FIGURES

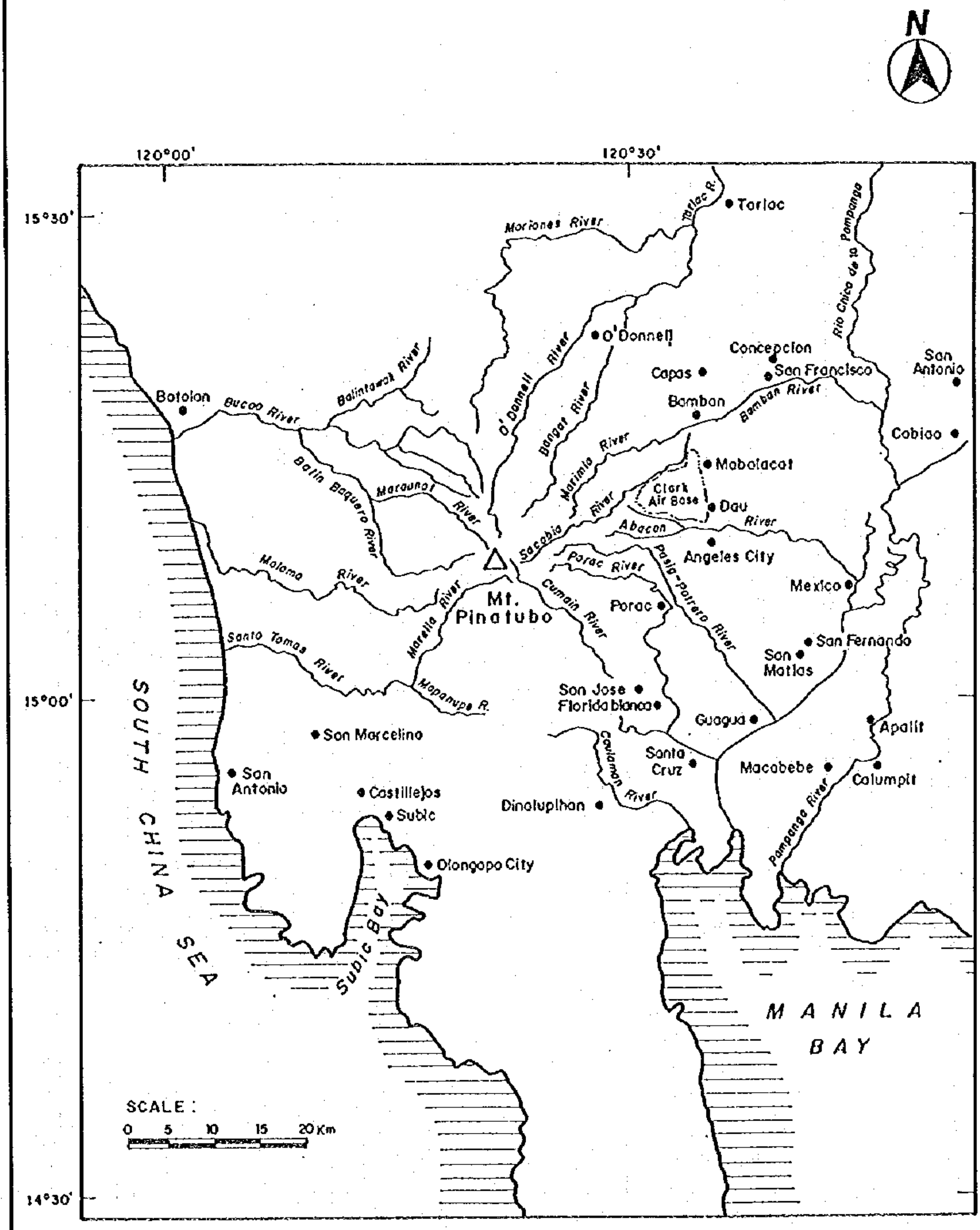


Figure C.1 River System Around Mt. Pinatubo

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

Source : Feasibility Report on the Pampanga Delta Development Project (JICA, 1982)

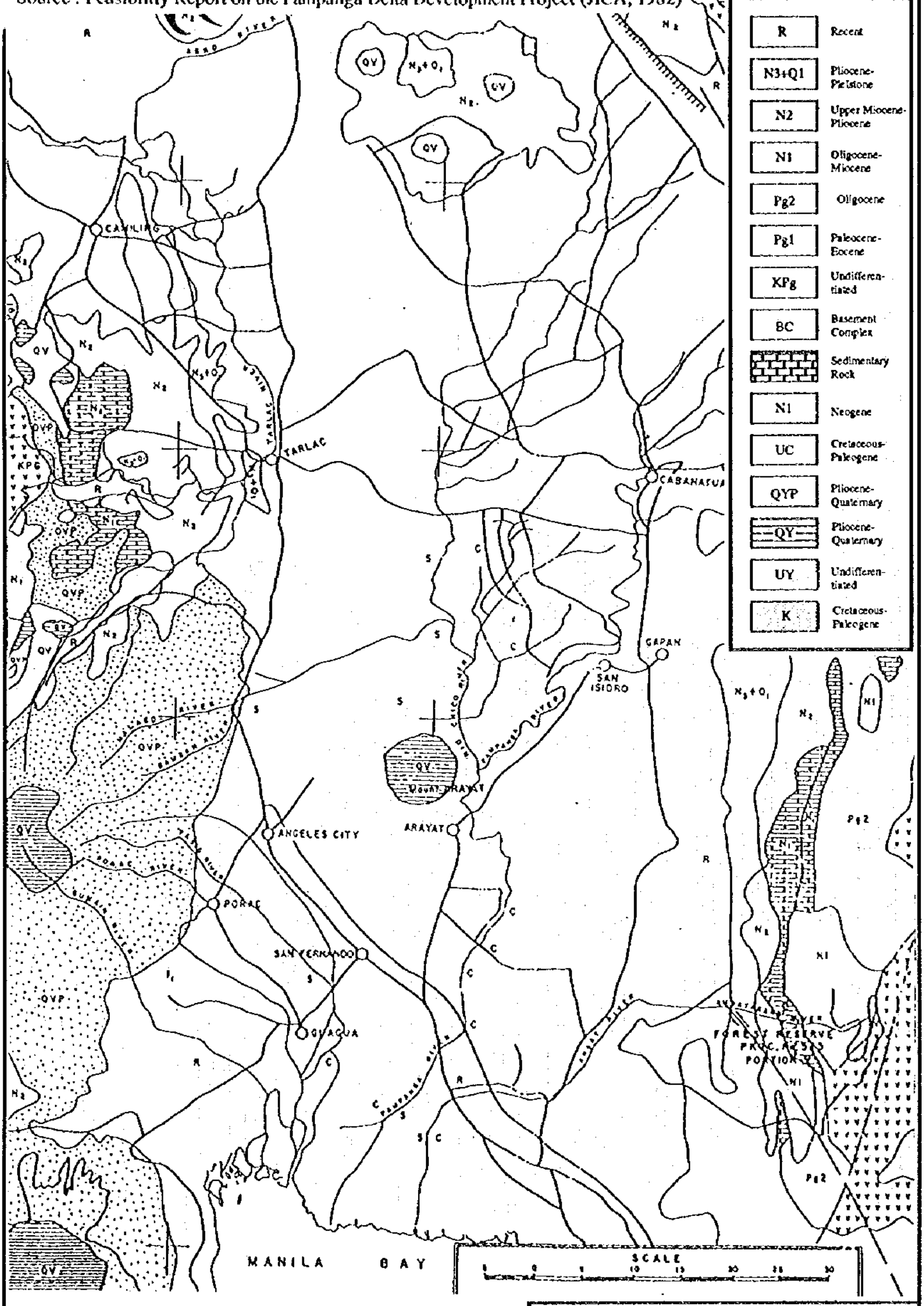
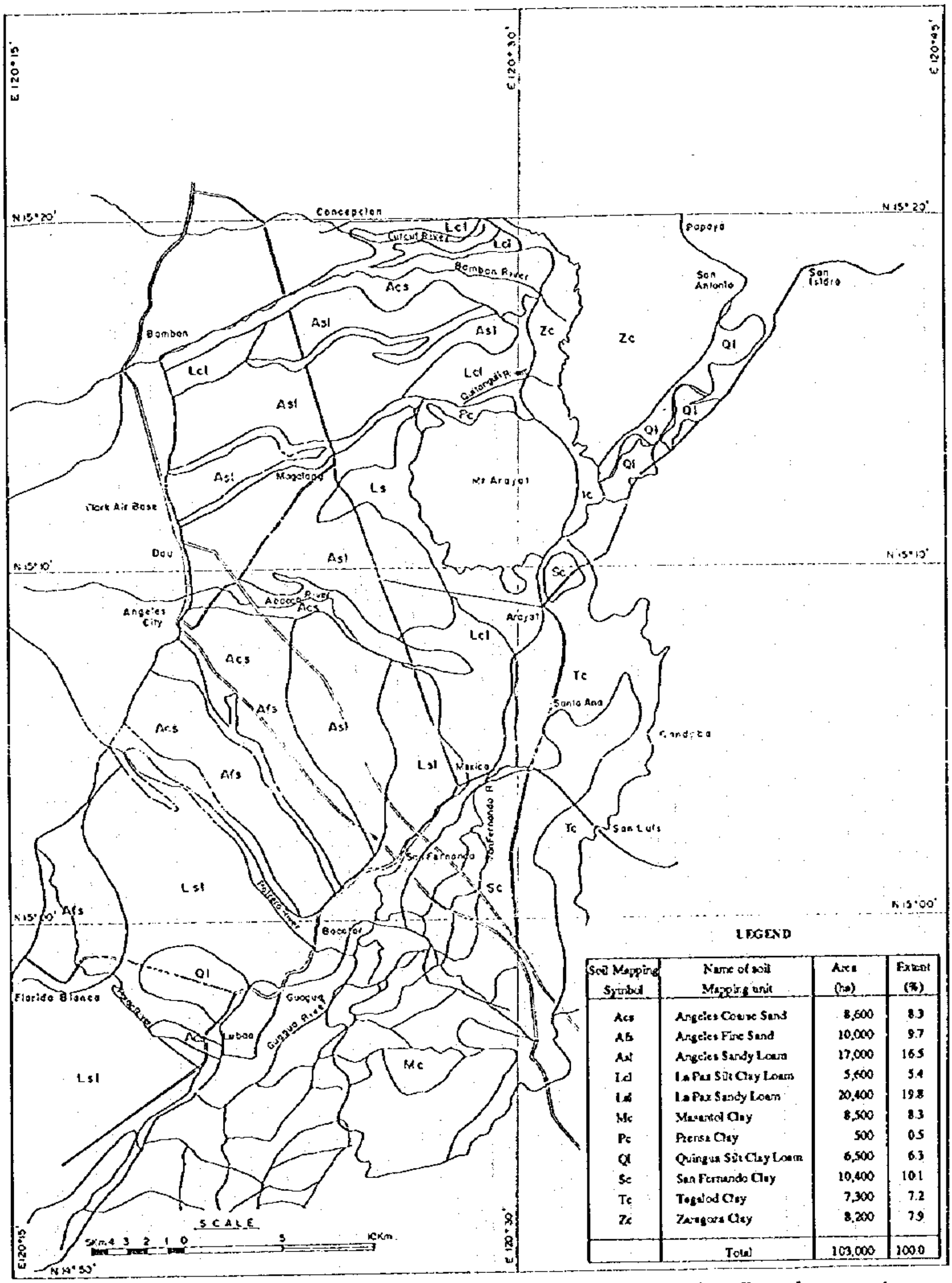


Figure 2.1
Geological Map in the Study Area

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



Soil Mapping Symbol	Name of soil Mapping unit	Area (ha)	Extent (%)
Acs	Angeles Course Sand	8,600	8.3
Afs	Angeles Fine Sand	10,000	9.7
Asl	Angeles Sandy Loam	17,000	16.5
Lcl	La Paz Silt Clay Loam	5,600	5.4
Lsl	La Paz Sandy Loam	20,400	19.8
Mc	Masantol Clay	8,500	8.3
Pc	Prensa Clay	500	0.5
Ql	Quingua Silt Clay Loam	6,500	6.3
Sc	San Fernando Clay	10,400	10.1
Tc	Tagalod Clay	7,300	7.2
Zc	Zaragoza Clay	8,200	7.9
	Total	103,000	100.0

Source : Feasibility Report on the Pampanga Delta Development Project (JICA, 1982)

Figure C.3 Soil Map in the Study 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

