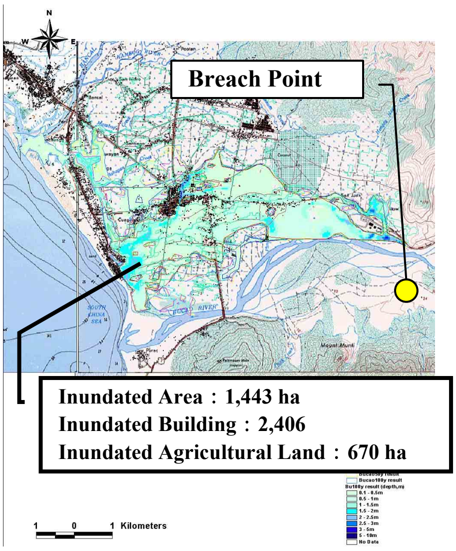



Figure 5.6 Mudflow Hazard Area in the Bucao River Basin under 100-year Probable Flood

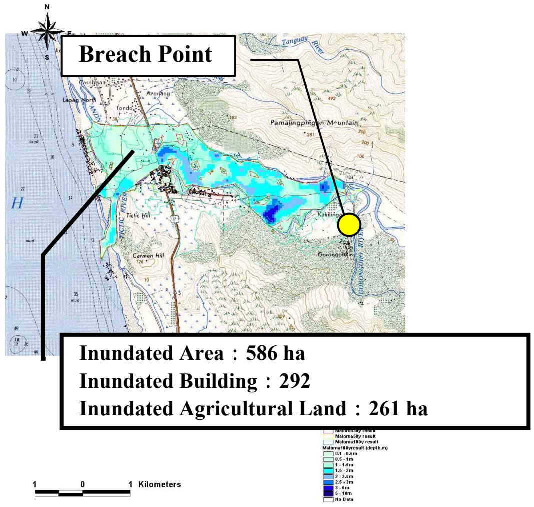



Figure 5.7 Mudflow Hazard Area in the Maloma River Basin under 100-year Probable Flood

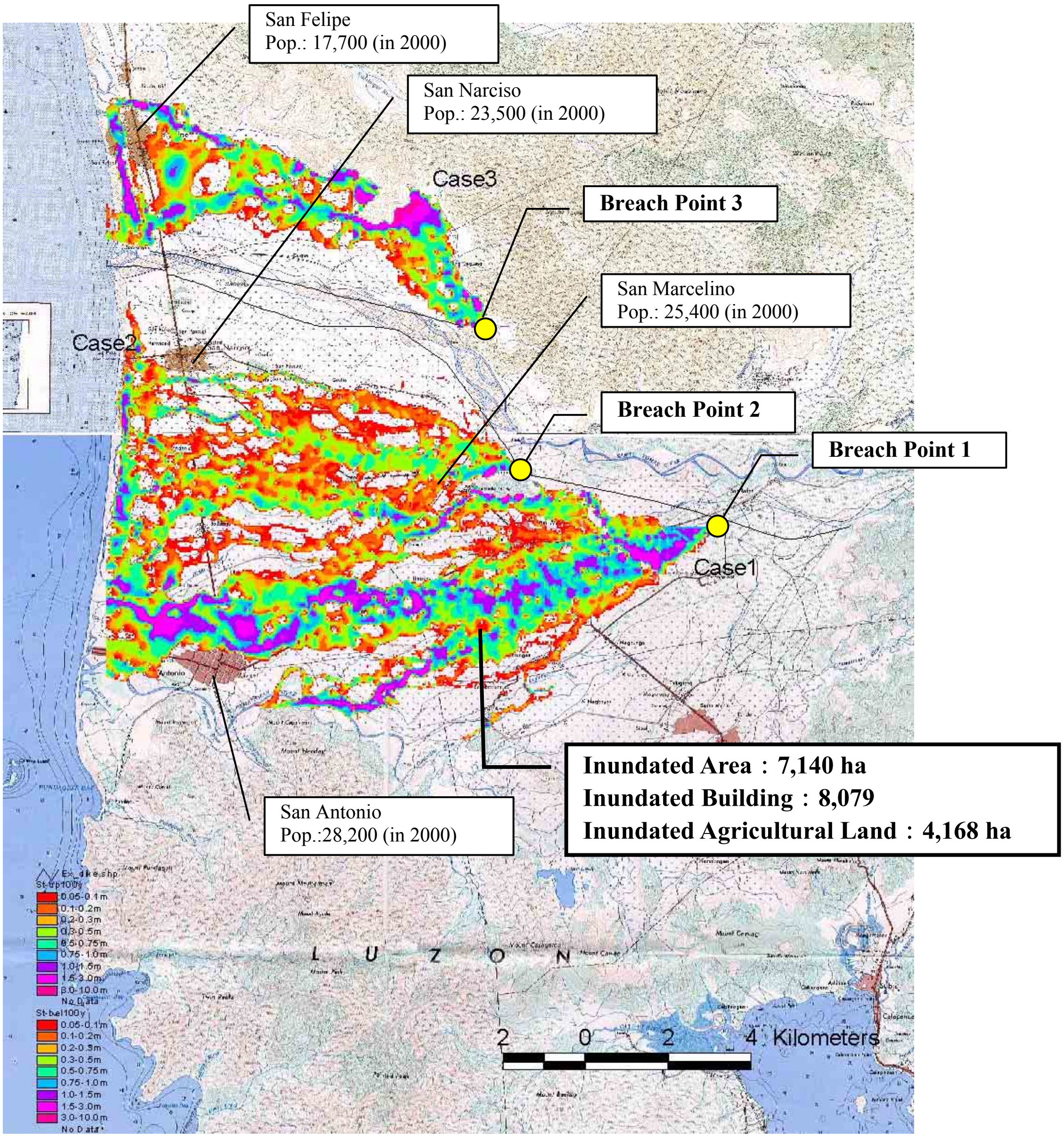



Figure 5.8 Mudflow Hazard Area in the Sto. Tomas River Basin under 100-year Probable Flood