FIGURES

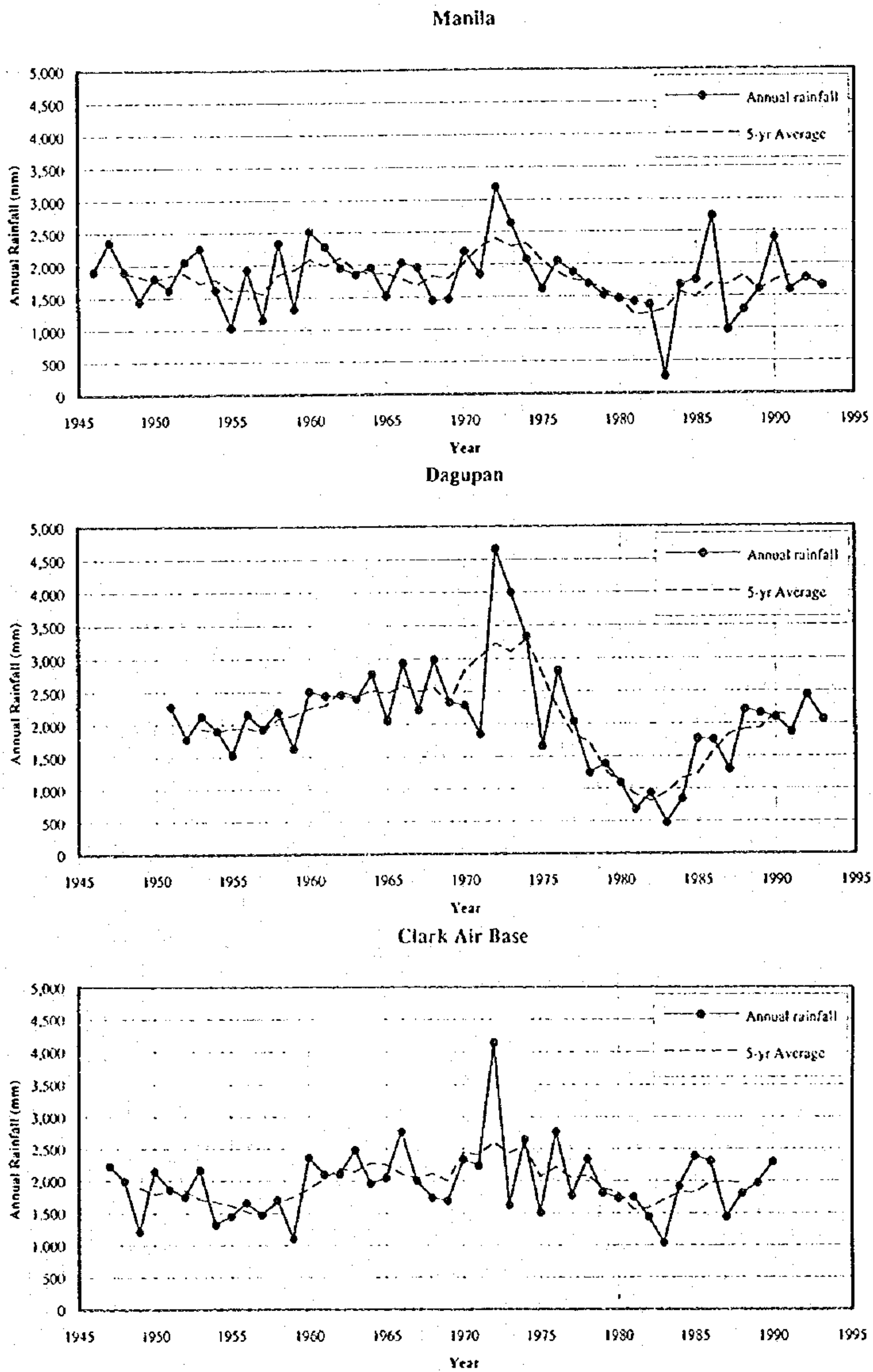
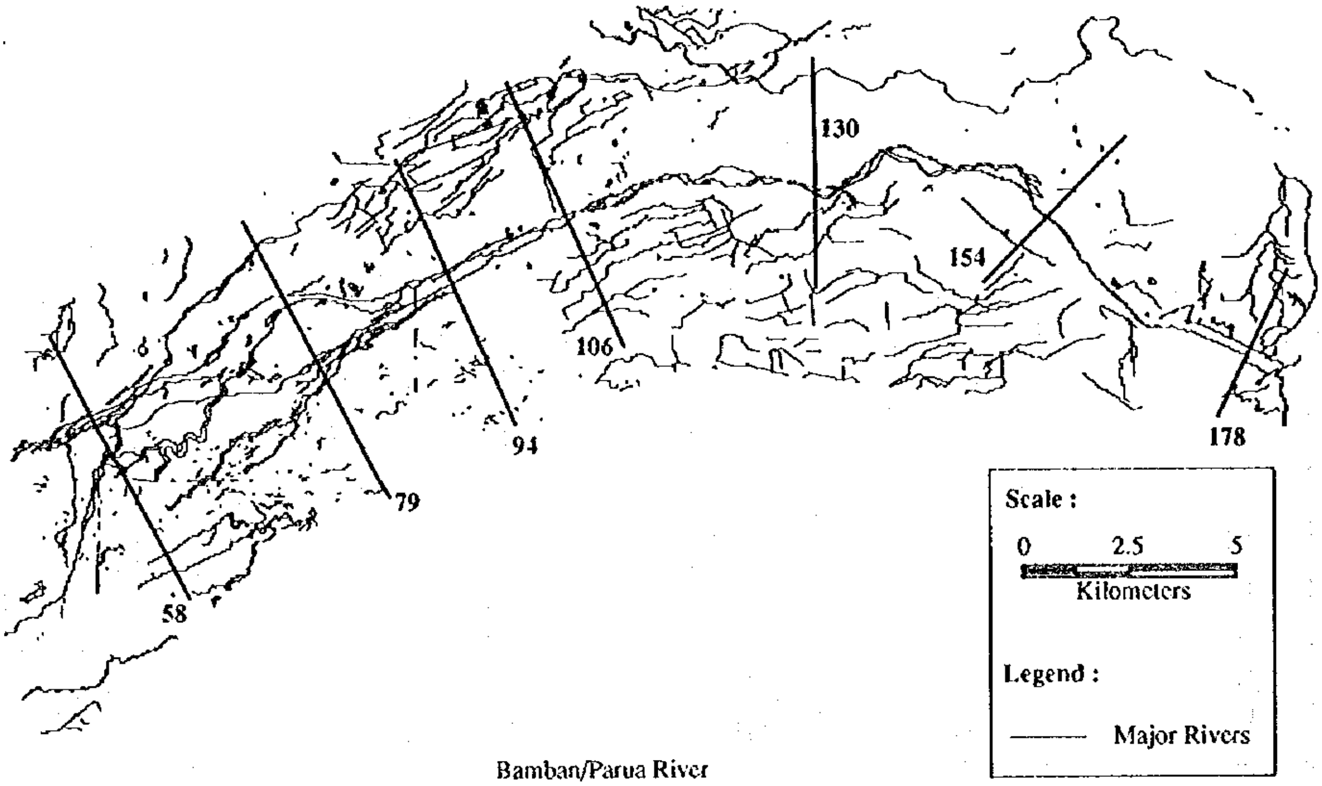
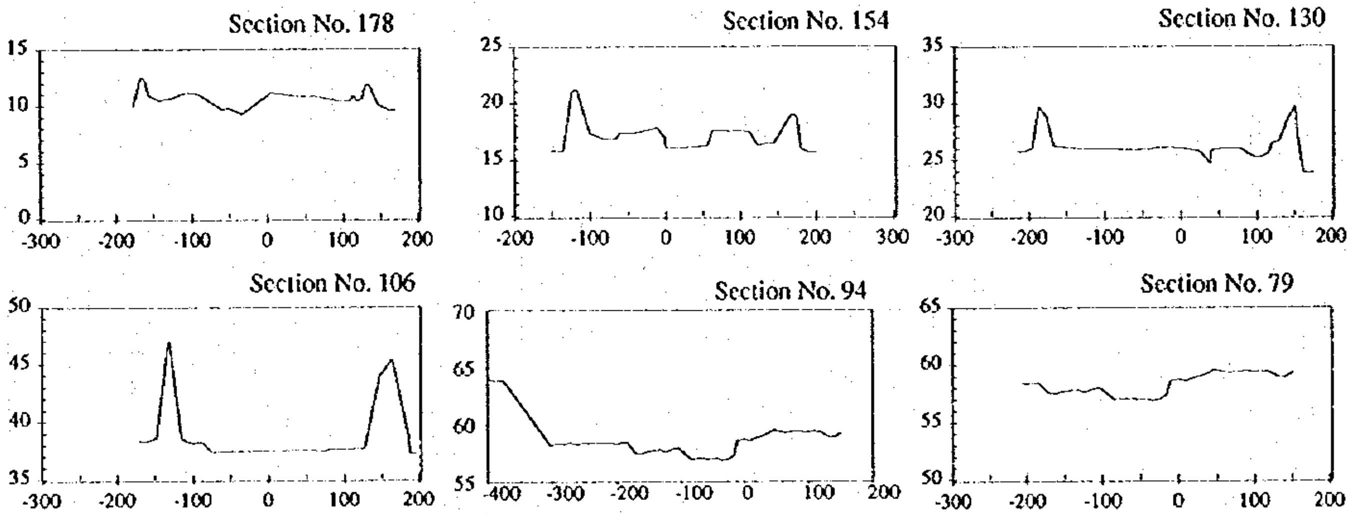


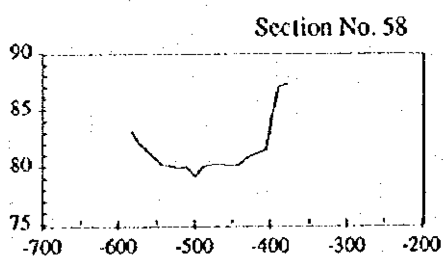
Figure G.1

Variation of Annual Rainfall

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





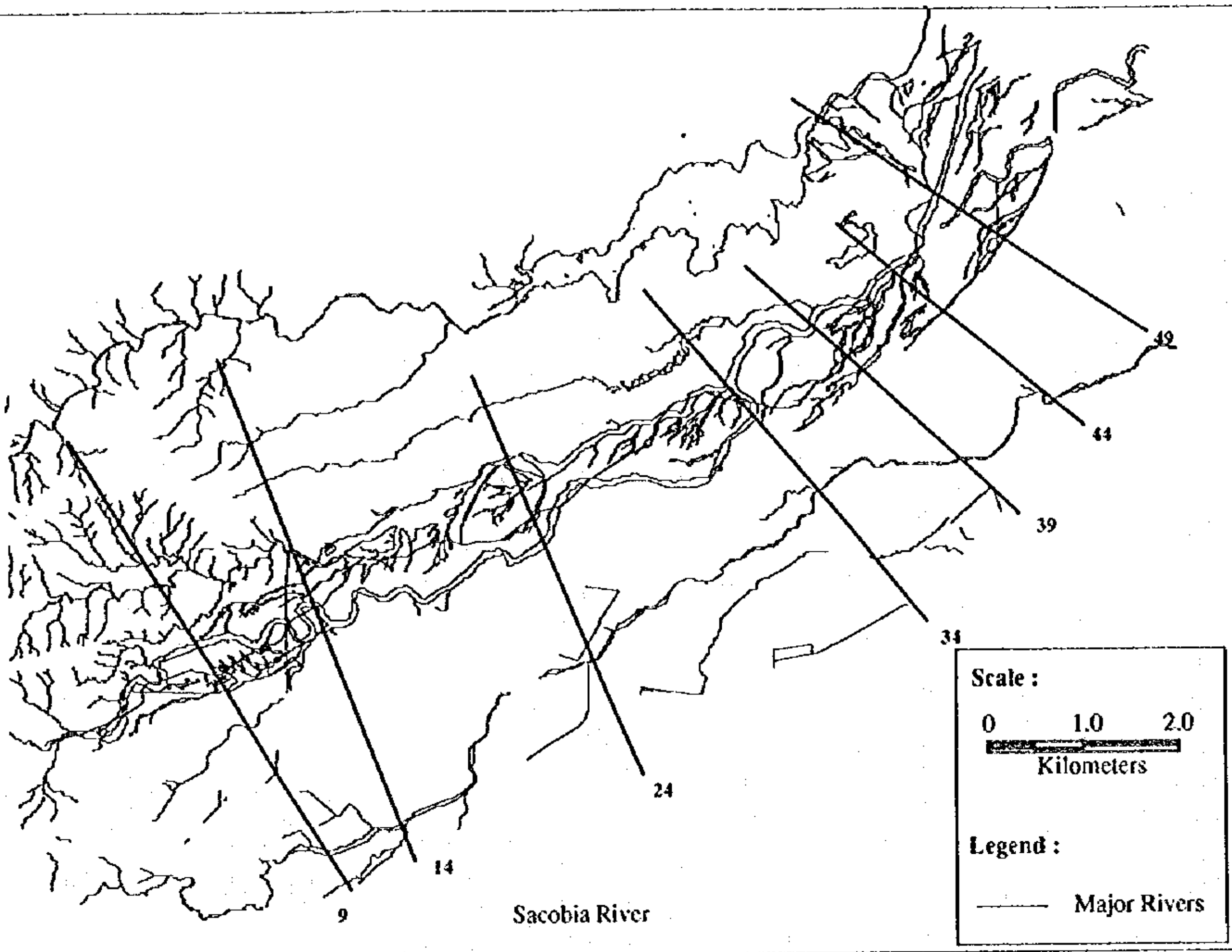


Comments :

Section No:	Distance from Confluence (km)
58	24.6
79	20.4
94	17.4
106	15.0
130	10.2
154	5.4
178	0.6

Figure G.2
Selected Cross Sections of Bamban River

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



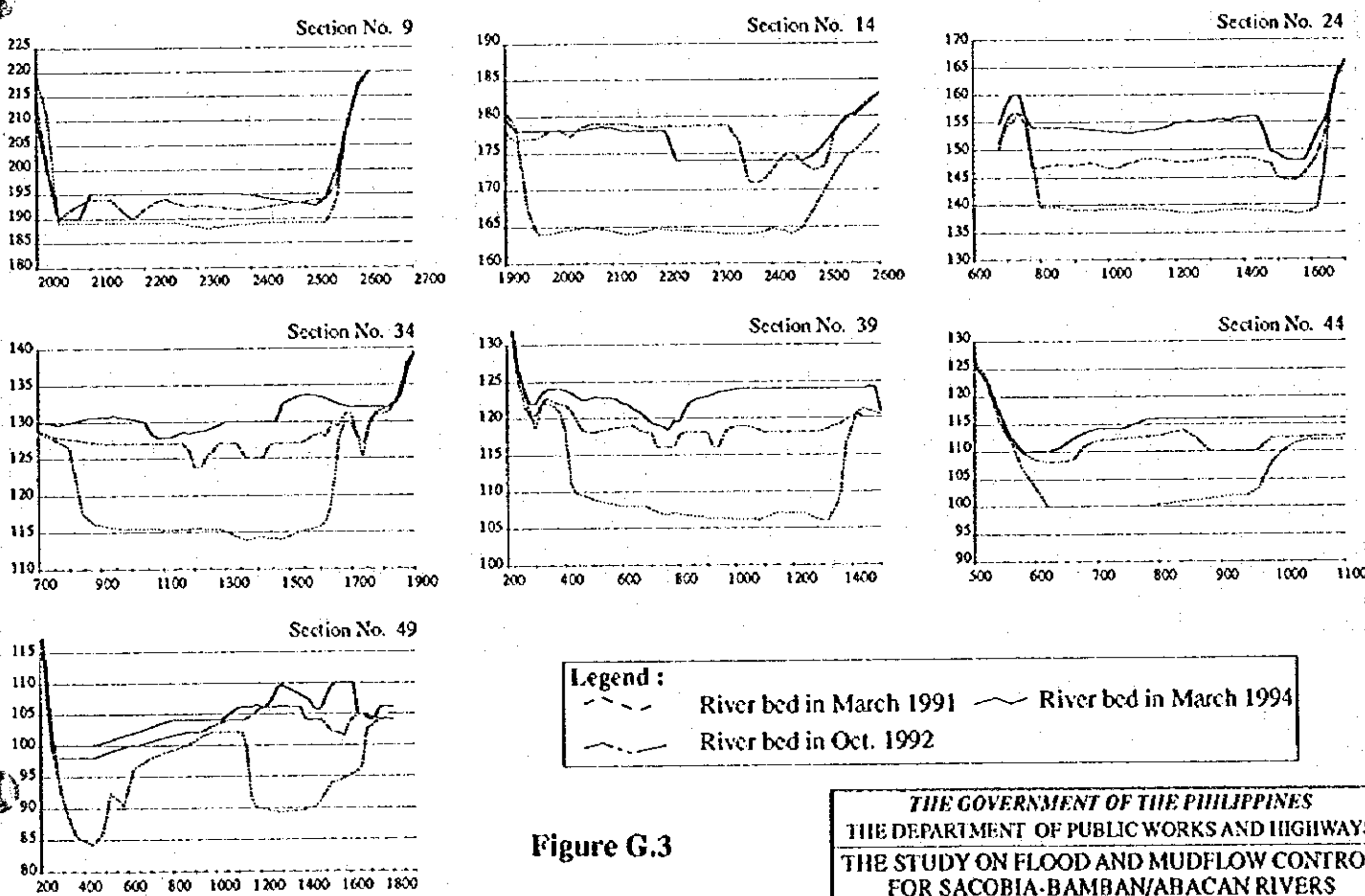


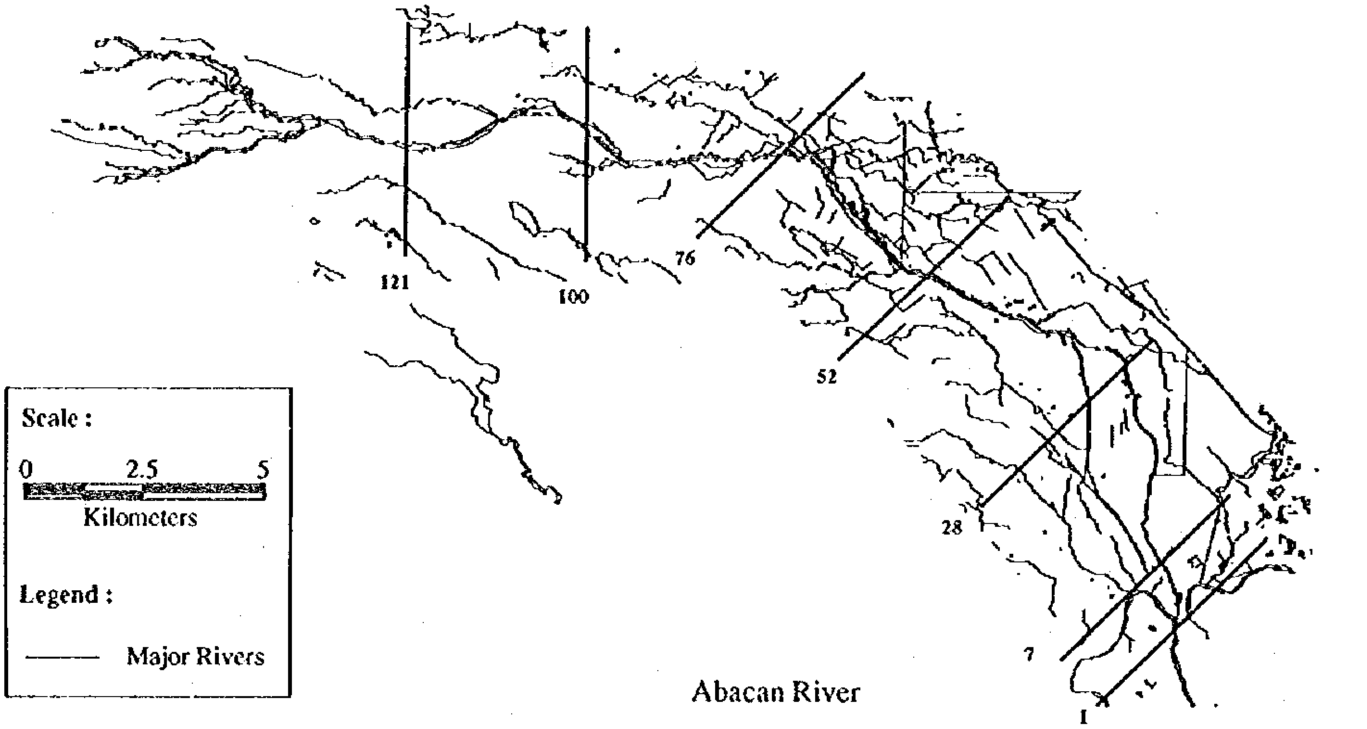
Figure G.3

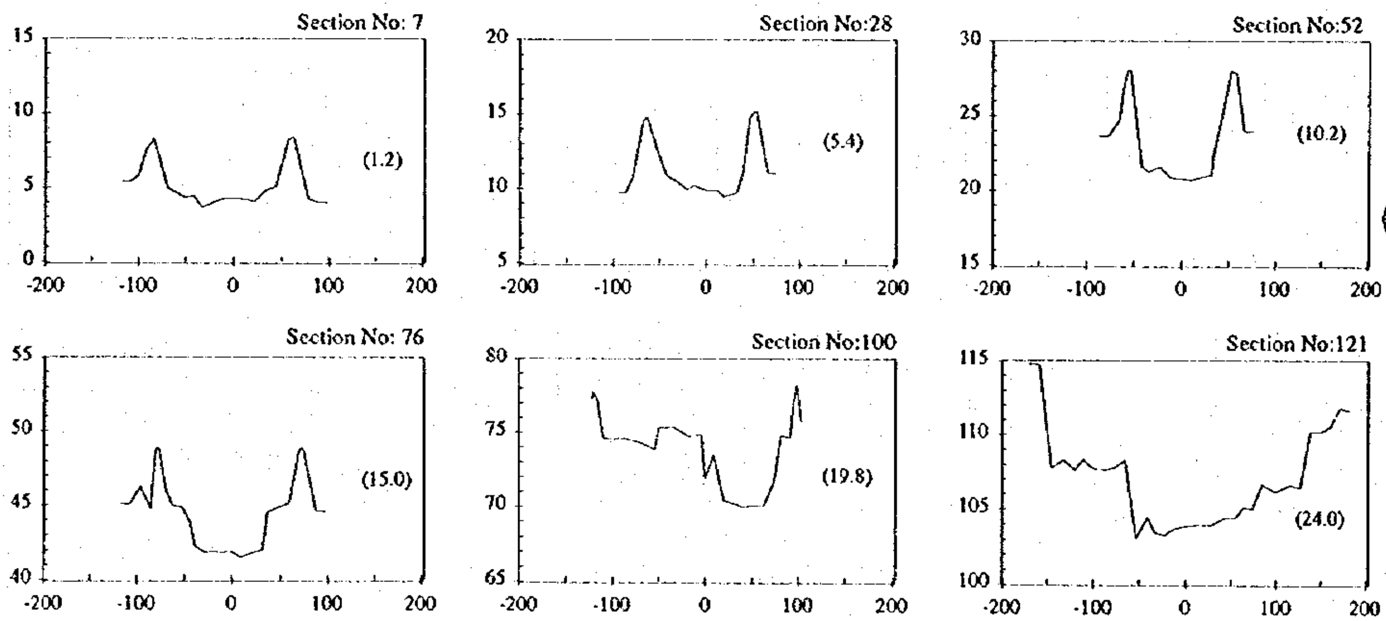
Selected Cross Sections of Sacobia River

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

THE STUDY ON FLOOD AND MUDFLOW CONTROL FOR SACOBIA-BAMBAN/ABACAN RIVERS DRAINING FROM MT. PINATUBO

JAPAN INTERNATIONAL COOPERATION AGENCY





Comments :

Section No.	Distance from Confluence (km)
7	1.2
28	5.4
52	10.2
76	15.0
100	19.8
121	24.0

Legend :