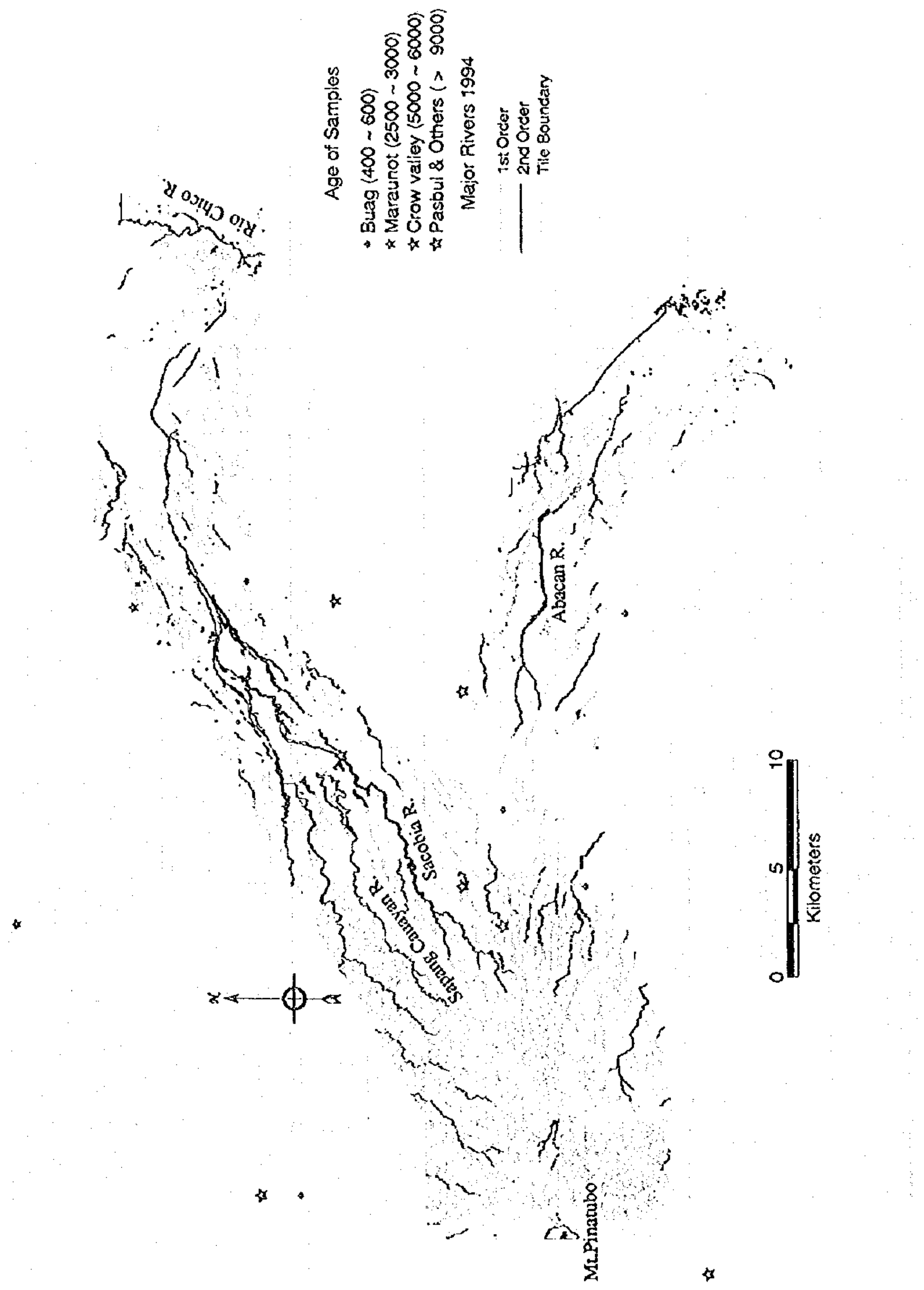
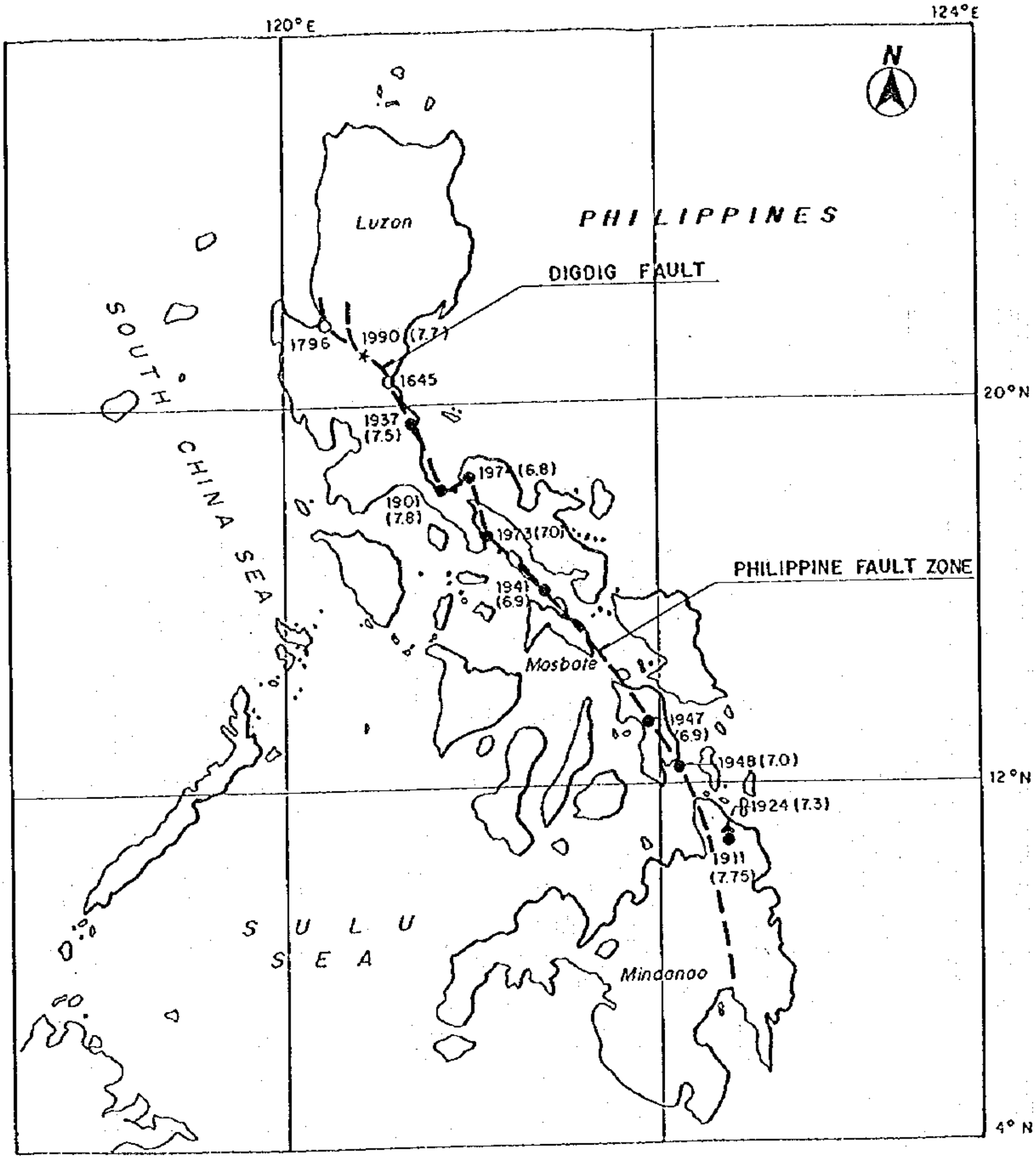


Figure C.4 Radiocarbon Data Sampling Point by USGS/PHIVOLCS

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



LEGEND

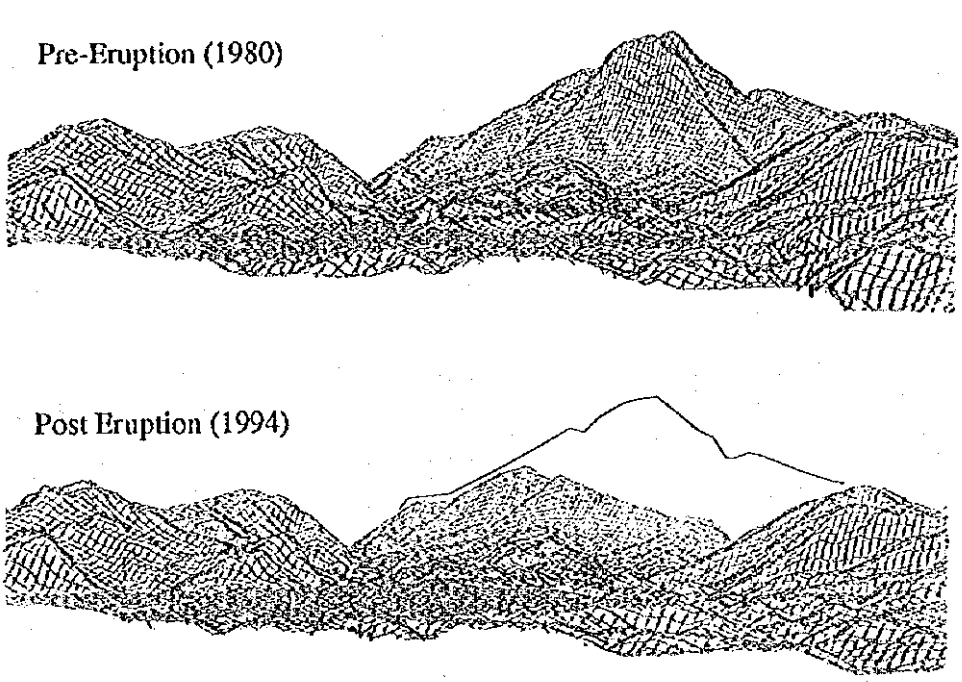
● *Epicenter in 20th Century*
○ *Assumed Epicenter in Historic Earthquake*
★ *Epicenter of 1990*

SCALE :
0 300Km

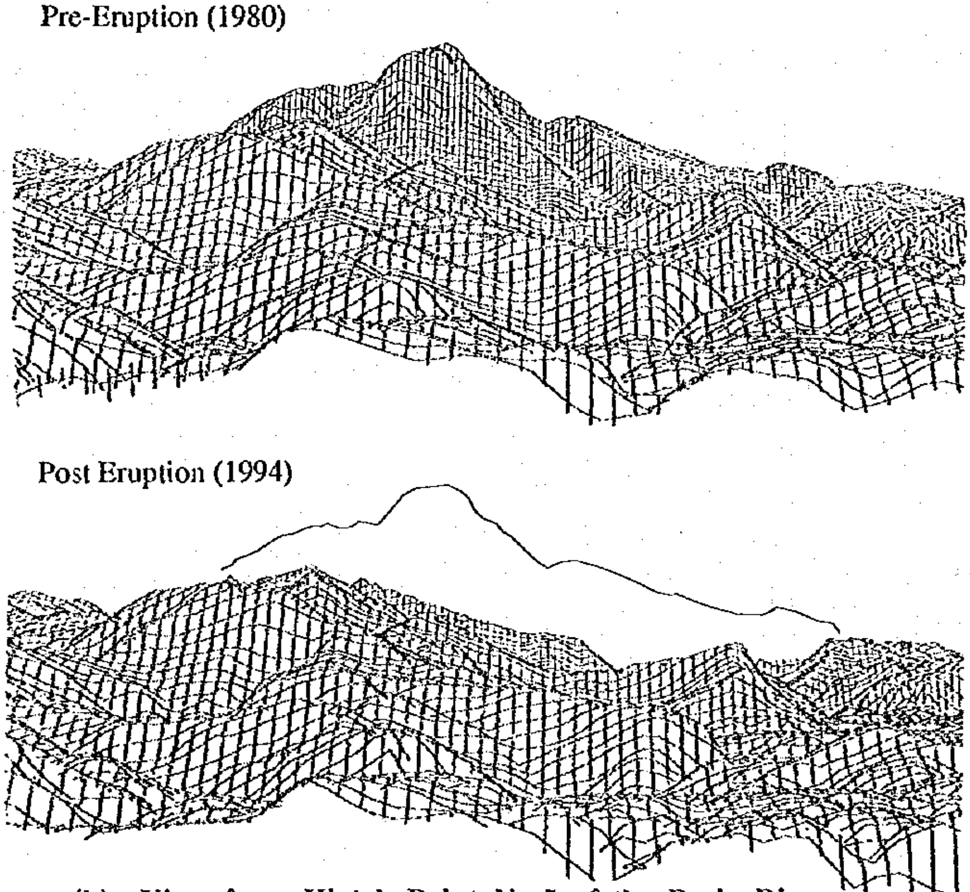
Source : T.Nakata, H.Tsutsumi, R.Punongbayan, "A Preliminary Report on the Earthquake Faults associated with Philippine Earthquake of 1990",1990

Figure C.5 Epicenter in Historic Earthquake

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



(a) View from Clark Field



(b) View from Watch Point No.5 of the Pasig River

Figure C.6
Bird's-Eye View of Mt.Pinatubo

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

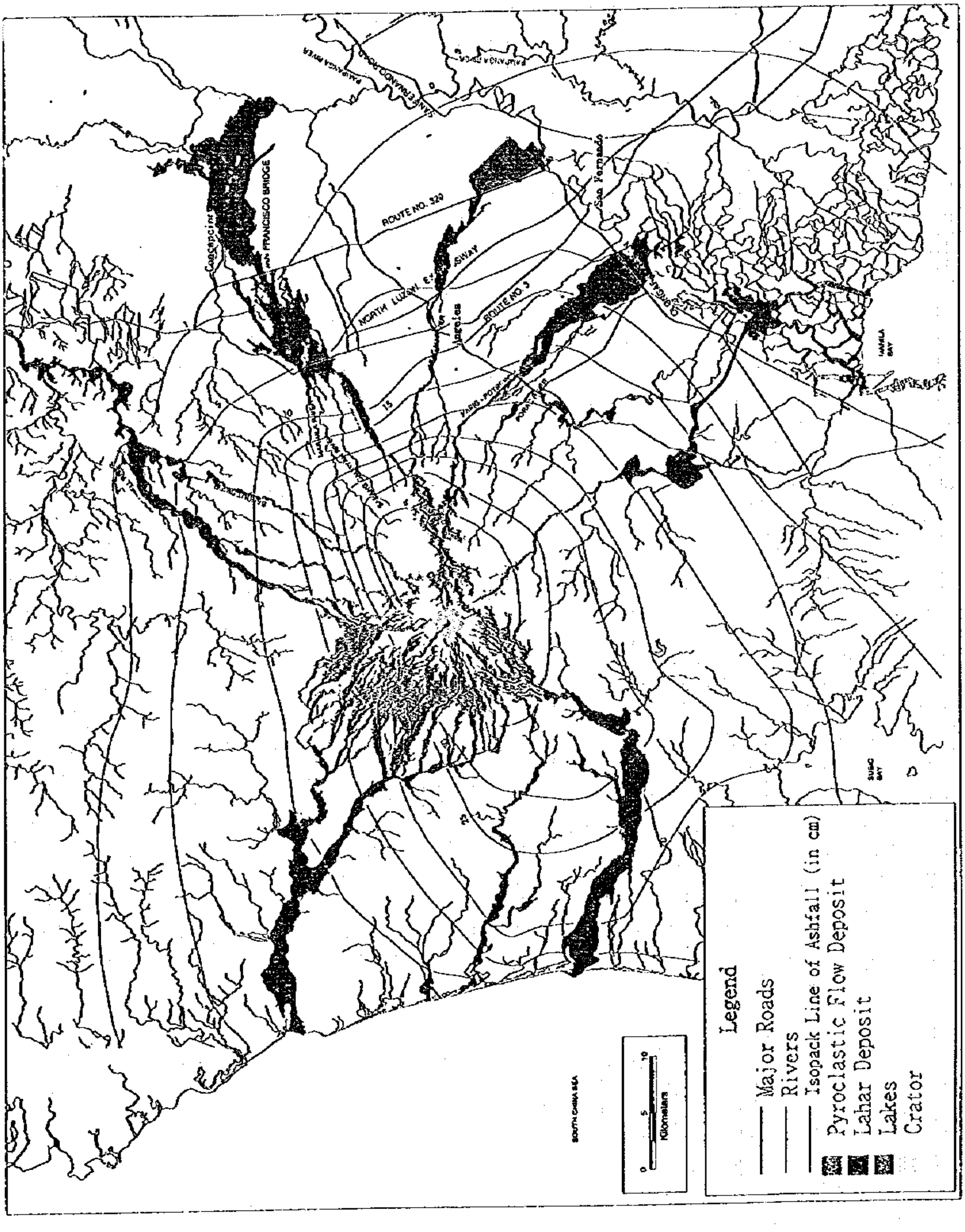
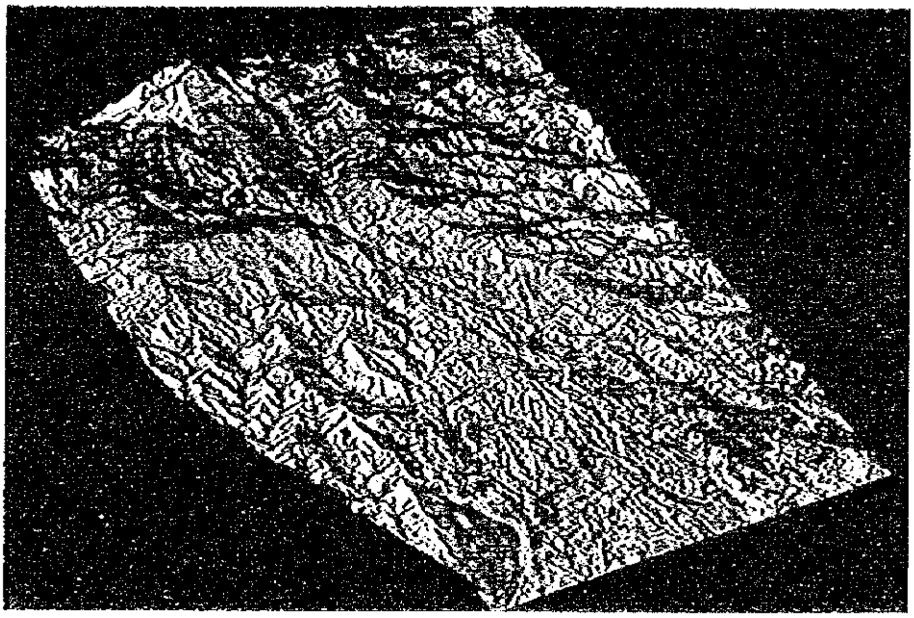