( ) distance in meters

Figure G.4
Selected Cross Sections of Abacan River

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

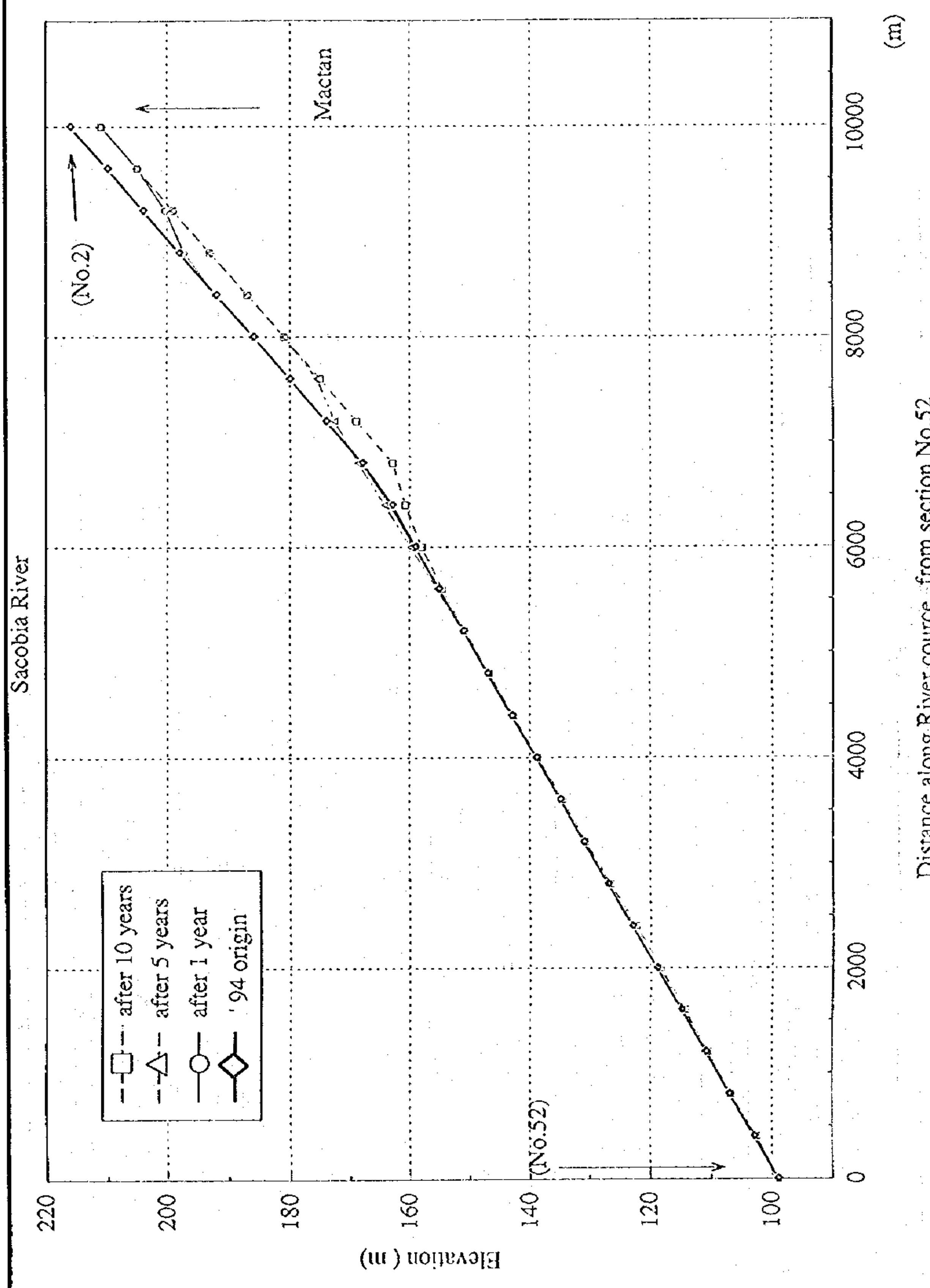


Figure G.5

River Bed Profile of Sacobia River

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

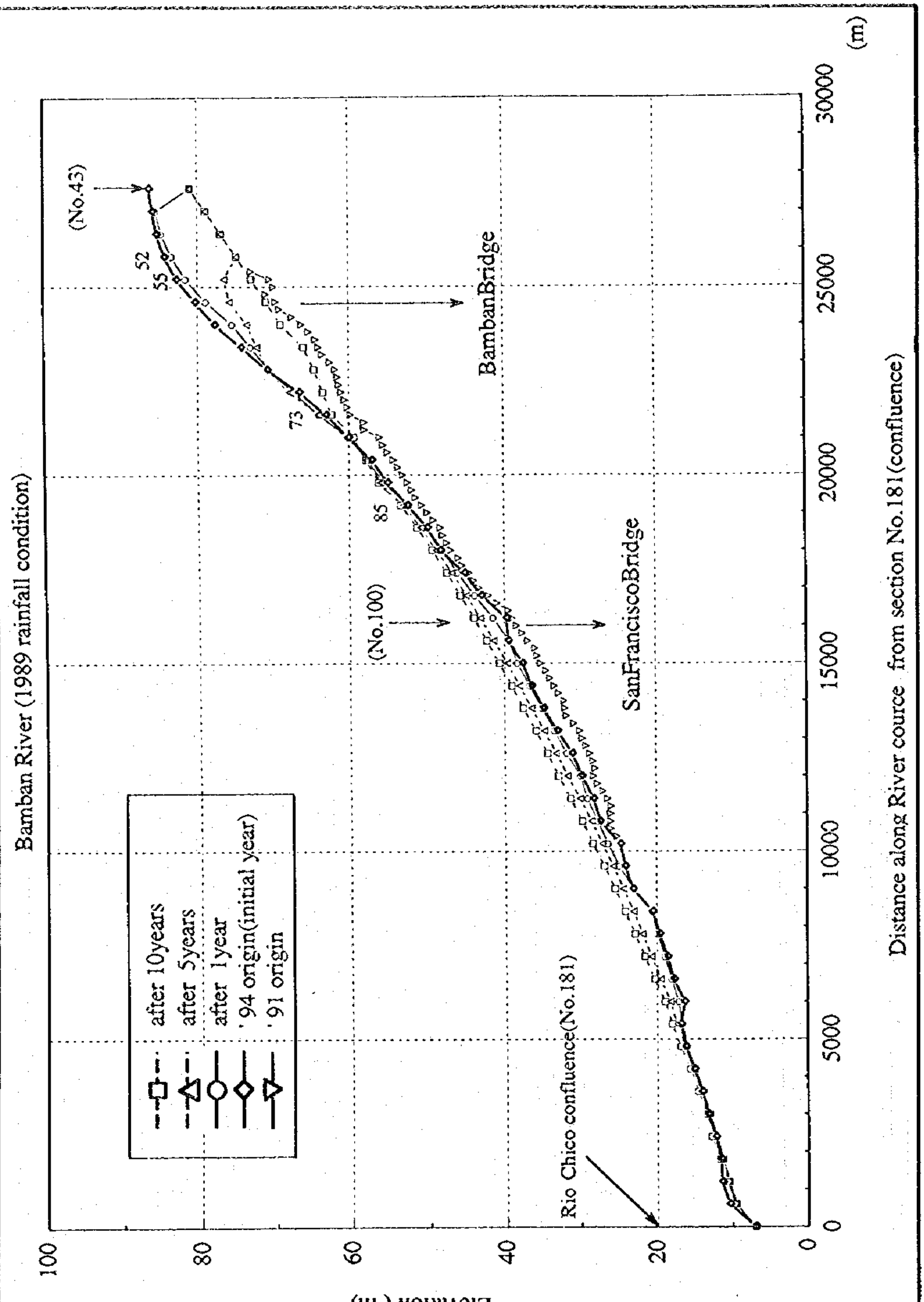


Figure G.6

River Bed Profile of Bamban River

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

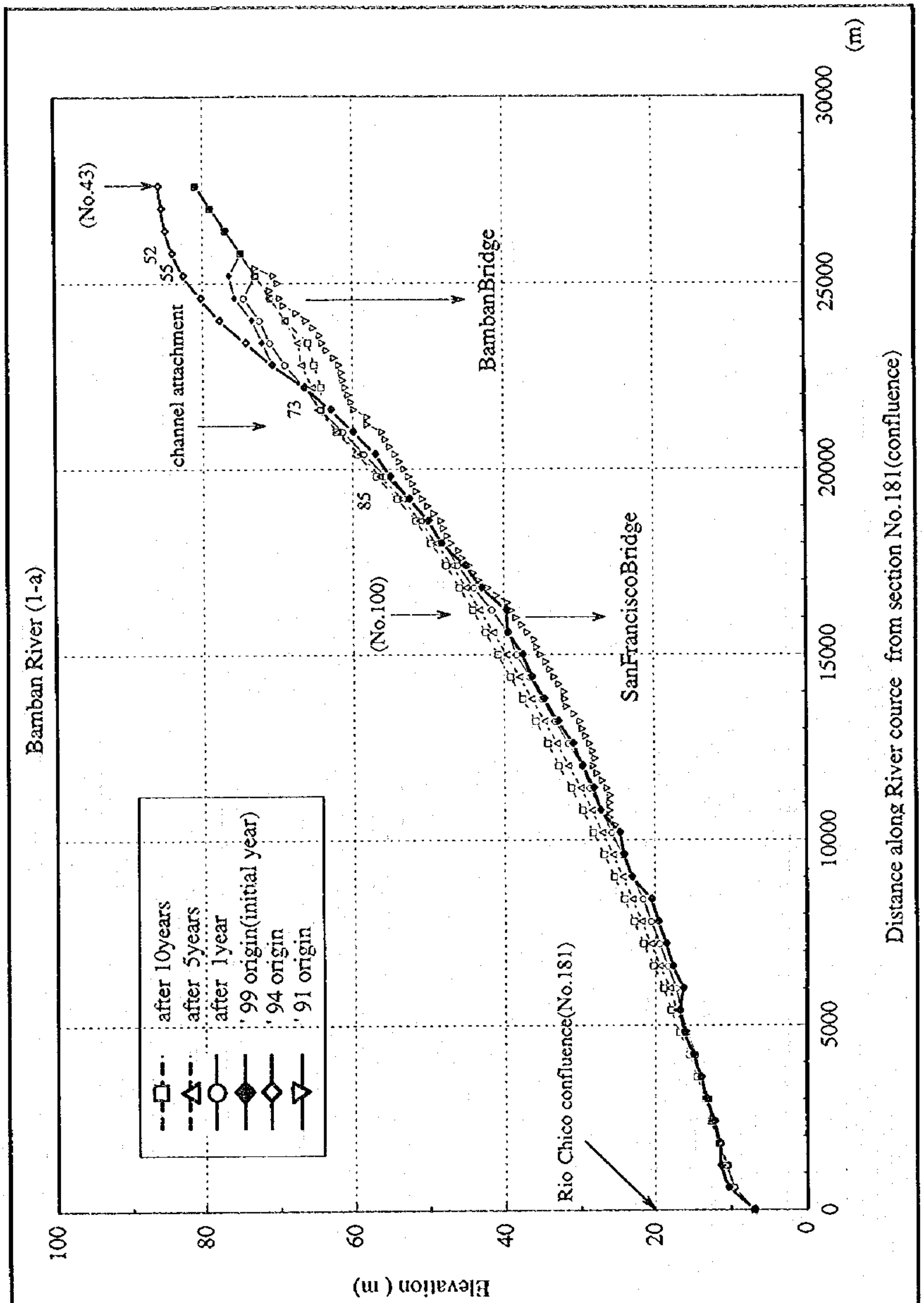


Figure G.7

River Bed Profile of Bamban River with Sacobia Diversion Channel Case 1-a Constant Sediment and No Dredging

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

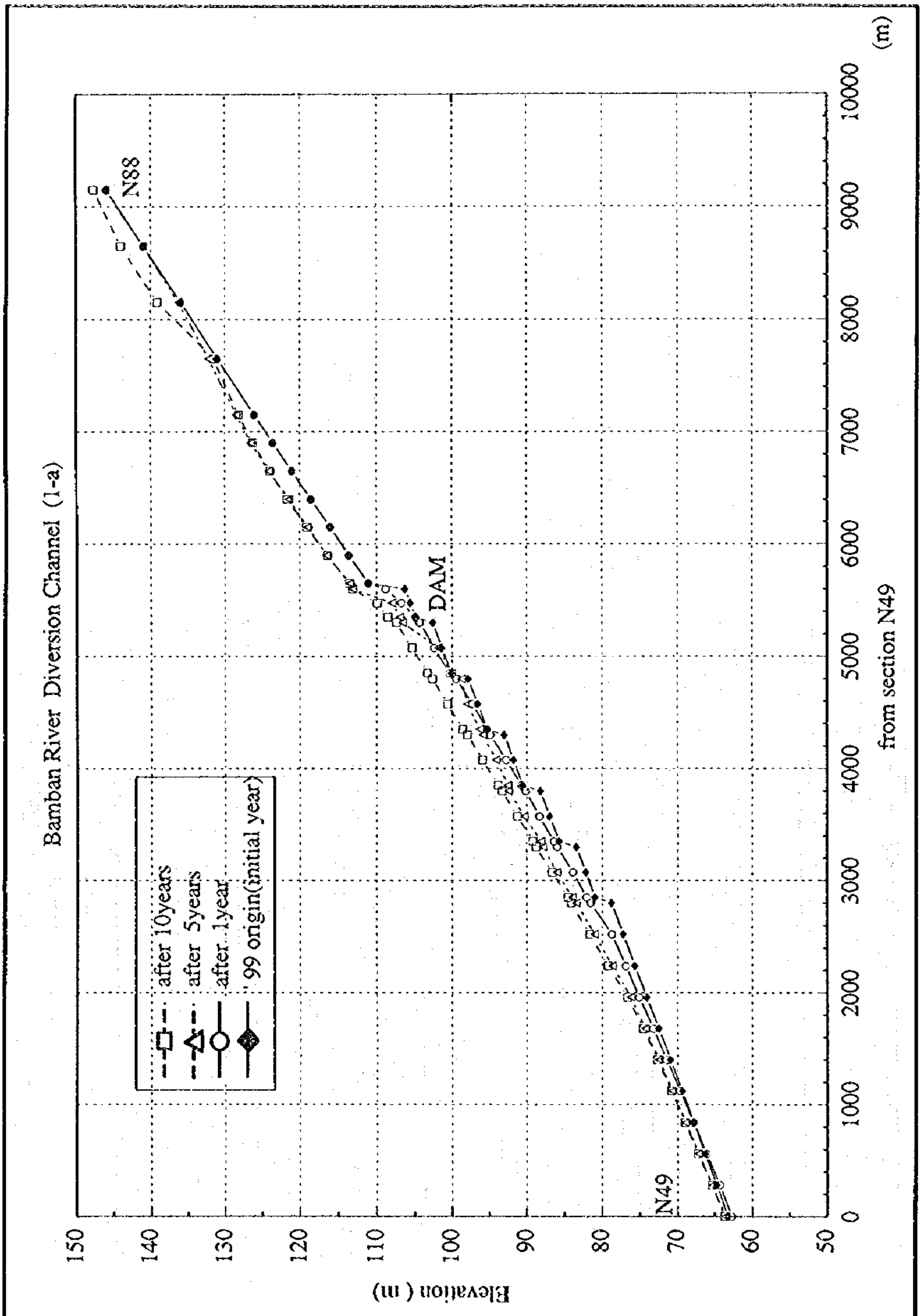


Figure G.8

River Bed Profile of Sacobia Diversion Channel
Case 1-a Constant Sediment and No Dredging

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

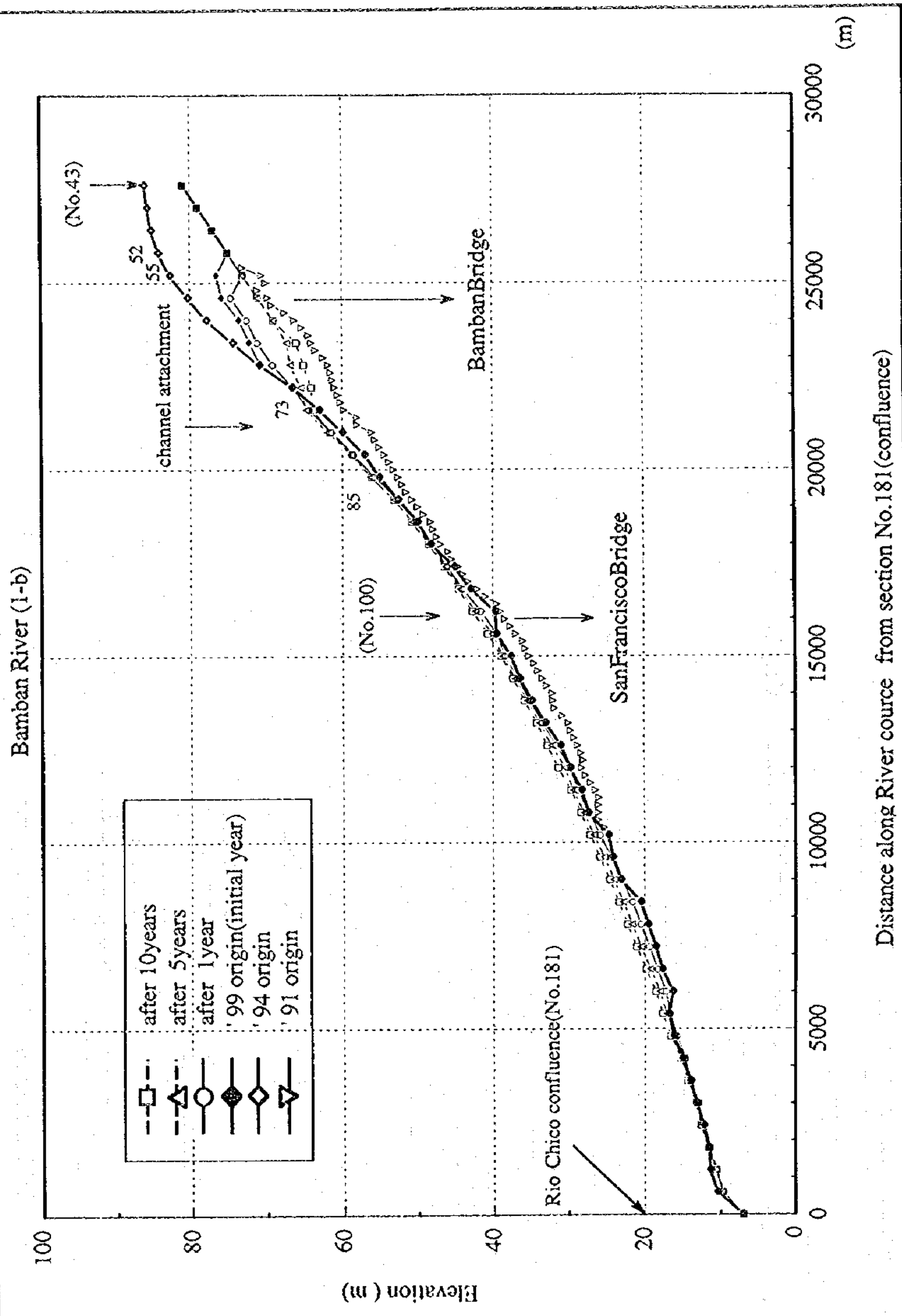


Figure G.9

River Bed Profile of Bamban River with Sacobia Diversion Channel Case 1-b Constant Sediment and Dredging Works

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

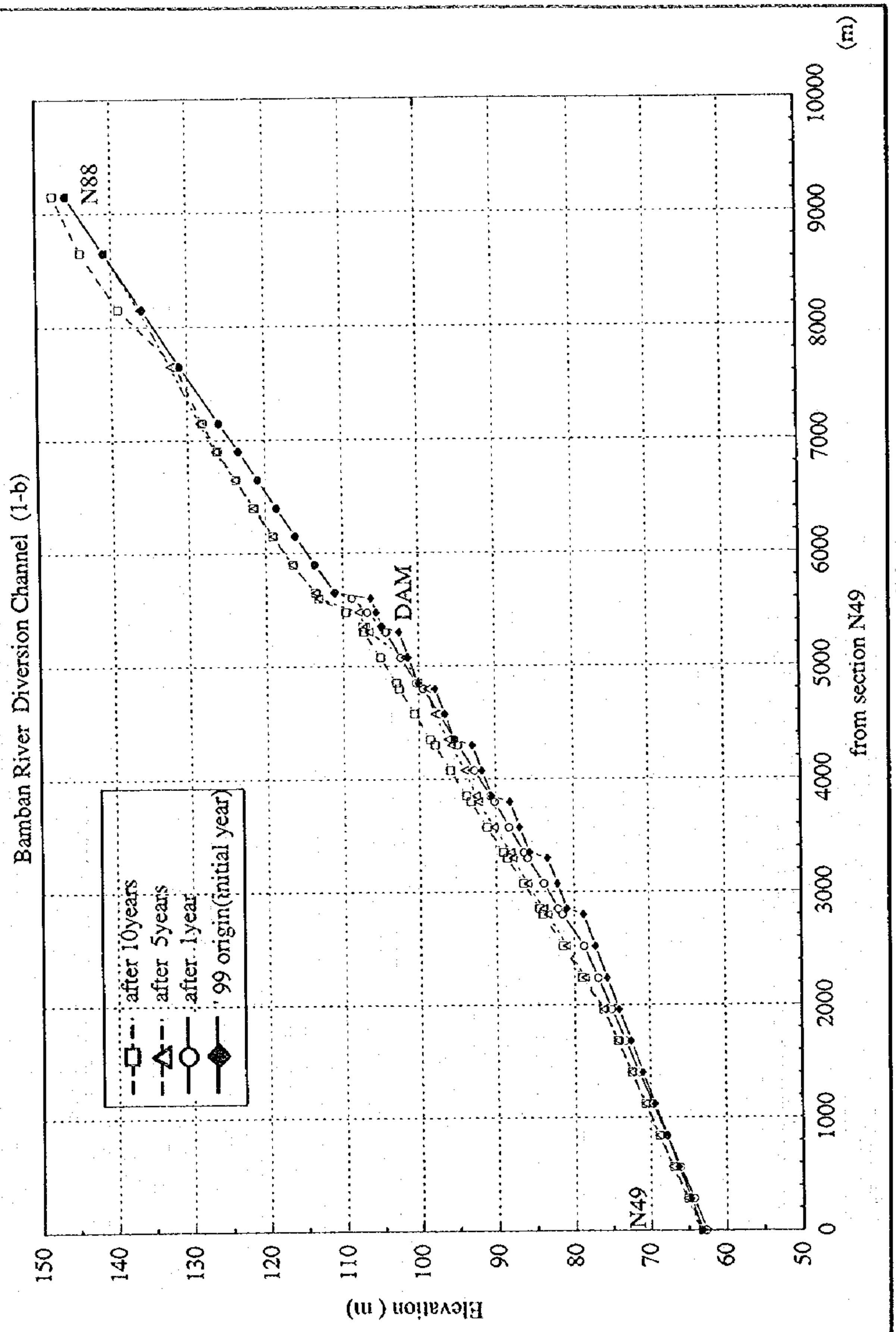


Figure G.10

River Bed Profile of Sacobia Diversion Channel Case 1-b Constant Sediment and Dredging Works

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

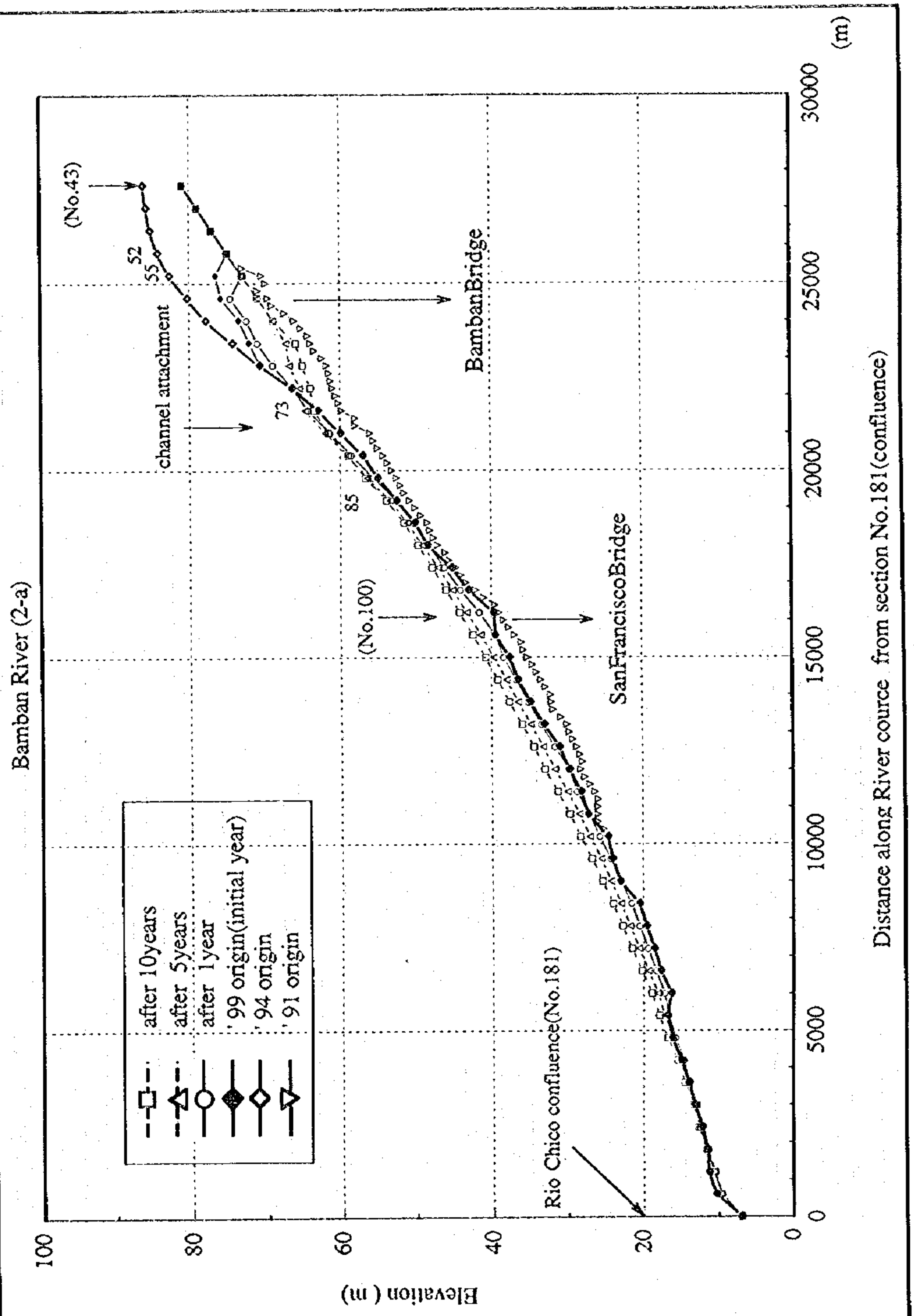


Figure G.11

River Bed Profile of Bamban River with Sacobia Diversion Channel Case 2-a Declining Sediment and No Dredging

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

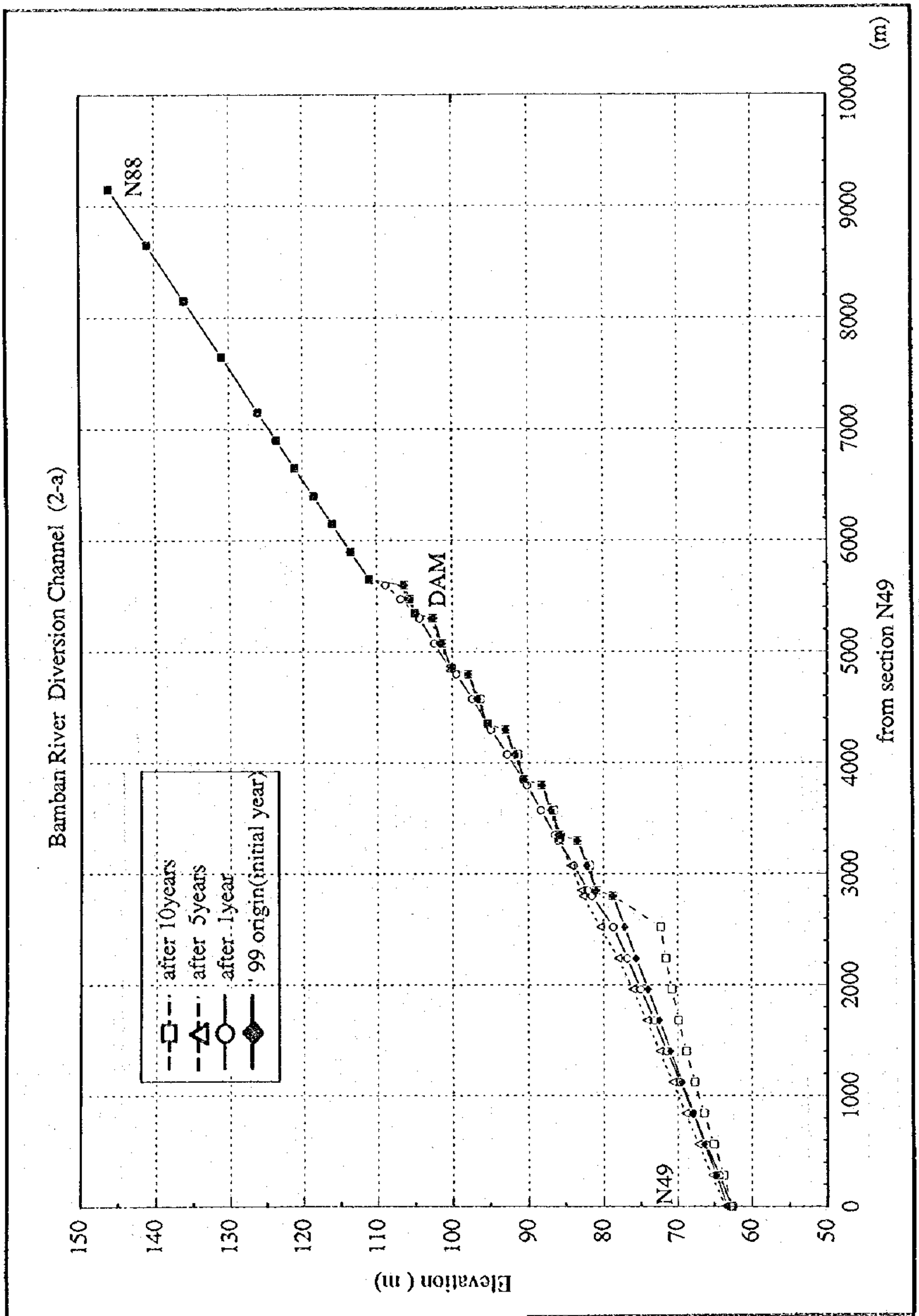


Figure G.12

River Bed Profile of Sacobia Diversion Channel
Case 2-a Declining Sediment and No Dredging

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

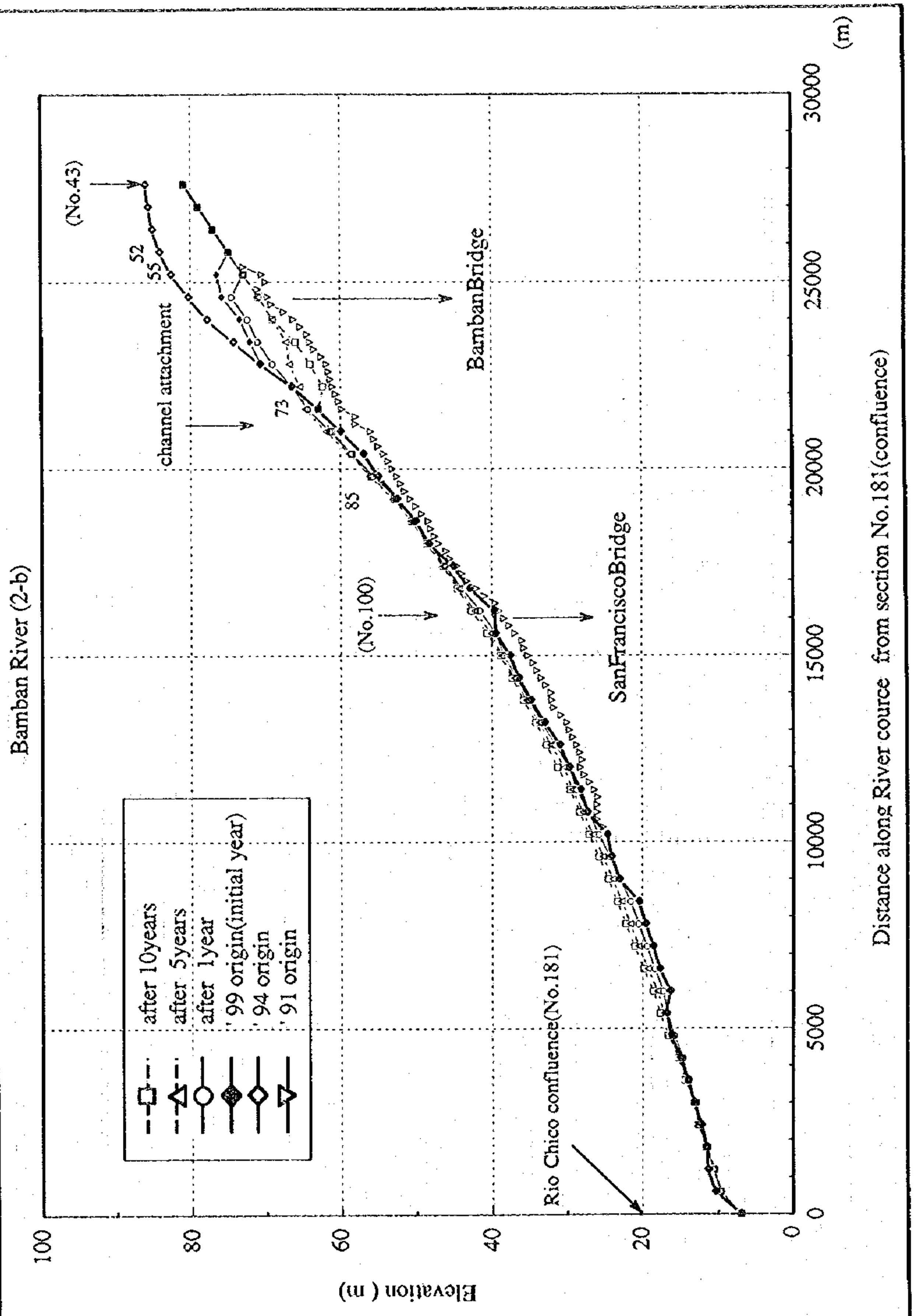


Figure G.13

River Bed Profile of Bamban River with Sacobia Diversion Channel Case 2-b Declining Sediment and Dredging Works

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

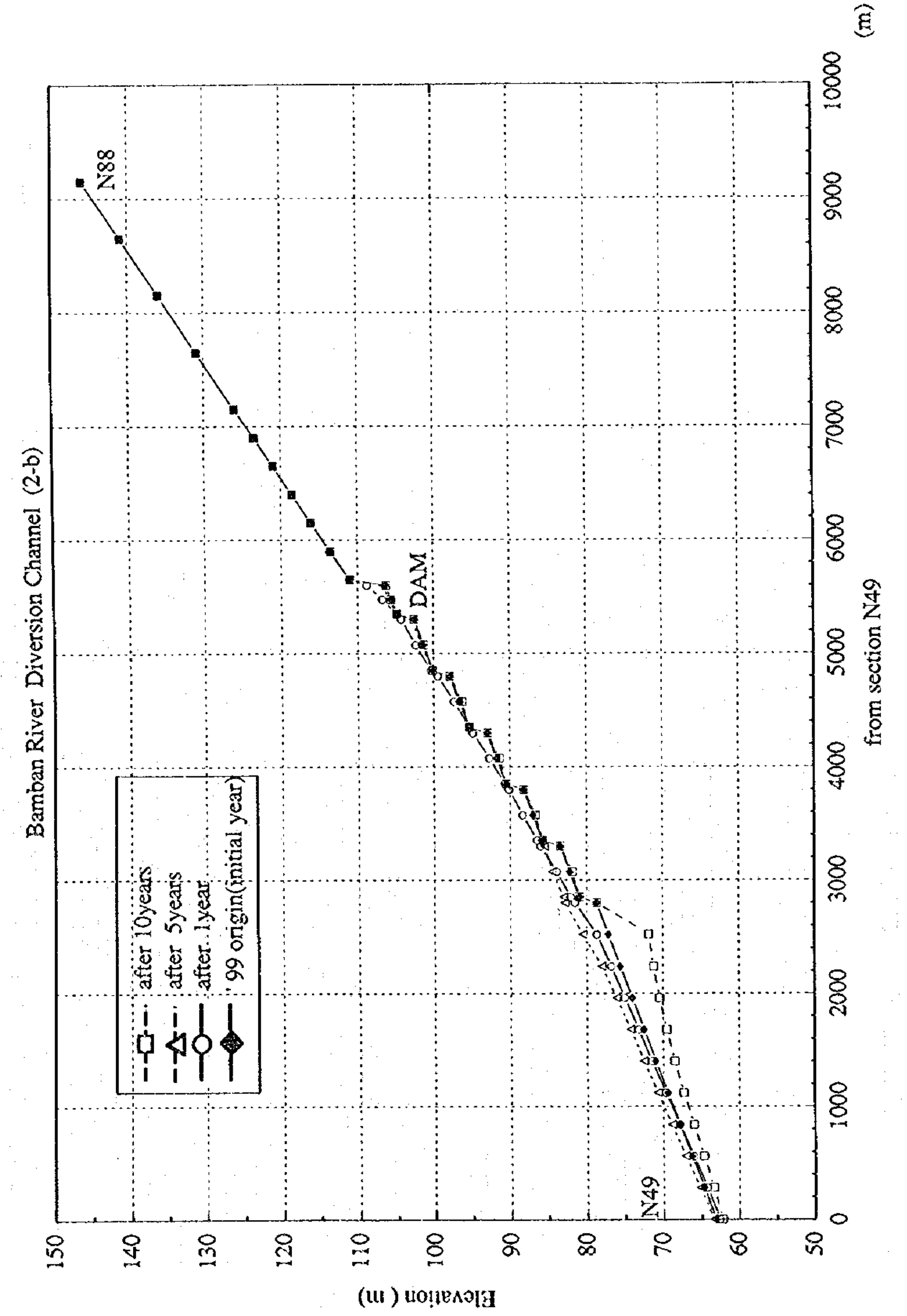


Figure G.14

River Bed Profile of Sacobia Diversion Channel Case 2-b Declining Sediment and Dredging Works

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

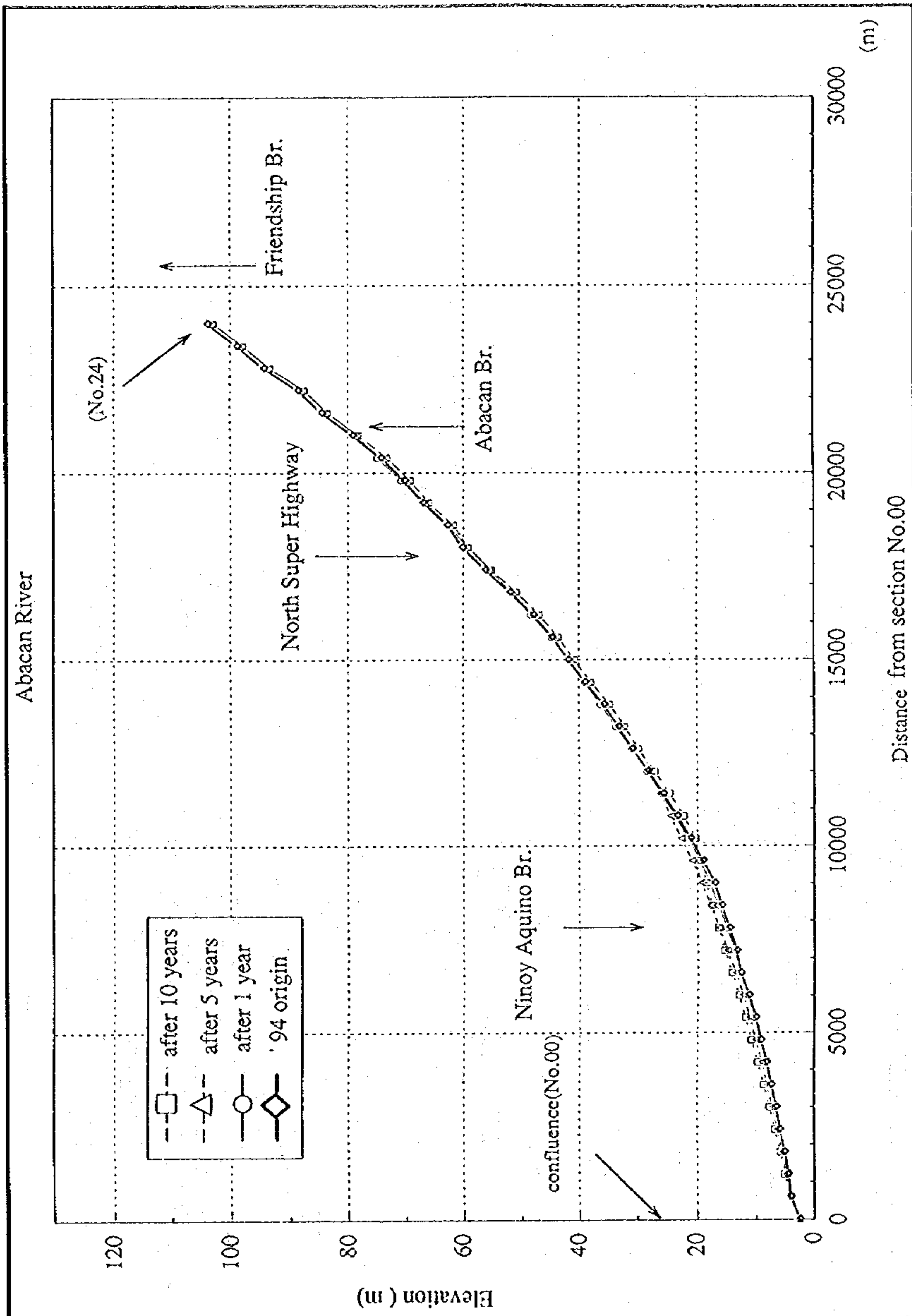


Figure G.15

River Bed Profile of Abacan River

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

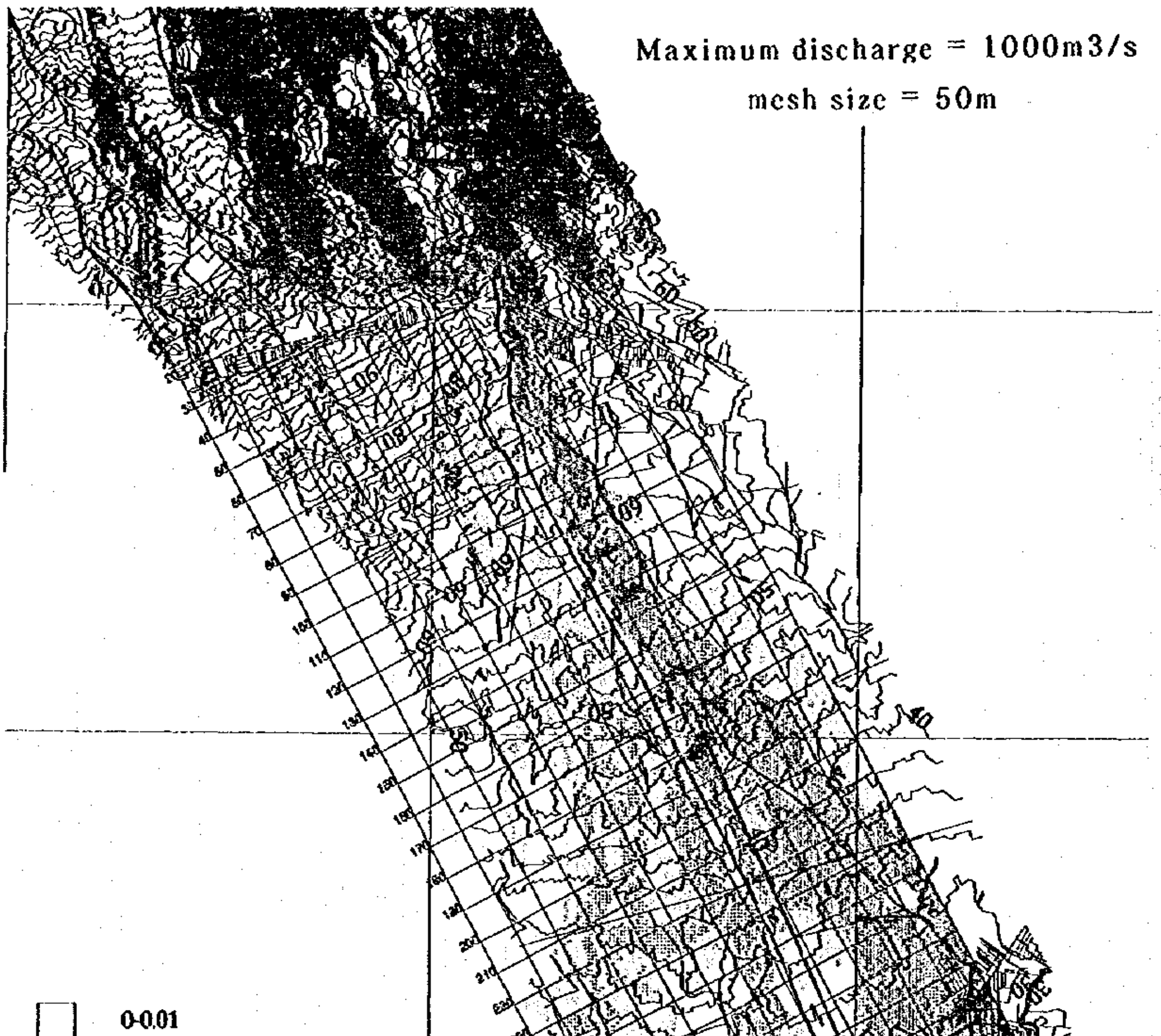


Figure G.16

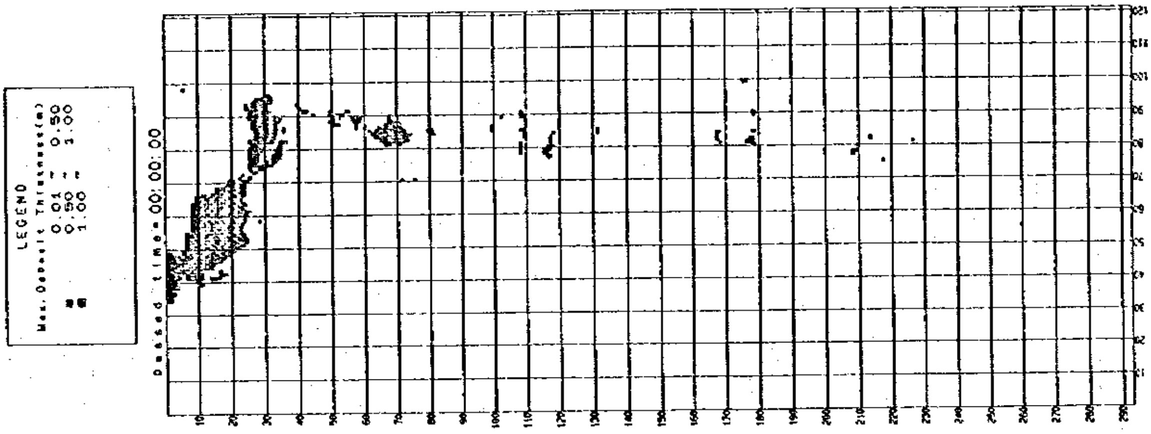
Flood and Mudflow Inundation in 1991 on DTM

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

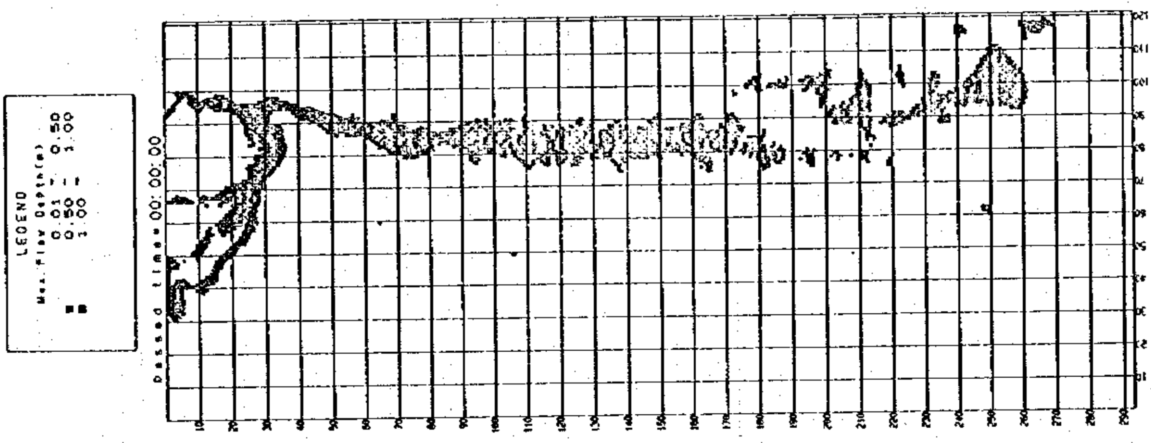
THE STUDY ON FLOOD AND MUDFLOW CONTROL FOR SACOBIA-BAMBAN/ABACAN RIVER DRAINING FROM MT.PINATUBO

JAPAN INTERNATIONAL COOPERATION AGENCY

Maximum discharge = 1000m3/s
mesh size = 50m



Maximum Deposit



Maximum Flow Depth

Figure G.17

Flood and Mudflow Inundation in 1991 (Flow and Deposit)

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

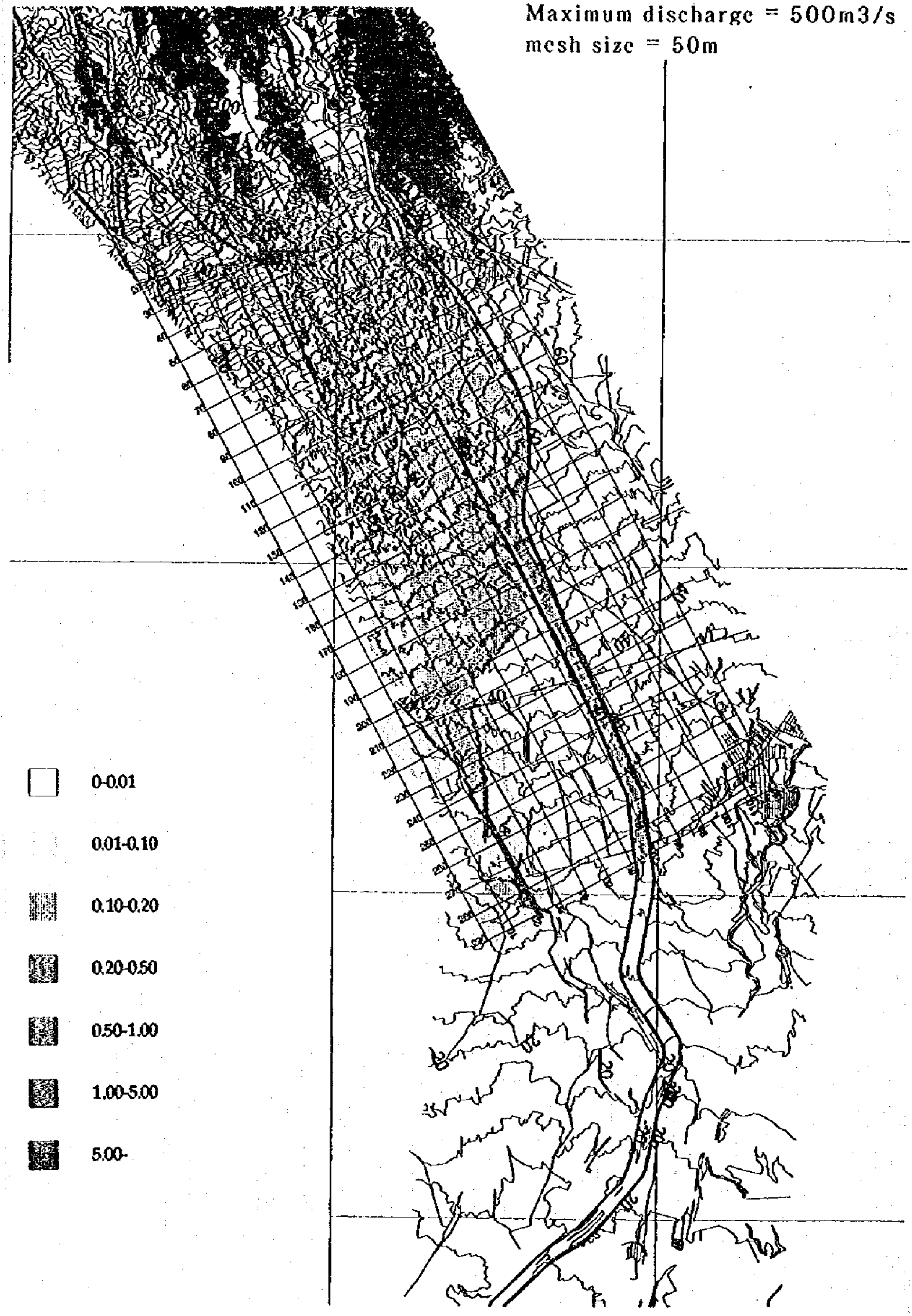


Figure G.18

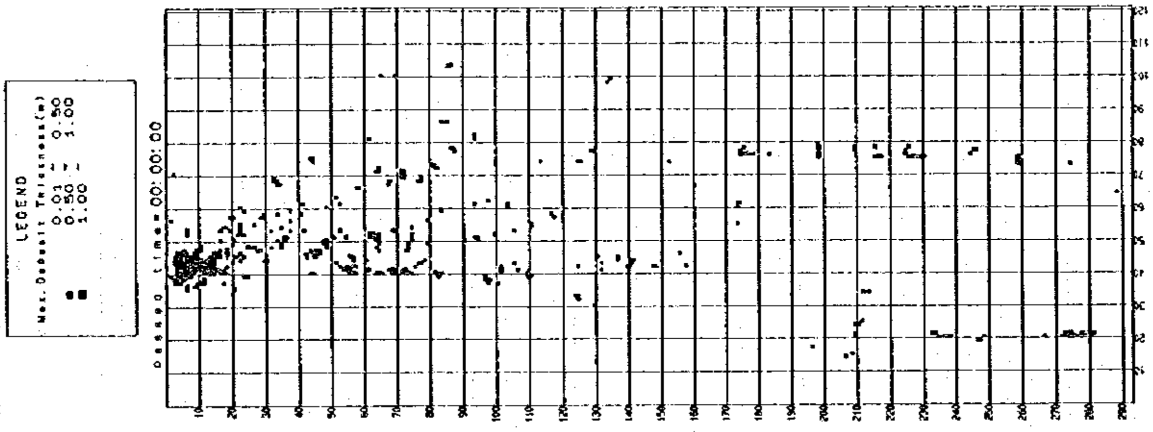
Flood and Mudflow Inundation in 1994 on DTM

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

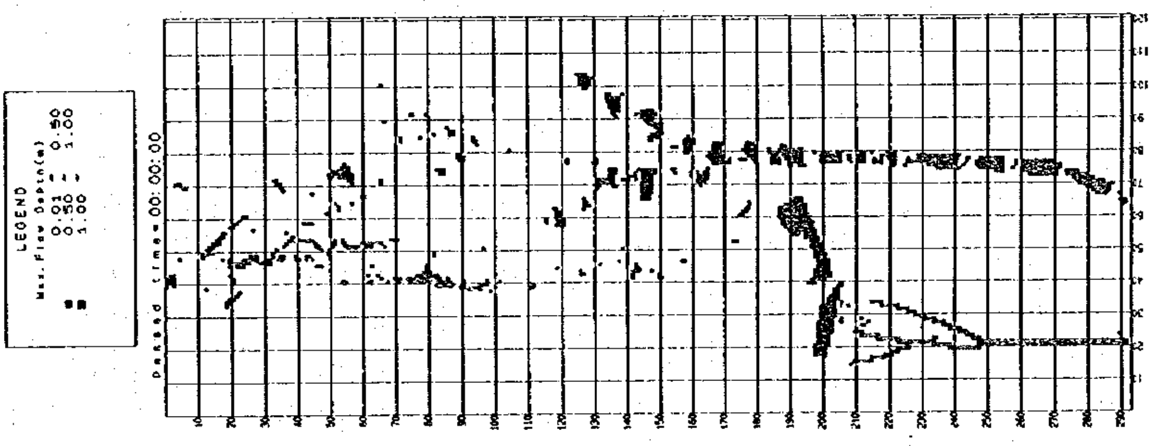
THE STUDY ON FLOOD AND MUDFLOW CONTROL FOR SACOBIA-BAMBAN/ABACAN RIVER DRAINING FROM MT.PINATUBO

JAPAN INTERNATIONAL COOPERATION AGENCY

Maximum discharge = 500m3/s
mesh size = 50m



Maximum Deposit

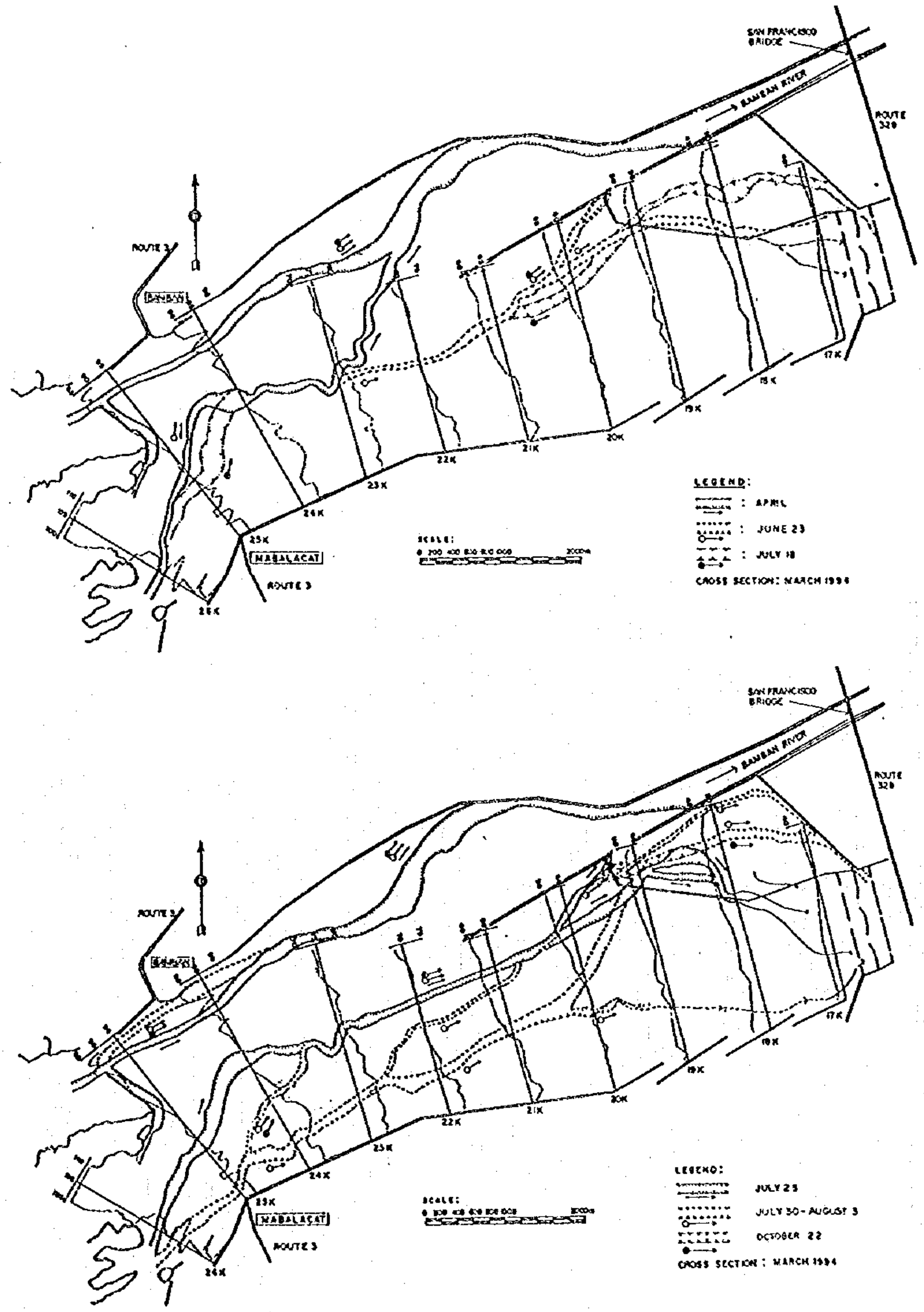


Maximum Flow Depth

Figure G.19

Flood and Mudflow Inundation in 1994 (Flow and Deposit)

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



(As of November 1, 1994)

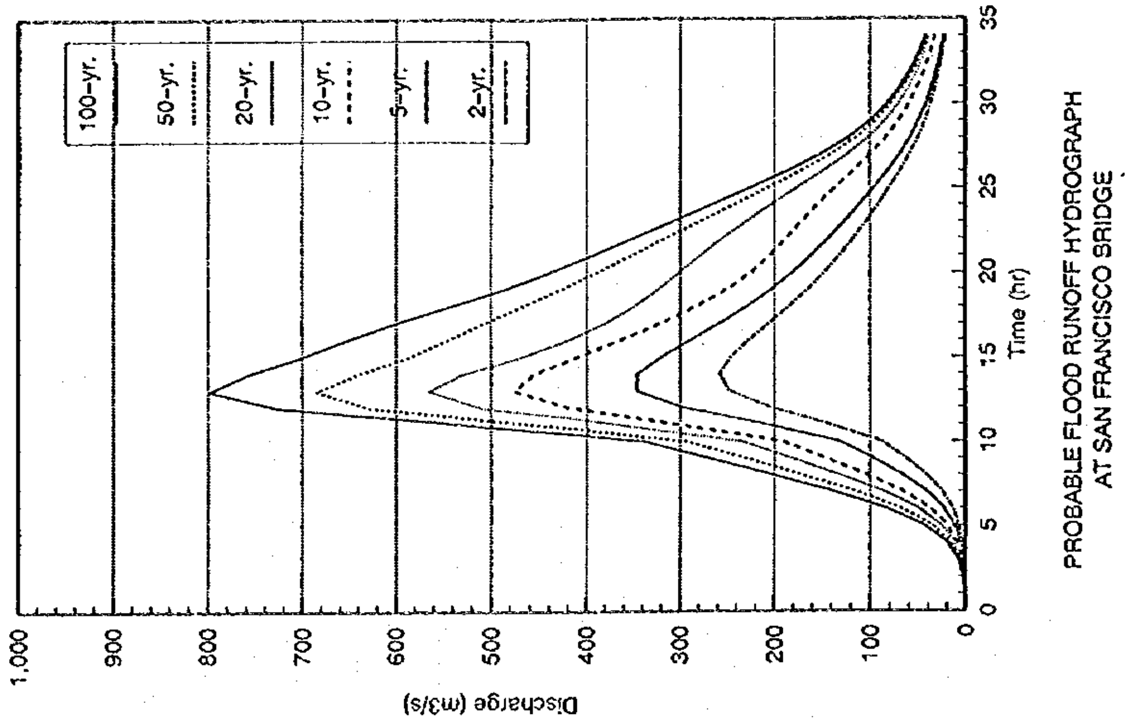
Figure G.20

Chronological Change of Sacobia-Bamban Water Course

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

THE STUDY ON FLOOD AND MUDFLOW CONTROL FOR SACOBIA-BAMBAN/ABACAN RIVER DRAINING FROM MT.PINATUBO

JAPAN INTERNATIONAL COOPERATION AGENCY



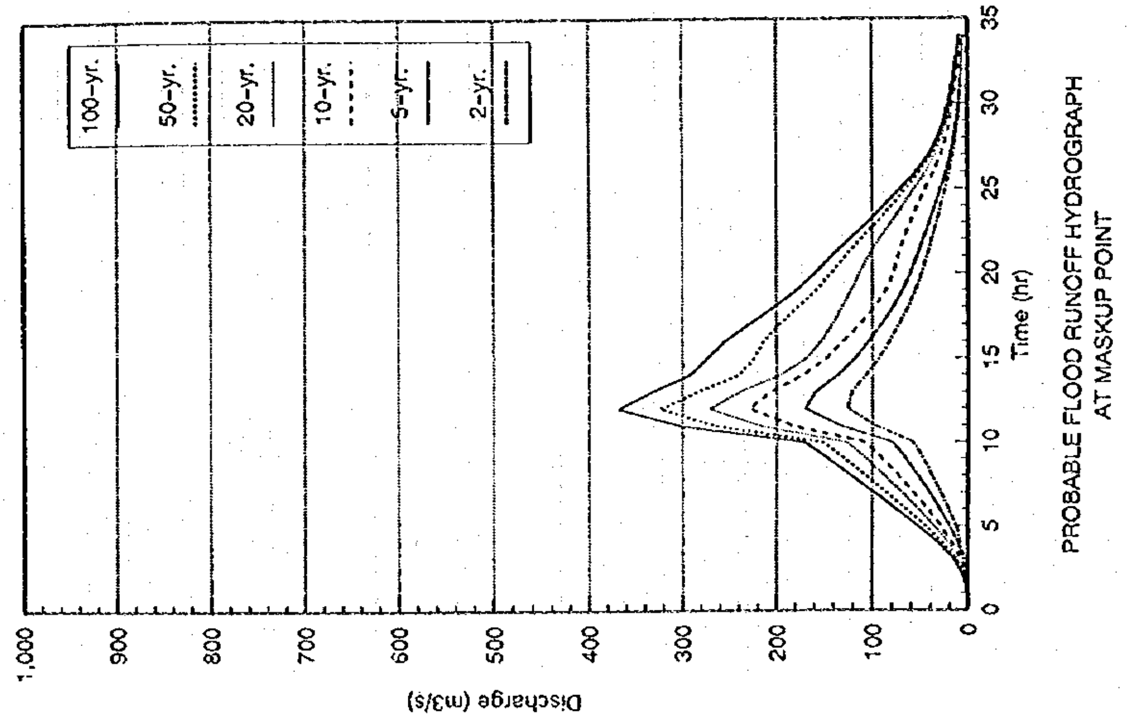


Figure G.21

Probable Flood Hydroghaphs in Sacobia River

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

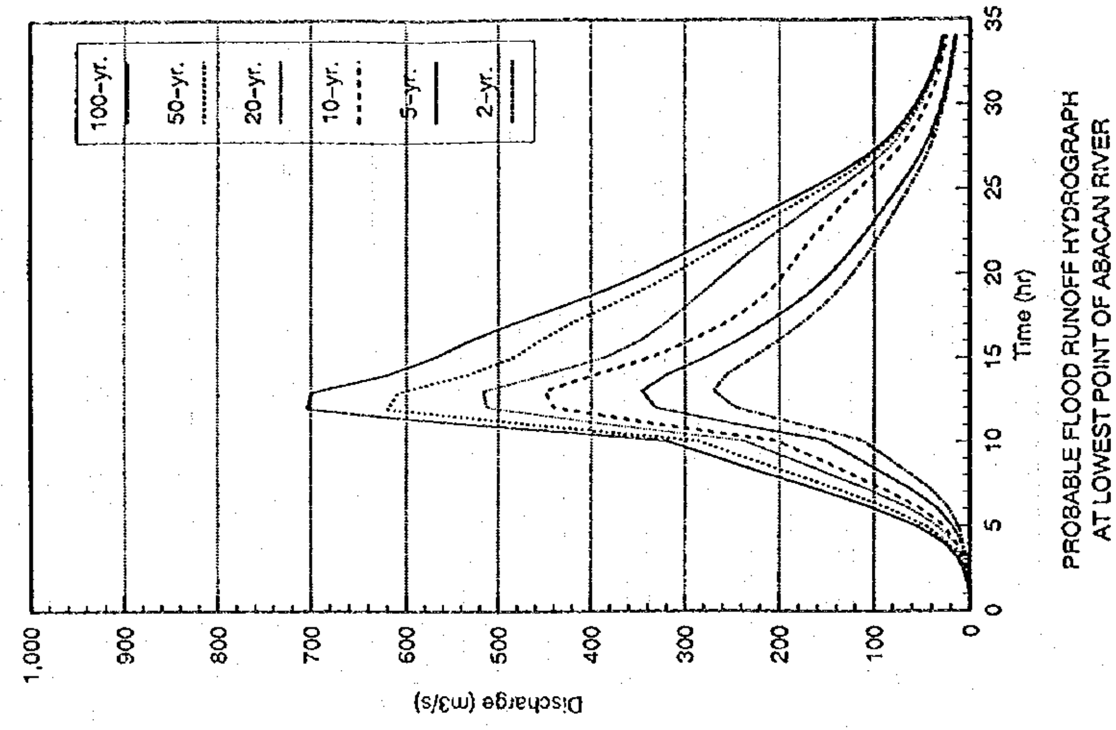


Figure G.22

Probable Flood Hydroghaphs in Abacan River

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

THE STUDY ON FLOOD AND MUDFLOW CONTROL
FOR SACOBIA-BAMBAN/ABACAN RIVER
DRAINING FROM MT.PINATUBO

JAPAN INTERNATIONAL COOPERATION AGENCY

Peak discharge (m3/s)