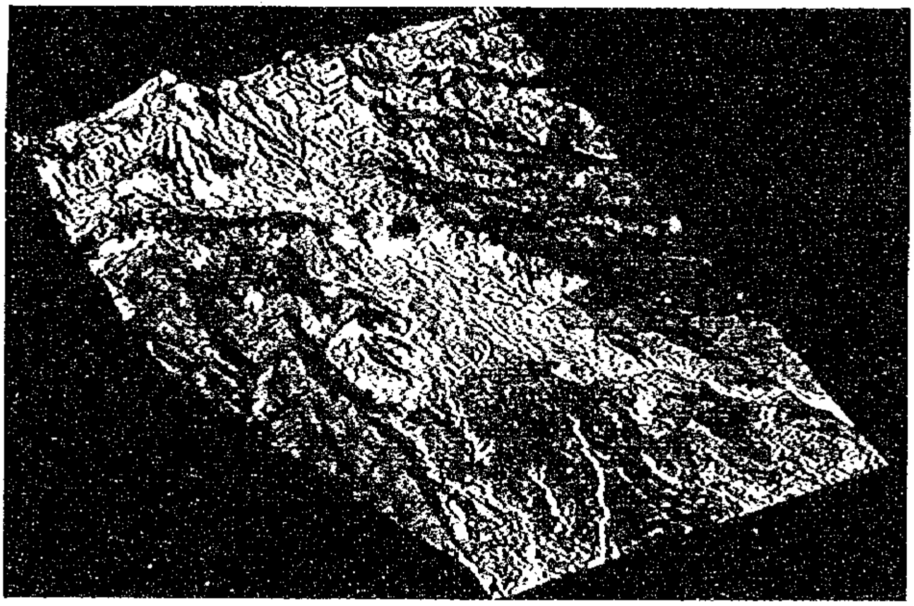
Figure C.7
Pinatubo Volcano Disaster Map

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

Pre-Eruption in 1991



Post Eruption in 1992
(after two rainy season)



Post Eruption in 1994
(after four rainy season)

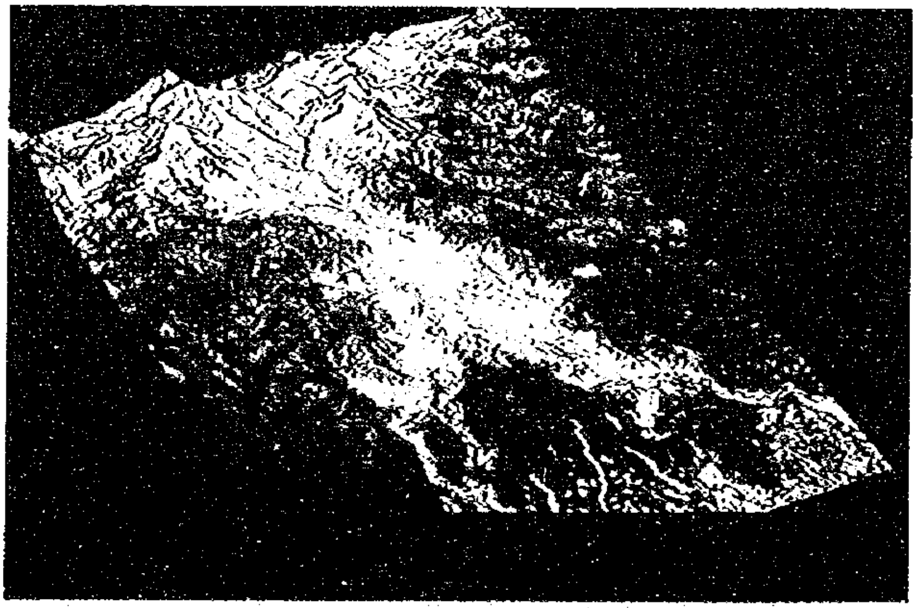


Figure C.8

Bird's-Eye View of Pyroclastic Flow Deposits

JAPAN INTERNATIONAL COOPERATION AGENCY

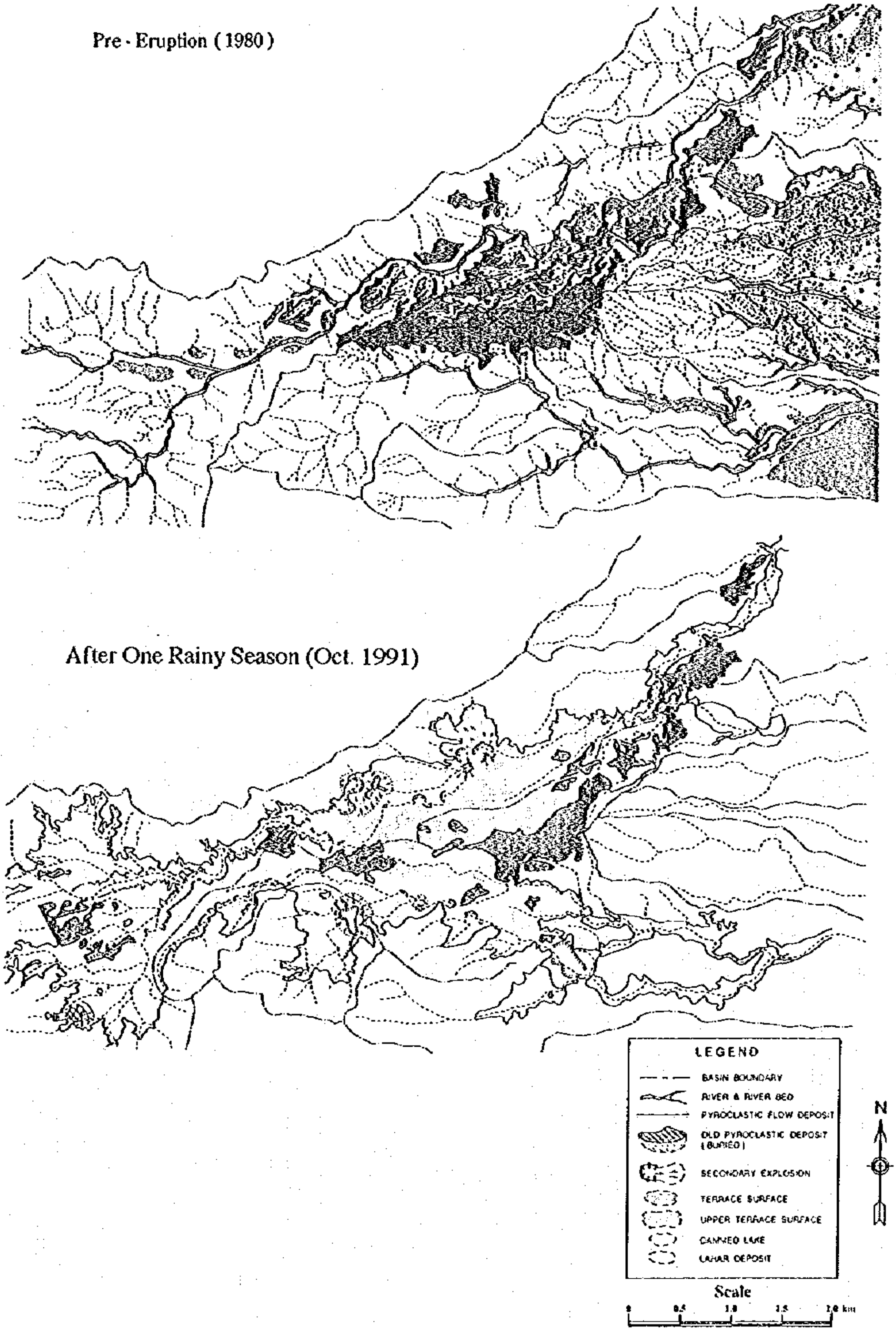


Figure C.9 Geomorphological Map in EPPFF (Pre-Eruption and October 1991)

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

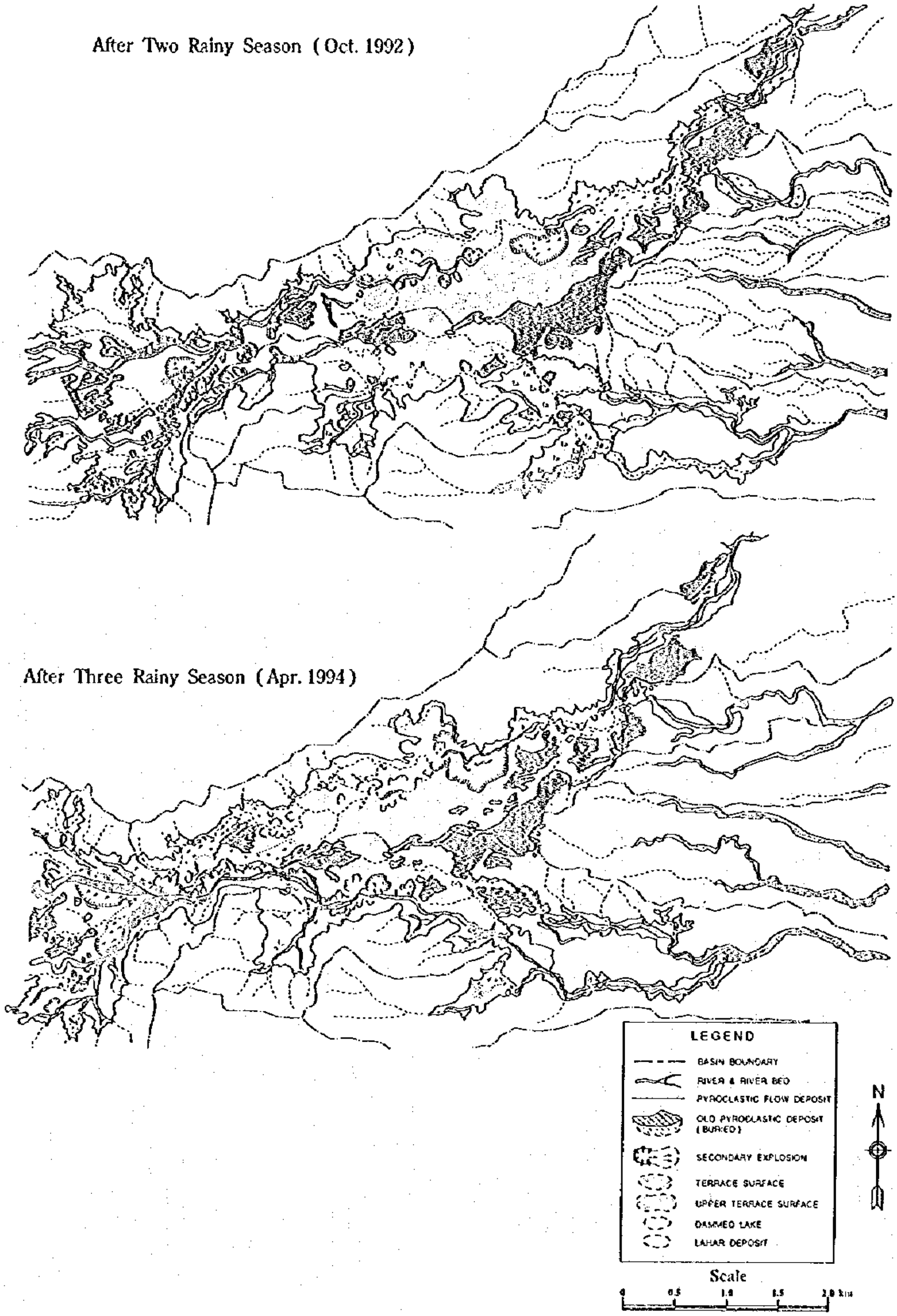
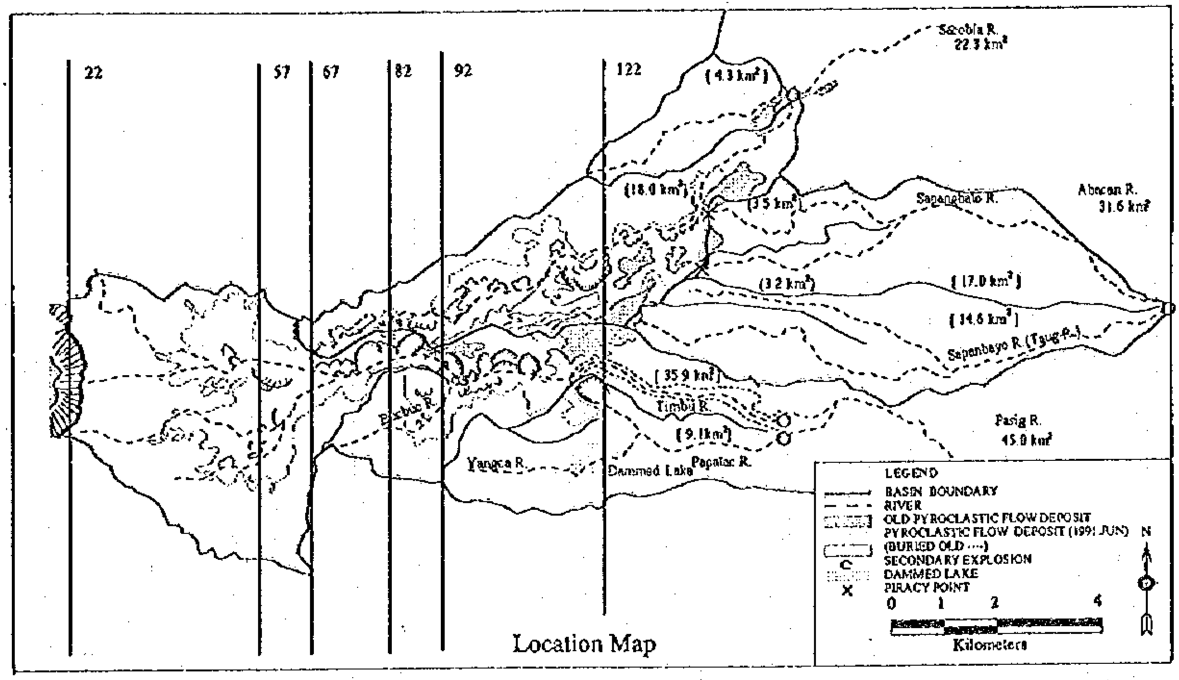
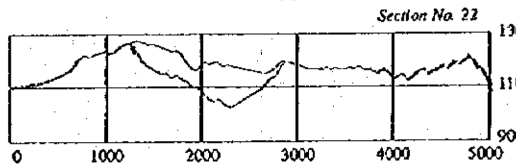