Maskup(370)   Marimla+Cauayang(800)

mesh size = 100m

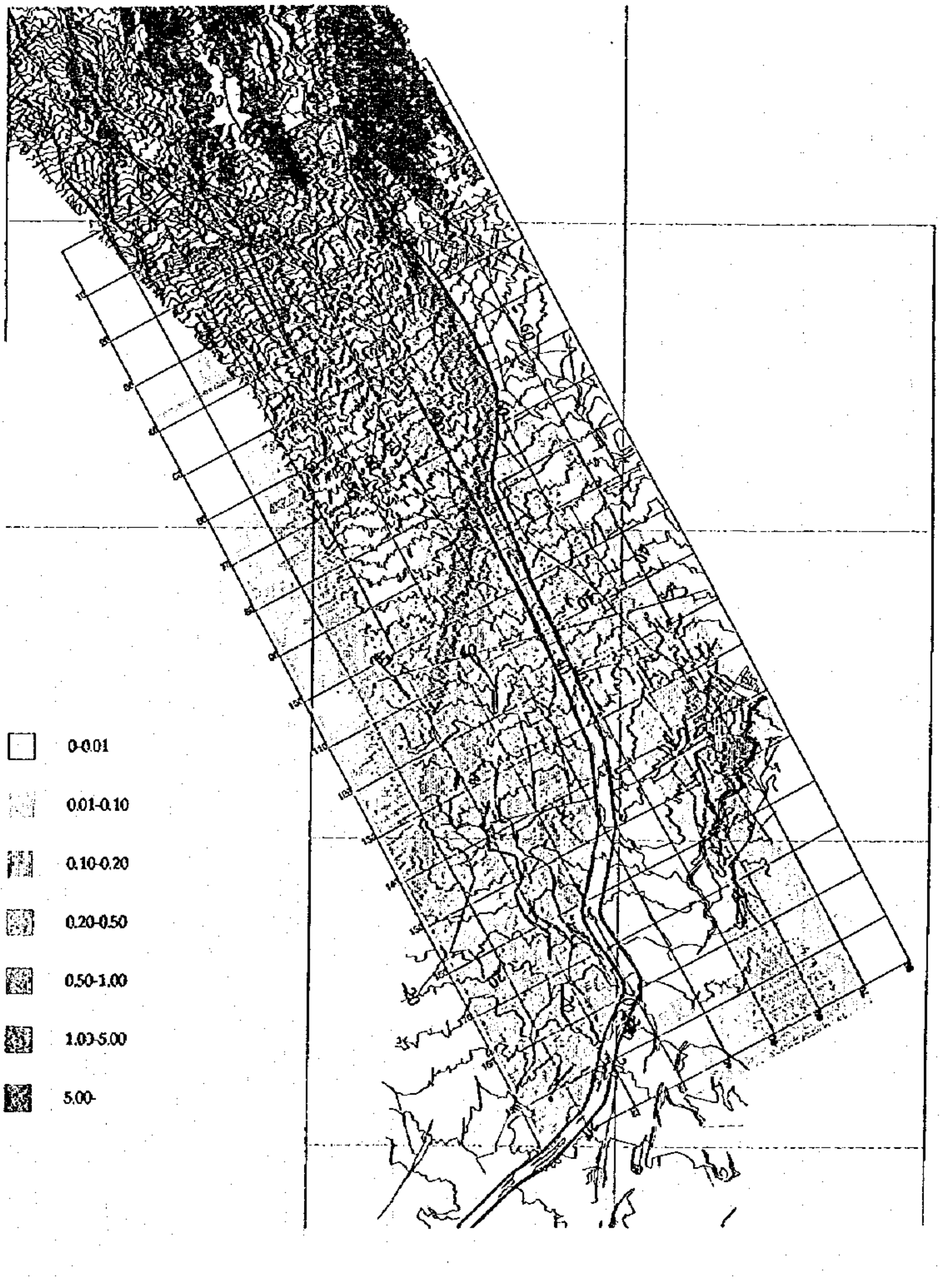
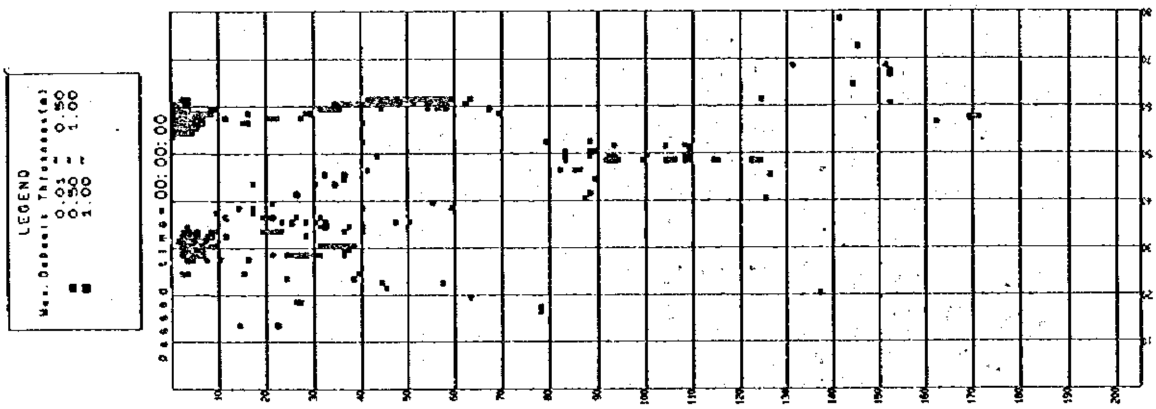


Figure G.23

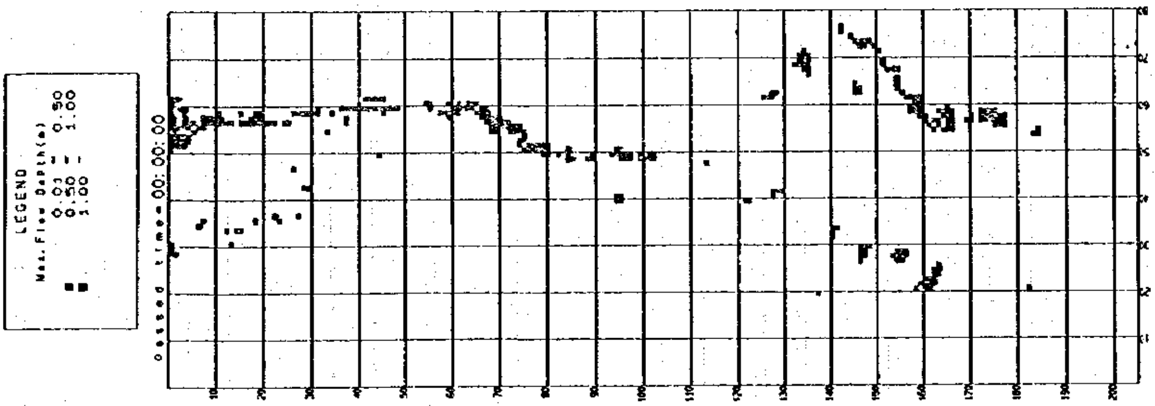
Maximum Flow Depth on Topographic Map due to 100-year Flood in Bamban River Basin

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



Maximum Deposit

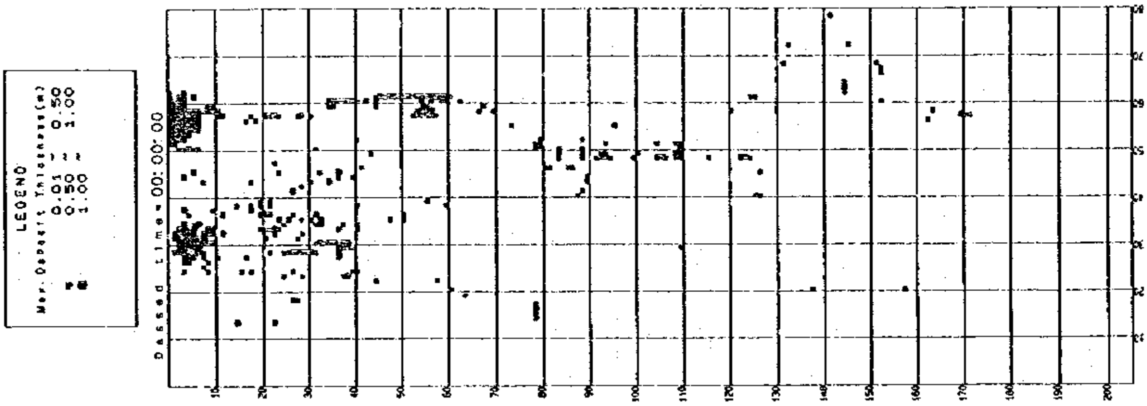
Peak discharge (m3/s)
Maskup(170) Marimla+Cauayang(360)
mesh size = 100m



Maximum Flow Depth

Figure G.24
Maximum Flow Depth and Sediment Deposits due to 5-year Flood in Bamban River Basin

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

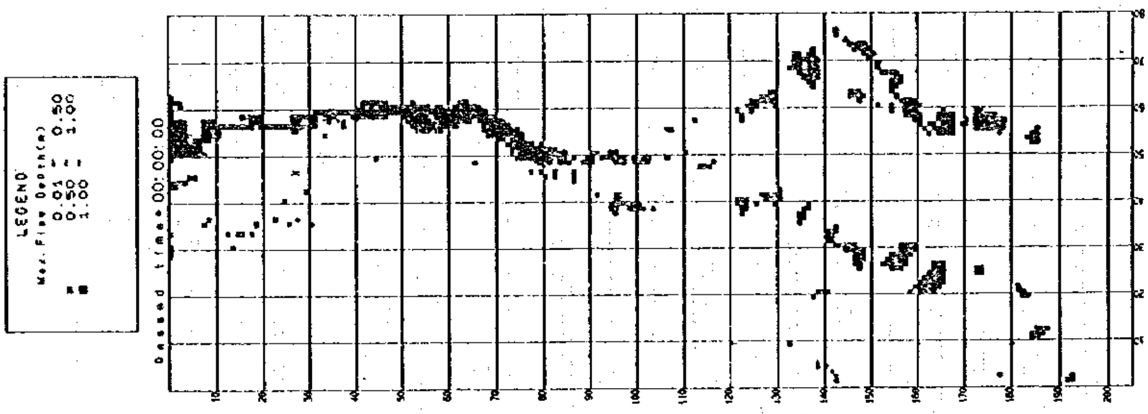


Maximum Deposit

Peak discharge (m3/s)

Maskup(270)   Marimla+Cauayang(580)

mesh size = 100m



Maximum Flow Depth

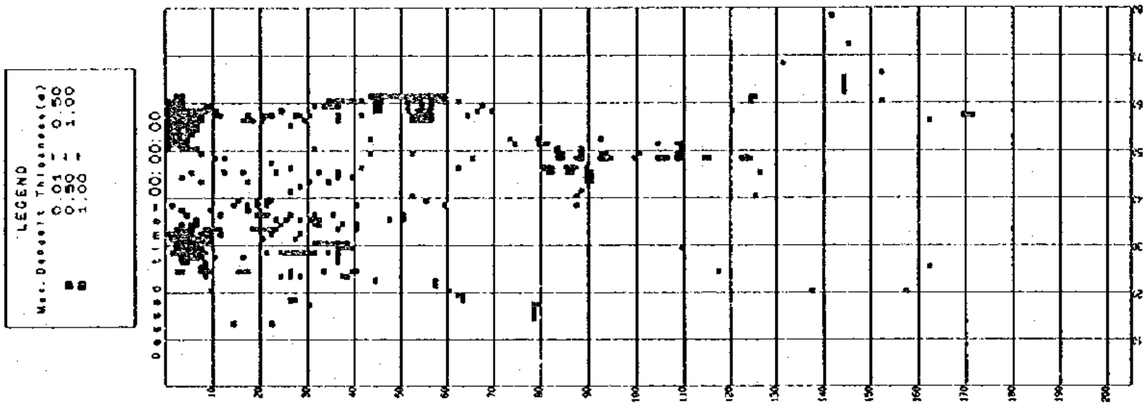
Figure G.25

Maximum Flow Depth and Sediment Deposits due to 20-year Flood in Bamban River Basin

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

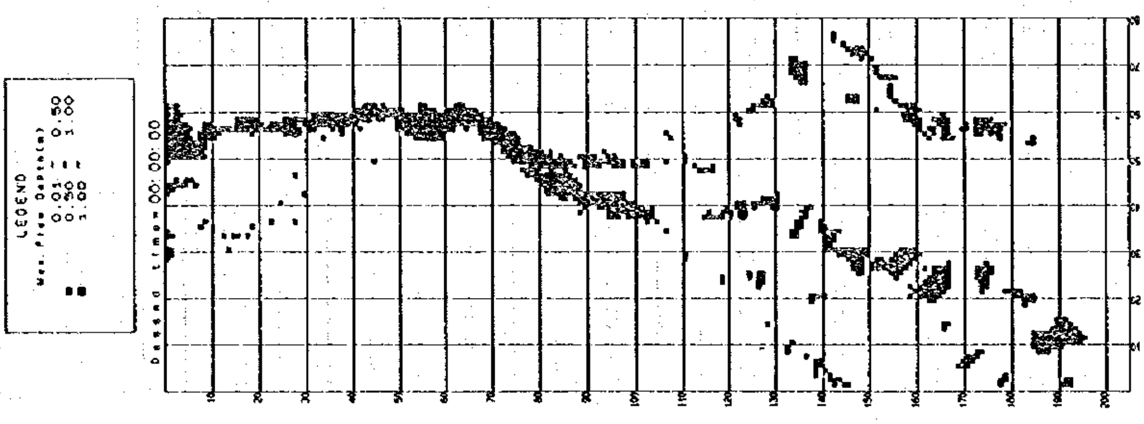
THE STUDY ON FLOOD AND MUDFLOW CONTROL FOR SACOBIA-BAMBAN/ABACAN RIVER DRAINING FROM MT.PINATUBO

JAPAN INTERNATIONAL COOPERATION AGENCY



Maximum Deposit

Peak discharge (m3/s)
Maskup(330) Marimla+Cauayang(690)
mesh size = 100m

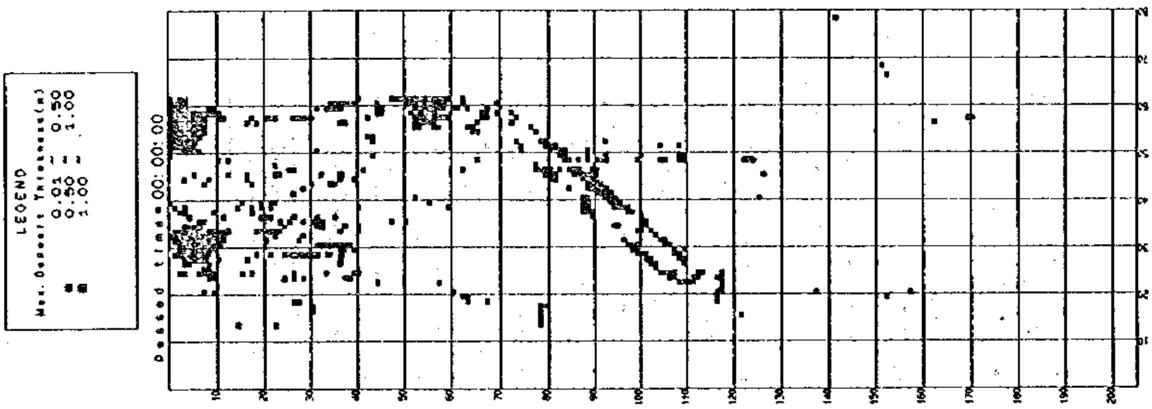


Maximum Flow Depth

Figure G.26

Maximum Flow Depth and Sediment Deposits due to 50-year Flood in Bamban River Basin

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

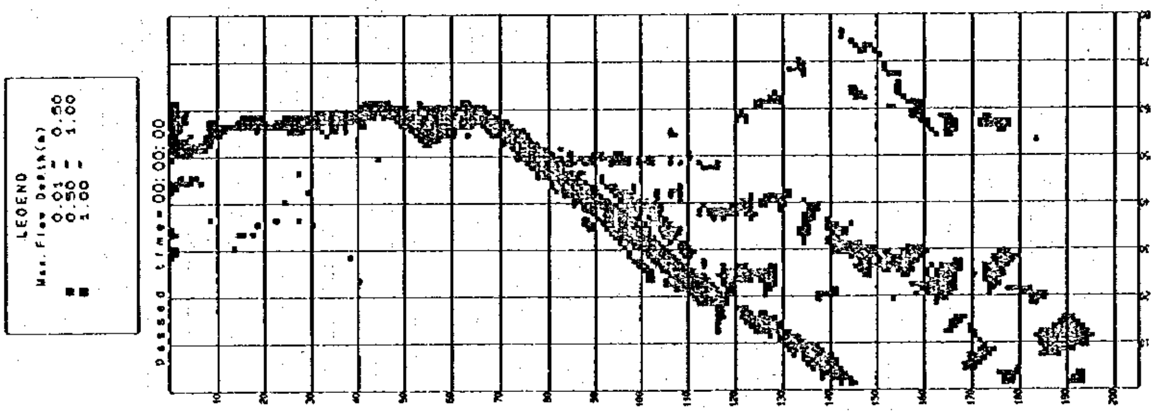


Maximum Deposit

Peak discharge (m3/s)

Maskup(370) Marimla+Cauayang(800)

mesh size = 100m



Maximum Flow Depth

Figure G.27

Maximum Flow Depth and Sediment Deposits due to 100-year Flood in Bamban River Basin

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

Maximum discharge = 490m3/s
mesh size = 100m

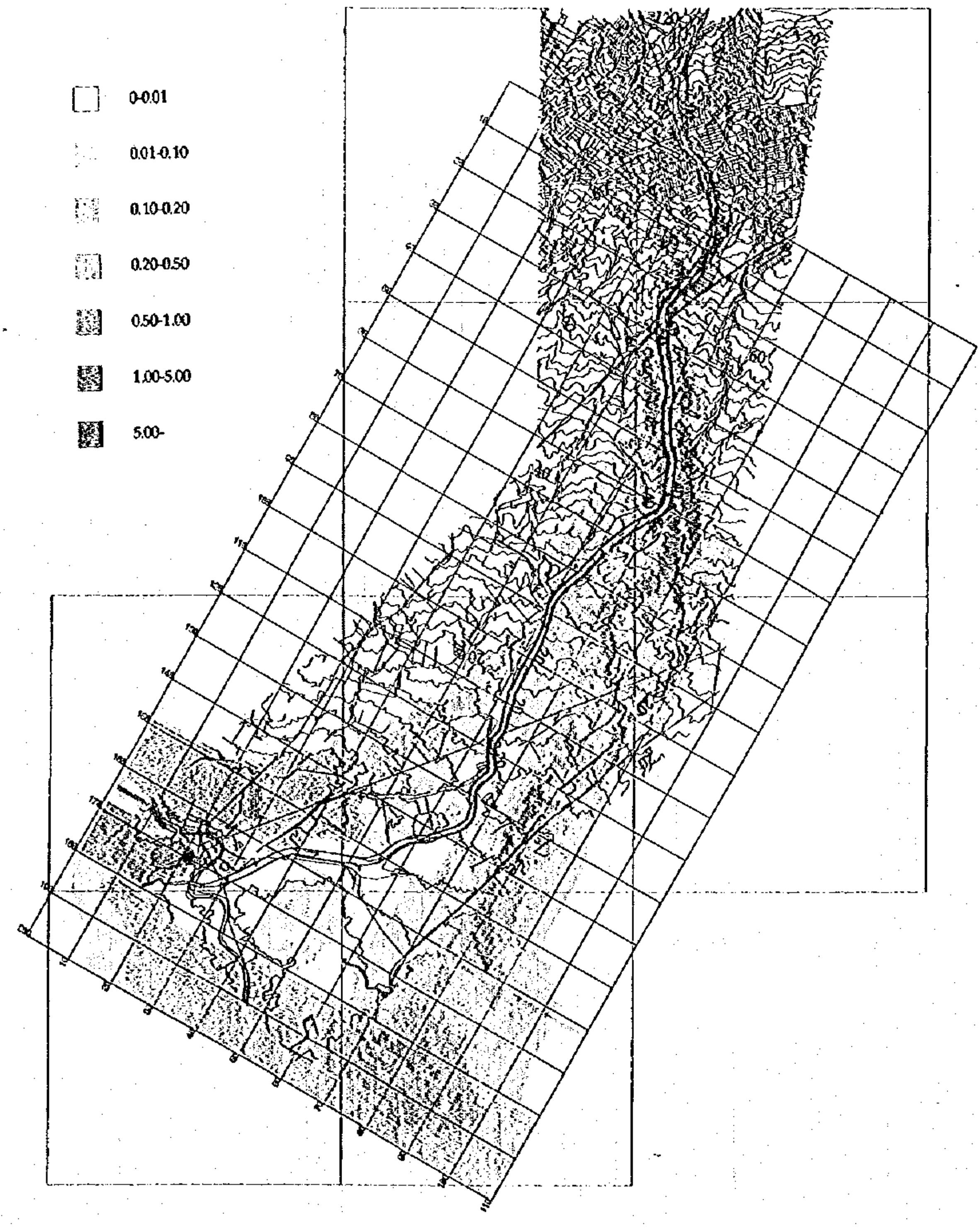


Figure G.28

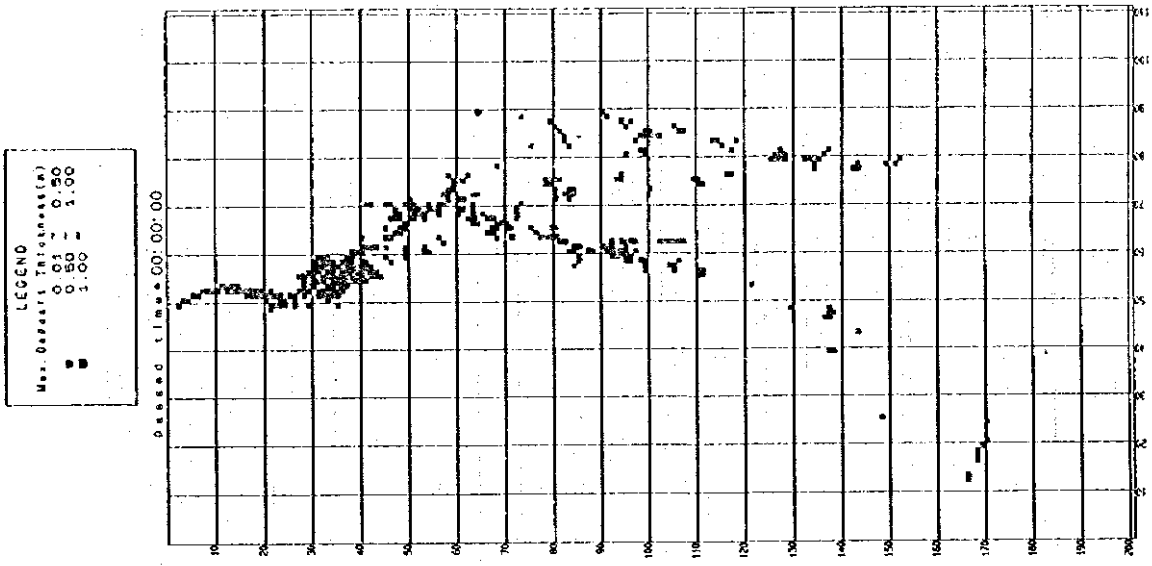
Maximum Flow Depth on Topographic Map due to 100-year Flood in Abacan River Basin

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

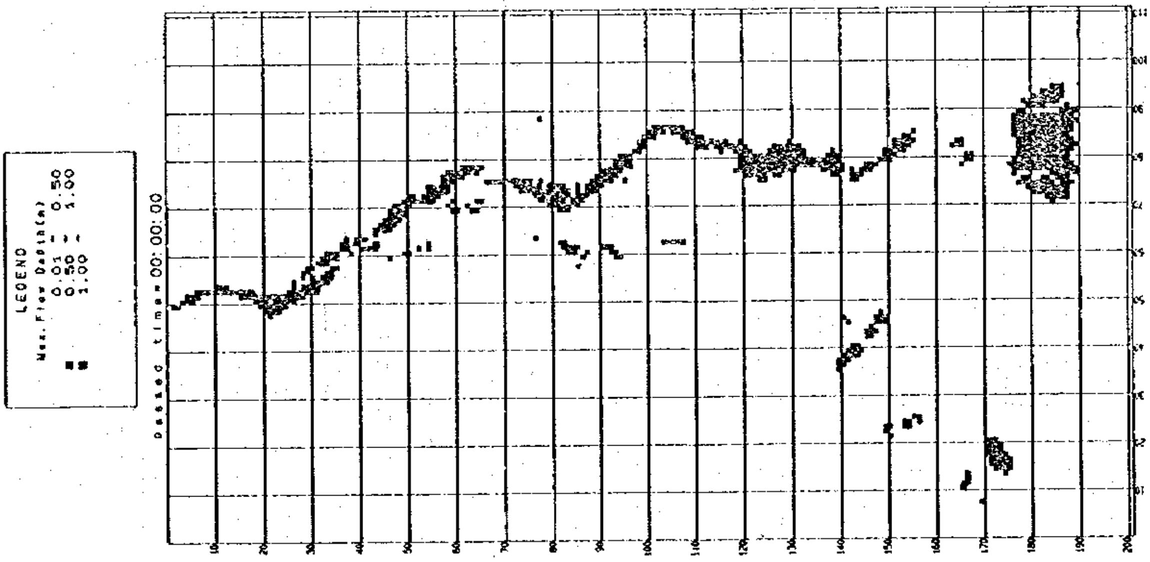
THE STUDY ON FLOOD AND MUDFLOW CONTROL FOR SACOBIA-BAMBAN/ABACAN RIVER DRAINING FROM MT.PINATUBO

JAPAN INTERNATIONAL COOPERATION AGENCY

Maximum discharge = 240m3/s
mesh size = 100m



Maximum Deposit



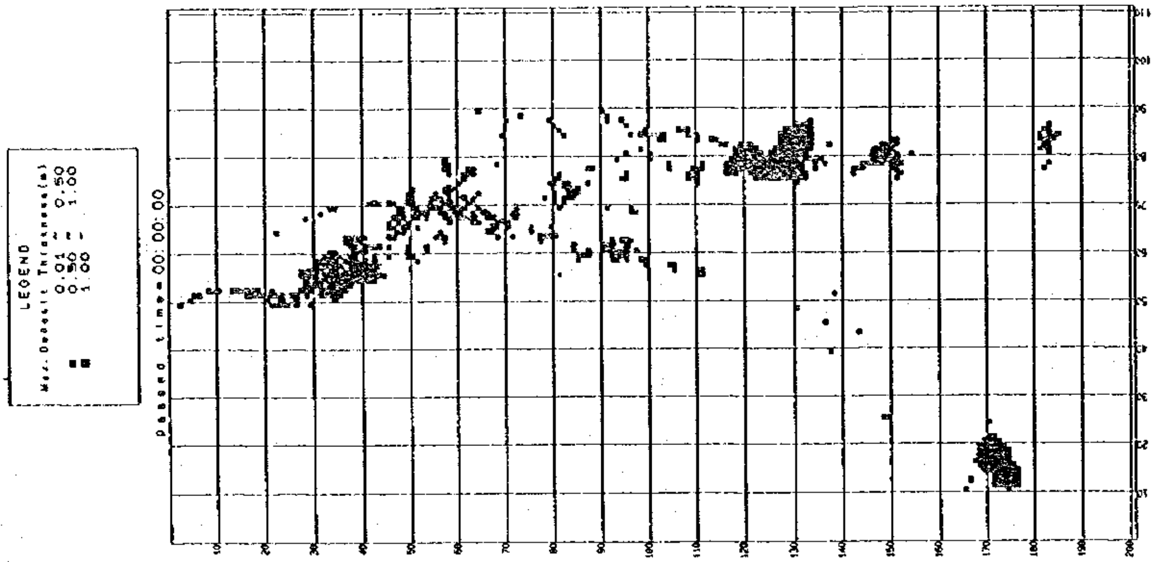
Maximum Flow Depth

Figure G.29

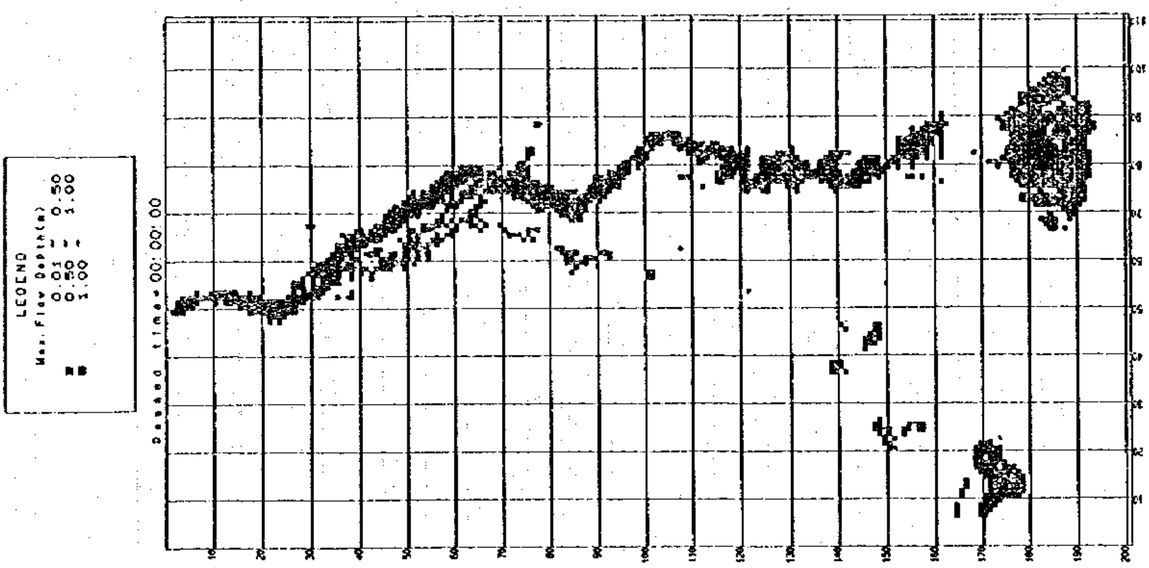
Maximum Flow Depth and Sediment Deposits due to 5-year Flood in Abacan River Basin

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

Maximum discharge = 370m3/s
mesh size = 100m



Maximum Deposit



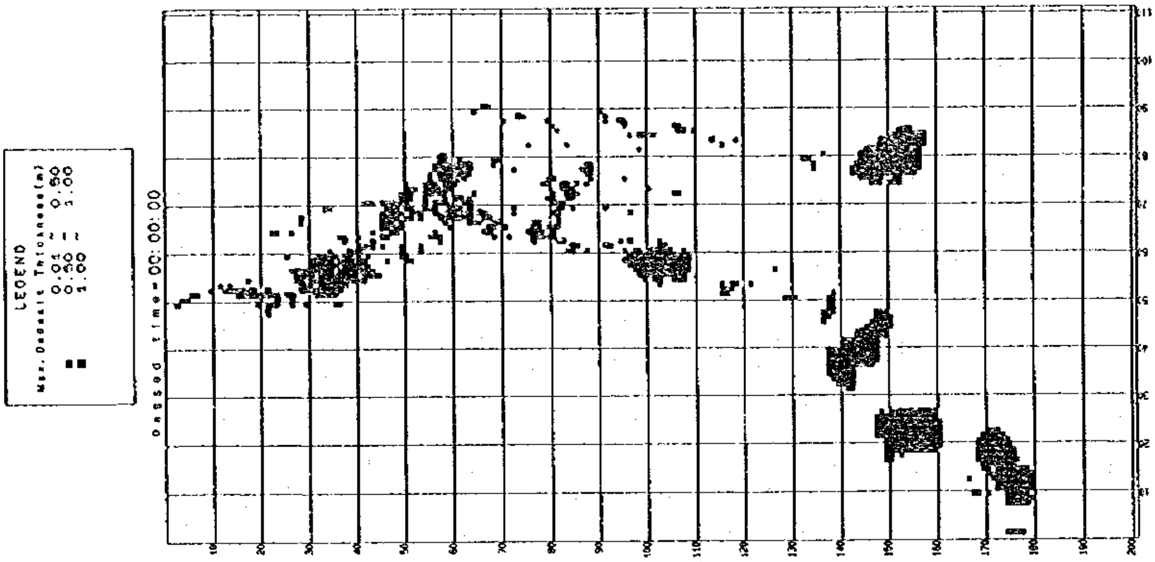
Maximum Flow Depth

Figure G.30

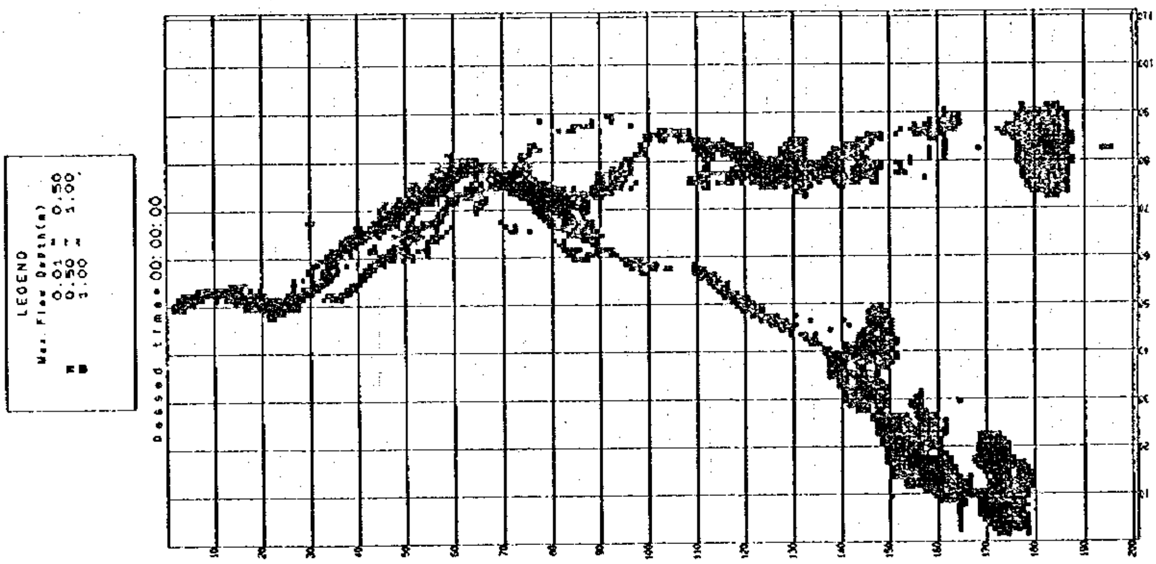
Maximum Flow Depth and Sediment Deposits due to 20-year Flood in Abacan River Basin

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

Maximum discharge = 430m3/s
mesh size = 100m



Maximum Deposit



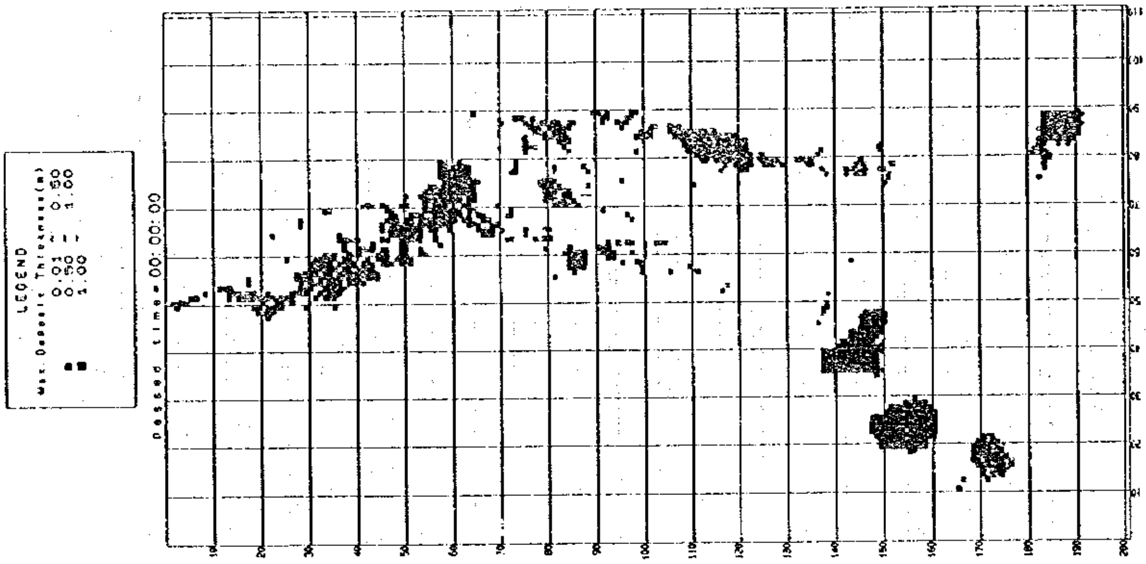
Maximum Flow Depth

Figure G.31

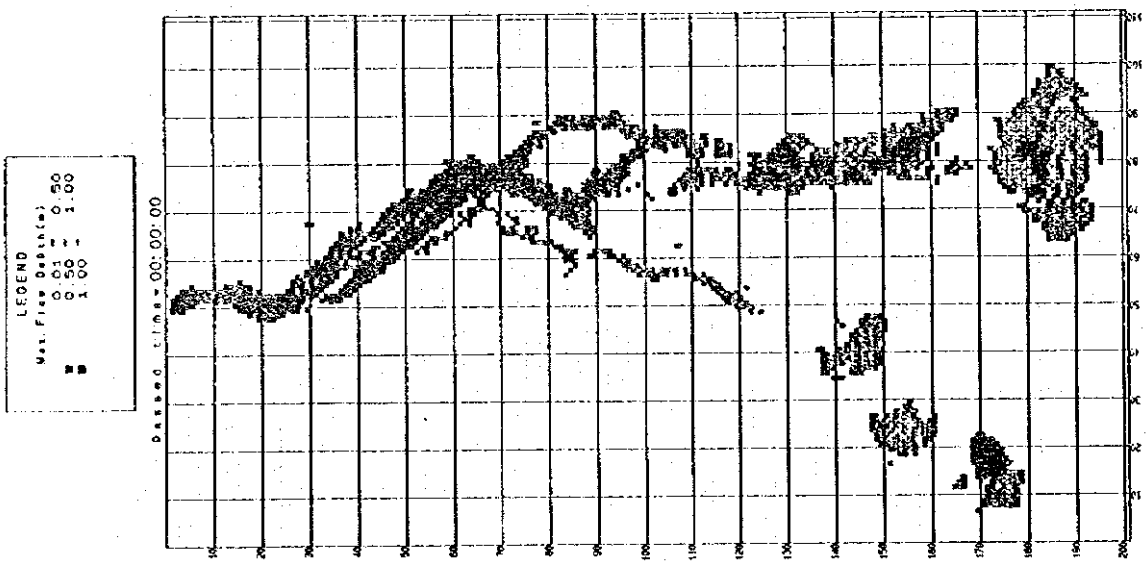
Maximum Flow Depth and Sediment Deposits due to 50-year Flood in Abacan River Basin

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

Maximum discharge = 490m3/s
mesh size = 100m



Maximum Deposit



Maximum Flow Depth

Figure G.32

Maximum Flow Depth and Sediment Deposits due to 100-year Flood in Abacan River Basin

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

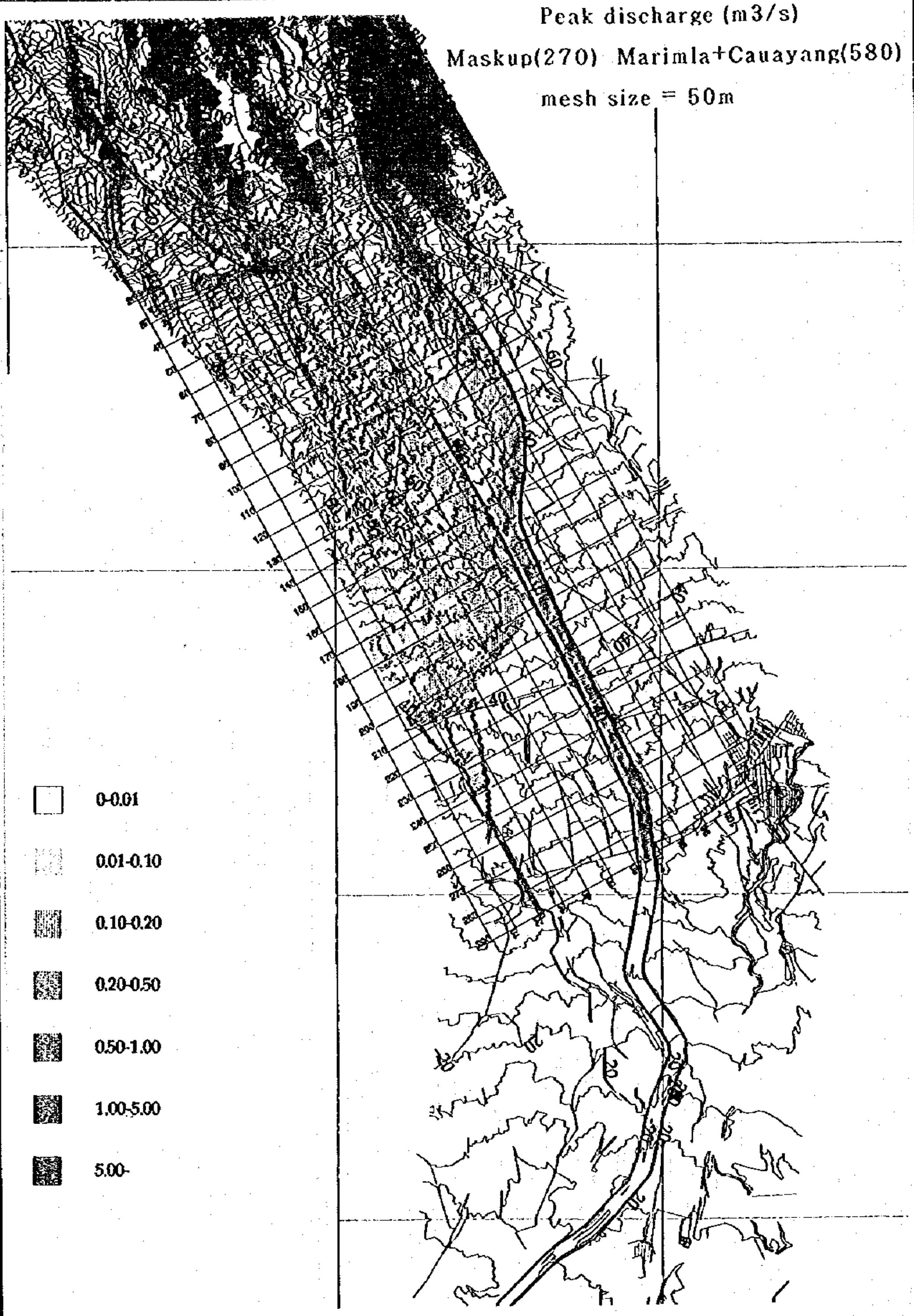


Figure G.33

20-Year Flood Flow in Sand Pocket on DTM

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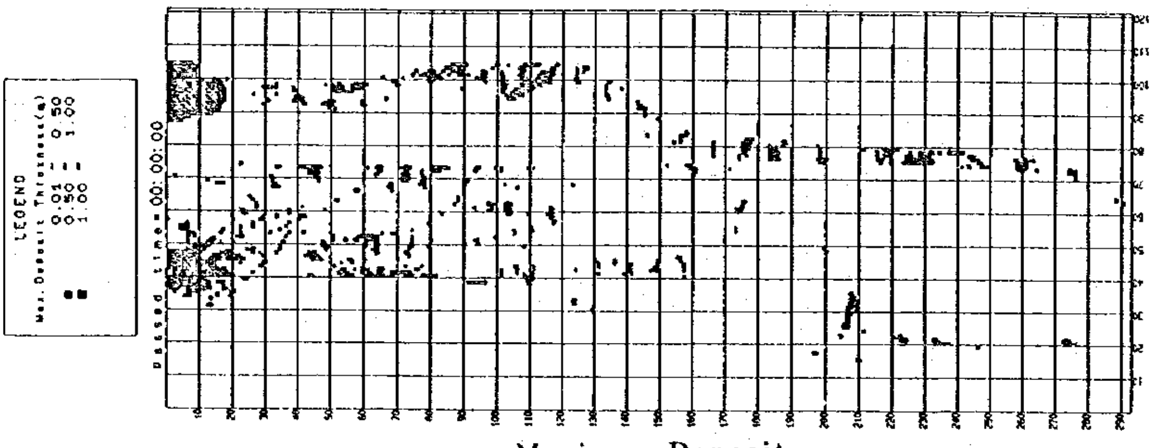
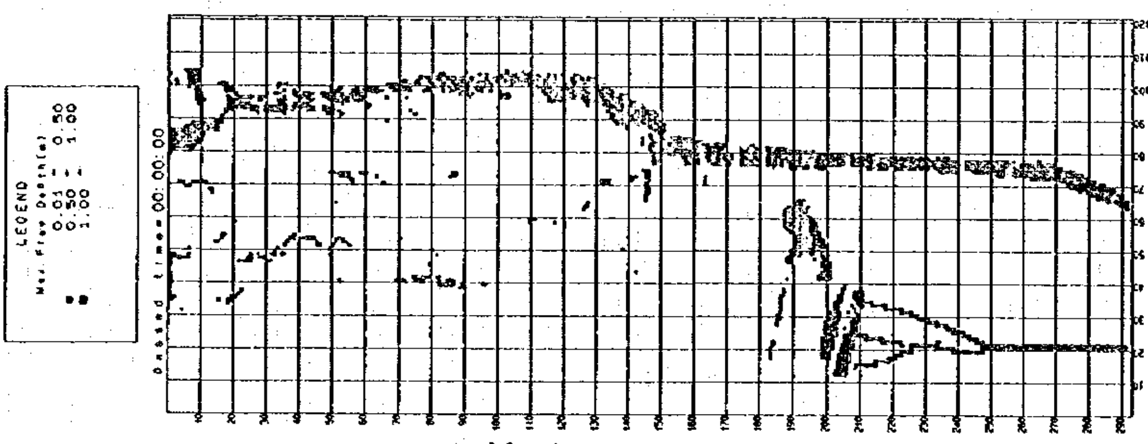


Maximum Deposit

Peak discharge (m3/s)

Maskup(270) Marimla+Cauayang(580)

mesh size = 50m



Maximum Flow Depth

Figure G.34

20-Year Flood Flow in Sand Pocket (Flow, Deposit)

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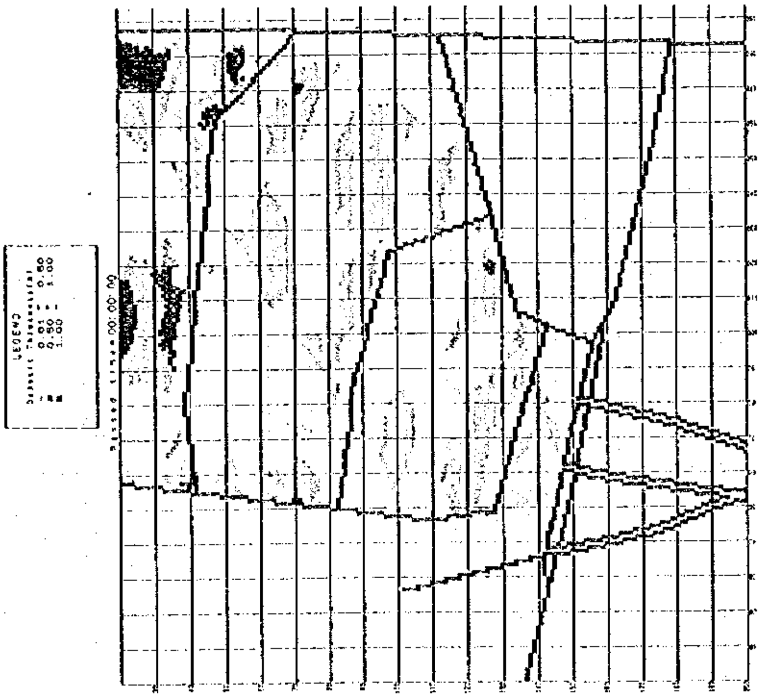
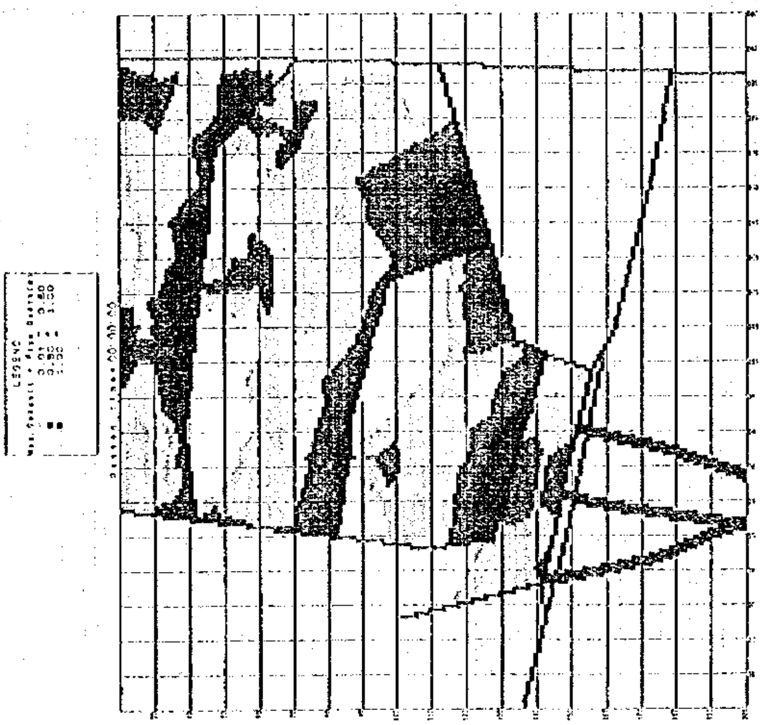


Maximum Deposit

mesh size = 20m



Maximum Flow Depth

Figure G.35

Effect of Control Structures in Lower Sand Pocket Area

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

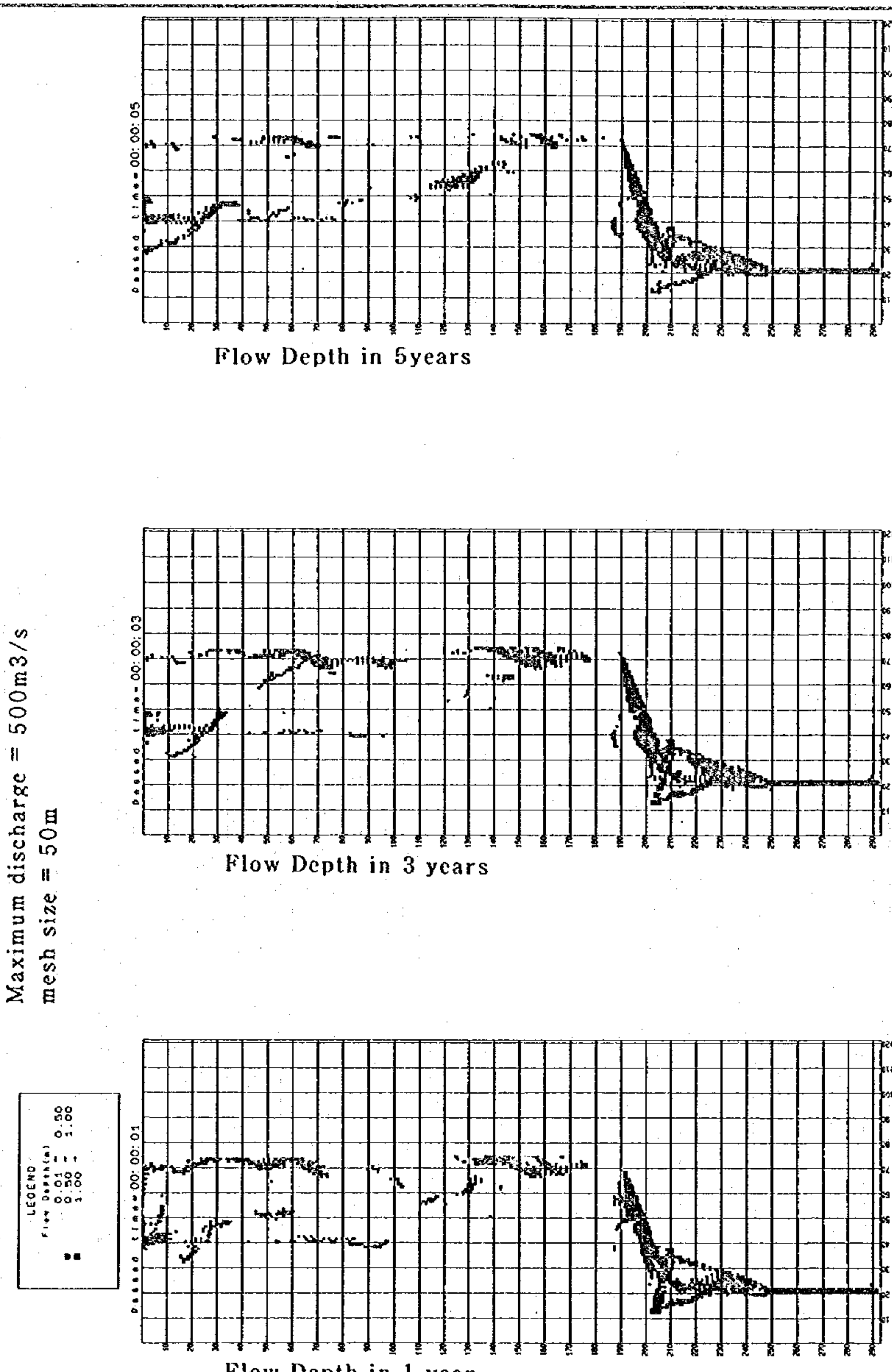
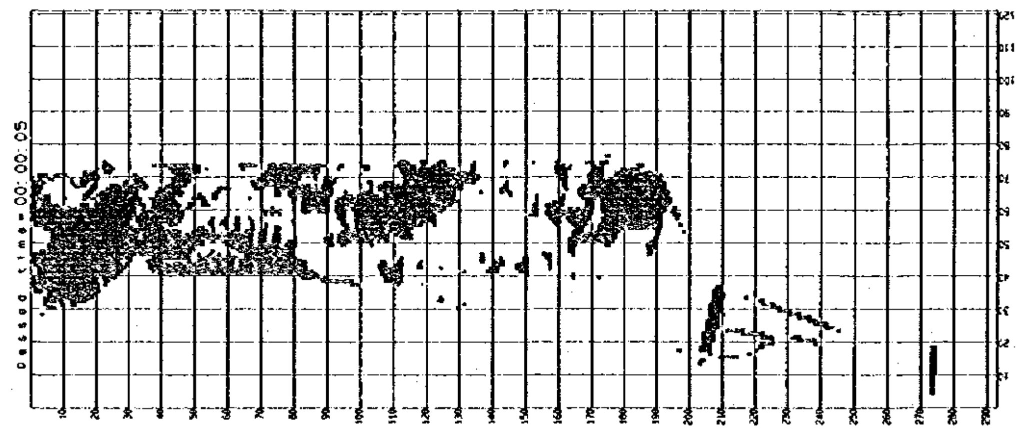


Figure G.36

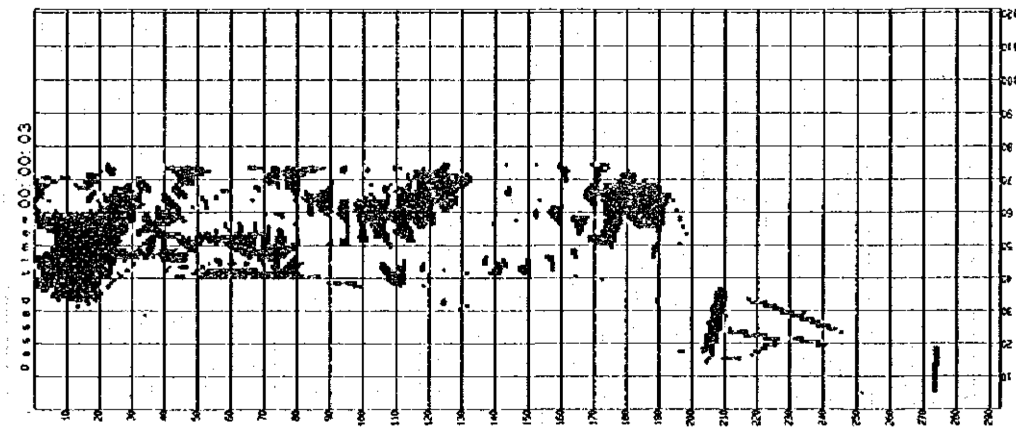
Long Term Topographic Changes in Sand Pocket

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

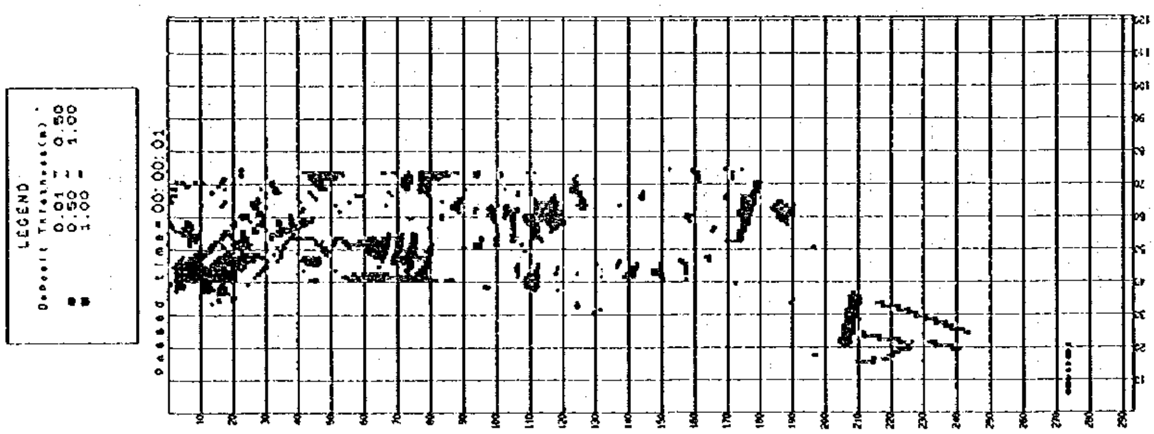
Maximum discharge = 500m3/s
mesh size = 50m