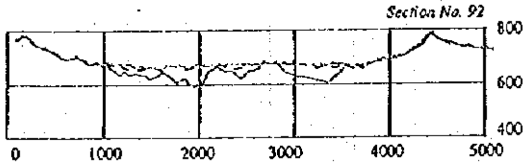
Figure C.10 Geomorphological Map in EPPFF (October 1992 and April 1994)

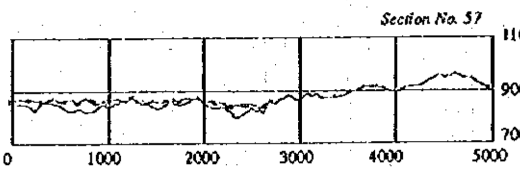
THE GOVERNMENT OF THE PHILIPPINES   THE DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS
THE STUDY ON FLOOD AND MUDFLOW CONTROL FOR SACOBIA-BAMBAN/ABACAN RIVER DRAINING FROM MT.PINATUBO
JAPAN INTERNATIONAL COOPERATION AGENCY

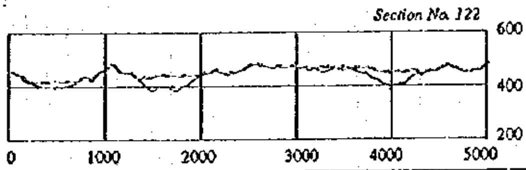


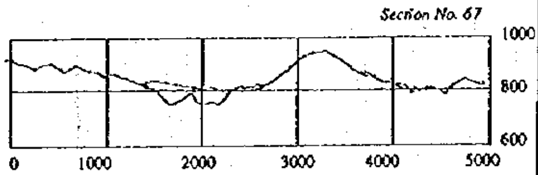
Typical Cross Section Data (distance in meters)

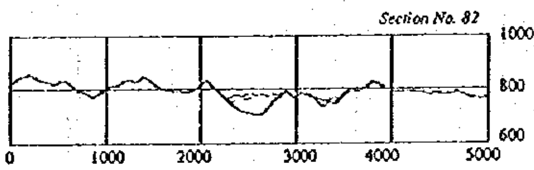












Legend :
( ) Section Number
Before Eruption (1980)
After 2 Rainy Seasons (1992 Oct.)
After 3 Rainy seasons (1994 Apr.)

Comments : The analysis was performed using the GIS database created by JICA Study Team from the DTM for 1980, 1992 and 1994 with a contour interval of 5m mapped to scale of 1:10000 from Aerial Photographs of varying scales. The data has been modelled with a spatial resolution of 10m. The volume analysis was performed by estimating the area along sections at every 200m near the Crator and every 500m at other locations.. The Pyroclastic flow area was identified by the Team Experts by Aerial Photo Interpretation.

Figure C.11
Geomorphologic Sectional Analysis for Pyroclastic flow Deposits

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

Pyroclastic Flow Deposit Volume in the Eastern Slope of Mt. Pinatubo

River Basin	C.A. (km2)	Pyroclastic Flow Deposit Volume (million m3) and Remaining Ratio (%)								
		1991 June	1991 October		1992 October		1994 March		1994 October	
Sacobia-Abacan		968	768	79%	688	71%	303	31%	295	30%
Sacobia-Abacan upstream	18	550	400	73%	347	63%	303	55%	295	54%
Sacobia-Abacan Uppermost reach	22	418	368	88%	341	82%	Annexed to Pasig River 320	77%	252	60%
Pasig upstream	23	430	380	88%	340	79%	285	66%	223	52%
Pasig		430	380	88%	340	79%	605	141%	475	110%
Total	63	1,398	1,148	82%	1,028	74%	908	65%	770	55%

Piracy

Annual Lahar Delivered Volume in the Eastern Drainage of Mt.Pinatubo

River Basin		Lahar Delivered Volume (million m3)				
		1991	1992	1993	1994	Total
Sacobia-Bamban		150	80	65	8	303
Abacan		50	0	0	0	50
Pasig		50	40	55	130	275
TOTAL		250	120	120	138	628

Comments: The Pyroclastic Deposit volume for 1994 March was estimated using the GIS database created from the DTM for 1991,1992, 1994 with a contour interval of 5m mapped to a scale of 1:10,000 from Aerial photographs. The Sacobia uppermost stream was annexed to the Pasig in 1993 October.
Lahar deposition volumes are based on PHIVOLCS for 1991 to 1993 and JICA for 1994.

Variation of Annual Pyroclastic Flow and Lahar Deposits

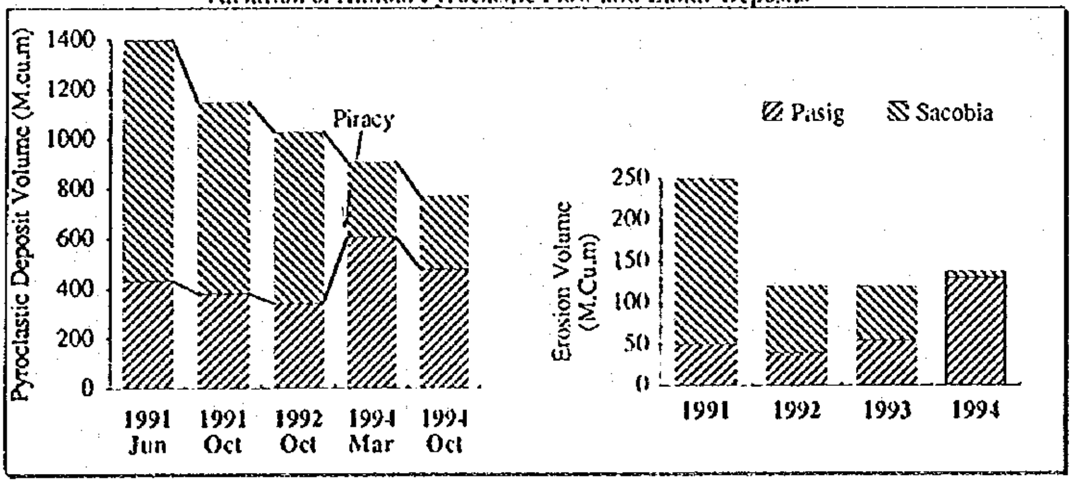


Figure C.12 Pyroclastic Flow Deposits and Lahar Delivered Volumes

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

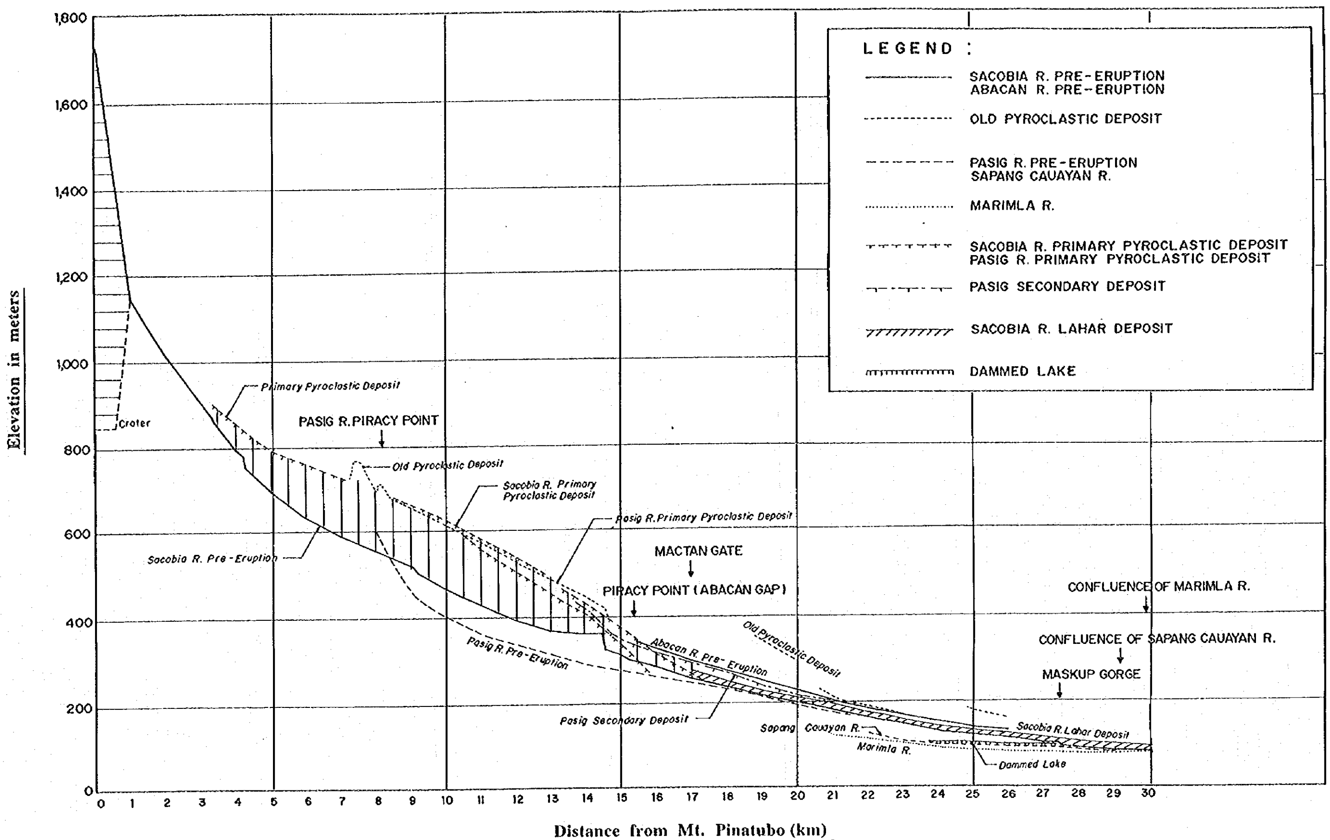


Figure C.13

Longitudinal Riverbed Profile in Sacobia and Abacan Rivers

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

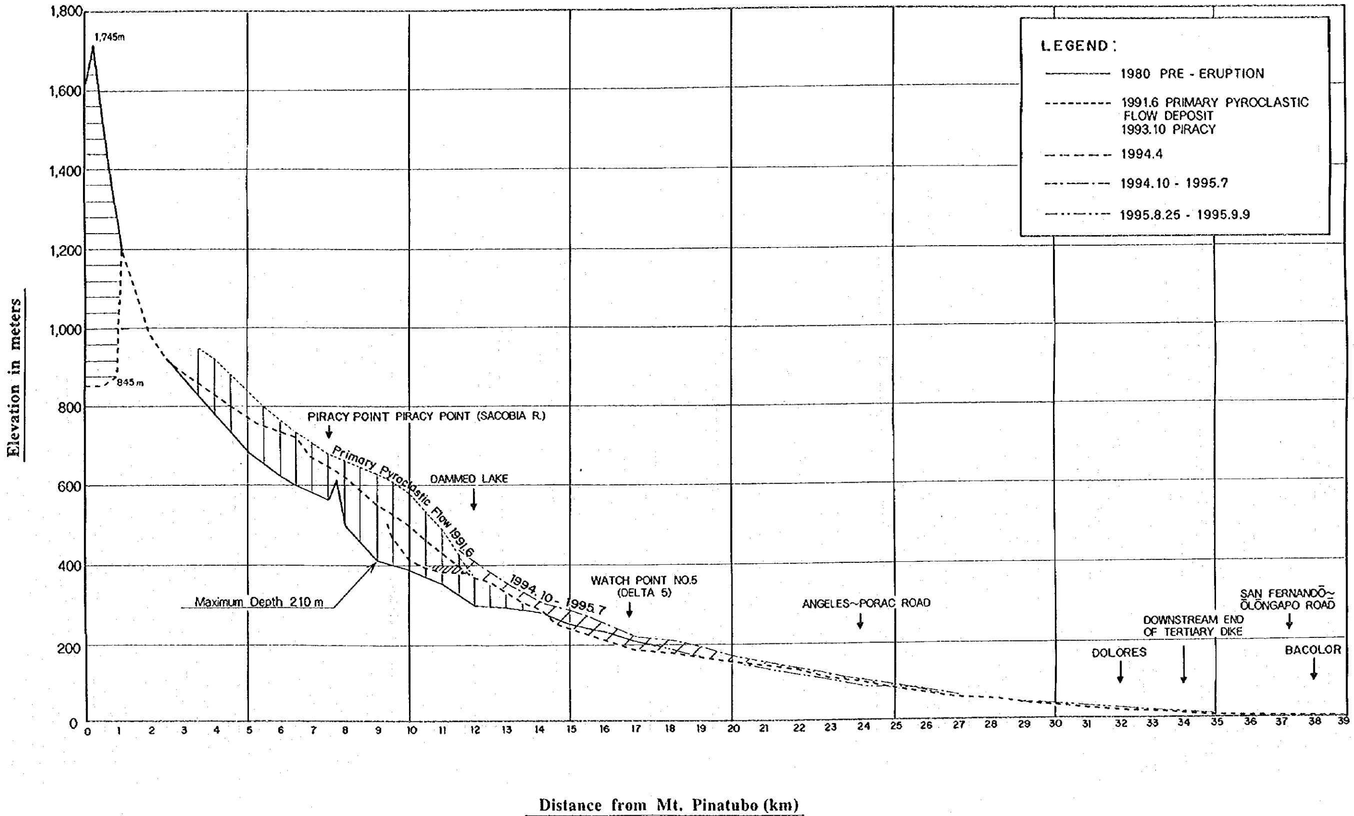


Figure C.14
Longitudinal Riverbed Profile in Pasig River

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
JAPAN INTERNATIONAL COOPERATION AGENCY