Deposits in 5years



Deposits in 3 years



Deposits in 1 year

Figure G.37

Long Term Topographic Changes in Sand Pocket

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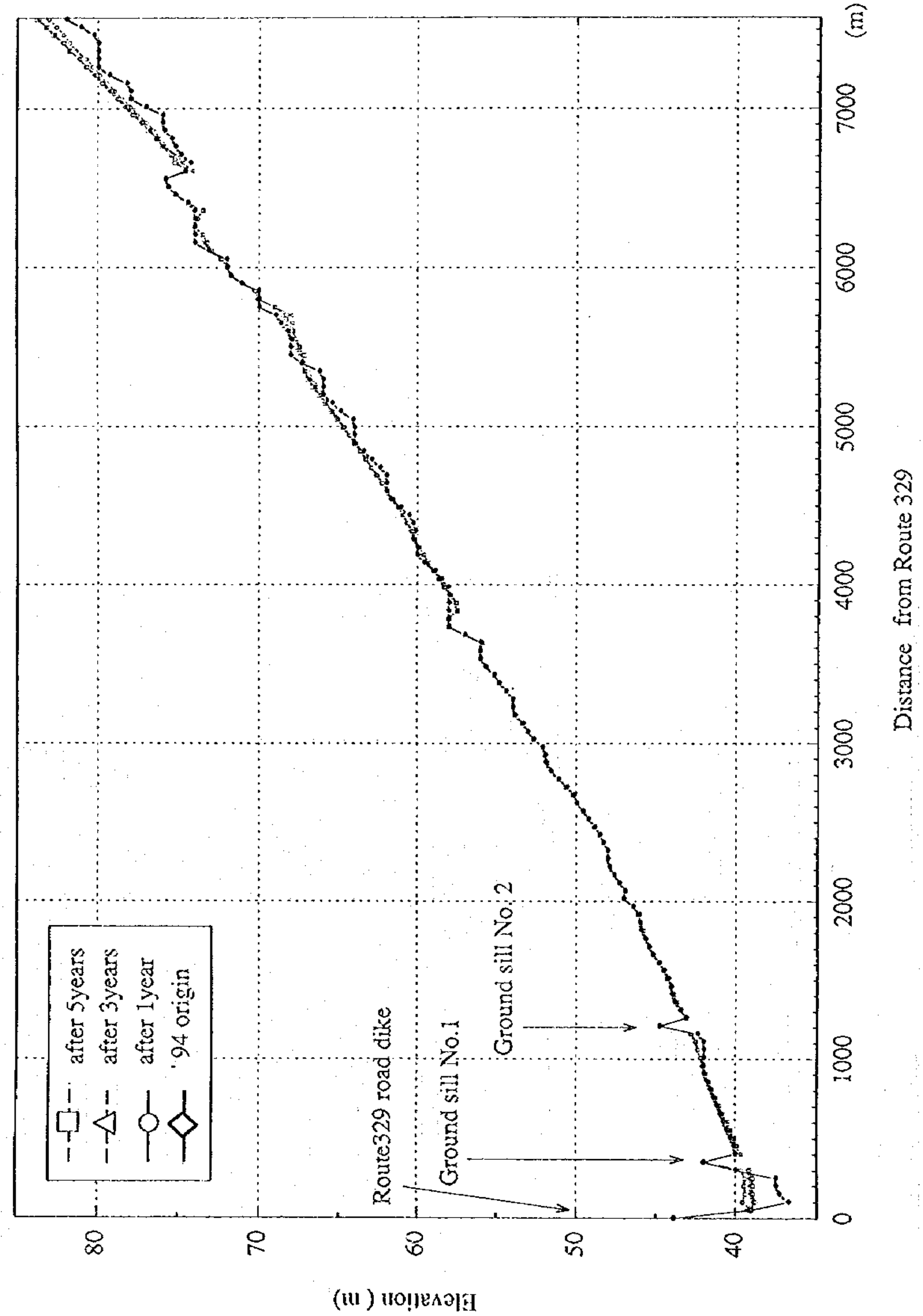


Figure G.38

Longitudinal Profile of Sand Pocket (Maskup-Outlet)

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

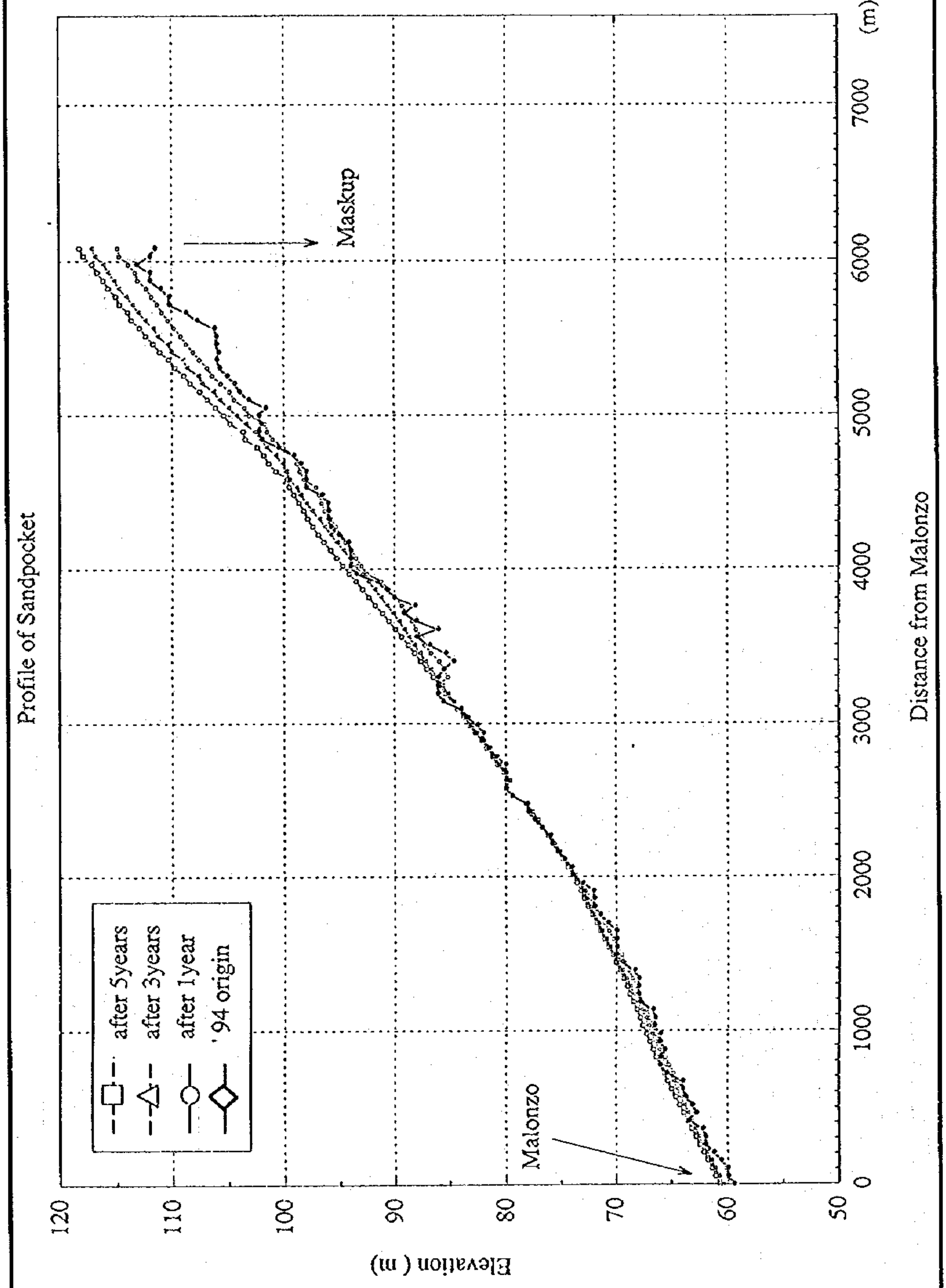


Figure G.39

Longitudinal Profile of Sand Pocket (Maskup-Malonzo)

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

Maximum discharge = 1000m3/s
mesh size = 50m

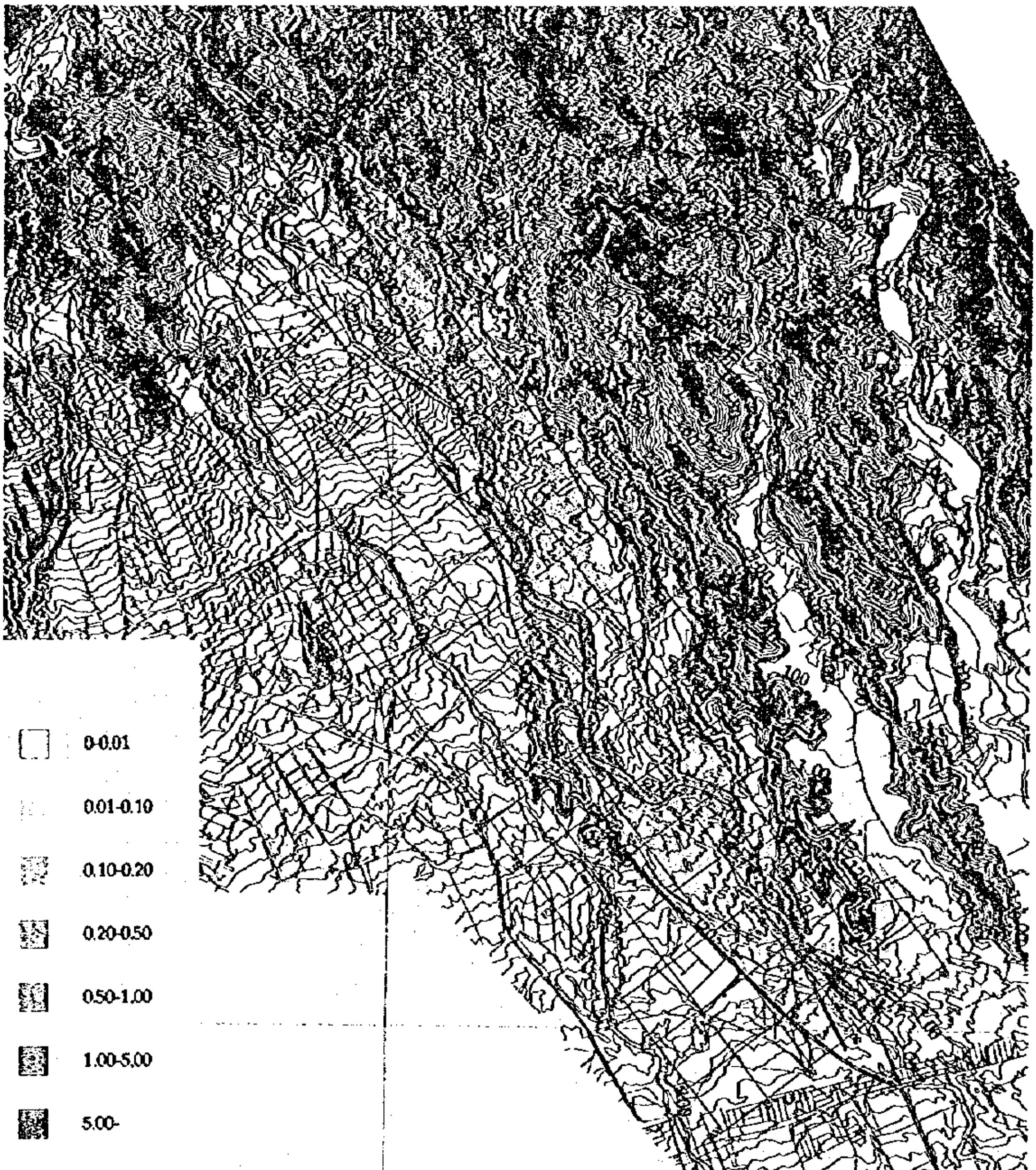
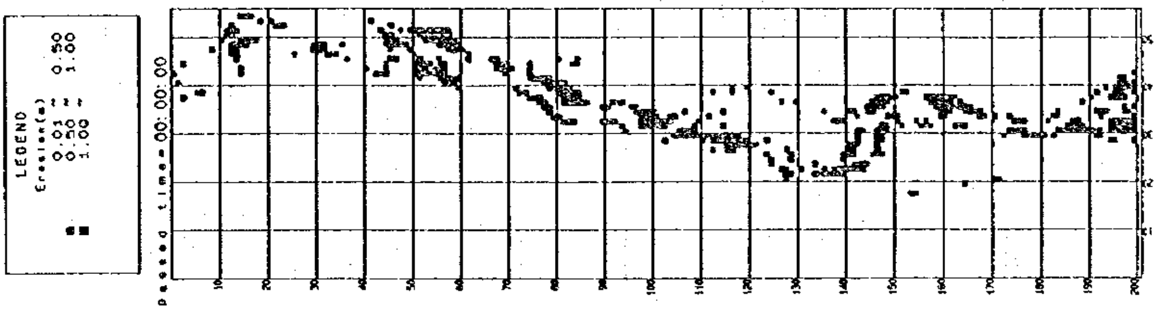


Figure G.40

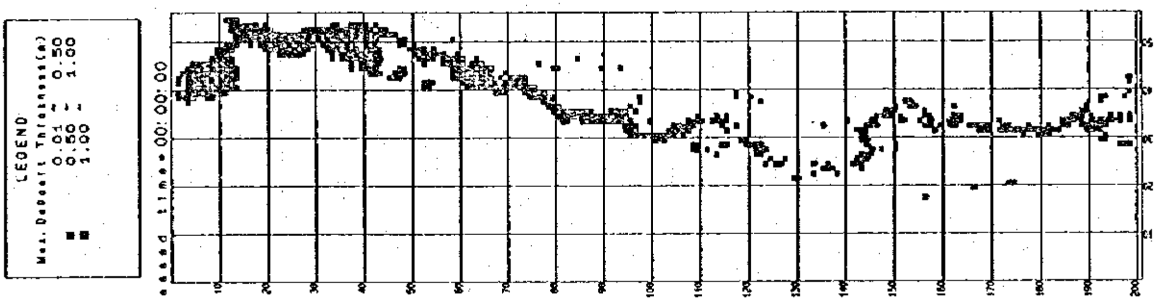
Flood Flow in Sacobia Valley on DTM

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

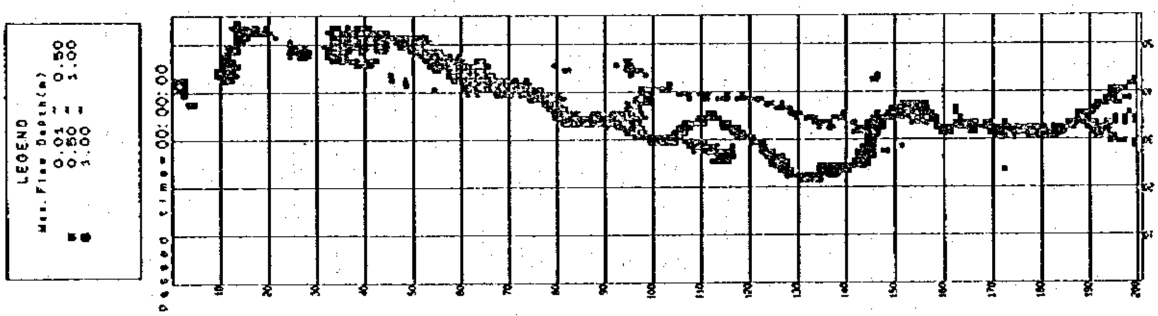


Erosion in 24 hours

Maximum discharge = 1000m3/s
mesh size = 50m



Deposits in 24 hours



Maximum Flow Depth

Figure G.41

Flood Flow in Sacobia Valley (Flow, Deposit and Erosion)

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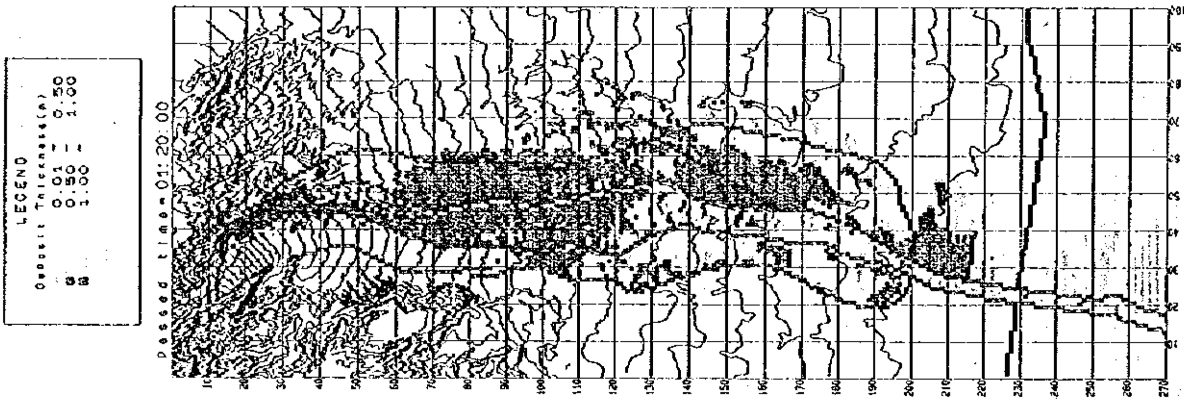
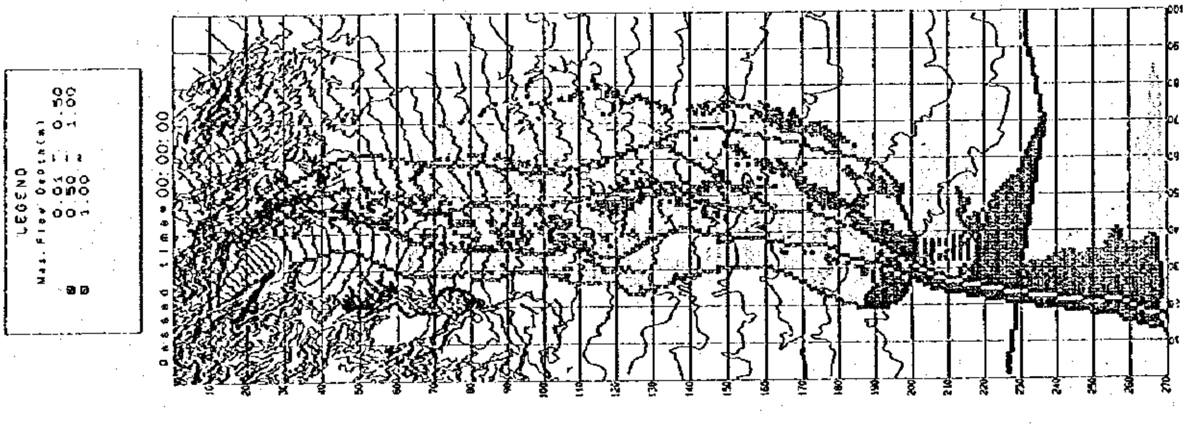


Maximum Deposit

mesh size = 100m



Maximum Flow Depth

Figure G.42

Flood and Mudflow Inundation in Pasig River in 1994 (Flow and Deposit)

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

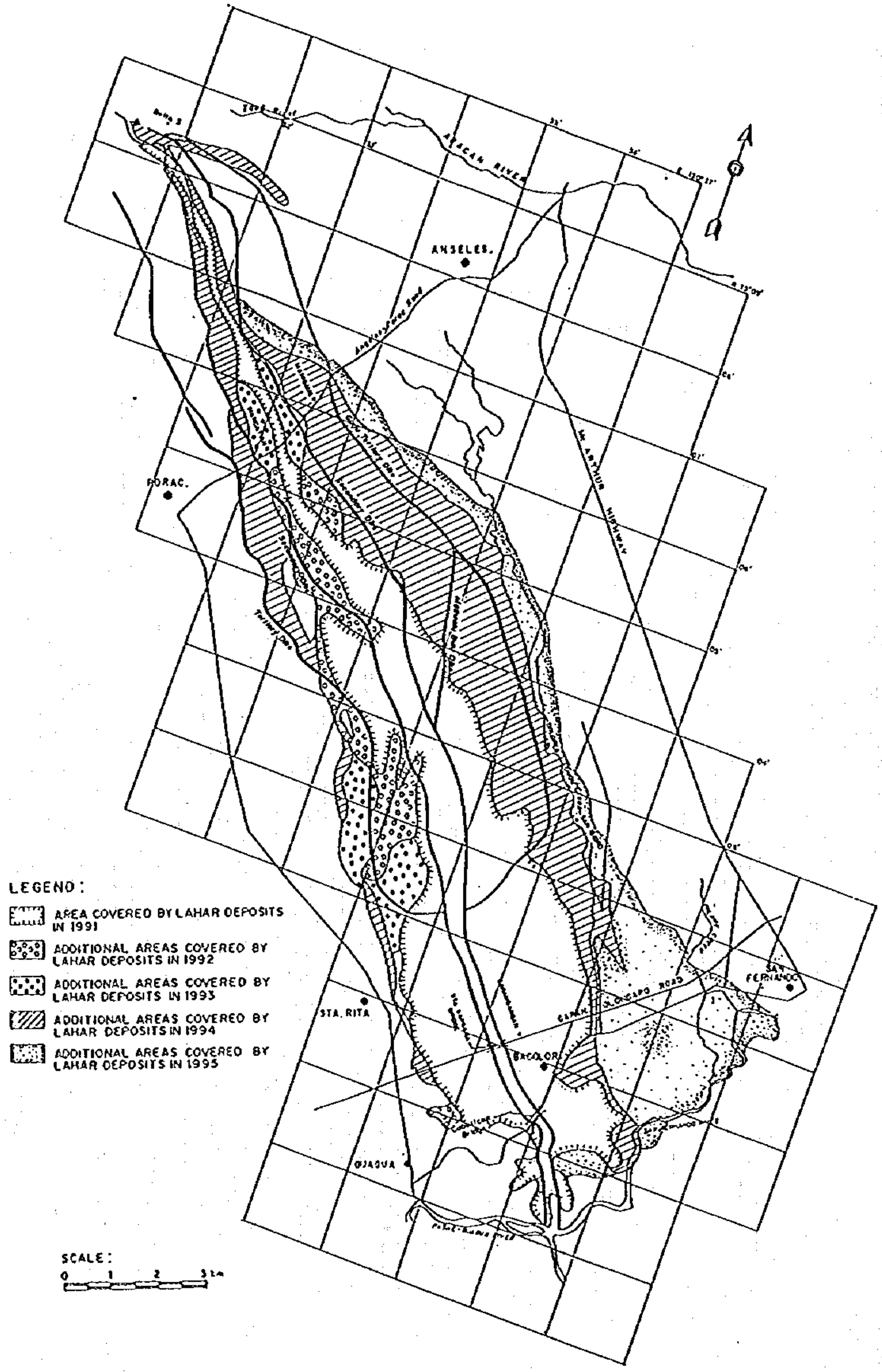


Figure G.43

Chronological Change of Inundation Area in Pasig River

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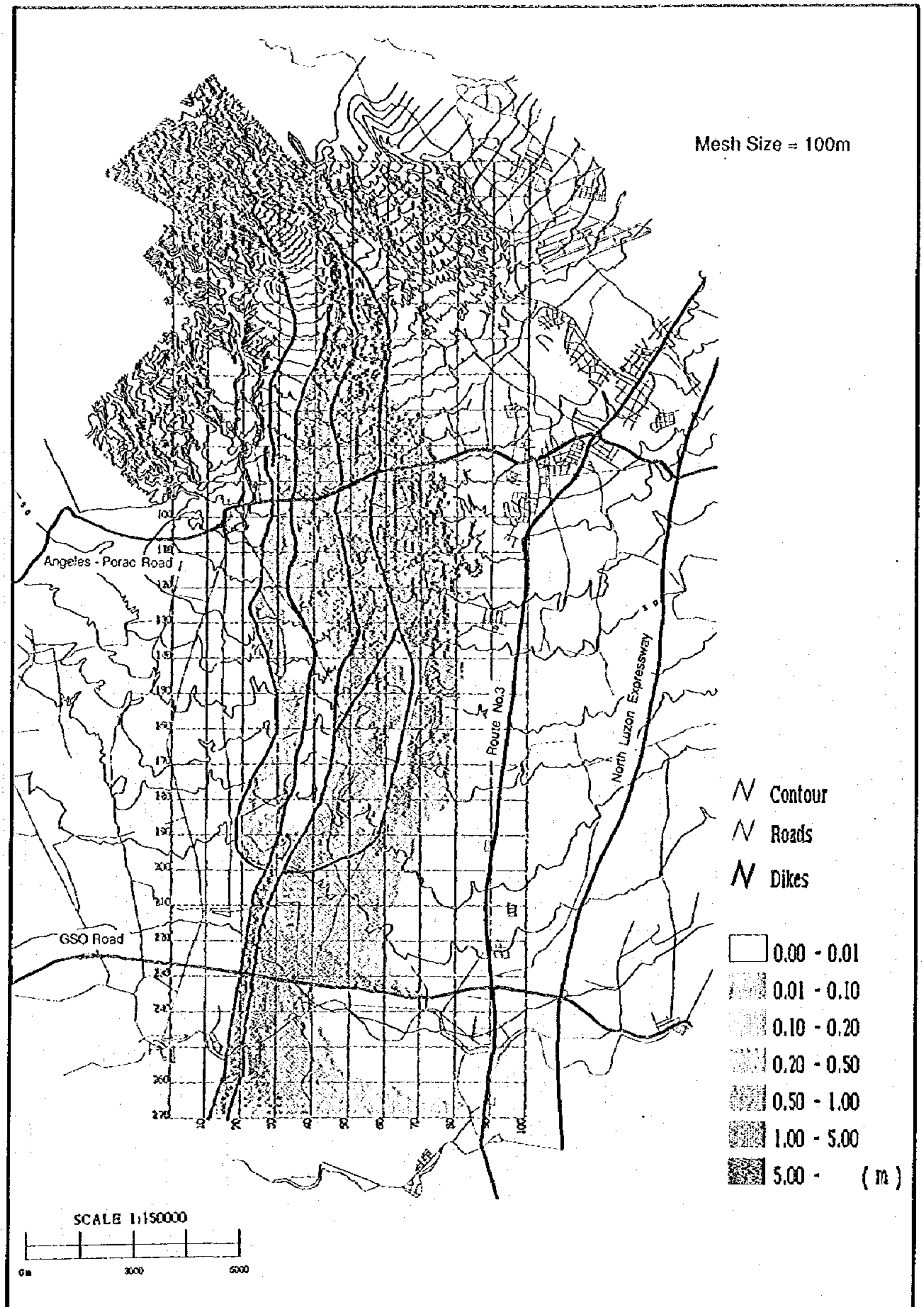
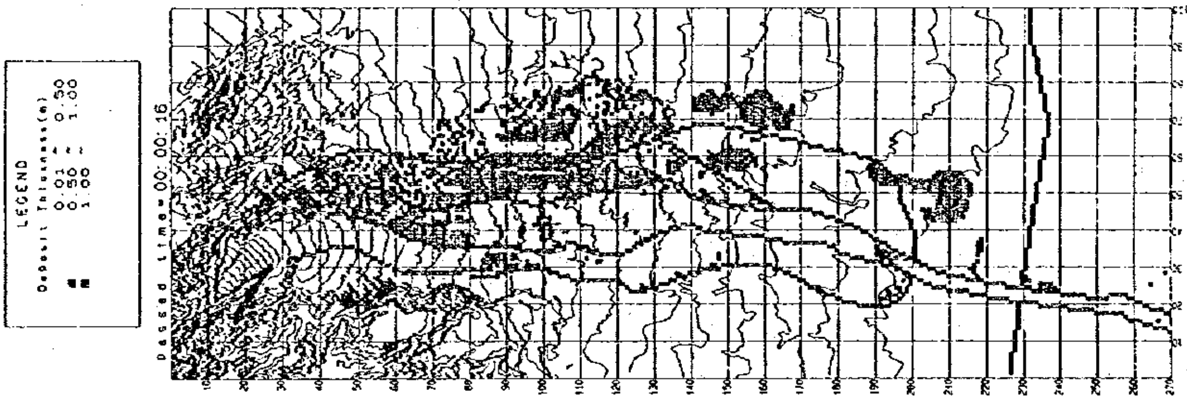


Figure G.44

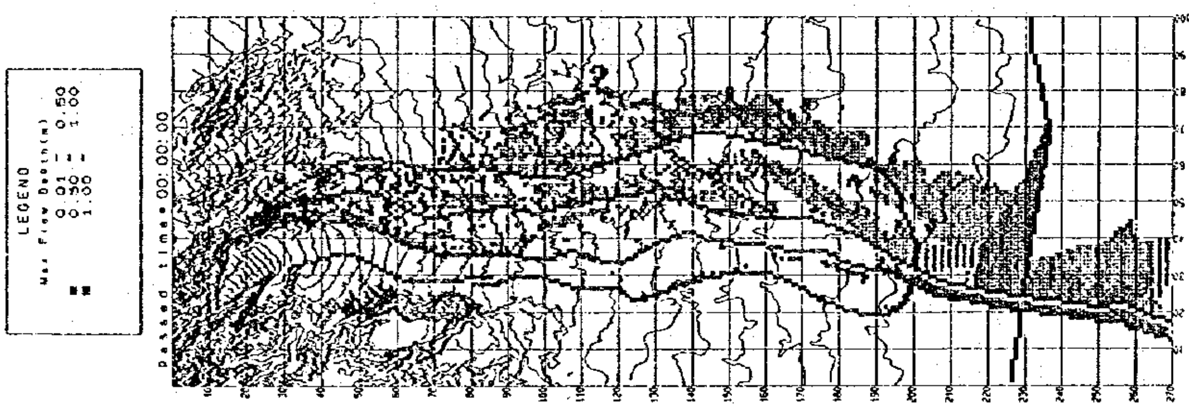
Flood and Mudflow Inundation in Pasig Rive in 1995 on DTM

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



Maximum Deposit

mesh size = 100m



Maximum Flow Depth

Figure G.45

Flood and Mudflow Inundation in Pasig River in 1995 (Flow and Deposit)

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

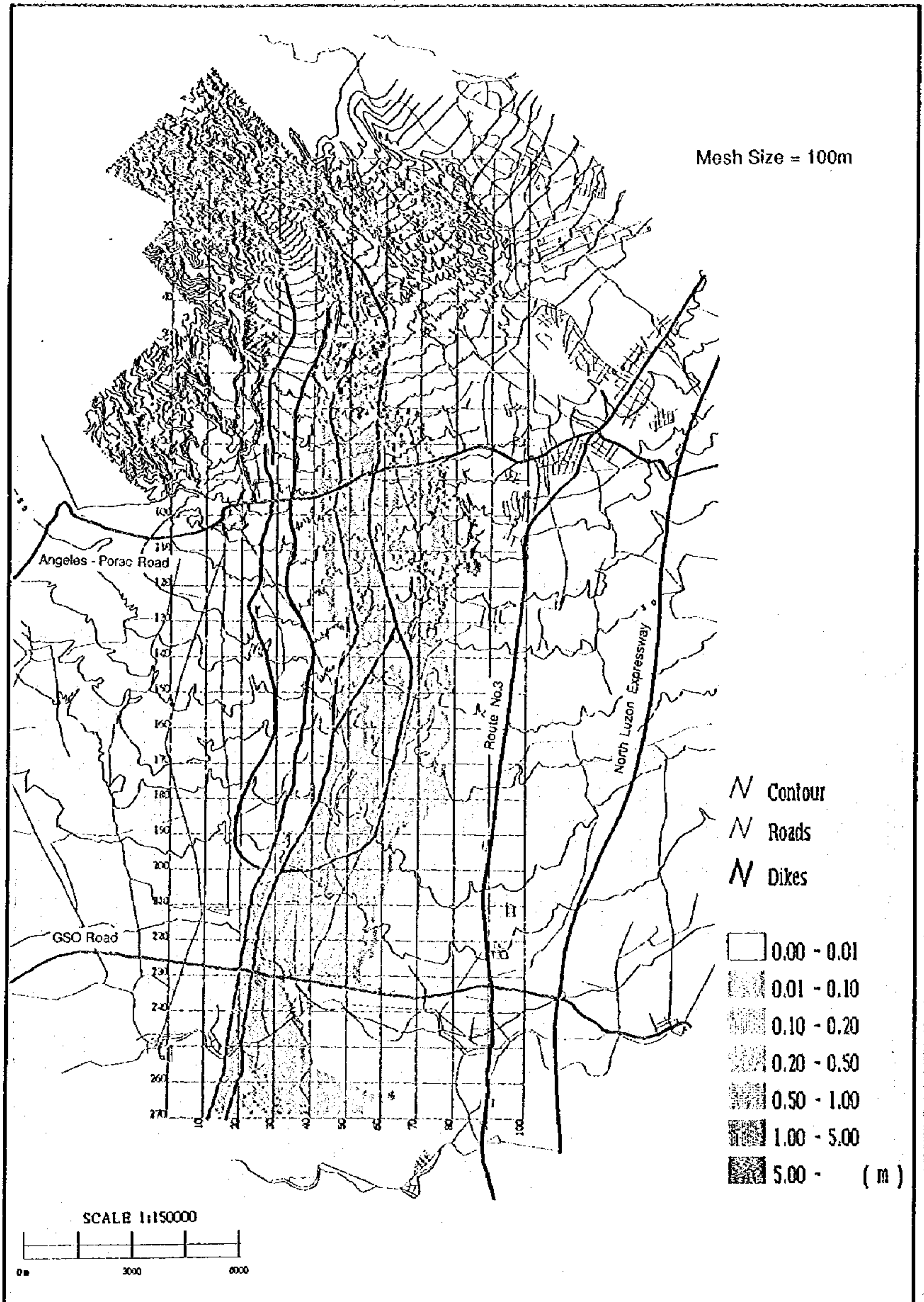


Figure G.46

Flood and Mudflow Inundation in Pasig River due to 20-year flood on DTM

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

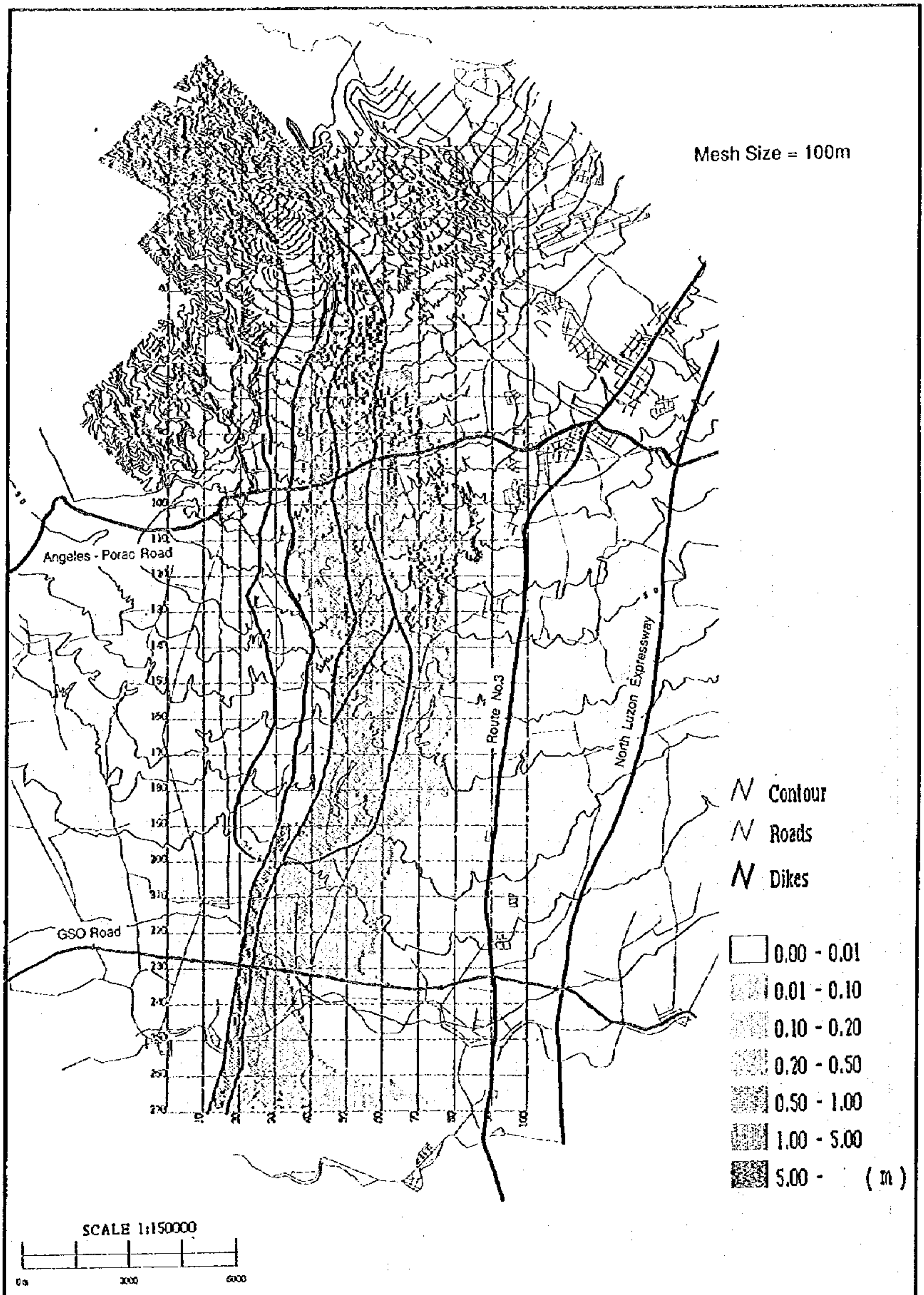
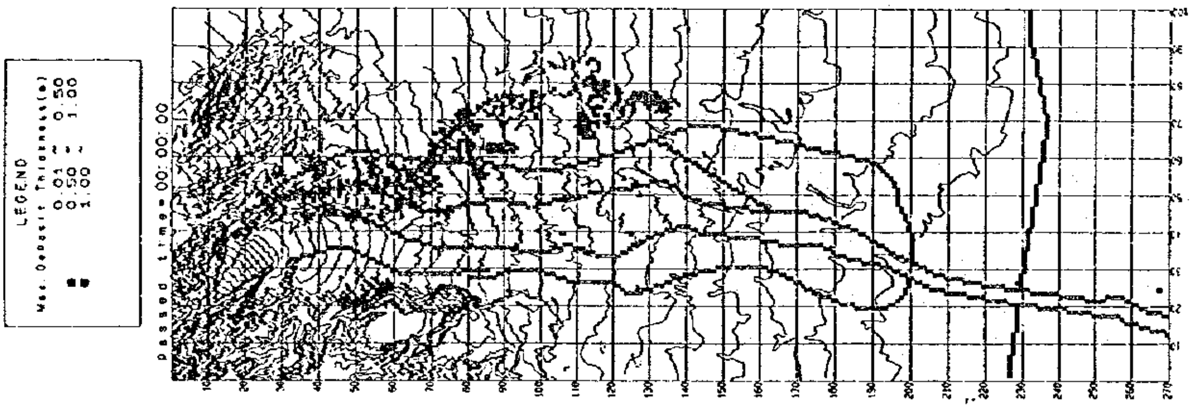


Figure G.47

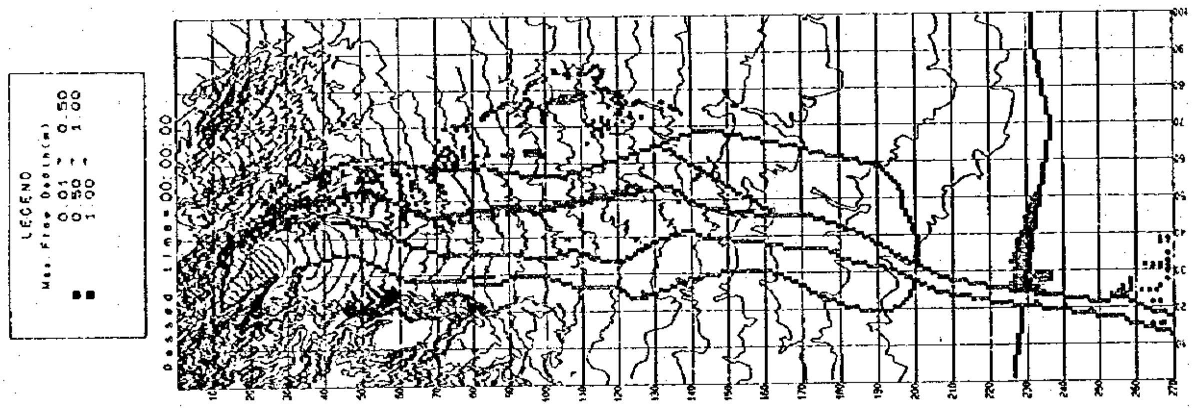
Flood and Mudflow Inundation in Pasig River due to 100-year flood on DTM

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



Maximum Deposit

mesh size = 100m



Maximum Flow Depth

Figure G.48

Flood and Mudflow Inundation in Pasig River due to 20-year flood (Flow and Deposit)

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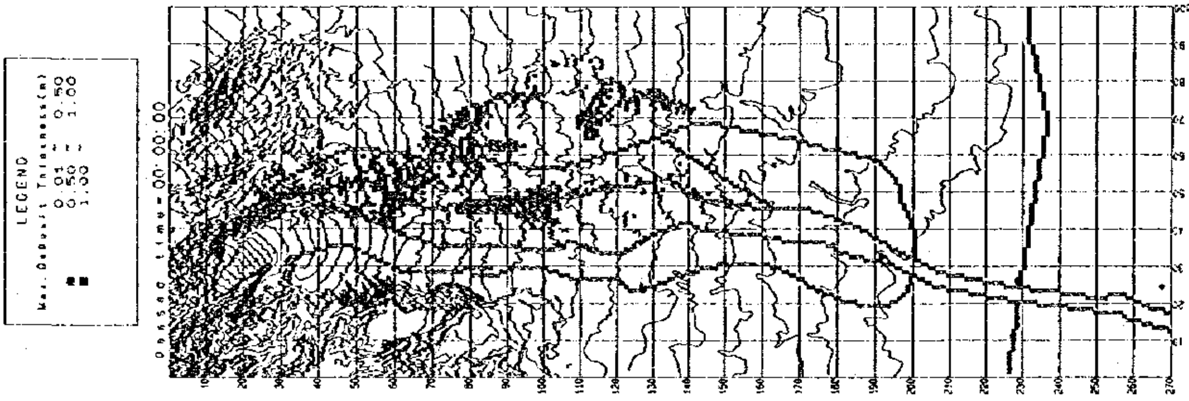
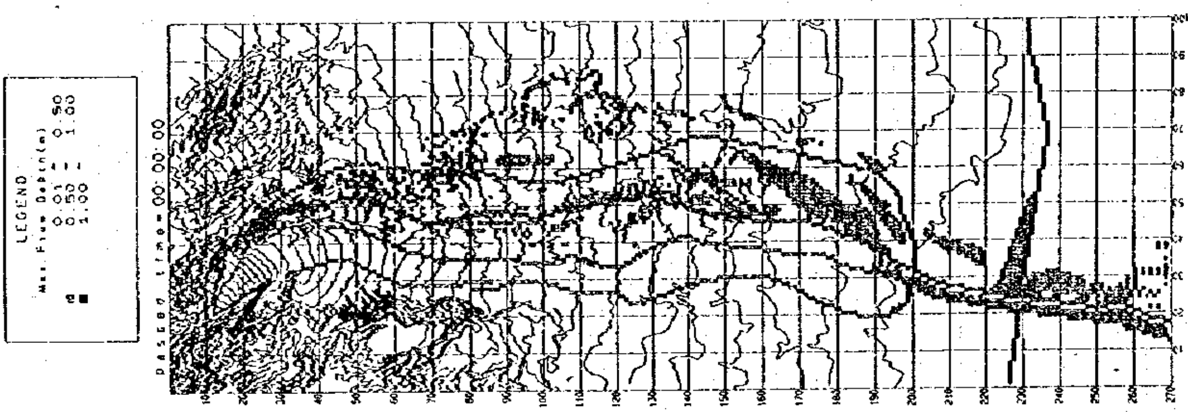


Maximum Deposit

mesh size = 100m



Maximum Flow Depth

Figure G.49

Flood and Mudflow Inundation in Pasig River due to 100-year flood (Flow and Deposit)

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

FLOOD CONTROL/ SABO STRUCTURES

APPENDIX H

FLOOD CONTROL/SABO STRUCTURES

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H.1 URGENT STRUCTURAL MEASURES

1.1 SABO DAM (CHECK DAM)

(1) Overall Schematic Diagram

After the eruption of Mt. Pinatubo, ten (10) sabo dams in the Abacan River and two (2) sabo dams in the Sacobia River were constructed for the period from November 1991 to June 1993. The location map is shown in Figure H.1. Although the sabo dams were built out of sand bags or gabions with the height of less than 10 m, the storage has a relatively large sediment retention effect for the range from 350,000 m^3 for No. 4 sabo dam to 1,714,000 m^3 for No. 9 sabo dam in the Abacan River.

(2) Abacan River

Sabo dams (Nos. 1, 2 and 3) are located at the most upstream reach of the Abacan River. The main dam body was built out of sand bags. Sabo dams (Nos. 1 and 2) have available storage although these are partly damaged in the downstream reaches. While the sabo dam No. 3 was already buried with lahar and has no longer a sediment retention effect. Dam bodies of the other sabo dams were built out of gabions and are organized into main dam, apron and sub-dam. Gabion was covered with less durable wire mesh with a diameter of 3 mm. In the Abacan River, sabo dams with gabions (Nos. 4, 5, 6, 9, TR-1, TL-1 and TM-1) were damaged on sub-dam. The rehabilitation works were done and these dams have available storage for sediment retention.

(3) Sacobia River

Sabo dams (S-1 and S-2) in the Sacobia River were constructed for the period from November 1991 to March 1992. These dams had stored lahar of more than 10 million m^3 in May 1992. However, during the rainy season in 1992, these dams were washed out by lahar. There is no sabo dam in the Sacobia River since 1993.

1.2 RIVER DIKE SYSTEM

(1) Abacan River

The Abacan River produced lahar and large volume of eroded sediment through the Sapangbato River for the period of June to September 1991. Sediment discharge damaged all of the bridges across the river, and caused the lateral erosion of river bank that has destroyed hundreds of houses in Barangay Sapangbato and in Angeles City. However, no lahar has occurred along the river ever since the piracy of the Sacobia River had occurred at "Abacan Gap" in 1992.

The construction works of diking system in the Abacan River commenced in November 1991. The river channel was confined with the dikes which were built of lahar materials for the reach from sabo dam No. 9 down to the Ninoy Aquino Bridge. While, the new river channel confined with dike was constructed in 1991 for the reach from the Ninoy Aquino Bridge to the confluence of San Fernando and Bungang Guinto rivers where the downstream end of the Abacan River is found. At the downstream end of the Abacan River, the river width is gradually reduced from 70 m to 30 m which corresponds to the width of the San Lorenzo Bridge at the starting point of the Bungang Guinto River. To avoid vertical and lateral erosions of river channel in the vicinity of the Capaya Bridge at North Super Highway, spur dikes were built with gabions at an interval of about 50 m. In early 1994, the breached dikes at several meandering portions in the downstream reach are being rehabilitated. At present, the sediment will be transported gradually from the upstream reach to the downstream end of the river.

(2) Sacobia-Bamban River

1) Pre-eruption

The flood protective dike with 1.5 m high was constructed in 1950's along the downstream reach from Bamban to the confluence with the Rio Chico River.

2) LAHAR I (1991 Occurrence)

Dikes along the Bamban River were first breached by lateral erosion or overtopping by lahar immediately after the eruption on June 15, 1991, and continued to be breached until early September 1991.

The Sacobia River produced lahar flows 183 times for the period from July 17 to September 4, 1991. Transient lakes emerged by the blockade of the Marimla River and the other tributaries due to the aggradation of the Sacobia River. On August 21, 1991, one of the transient lake was breached and added to the lahar that destroyed the Bamban bridge. As a result, the river channel of Sacobia-Bamban River aggradated about 20 m in about two (2) months around the confluence between Sacobia and Marimla rivers. The lahar deposit thickness was 1.5 to 2.0 m on the average in the downstream reach of the San Francisco bridge. At the downstream end of the Bamban River, the Rio Chico River was partly dammed by lahar deposition that backflooding and inundated at additional 10 km^2 on September 10, 1991.

3) LAHAR II (1992 Occurrence)

Prior to the rainy season in 1992, the downstream reach of the Bamban River at left bank and 3 km upstream of San Francisco Bridge at right bank down to the confluence of the Rio Chico River was wholly confined by river dikes made of lahar. The 1992 lahar extended with a thickness of 2.0 to 3.0 m to the right bank between Bamban to Mabalacat-Concepcion Road. The additional 20 km^2 was affected by lahar deposition.

4) LAHAR III (1993 Occurrence)

Prior to the rainy season in 1993, the dikes at right bank along the northern part of the Clark Air Base was constructed with concrete facing 6 km long with a height of about 5 m. The upstream end of the dikes was anchored to the hill. While in the left bank, the dikes of about 1.5 km long to the upstream of Bamban was reinforced by concrete facing.

On October 4 and 5, 1993, lahar deposits were evident from Macapagal village, near the northern boundary of Clark Air Base, down to the Magalang-Concepcion road. Most of these deposition areas were previously affected in 1991 and 1992. However, a part of lahar deposition was extended to Sapang Balen village 2 to 3 m thick, and in-channel lahar deposition of 2.0 to 2.5 m was observed from Bamban to San Francisco bridge. The mudflow of about 200 m upstream of San Francisco bridge outside the dike at right bank damaged some portions of the Concepcion-Magalang road. No significant lahar flow were observed along the downstream channel of San Francisco bridge. Desilting operations were undertaken upstream and downstream of the San Francisco bridge to increase the freeboard and prevent overtopping of the bridge by lahar during the next rainy season.

5) LAHAR IV (1994 Occurrence)

In 1994, the sand pocket structures of about 20 km^2 were constructed in the middle reach of the Bamban River. Furthermore, the DPWH implemented the construction of separation diking system of about 5 m high between Bamban and Sacobia rivers. The objective of separation dike is (i) to diversify the Sacobia River which still contains much sediment into sand pocket area, (ii) to avoid riverbed aggradation of the Bamban River at San Francisco Bridge where the relatively clear water flows down from Sapang Cauayan and Marimla rivers.

Although about 10 million m^3 of sediment deposition was observed in the sand pocket area in 1994, the water collecting channels which are located in the downstream reach of sand pocket area were heavily silted. The flood water with much sedimentation caused siltation in the downstream area of sand pocket.

II.2 SHORT AND MEDIUM TERM PLAN FOR SACOBIA-BAMBAN RIVER SYSTEM

2.1 POSSIBLE STRUCTURAL MEASURES

(1) Sediment Source Zone

1) Revegetation

Seeding/planting of suitable vegetation on the pyroclastic flow deposit fields is one of the effective method not only to avoid an excessive sediment yield due to sheet and gully/rill development but also to contribute the environmental conservation of mountain slope. The appropriate species for this purpose are characterized by robust perennial with vigorous rhizome and an extensive root system. Since the pyroclastic flow deposit is reported to be as hot as 500°C even in the year 2000, the revegetation would be effective when the pyroclastic flow deposit fields become cool. The satellite images were analyzed in order to evaluate the rate of spreading growth of plant in centrifugal pattern on the pyroclastic flow deposit fields.

2) Simple Sabo Dam

A series of small-scale sabo dam at downstream end of tributaries would be effective in controlling the sediment yield from tributaries in the pyroclastic flow deposit fields. However, the construction works of these structures may involve some risks even in dry season, and the sediment control effect might be small comparing with the volume of secondary erosion in the middle stream of the Sacobia River.

(2) Sediment Deposition/Secondary Erosion Zone

1) Sand Pocket

The construction of sand pocket structures was almost completed immediately after the onset of rainy season in 1994. Although a part of sandbagging dike system was washed out by flooding, the sand pocket structures functioned well to store the sediment inflow of 10 million m^3. On the other hand, the incomplete first (downstream end) row of lateral open dike, which was unable to construct in 1994 since the rainy season in 1994 has begun earlier than usual, resulted in the siltation of downstream channel of sand pocket structures. During flooding in August to September, the flood water breached the dike near Navaling due to insufficient flow capacity. About 110 ha of paddy field was affected by siltation.

Through the observation and monitoring carried out by the Study Team in 1994, the following structures are also required to ensure the safety against flood/mudflow:

a) Slope protection work of closing dike of sand pocket structures,
b) A series of lateral groundsill in sand pocket area to trap a sediment,
c) A sump to trap fine particles immediately upstream of Route 329, and
d) Channeling works and maintenance excavation of the Sapang Balen River

2) Sabo Dam

Although two (2) sabo dams were constructed in the Sacobia River for the period of November 1991 to March 1992, these dams were completely washed out by lahar in 1993. The reconstruction of sabo dam at Mactan may be preferable to store the sediment. However, the storage capacity of the dam is estimated at 100,000 m^3 which is equivalent to only 25 % of total sediment volume in the rainy season of 1995 in case of sabo dam with 10 m high as shown in Figure H.2. The construction cost is estimated at 33 million Pesos which is not economically viable when it is compared with the cost of excavation works in the downstream reaches.

3) Consolidation Dam

A consolidation dam is effective in stabilizing in-channel deposition and also control sediment discharge to the downstream reach. The most suitable site for consolidation dam is located in the vicinity of Maskup where the Sacobia River forms narrow river channel. At present, sediment deposition of 80 million m^3 was stored in the spindle-shaped valley between Mactan and Maskup, and a remarkable sediment deposit will be eroded in the successive years. Therefore, the consolidation dam at Maskup is inevitable as a part of the overall sediment control system and restoration of Route 3 Highway between Mabalacat and Bamban. Furthermore, in order to construct a new bridge of the Route 3 Highway astride the river channel, a consolidation dam at Dolores site is essential.

On the other hand, a series of consolidation dams can be constructed so as to stabilize accumulated sediment in the spindle-shaped valley. Although a series of consolidation dams are effective against secondary erosion, the construction cost may be costly.

4) Bed Girdle

A remarkable in-channel deposition still remains in the upper reaches of the Bamban River. The secondary erosion and re-deposition will occur repeatedly in the lower reach of the Bamban River. A series of bed girdles is the one of alternatives to regulate the secondary erosion of in-channel deposition. In 1994, the most critical problems in the Bamban River was the diminishing of freeboard at San Francisco Bridge. A series of groundsill in the upper reaches of the Bamban River would be effective in regulating the riverbed aggradation at San Francisco Bridge.

5) Training Works

As far as the Sacobia River flows into the sand pocket area, water channeling in the downstream reach from the sand pocket structures is required to ensure the safety for releasing flood water to the downstream reach.

On the other hand, the Sacobia River is expected to join with the Bamban River when the river water of Sacobia River does not contain much sediment and sand pocket structures had performed their role. Channeling works with protective dike system along the Sacobia River will be required for the reach from Maskup down to the confluence with the Bamban River.

6) Channel Excavation Works

The riverbed tends to aggradate gradually in the sediment deposition/secondary erosion zone as well as in the sediment conveyance zone. Annual excavation of the river channel is required to maintain the riverbed elevation to equal or less than the existing one.

(3) Sediment Conveyance Zone

1) Dike

Dike system in the lower reaches of the Bamban River for a stretch of 8 km from the confluence of the Rio Chico River was constructed before the eruption. The dike is made of clay soil with grass/shrub cover. On the other hand, in the upper portion of the Bamban River, the old dike system was completely damaged during lahar events in 1991. A newly-constructed dike made of sandy lahar materials always suffered from lateral erosion by flood water during rainy season. Thus, the dike in the upper portion of the Bamban River shall be covered at least with mountain soil for slope protection.

2) Spur Dike/Groin

A spur dike/groin is placed at approximately right angle to the bank to control flow direction towards a center of the channel. A series of spur dike/groin is required to be placed at the meandering part to reduce the flow velocity along the dike.

3) Channel Excavation

Channel excavation is required to protect the dike system. Excavated materials will be placed to the spoil banks which is located at the left bank of the lower Bamban River.

Table H.1 shows the summary of the evaluation of possible structural measures.

2.2 *ASSESSMENT OF PRESENT CONDITION OF RIVER BASIN*

(1) Present River System

A part of catchment of the Sacobia River was annexed to the Pasig River in October 1993. In 1994, the Sacobia River diverges from the Sapang Cauayan and Marimla rivers, and flows into the sand pocket. It joins with the Sapang Balen River at Route 329 in the downstream of sand pocket. The Sapang Balen River after joining with the Sacobia River flows on a channel of 20 to 30 m wide and 2 m deep for a stretch of about 10 km downstream from Route 329 to Barangay Balutu and diffuses its water into the San Antonio Swamp along the right bank of the Bamban River.

The present Bamban River which collects water from the Sapang Cauayan River (a catchment area of 20.8 km^2) and Marimla River (64.6 km^2), flows for about 25 km in a channel of 200 to 300 m wide confined by dikes and empties into the Rio Chico River.

Damming of the Sapang Cauayan River by aggradation of the Sacobia River has led to the intermittent formation of lakes. The storage of the dammed lake is estimated to be 7 million m^3 at El. 90 m. A 50 m wide outlet channel is formed 2.2 km from the lake to the confluence with the Marimla River.

(2) Vegetation Recovery in the Pyroclastic Flow Deposit Field

Landsat data shows that the presence of cloud cover in the Mt. Pinatubo area is considerably high throughout the year leaving only thirteen data sets are usable for the study for the period from January 1991 to October 1994. Among these data sets there was only two were with zero cloud cover. Comparing these available data with major volcanic activities in the area, datasets shown in below were acquired for the Study.

Acquired satellite data and date of major volcanic activities

Year	Landsat TM data	Major Eruptions
1990	1990.01.20	
	1990.07.15	
1991		June 12 - 17
1992	1992.02.11	Apr. 4
		July 13
	1992.10.08	Sep. 20-21
	1992.11.25	Nov. 20-24
1993	1993.02.13	
	1993.04.02	Oct. 5-6
	1993.12.30	
1994	No data	

Attempt was made to investigate for any sign of re-growth in the vegetation cover in areas where the pyroclastic flow deposits cover. The river drainages in the slope of Mt. Pinatubo were subdivided into four zones considering the distribution of river network and the extent of lahar and pyroclastic flow deposit. The subdivided areas are shown in Figure H.3. Normalized Difference Vegetation Index (NDVI) was used as interpretation key, which is one of the most popular index in the vegetation type mapping, vegetation stress evaluation, vegetation and non-vegetation mapping.

To avoid the effect of seasonal changes, the NDVI interpretation was carried out with datasets acquired during the same season of the different year. Comparison was done for the time interval of November 1992 to December 1993 and February 1992 to February 1993. Pyroclastic flow deposited areas in February 1992 was extracted, and the NDVI values of February 1993 was investigated to identify the areas for increase in vegetation cover during the time span of the two datasets. Similarly, November 92 data was compared with December 1993 to identify the areas of vegetation recovery.

The cover classes established for NDVI representation are bare lands, grass lands, low-density forest and high-density forest. The increase in the amount of NDVI is represented by the typical land cover classes in the Study Area as enumerated below.

Increase of vegetation cover for grass and low density forest estimated by NDVI for the period February, 92 to February, 1993 (Unit:ha)

	North	East	South-West	West
Grass	280	267	187	352
	(9%)	(5.7%)	(3.8%)	(2.8%)
Low-density forest	38	98	16	3
High density forest	0	0	0	0

Increase of vegetation cover for grass and low density forest estimated by NDVI for the period November, 92 to December, 1993 (Unit:ha)

	North	East	South-West	West
Grass	229 (9%)	237 (5.6%)	201 (5%)	537 (4%)
Low-density forest	33	50	37	42
High density forest	0	0	0	0

The figures are given for increase in vegetation for each land cover class. Further, the parenthesized values represent the percentage recovered with respect to the damaged area in each zone. The above result shows that the highest recovery is observed in the West zone for both comparison and least recovery in the south-west direction. In general terms, the percentage of recovery is higher in the eastern slope of the mountain than the western slope. The re-growth of the vegetation in the eastern slope is increasing at the annual recovery rate of 5 to 6 %. Although the annual recovery rate of vegetation continues generally to increase steadily in accordance with the stability of mountain slopes, it takes about 15 to 20 years to be recovered entirely by the vegetation in the eastern slope.