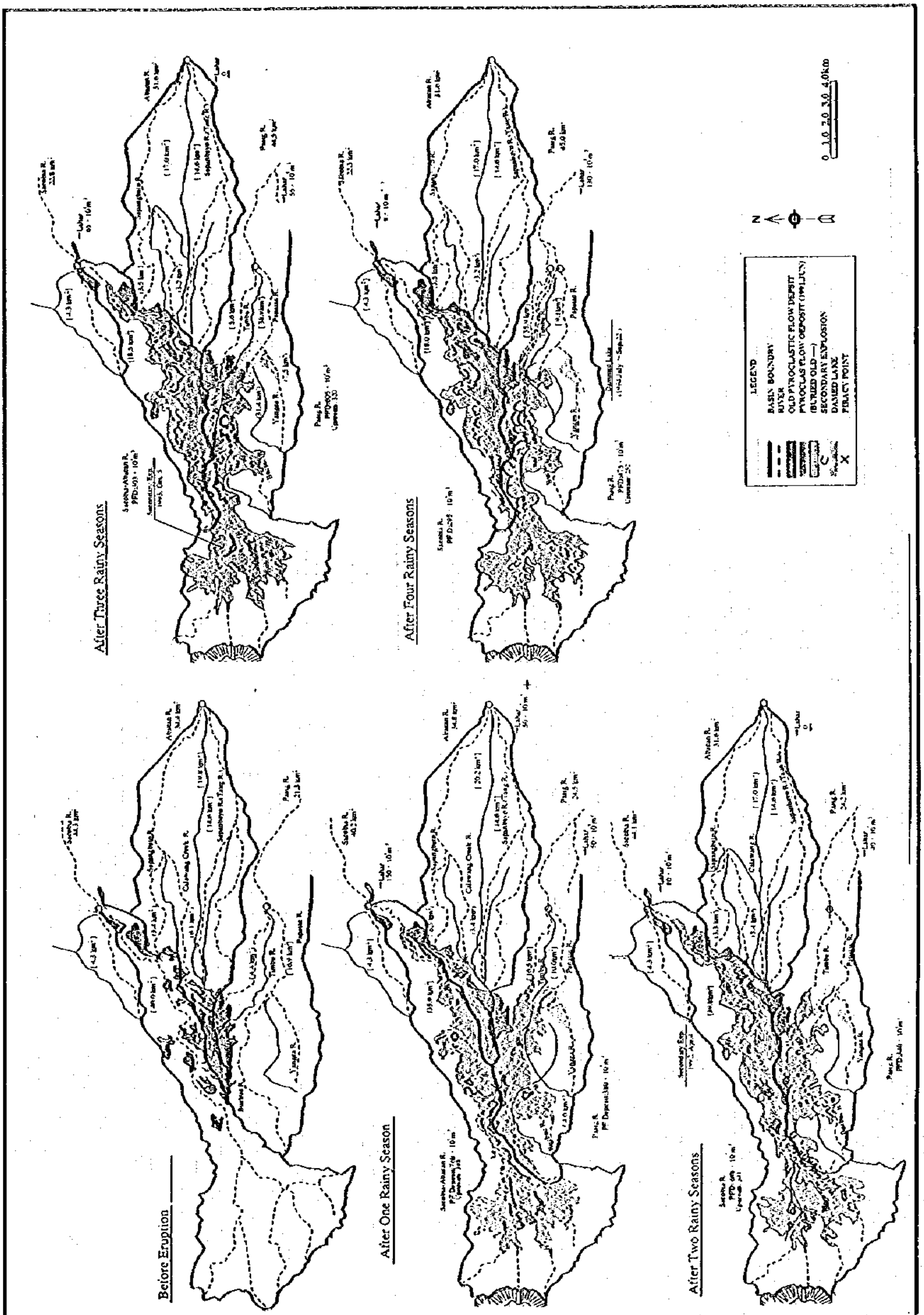


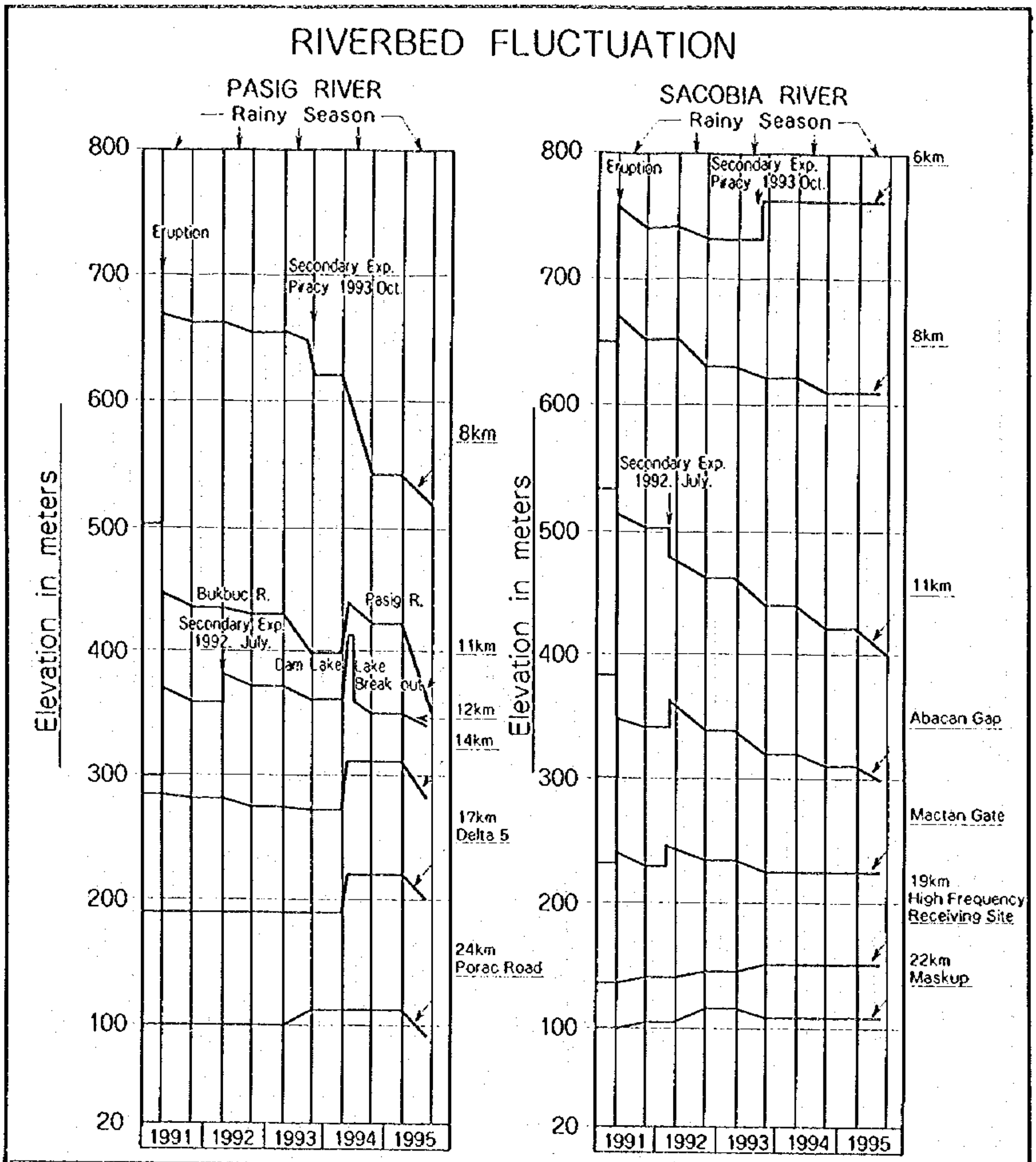
Figure C.15

Chronogical Changes of Catchment Areas

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



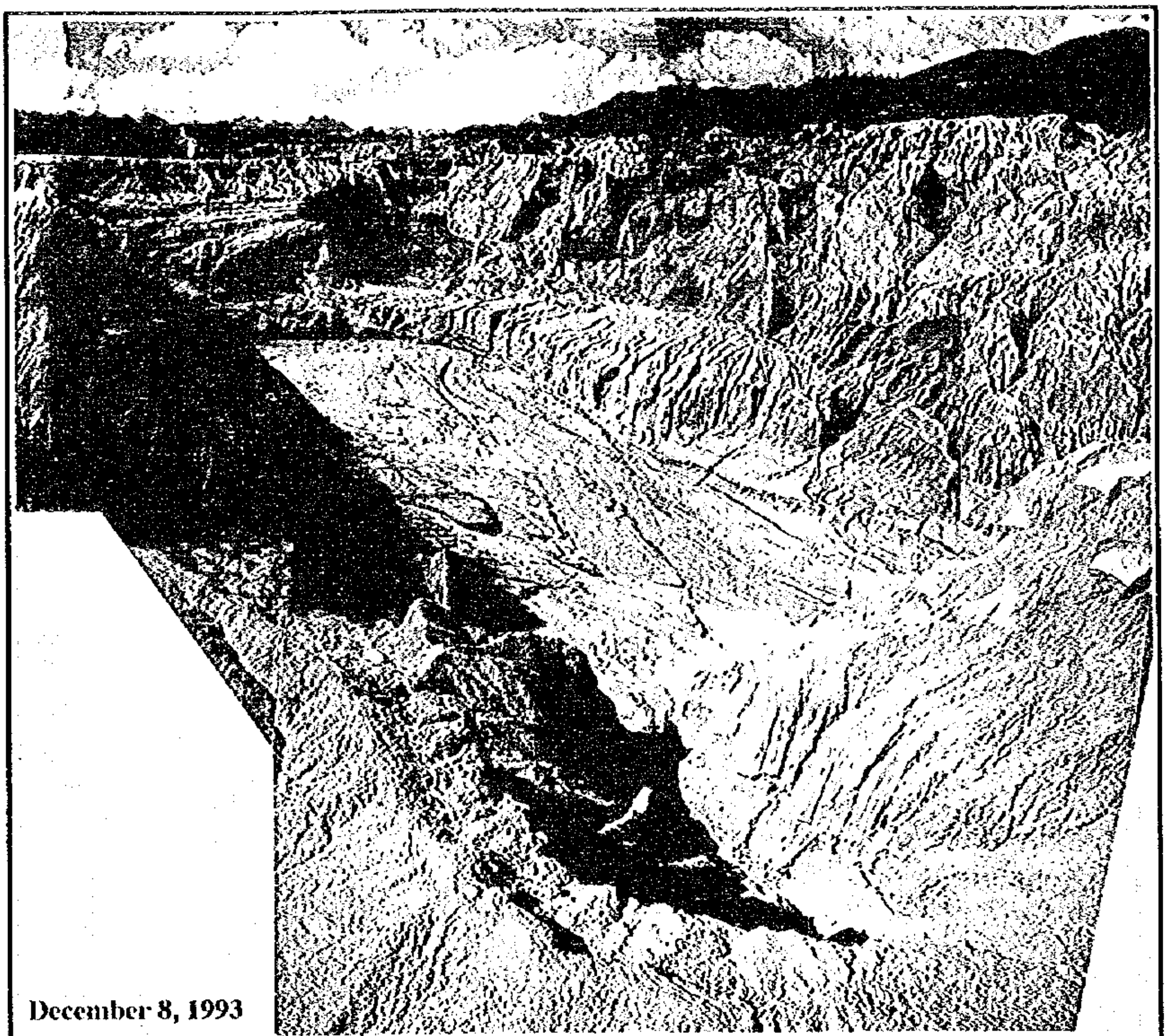
Pasig River											
Pyroclastic Flow Deposit Volume (million m³)	450		400		360		725		595		550
Sediment Volume at Delta 5 (million m³)		50		40		55		130		45	
Drainage Area at Delta 5 (Km²)	21.3		24.5		24.2		44.5		45.0		

Sacobia River											
Pyroclastic Flow Deposit Volume (million m³)	1150		950		870		385		377		373
Sediment Volume in Sacobia River (million m³)		150		80		65		8		4	
Sediment Volume in Abacan River (million m³)		50		0		0					
Drainage Area at Mactan Gate (km²)	40.0		35.3		38.8		22.8		22.3		22.3

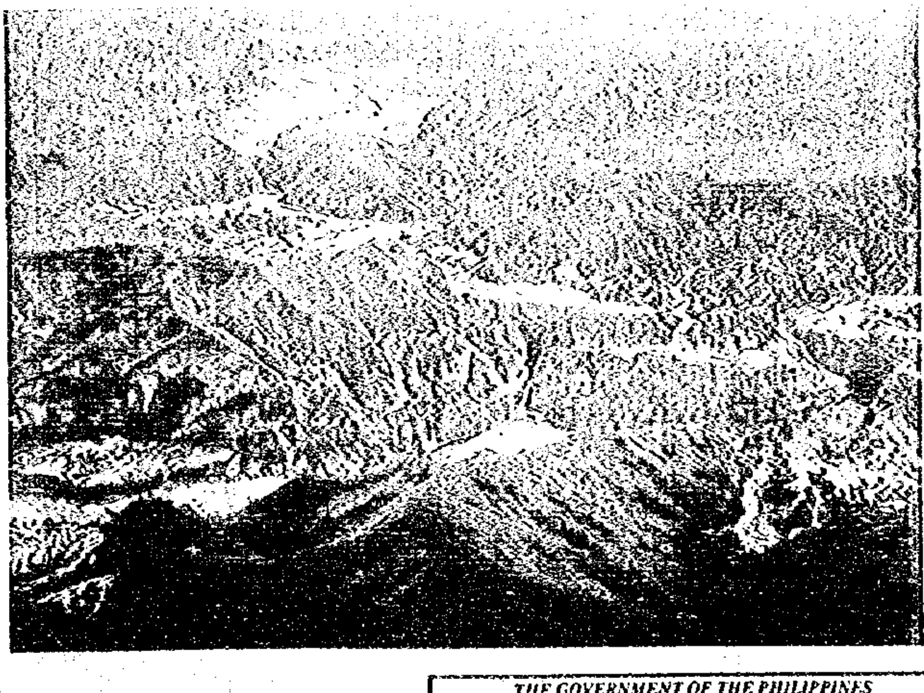
Remarks : Figures in km show the distance from Mt. Pinatubo.