(3) Present River Condition

The present Sacobia-Bamban River system creates the following situations:

1) The longitudinal profiles of the Bamban River surveyed in early 1994 as illustrated in Figure H.4 shows the slopes of 1/800 to 1/460 downstream, 1/370 to 1/260 midstream and 1/100 upstream. The existing riverbed elevations are higher than land-side ground levels.

2) The riverbed materials are made of lahars. Samples of lahar deposits obtained by the Study Team in 1994 from the Sacobia-Bamban river basin shows that lahar deposits consist of sand (80.4 - 95.4%), silt (0.6 - 10.6%) and clay (4.0 - 9.0%). At the downstream of the Sacobia-Bamban River, the lahar deposits are finer and also consist of silt (53.6%), sand (20.4%) and clay (26.0%).

3) The coarse sandy deposits in the upper reaches have a medium to fast hydraulic conductivity which ranges from 1.2×10^{-4} to 6.5×10^{-2} cm/sec. Bulk density varies from 0.98 g/cm^3 of the loosely-structured loamy sand to 1.83 g/cm^3 of the compacted loamy sand by bulldozers.

4) According to grain-size analyses carried out by NIA in March 1992, and March and December 1993, the riverbed in the Rio Chico River in March 1992 and March 1993 has a lot of fine particles with a diameter less than 0.074 mm.

(4) Existing Structures

Protection/rehabilitation works mainly including dikes with/without slope protection and the sand pocket are being done continuously. As of the end of 1994, the following facilities have been constructed (refer to Figure H.5).

1) Sand pocket of 23 km^2

2) Bamban River

Left and right dikes without slope protection downstream from the San Francisco Bridge, 32 km long in total.

Left dikes with concrete facing slope protection from the San Francisco Bridge to the confluence with the Sapang Cauayan River, 9.5 km long.

Right dikes without slope protection from the San Francisco Bridge to the Sapang Cauayan River, 10 km long.

3) Sacobia River

Right dikes with concrete facing slope protection along the northern part of Clark Air Base, 6 km long.

The following works are scheduled in the Bamban River in 1995:

1) Maintenance works of dike including mountain soil covering and gravel paved road downstream from the San Francisco Bridge.

2) Slope protection works of dike downstream from the San Francisco Bridge.

3) Slope protection works of dike enclosing the sand pocket.

(5) Present Flow Capacity

The present flow capacity of the Bamban River was examined by means of non-uniform flow calculation using the cross sections of channel at an interval of 600 m surveyed in early 1994.

Figure H.6 shows the present flow capacities. These capacities are estimated at a level with freeboard of 0.8 m or 1.0 m. The upper reaches of the Bamban River have the flow capacity of more than 1,500 m^3/s, while the lower reaches have the flow capacity of 500 to 1,000 m^3/s taking into account the flood water level of the Rio Chico River.

2.3 *PRELIMINARY SCREENING OF STRUCTURAL MEASURES*

(1) Future Prospect and Basic Concept

It is expected that the amount of sediment to be delivered from the pyroclastic field would be decreased by 40-50% every year to a certain level of the pre-eruption condition in the Sacobia river basin. There would be little chance that the Sacobia River would re-capture the summit basin from the Pasig River within a decade, and a large part of pyroclastic materials has been already eroded in the valley of the Sacobia River and remaining materials are deposited mostly on terraces and hills with relatively gentler topography.

In the Marimla and Sapang Cauayan river basins, pyroclastic materials are scarcely remained and the river water contains a small proportion of sediment as the basins are well covered by vegetation.

On the other hand, there are about 110 million m^3 of sediment deposits in the valley upstream of the previous No. 3 Highway between Mactan and Dolores, 100 million m^3 in the right overbank area of the Bamban river between No. 3 and No. 329 Highway, and 25 million m^3 in the Bamban River channel upstream of San Francisco bridge. These sediment deposits would be re-eroded by river water and rainfall and would be further transported downstream. Although lahars from the mountainous area could be still significant during a next few years, the major problem of the Sacobia-Bamban river basin would be the movement of sediment transported by flood waters.

Because the situation of the Sacobia-Bamban basin is changing every rainy season since the eruption in 1991 and will not be stable for some more years, the plan should be based on the present situation and future prospect of the area and should be flexible to the changes of the natural conditions.

The most critical problem in the Bamban River at present is the safety of the San Francisco Bridge. The clearance of the San Francisco Bridge is about 90 cm on an average at present. The flood flowing capacity of the river at the bridge would be about 250 m^3/s which is equivalent to a moderate flood peak discharge of the Bamban River alone (20 cm of allowance is taken for waves). If the flood runoff is blocked by the bridge, there is a high risk that not only the bridge would be destroyed but also the blocked flood water would overtop or breach the dikes just upstream of the bridge.

Although it is planned that a new bridge having enough clearance would be constructed just upstream of the existing bridge and the existing one would be removed, the new bridge would be serviceable in 1996. Thus, in the 1995 rainy season at least 0.5 m of dredging should be implemented in the 6 km reach between Malonzo to 3 km downstream of the bridge(about 0.8 million m^3 in volume), or riverbed consolidation works be implemented to obtain necessary flood flowing capacity.

There are a few alternatives for flood and mudflow protection in the Sacobia-Bamban river basin (Ref.H.1), and the following four alternatives were first examined for finding appropriate direction of the plan configuration.

1) Case-1 : No action

The present situation of the flood and mudflow would continue in the Sacobia river and Bamban River and no countermeasure is taken.

2) Case-2 : To divert the Sacobia River to join with the Bamban River upstream of the San Francisco bridge immediately before onset of 1995 rainy season

The idea does not consider any control structures but continuous dredging of the Bamban River is proposed as the USACE's excavation alternative. Under the present situation, the two routes of diversion of the Sacobia River can be planned as illustrated in Figure H.7. One is by setting of the confluence upstream of Malonzo, the other is between Malonzo and the San Francisco Bridge.

3) Case-3 : To retain the Sacobia mudflow in the sand pocket on the right bank of the Bamban River and released excess water downstream

The Sacobia river water is immediately drained into the Bamban river upstream of the San Francisco bridge by constructing high levees and a control structure to regulate flood runoff and trap sediment. This is proposed by the USACE's levee alternative as shown in Figure H.7.

(2) Preliminary Screening Based on the Present Situation

These alternatives are planned in the USACE study executed for the major study period of 1992 to 1993. After completion of the study, the situation of lahars in the Sacobia-Bamban River drastically changed in the 1994 rainy season due to 50% reduction of its headwaters by river piracy. Thus, it is indispensable that a flood and mudflow control plan shall be formulated in reconsideration of the updated situation. The following discusses the alternatives under the 1994 situation as summarized in Table H.2.

1) Case-1 : No action

It is expected that 7 million m^3 of sediment would be delivered from the Sacobia valley (4 million m^3 from the pyroclastic field and 3 million m^3 eroded from the Mactan-Maskup valley) to the right overbank area of the Bamban river in the next rainy season. Out of 7 million m^3 of sediment, a part of them would deposit in the sand pocket and some 1.6 million m^3 would be further transported downstream of the sand pocket, if no countermeasure is provided to prevent movement of the sediment. It would accumulate 14 million m^3 of sediment in the low-lying area below No. 329 Highway by year 2000. The area affected would be some 4000 ha. The risk of floods would be extremely high because the river channel would be completely silted up.

The riverbed in the middle and lower reaches of the Bamban River will rise by some 1.2 meters in year 2000 due to erosion of river bed materials in the upper reaches and a risk of breaching of dikes become high. If the levees along the Bamban river would be breached, flood water would intrude into the overbank area along the Bamban river, about 10,000 ha in the left (north) side of the river or 8,000 ha in the right (south) side area would be affected.

2) Case-2 : Immediate diversion of the Sacobia river without sediment retention.

If the Sacobia river would be diverted to join with the Bamban river, the average annual maximum discharge would be 400 m^3/s while a 10-year flood would have 650 m^3/s of peak discharge which requires 1.5 m of clearance of the San Francisco bridge.

If the Sacobia river directly joins with the Bamban river upstream of the San Francisco bridge, it is assumed that most of the sediment of the Sacobia river would be transported into the Bamban river and some 7 to 8 million m^3 of sediment would be accumulated in the river channel in 1995 and it would result in elevating the river bed by 1.2 to 1.4 m on an average, although the amount would be reduced to some 3 to 4 million m^3 in year 2000.

Thus, at least 4 million m^3 in total should be removed in 1995 to obtain 1.5 m of clearance even if the dredging works are limited to the area near the bridge. In addition, the Sacobia river channel shall be confined by levees to maintain the river course and therefore there is a risk that the Sacobia channel is easily filled up by even a single flood event.

It is noted that there is an uncertainty in the situation of sediment delivery in the next rainy season, monitoring during rainy season is indispensable and additional dredging work might be required in the rainy season although it is very difficult and costly.

In 1996 and thereafter, 3 to 6 million m^3 of sediment should be removed annually for more than 10 years to maintain the river bed at present situation which is already about 2 meters higher than the pre-eruption condition.

Under such situation, it is not recommended to divert the Sacobia River to join with the Bamban River without any sediment retention structures and the safety of the area along the river and bridge from flooding should not depend only on dredging works. It means that the sediment from the Sacobia River should be stored or retained in the reaches of upstream of the San Francisco Bridge.

3) Case-3 : USACE's levee alternative

The USACE's levee alternative consists of ;

i) A levee on the right bank following the existing levee alignment crossing No. 3 Highway in Mabalacat and making long curve from 4 km downstream of the highway to a control structure near San Francisco bridge. The height is transitioning from 10 meters to 13 meters

ii) A levee 6 meters high transitioning to 13 meters high on the left bank of the Sacobia river separating the Sacobia from the Sapang Cauayan river and Marimla river. It would begin at the ridge west of Dolores and end at the control structure.

iii) A control structure with a 200 meters wide spillway placed between the 13 meters high levees near the San Francisco bridge. It is planned that flood runoff will be regulated by the control structure which would create a pool confined by 13 meters high levees and most of sediment would be trapped in the pool.

Construction of levees and foundation treatment should be carefully carried out because the pool would store more than 6 meter-deep water and the levees are constructed on the lahar deposit area. Lahar materials would not be appropriate for such a water storing structure.

Considering construction schedule, the completion of the structures would not be possible in 1995 may be in 1996 at the earliest. During one or two rainy seasons of the construction period, the Sacobia river have to be diverted into the Bamban river without any sediment retention or to flow down the right overbank area and drain into the Sapang Balen River across the No. 329 Highway.

There is a risk that a high velocity flow released from the spillway of the control structure into the Bamban river would disturb the Bamban runoff during flooding times and cause adverse effects to the opposite side levees of the Bamban River, and the San Francisco Bridge should have enough clearance for the turbulent flow. Operation of the system is possible only after elevating the bridge and reinforcing the levees.

Although sediment supply from the mountain and secondary erosion of lahar deposit materials are expected to last for several years, the sediment supply would become stable at a level of pre-eruption condition in some 10 years. Under such situation, the Sacobia river could be confined in a river channel of appropriate width of some 100 m and be joined with the Bamban river at the same elevation without any control structures. The sediment retained area could be utilized for productive purposes and the No. 3 Highway would be restored. It means that the USACE's levee plan should be considered as a step of rehabilitation works rather than the permanent one. Otherwise, the sand deposit area created by 13 meters high levees would be abandoned and risks of breaching of high levees and high velocity water from the drop structure would last.

Through the discussions in the preceding sections, it has been cleared that

i) The Sacobia River should not be diverted back to the Bamban river in 1995. It should be drained into the Sapang Balen river or other small creeks safely at least in 1995 before the completion of the elevated San Francisco bridge.

ii) It is the most critical work that the Sapang Balen river is rehabilitated to have a sufficient flood flowing capacity

iii) The sediment delivered from upstream reaches of the Sacobia river should be retained and stabilized in the sand pocket by structural measures to be provided upstream of No. 329 Highway.

iv) Secondary erosion of the sediment deposits in the upper reaches of the Sacobia and Bamban river should be minimized.

v) The Sacobia River should be diverted back to the Bamban river at an appropriate location upstream of the San Francisco bridge when the sediment supply from the Sacobia river is to a certain level allowable for the Bamban river.

Based on the above considerations, the flood and mudflow control plan should be formulated as a stepwise plan in accordance with the changes in natural conditions and the estimate of sediment balance resulted from actions taken. The plan also should clarify the procedure of implementation and the future prospect of the affected area.

2.4 *PRELIMINARY DESIGN OF STRUCTURAL MEASURES*

Through the screening of possible structural measures as given in Table H.1, the following measures can be selected as suitable measures for the flood and mudflow control plan. Preliminary structural analyses are done for structural measures as described hereinafter.

1) Sand pocket
2) Consolidation dam
3) Training works
4) River improvement including bed girdles and spur dike/groin

(1) Sand Pocket Structure

1) Effect of Sand Pocket Structure

The expected functions of the sand pocket are protection from secondary erosion of deposited lahars and retention of sediment inflow and prevention of dispersing sediment in the low-lying area. The effects of proposed control structures in sand pocket were examined under 1994 topographic conditions for the 20-year flood. As the control structures, separation dikes between Sacobia and Bamban rivers, lateral dikes in lower end of sand pocket, sump and 329 highway elevated by 5 meters and collect canals are considered. Figure H.8 shows the maximum flow depth and sediment deposits. The flood flows in sand pocket were well drained into the Sapang Balen River and sediment materials were trapped at the lower lateral dike and sump. Most of sediment deposits were deposited in upper part of the sand pocket. It means that sediment materials will not be transported downstream by a single flood event although it might be gradually transported by normal flows.

2) Long-Term Topographic Changes in Sand Pocket

For the purpose of examining the long term changes of topography of the sand pocket, constant runoff of 500 m^3/s was input at Maskup continuously for 120 hours which is equivalent to 5 years runoff volume from the Sacobia river at Maskup. Figures H.9 and H.10 show the maximum flow depth and sediment deposits in 1 year, 3 years and 5 years. Because of the siltation of collect canals and sump located lower end of sand pocket, overflow of the canal and river channel occurred in the Sapang Balen River. The sediment deposit is obvious in the upper half of the sand pocket as well as north east corner of the sand pocket. According to this long-term changes and flow conditions due to the probable floods, major flood flow in the sand pocket would run along the separation dike between the sand pocket and the Bamban River. Reinforcement of the dikes along the possible water way should be considered.

Judging from the above short and long-term simulation of topographic changes in the sand pocket, road dike on Route 329 and reinforcement of lateral dike are essential to ensure the safety for flood and sedimentation..

1) Road Dike on Route 329

In the worst case, the depth of mudflow deposition in the downstream end of the sand pocket may reach 3 to 4 m deep taking the flood water level into consideration. In addition to the reinforcement of sand pocket structures, the construction of a road dike by elevating Highway Route 329 for about 4.5 km long and 5 m high is essential to ensure the transportation system between Pampanga and Tarlac. The proposed road dike is shown in Figure H.11, and the dimensions are as shown below.

Location	:	Magalang-Concepcion Road (Route 329), between San Roque Creek and San Francisco Bridge
Length	:	4,300 m
Height	:	5.0 m
Width of Crest	:	12.7 m
Slope of Embankment	:	1:1.5
Embankment Volume	:	439,100 m^3

2) Reinforcement of Lateral Dike

In the 1994 rainy season, the lateral open dike system made of lahar materials with sandbagging cover was thoroughly breached by flood water. In order to ensure the functions of sediment retention and consolidation of accumulated sediment, the lateral open dike shall be closed and reinforced with durable materials against flood water. Figure H.12 shows the proposed lateral dike system composed of low gabion groundsills. This system shall be constructed upwards by row in accordance with the condition of sediment accumulation.

Taking local scouring at front portion and overflowing on the non-overflow section into consideration, drop head shall be made small and the foundation shall require plenty of allowance. The design dimensions are as follows:

Average Length	:	about 3,000m
Height	:	1.5 m
Foundation Depth	:	1.0 m
Width of Crest	:	3.0 m
Overflow Section	:	200 m wide x 0.5 m high x 4-5 portions in each row, with apron of 0.5 m high x 1.0 m wide x 2 steps
Distance between Rows	:	1,000 m
Materials	:	Gabion with boulders

(2) Consolidation Dam

1) Type Selection

The applicable types of consolidation dam to be considered, which can store sediment of fine sand, are gabion type ,concrete gravity type, masonry type and steel type (double-walled structure). Comparison among them is shown in Table H.3. The steel double-walled structure dam can be selected through the comparison, additionally taking the following reasons into consideration:

a) Construction period of a double-walled structure dam is very short so that a consolidation dam can be constructed within the dry season.

b) Double-walled structure dam can be constructed on the loose sandy foundation of thick lahar because of its light weight and flexibility.

c) Double-walled structure dam is the most economical in construction cost.

d) Double-walled structure dam is widely applied in volcanic disaster areas.

The steel double-walled type dam is composed of a steel wall installed at both sides. The space between both walls is filled with sand which could be obtained from lahar deposits, and both walls are tied together with steel bars.

2) Design Conditions

The embedment depth of the dam foundation is set at 3 m in consideration of looseness of the base ground. A low height of 4 to 5 m is planned as the effective height, which is the difference of elevation between the crest of spillway and the base ground, to keep the dam body safe from heavy scouring and unexpected loading. The height of wings is determined based on the comparison between the overflow depth with enough freeboard and the height of accumulated terrace in the retention area.

The spillway is designed to have the flow capacity of a 100-year flood with sediment concentration of 30%. The design discharge of a 100-year flood is computed under the pre-eruption conditions that the Sacobia basin encompassed its headwaters annexed to the Pasig basin in October 1993. Freeboard is designed to keep enough height more than 1.0 m based on the design criteria of sabo structures in Japan.

A series of counter dams, apron, cut-off and riverbed protection works are designed as the protection works of the front side from scouring. Furthermore, the spillway and the apron shall be covered with concrete of 0.5 to 1.0 m thick as protection against abrasion and collision by sediment, and sheet piles shall be driven into the ground at both sides of main and counter dams to prevent seepage and piping.

3) Series of Consolidation Dams between Mactan and Maskup

The spindle-shaped valley between Mactan and Maskup will become one of the main sediment sources to the lower reaches of the Sacobia-Bamban River system in the succeeding years. Thus, a series of consolidation dams are the most effective measures to stabilize the erodible accumulated sediment in the valley.

Nine consolidation dams with the effective height of 5 m are required to realize stabilization of the existing river bed, as shown in Figures H.13 and H.14. These consolidation dams will inevitably become wide and large-scale structures crossing the wide deposited area which has an average width of 900 m. As a result, the construction cost also will be high.

4) Maskup Consolidation Dam

Maskup narrow path is the lowest end of the sediment accumulated area in the spindle-shaped valley. Maskup dam is also located at the most downstream site of the series of consolidation dams mentioned above, and the highest priority among the consolidation dams can be placed on this dam because of its suitable location for sediment retention.

The river course of the Sacobia River has frequently shifted on the sediment accumulated bed due to bank erosion and channel clogging, so that channeling work will be difficult to sustain the stability of the river course. Even under these situations, the water course can be easily stabilized by installation of sediment control structures at the narrow path. The restoration work on Highway Route 3 with two bridges can be commenced as a permanent structure only when the Maskup consolidation dam stabilizes the river course downstream of Maskup.

The wing dam on the right terrace connected with the right dike can be similarly designed as a protective dike. The spillway crest is set at 5 m in effective height in consideration of the height of terrace and the existing right dike along Clark Field.

Figure H.15 shows the preliminary plan of Maskup consolidation dam and the following gives the design discharge and principal features.

Design discharge	:	820 m^3/s
Effective height	:	5.0 m
Main dam height	:	8.0 m
Length of main dam	:	460 m
Spillway width	:	100 m
Freeboard	:	1.0 m

5) Dolores Consolidation Dam along Highway Route 3

Dolores consolidation dam in parallel with Highway Route 3 aims at stabilizing the river course and preventing secondary erosion of deposited sediment so as to make the restoration of the Highway Route 3 possible.

The effective height of the consolidation dam is planned to be 4 m in order to prevent secondary erosion of deposited sediment between Maskup and the dam site. The length of consolidation dam is 800 m and a new training dike with length of 2 km is required to be constructed as the left abutment.

Figure H.16 shows the preliminary plan of Dolores consolidation dam and the following gives the design discharge and principal features.

Design discharge	:	820 m^3/s
Effective height	:	4.0 m
Main dam height	:	7.0 m
Length of main dam	:	800 m
Spillway width	:	100 m
Freeboard	:	1.0 m

(3) Training Works of Sacobia River

After completion of construction of Maskup and Dolores consolidation dams, restoration of Highway Route 3 with bridges will be possible. Then the Sacobia River can be connected again with the Bamban River. From the viewpoint of sediment balance as described in Appendix F, the location upstream of Malonzo is preferable to the confluence between the Sacobia River and the Bamban River. Thus, a stretch of 5 km shall be planned as river training works between Maskup consolidation dam and the confluence. Plan and standard cross section are shown in Figure H.17.

1) Design Scale and Design Discharge

A 20-year return period is applied for design scale. Design discharge as shown in Figure H.18 is 340 m^3/s.

2) Design Longitudinal Profile

Slope of 1/150 is proposed based on the existing topographic condition surveyed in early 1994.

3) Design Cross Section

Design cross section shape	:	single trapezoid
Design freeboard	:	0.8 m
Design depth	:	1.2 m
Roughness coefficient	:	0.035
River width	:	108 m
Riverbed width	:	100 m
Design velocity	:	2.175 m/s

4) Structures

Dikes along both sides of the river with slope protection are proposed. They are designed in the same manner as the Bamban River mentioned in the succeeding section.

(4) River Improvement Works of Bamban River

1) Planning Conditions

Generally, the design scale of the flood control master plan for rivers with a relatively small catchment area is proposed at a 50-year flood in the Philippines. Regarding the Bamban River, the design scale of a 20-year flood is proposed as the medium-term plan because the river channel still shows unsteady and changeable conditions and the plan should be flexible to the natural changes. In addition, the Pampanga River Improvement Works are being implemented on a scale of 20-year return period. For the long-term plan, upgrading is recommended after natural changes become stable in the future.

The following summarizes the design discharges depending on the channel planning of the Sacobia River:

a) Sacobia will flow into Bamban downstream from San Francisco Bridge together with Sapang Balen (refer to Figure H.18)

River Reach	Design Discharge (m^3/s)
No. 7	520
No. 8	1,060

b) Sacobia will be shifted to join with Bamban upstream from Malonzo (refer to Figure H.18)

River Reach	Design Discharge (m^3/s)
No. 5	580
No. 6	890
No. 9	1,110

The freeboard of 1.0 m is determined referring to the design criteria in Japan where the freeboard of 1.0 m can be applied within the design discharge ranging from 500 m^3/s to 2,000 m^3/s.

2) River Improvement Plan

According to the present flow capacities, it is not necessary to improve the existing channel by means of channel excavation, widening and dike raising in the upper reaches. On the other hand, since the present flow capacities are less than the design discharges at some portions in the lower reaches, river improvement by means of channel excavation is recommended in consideration of the progressing aggradation of the riverbed.

Figures H.19 and H.20 show the proposed longitudinal profiles and typical cross sections designed on the following considerations.

a) Channel Alignment

The alignment of river channel to be improved will follow the present alignment in consideration of the existing parallel dikes.

b) Channel Longitudinal Profile Planning

According to Figure H.4 showing the present longitudinal profile surveyed in early 1994, the present lowest riverbed elevations are higher than the landside ground elevations.

Although the riverbed elevation should be lower as much as possible from the viewpoint of flood control, the existing longitudinal profile is proposed to be adopted in consideration of the naturally changeable present channel conditions and the stability of existing revetments except the downstream reaches of the confluence with the Sapang Balen River. Excavation of the riverbed is proposed for downstream reaches of the confluence because of insufficient flow capacities.

For computation of high water level, the following basic figures are used:

a) Design high water level of EL. 12.53 m at the most downstream point which is adopted from the design high water level of 20-year flood of the Rio Chico River designed in the Pampanga Delta Development Project.

b) Roughness coefficient of 0.035

3) Structural Arrangement

Figure H.21 shows the arrangement of proposed structures for the Sacobia-Bamban River improvement.

a) Dike

Since there are existing dikes in the whole reaches, maintenance works for dikes such as mountain soil covering, sodding, gravel metaling road are necessary.

b) Slope protection

Although slope protection for dikes for a total length of 15 km including the Sacobia River has been constructed, an additional 14 km long slope protection is needed, especially for the right dikes upstream of the San Francisco Bridge.

Moreover, the left side in the 4 km long reaches downstream from Highway Route 3 is planned to be reveted by slope protection with low height so that land of about 220 ha may be useful as farmland except in big flood occurrence.

c) Bed girdle

To regulate downcutting of accumulated sediment at the most upstream reaches (4 km long) of the Bamban River, a series of bed girdles with height of 1 m above riverbed will be provided. A series of bed girdles for a total length of 2.5 km consists of six rows at intervals of 800 m.

d) Spur dike

Spur dikes for a total length of 500 m will be installed at the four critical bending portions to avoid bank erosion and train flow directions toward the center of river course.

e) Channel excavation

To maintain the design riverbed elevations and to secure the design flow capacity in the downstream reaches, channel excavation work is necessary.

4) Preliminary Design of Structures

a) Dike

The dimensions of dikes to be constructed/repaired in accordance with existing dike conditions are as follows (refer to Figure H.22).

- Top width of dike: 7 m
- Side Slope of 1H: 2V
- To be covered with mountain clayey soil
- Provision of gravel metaling maintenance road on the top of dikes

b) Slope Protection

Slope protection is necessary for dikes made of lahar sand. Figure H.22 shows a typical section of wet stone masonry type slope protection constructed in the rehabilitation/protection works.

c) Bed Girdle

Figure H.22 shows a typical section of bed girdle made of steel double wall with tie rods filled with lahar materials. Concrete apron and gabion mattress are needed just downstream of it to avoid local scouring.

d) Spur Dike

The function of spur dikes with revetments is to protect concave sides of channel meanders promoting sediment deposition. Spur dikes are termed permeable spur dike when built of materials such as timber, steel and brush, and impermeable spur dike when built of earth, rock, etc. Permeable spur dikes are generally used for river channels with gentle gradient, while impermeable spur dikes are adopted for steep gradient rivers. Some impermeable spur dikes made of gabion mattress were constructed as the urgent works. At present, they partially collapsed due to riverbed degradation. Therefore, a group of permeable spur dikes suited to erodible-bed rivers is recommended for the objective river channel.

There are no rules of general applicability for determining the spacing, length and angle. Practically the following can be applicable based on experiences in Japan. Figure H.22 shows a typical spur dike that can be applied.

- Direction	:	right angle to flow
- Length	:	less than 10% of river channel width
- Spacing	:	1 to 4 times of length
- Height	:	as low as 0.5 to 1.0 m above low water level to minimize scouring around spur dikes
- Structure	:	reinforced concrete piles

c) Channel Excavation

Materials to be excavated will be transported to the spoil banks. Swampy areas of lowest Bamban River could be one of the candidates for spoil bank.

(5) River Improvement Works of Sapang Balen River

1) Planning Conditions

There are two planning stages of flood control of the Sapang Balen River depending on the expected role of the sand pocket and the direction of the Sacobia River improvement; namely, permanent use of the Sapang Balen River channel for draining flood water of the Sacobia River, and provisional use of the channel for the same purpose.

a) Permanent use

Design scale of the Sapang Balen River permanently joining with the Sacobia River is 20-year return period, the same as the Bamban River. Estimated design discharge is 610 m^3/s (refer to Figure H.18).

b) Provisional use

Only for a few years, the Sapang Balen River will be used to drain flood water from the Sacobia River basin so that design scale of 5-year return period can be adopted. A scale of 5-year flood is equivalent to a 50-year flood after shifting the Sacobia River back to the Bamban River in near future. Estimated design discharge is 380 m^3/s (refer to Figure H.18).

The design discharges are almost 4 to 6 times of the flow capacity of 100 m^3/s, more or less. In order to accommodate those design discharges, river improvement works such as channel widening and deepening, and diking are likely measures.

The freeboard of 0.8 m and 1.0 m is applied in the range of flood discharge of 200-500 m^3/s and 500-2,000 m^3/s, respectively, following the criteria in Japan.

2) River Improvement Plan

The longitudinal profile and standard cross section are shown in Figure H.23 for each case of usage of the Sapang Balen River.

The planning features of each standard section are as follows:

	Permanent Use	Provisional Use
Design discharge (m^3/s)	610	380
Slope of channel	1/440	1/440
Roughness coefficient	0.035	0.035
Design velocity (m/s)	2.678	2.338
Shape of cross section	Composite trapezoid	Single trapezoid
Channel width (m)	96.5	73.2
Channel bed width (m)	60.0	60.0
Maximum depth (m)	3.1	2.5
Freeboard (m)	1.0	0.8
Dike top width (m)	5.0	5.0
Slope of excavation	1V:2H	1V:2H
Slope of dike	1V:2H	1V:2H

3) Channel Alignment

Two channel alignments are compared as shown in Figure H.24.

- Route A : Proposed channel is straightened to keep smooth flow and less slope protection works and maintenance effort because of no curves. Acquisition of land including undamaged area by lahar is needed. Proposed channel length is 9.0 km.

- Route B : Proposed alignment follows existing river course. Channel length is 9.9 km. Required earthwork is more than Route A. Proposed alignment is confined in the area affected by lahar.

Comparing the two alternative routes from the economical, technical and social viewpoints, Route A is advantageous, but the difference between them is small. In addition, from the social point of view there are some difficulties to realize Route A alternative in the area unaffected by lahars. Consequently, Route B is recommendable.

4) Channel Longitudinal Profile

Design longitudinal slope is determined considering the existing ground slope.

To establish the design high water level at the confluence with the Bamban River, non-uniform flow calculation was done in the reach of backwater of the Bamban River. The design high water level at Sta. 7+000 of the Bamban River, El 21.0 m, is applied to the boundary condition.

5) Channel Cross Section

The following criteria are applied to the design standard cross section:

- Side slope of 1V : 2H for excavation of channel and dike embankment

- Provision of maintenance road with 3 m wide and gravel metaling