Figure C.16
Chronological Riverbed Fluctuation

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



December 8, 1993



October 28, 1995

Figure C.17 Overview of Abacan Gap

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

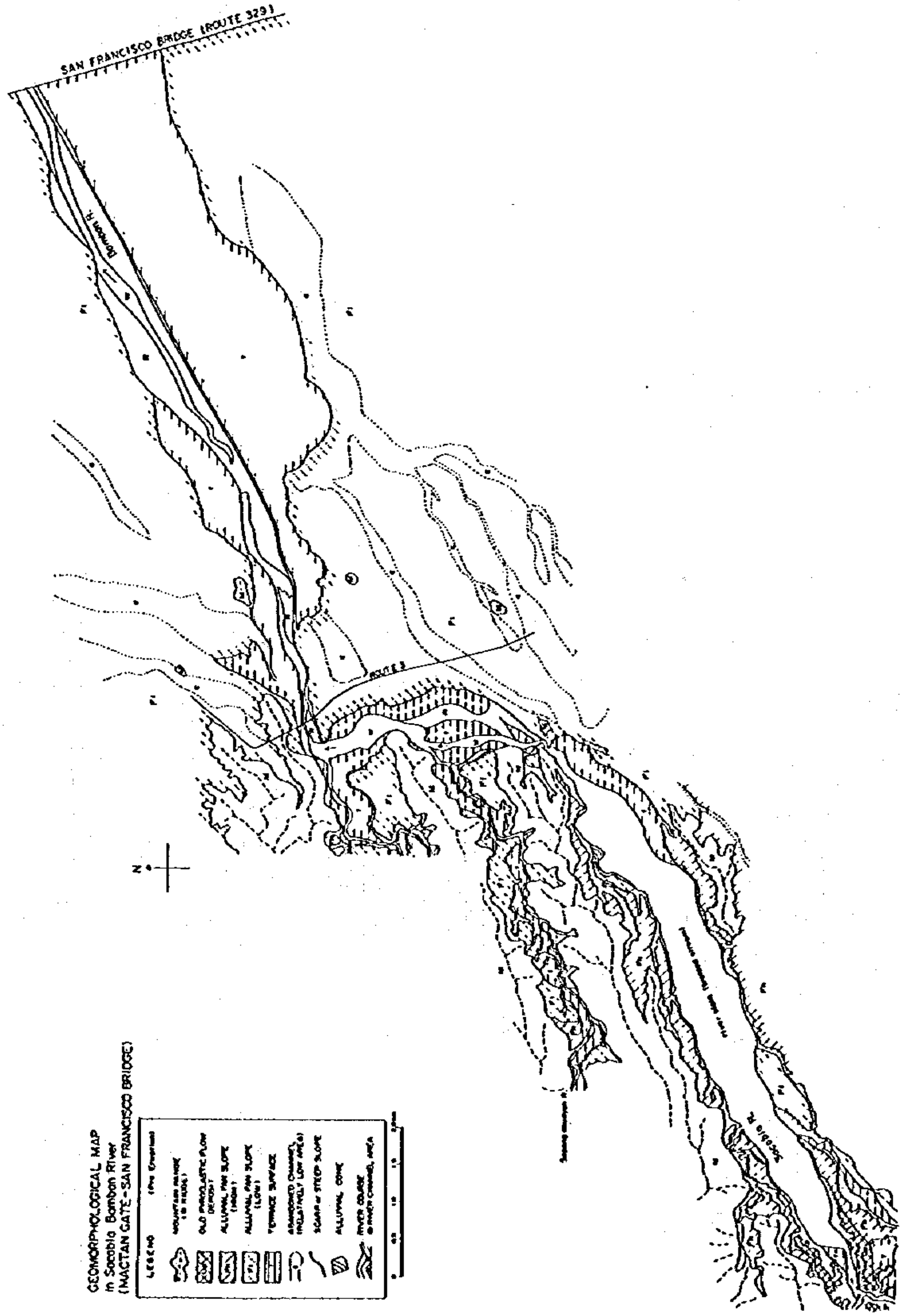


Figure C.18 Geomorphologic Map in Sacobia River (Pre-Eruption, 1980)

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

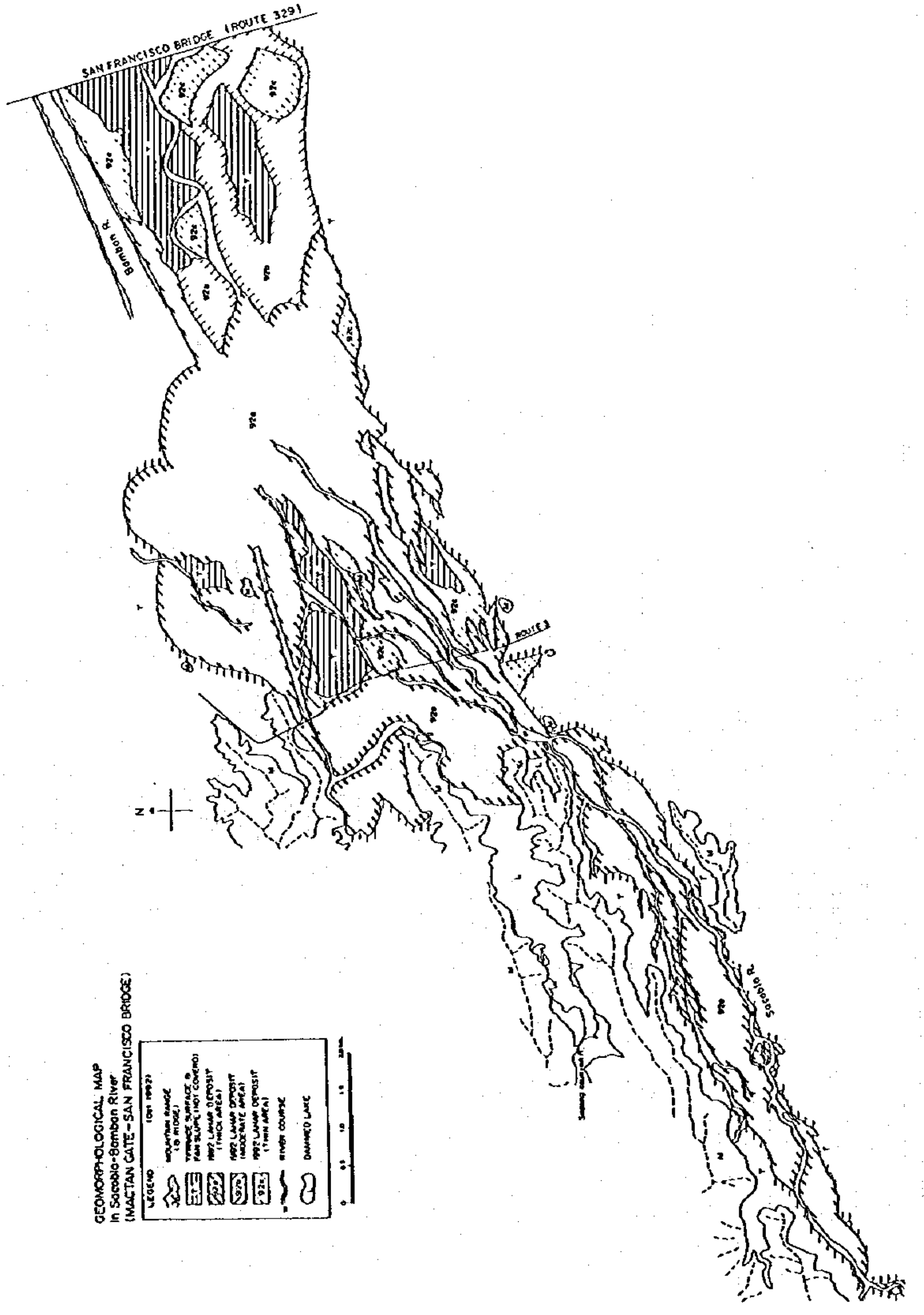


Figure C.19 Geomorphologic Map in Sacobia River (October 1992)

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

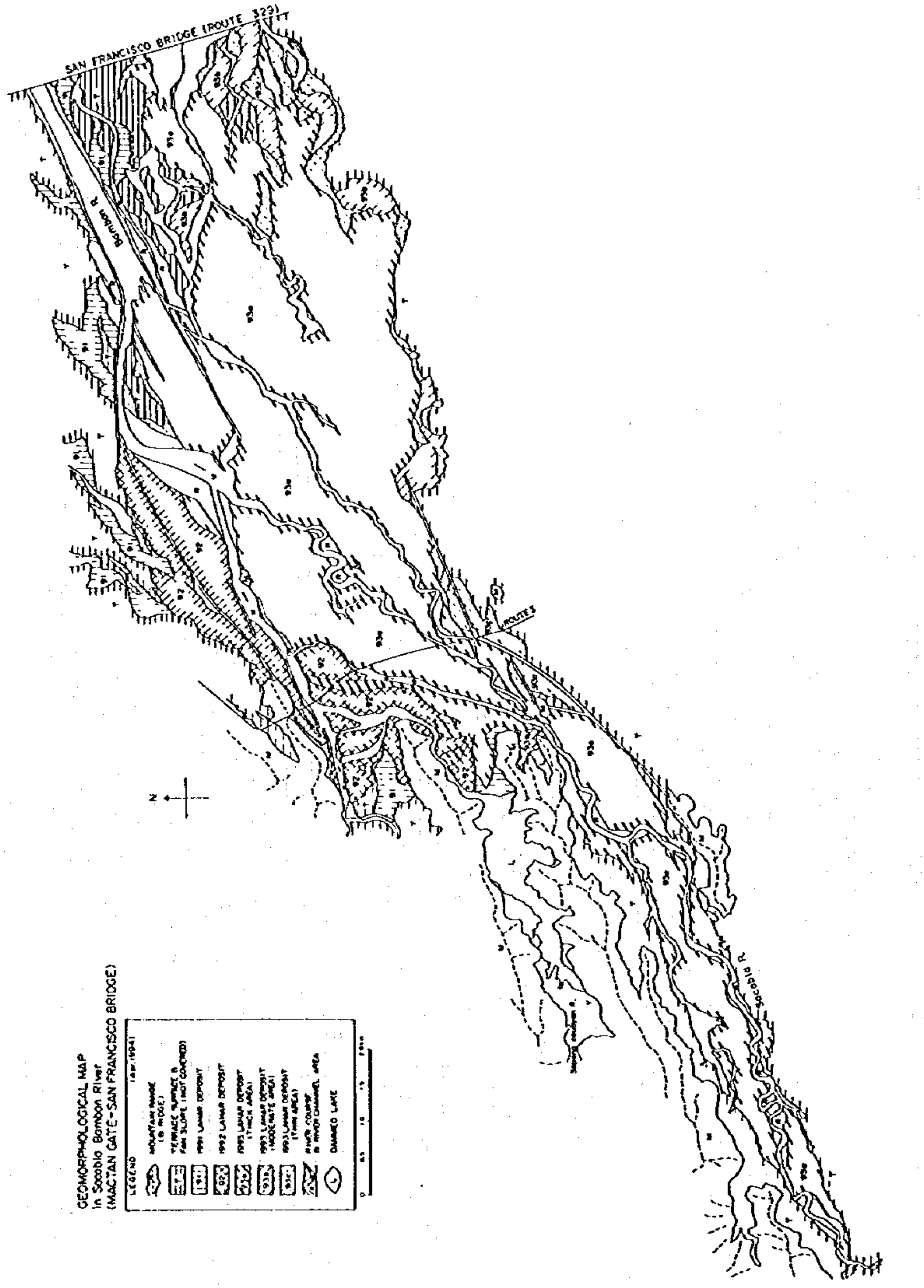


Figure C.20 Geomorphologic Map in Sacobia River (April 1994)

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

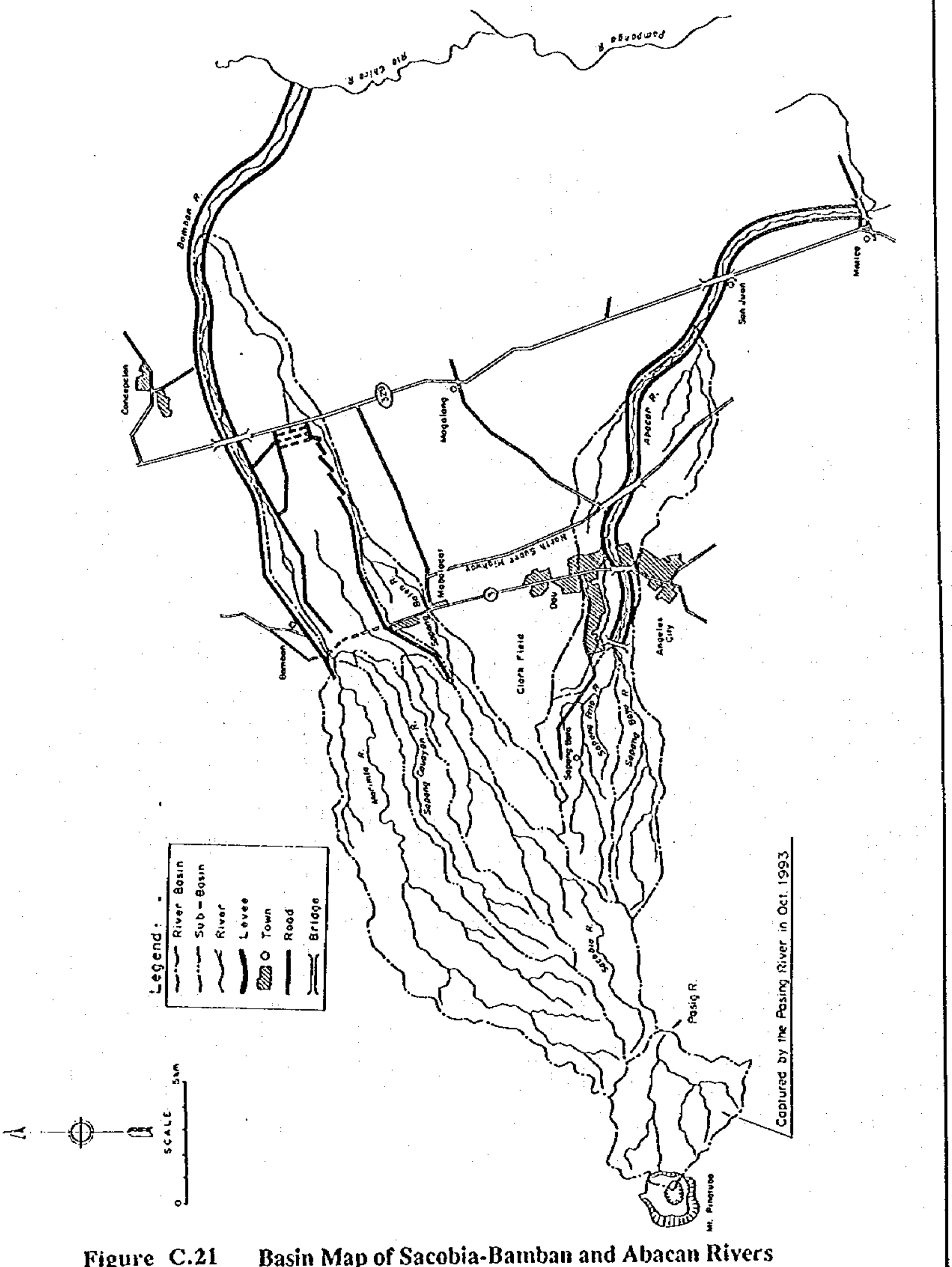


Figure C.21 Basin Map of Sacobia-Bamban and Abacan Rivers

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

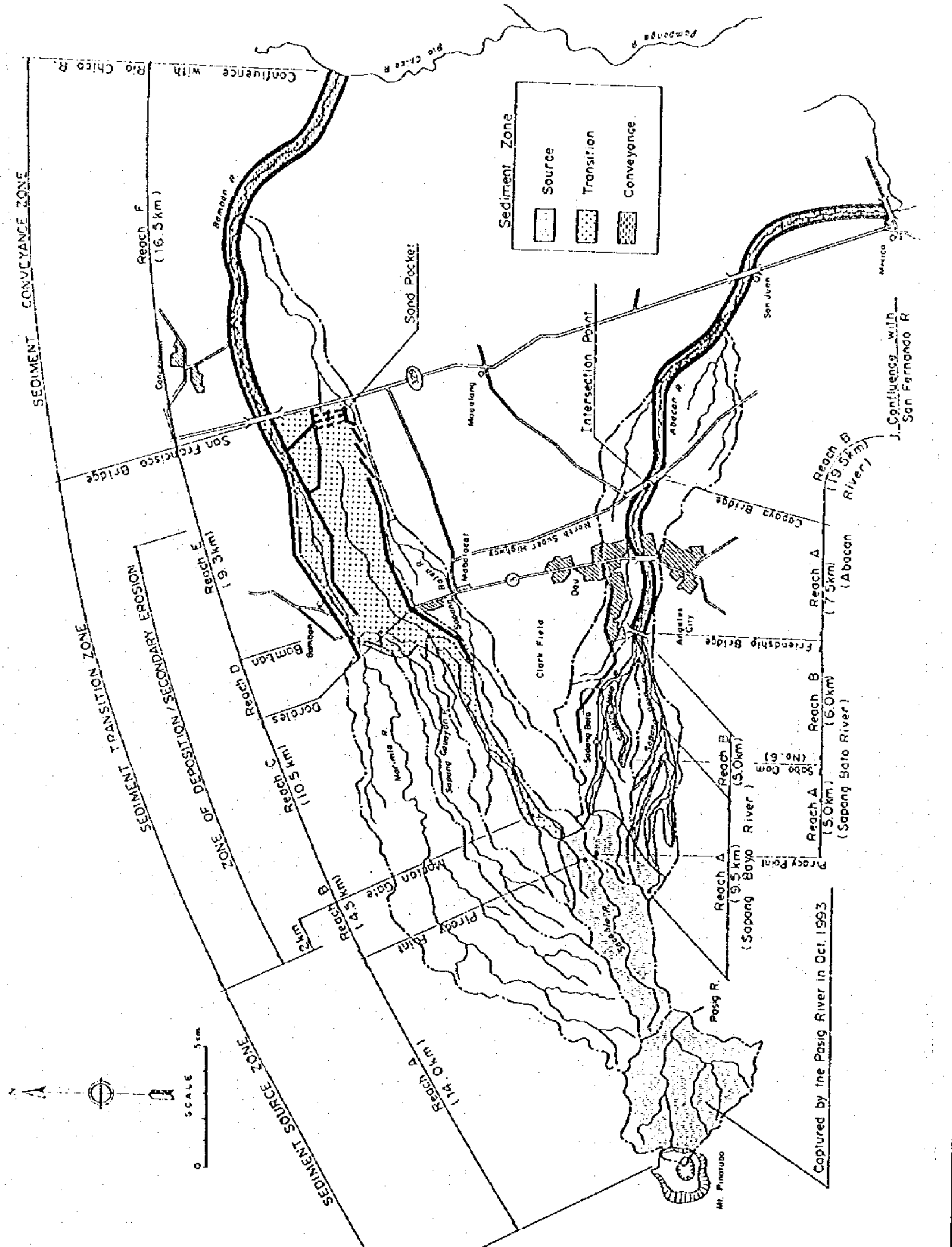


Figure C.22 Sediment Delivery Zone

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

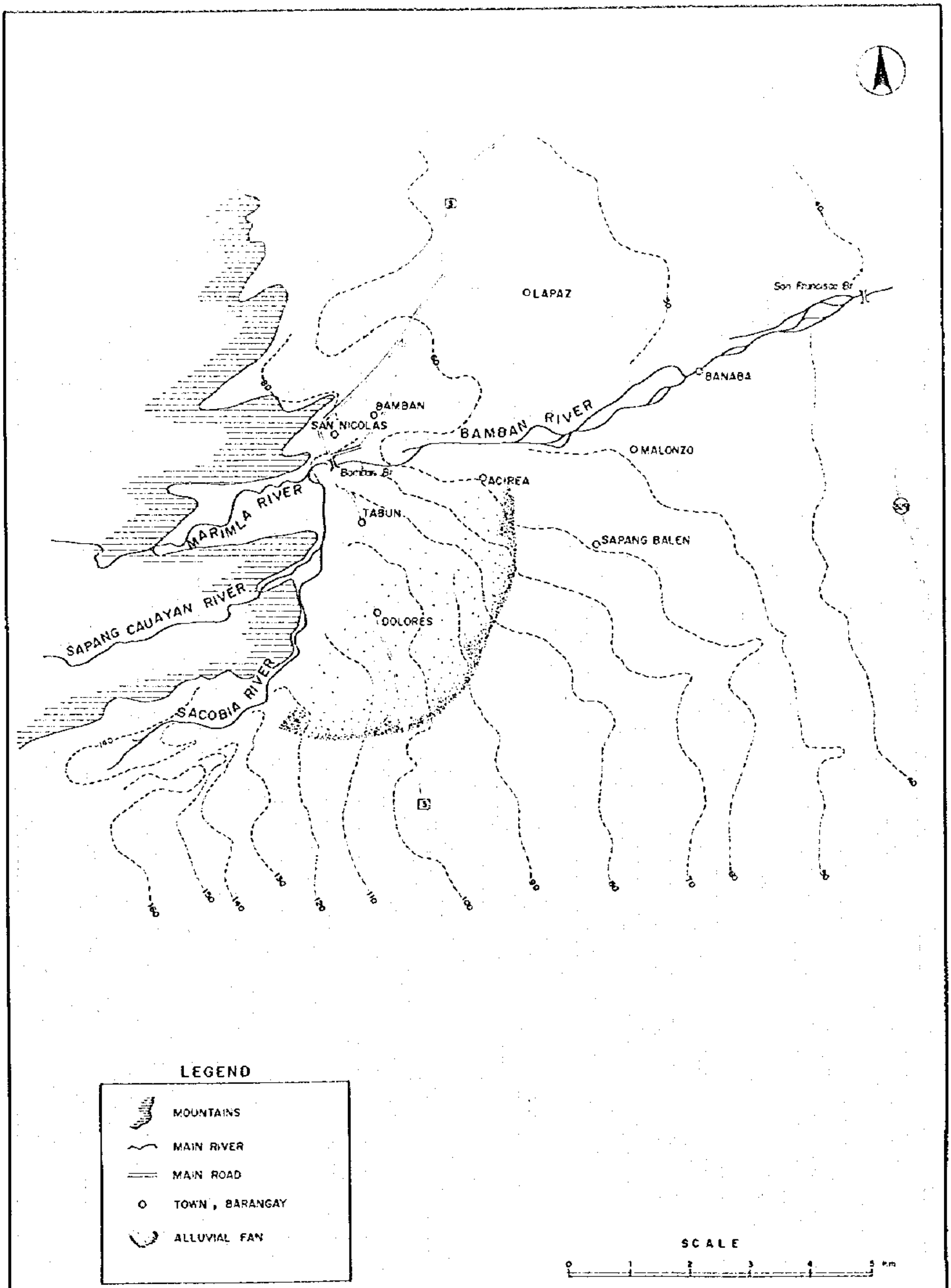


Figure C.23 Development of Alluvial Fan in the Sacobia-Bamban River

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

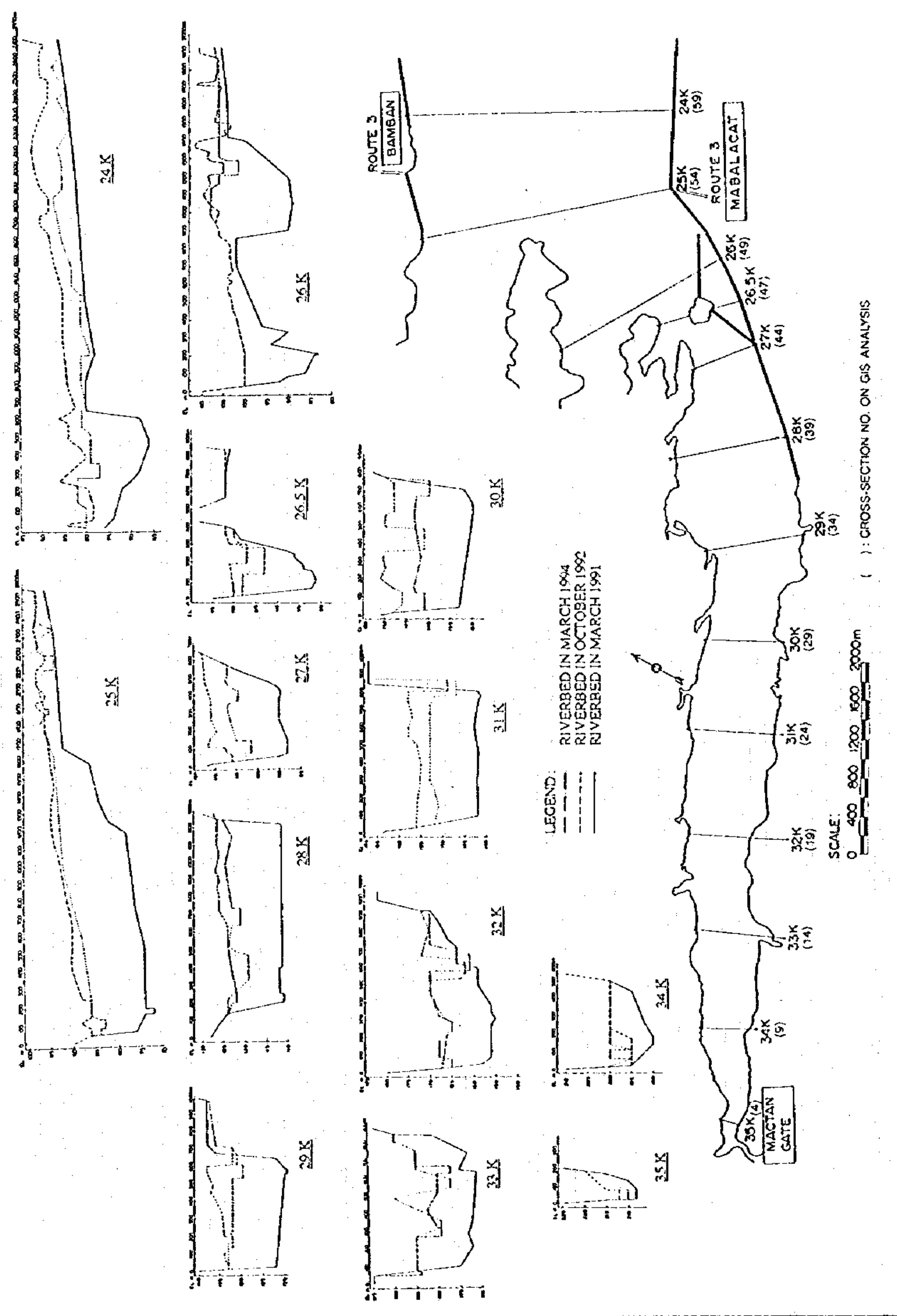
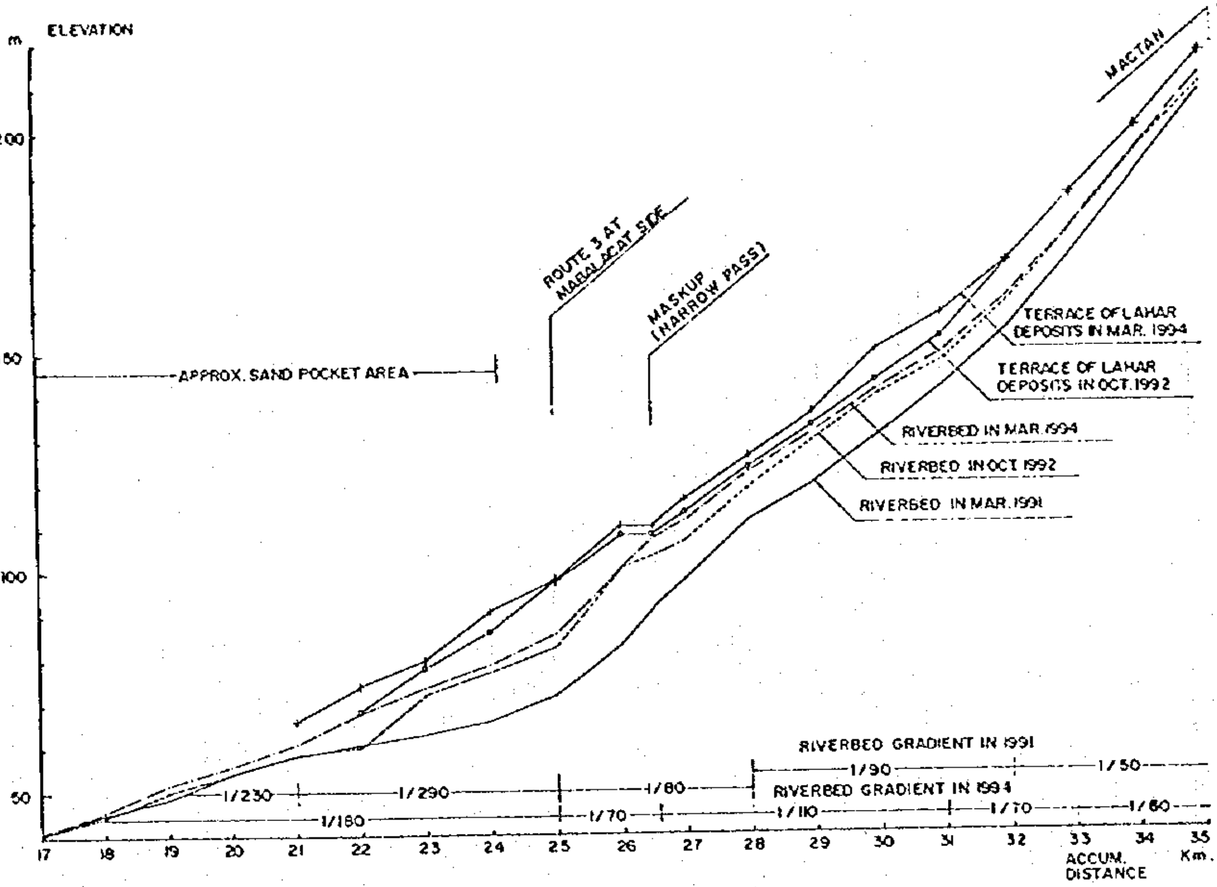


Figure C.24 Cross-Sectional Changes from Mactan to Mabalacat, 1991-1994

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



VOLUME OF SEDIMENT DEPOSITION MACTAN-MASKUP

Section	Distance (m)	Volume of Sediment Deposition (million m3)		
		'91-Oct '92	Oct '92-Mar '94	Total
26.5-27 k	500	3.05	1.44	4.49
27-28 k	1,000	7.53	3.88	11.41
28-29 k	1,000	13.12	5.43	18.55
29-30 k	1,000	6.54	6.14	12.68
30-31 k	1,000	5.55	5.25	10.8
31-32 k	1,000	8.44	2.99	11.43
32-33 k	1,000	6.97	0.81	7.78
33-34 k	1,000	2.62	1.24	3.86
34-35 k	1,000	1.31	1.20	2.51
Total		55.13	28.38	83.51

VOLUME OF SEDIMENT ACCUMULATION

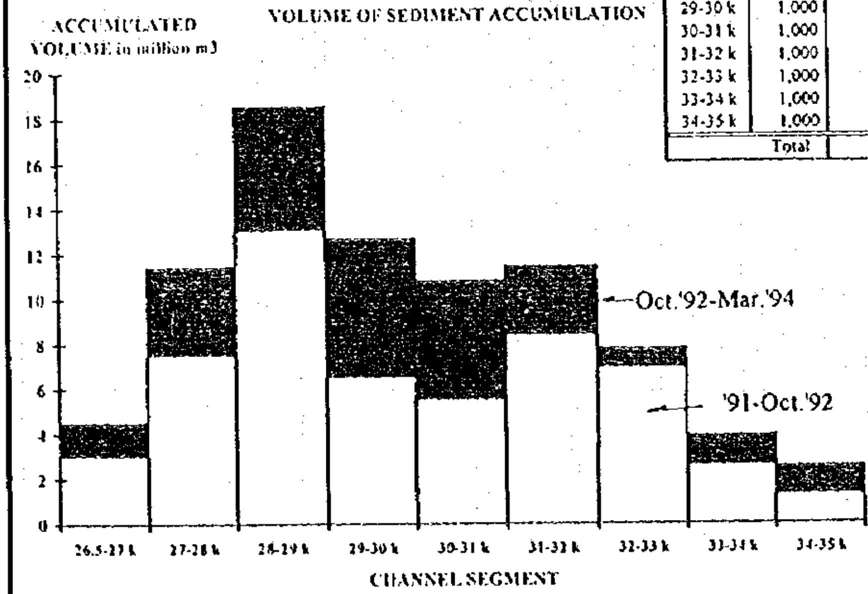
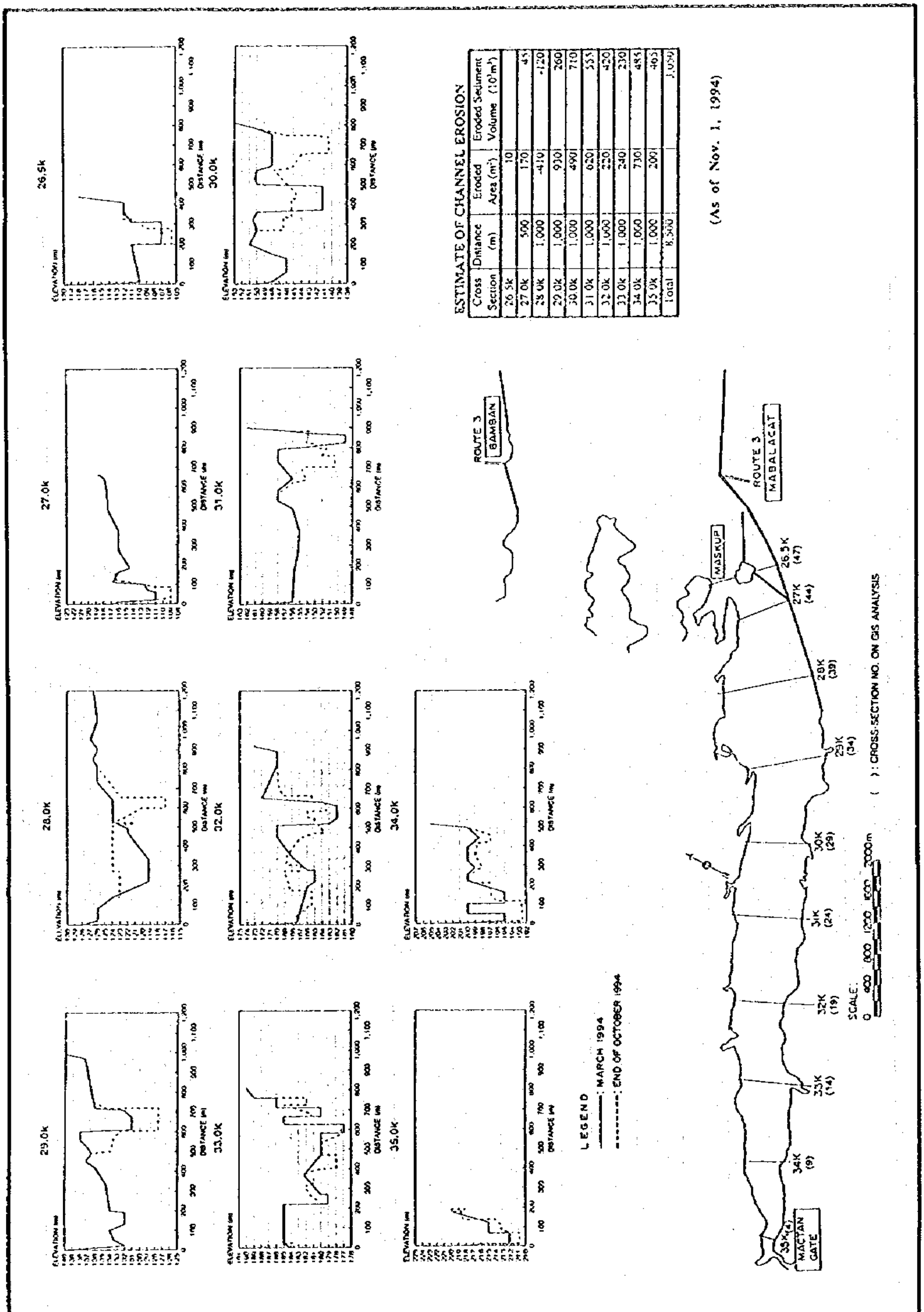


Figure C.25 Longitudinal Profile and Sediment Accumulation from Mactan to Maskup, 1991-1994

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



ESTIMATE OF CHANNEL EROSION

Cross Section	Distance (m)	Eroded Area (m^2)	Eroded Sediment Volume (10^3m^3)
26.5k		10	
27.0k	500	170	45
28.0k	1,000	-410	-120
29.0k	1,000	930	260
30.0k	1,000	490	710
31.0k	1,000	620	555
32.0k	1,000	220	420
33.0k	1,000	240	230
34.0k	1,000	730	485
35.0k	1,000	200	465
Total	8,500		3,050

Figure C.26 Cross-Sectional Changes and Estimated Channel Erosion from Mactan to Maskup in 1994

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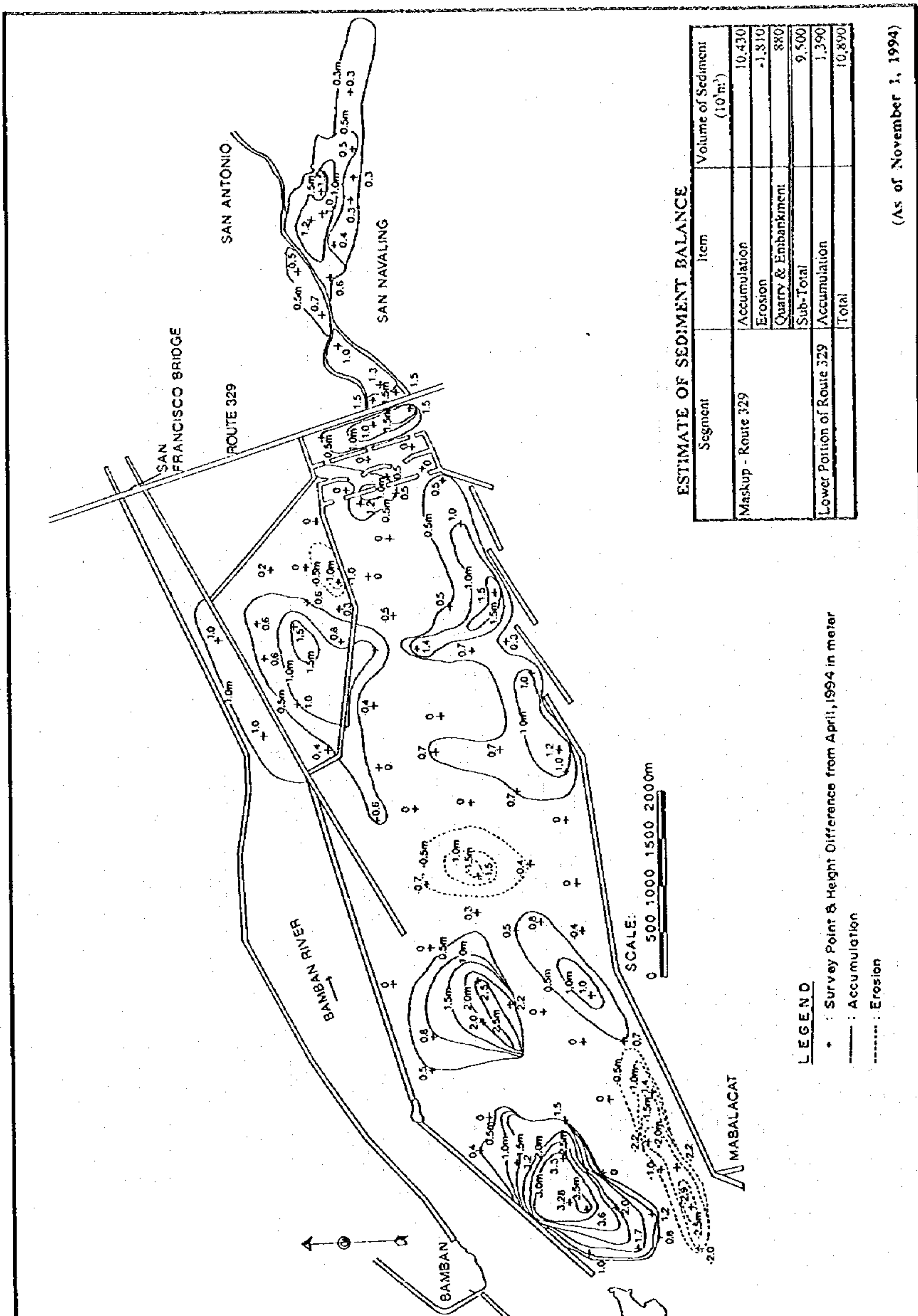

ESTIMATE OF SEDIMENT BALANCE

Segment	Item	Volume of Sediment ($10^3 m^3$)
Maskup - Route 329	Accumulation	10,430
	Erosion	-1,310
	Quarry & Embankment	880
	Sub-Total	9,500
Lower Portion of Route 329	Accumulation	1,390
	Total	10,890

(As of November 1, 1994)

Figure C.27 Isopach Map of Sediment Deposition/Erosion in Lower Sacobia in 1994

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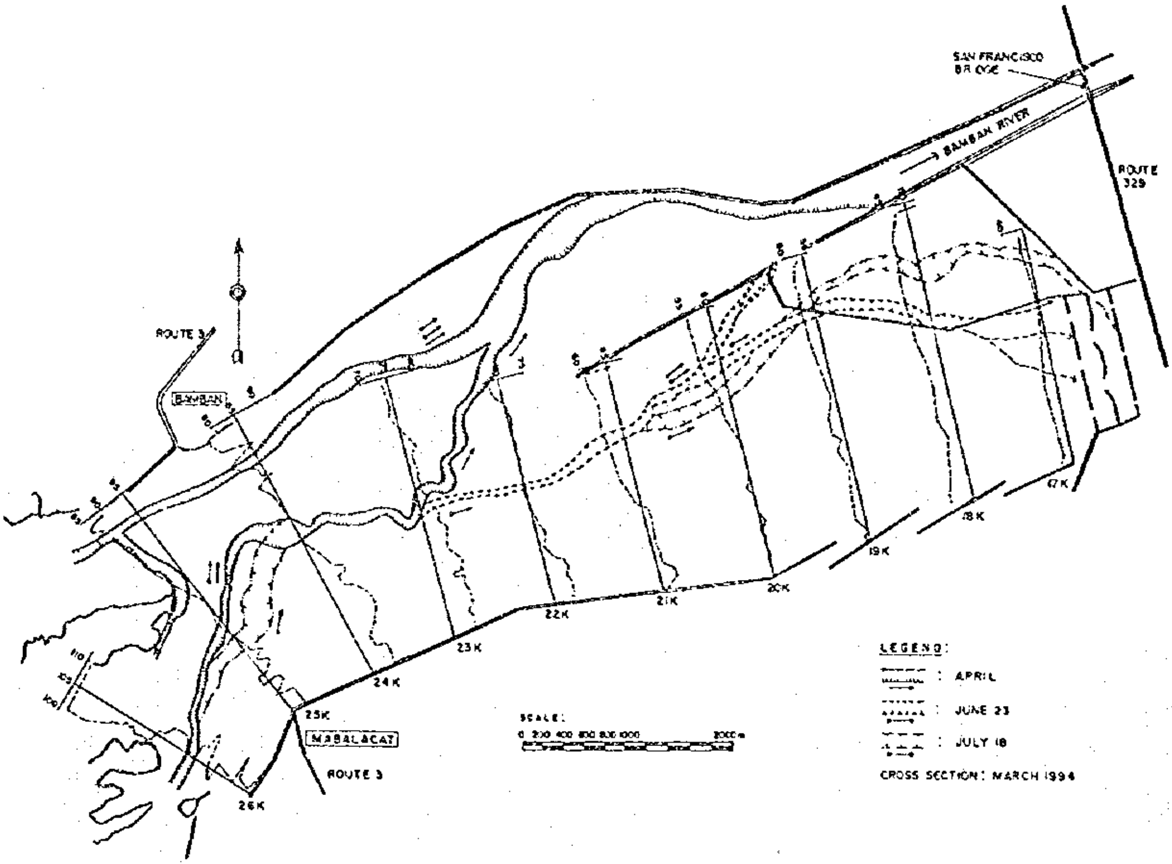

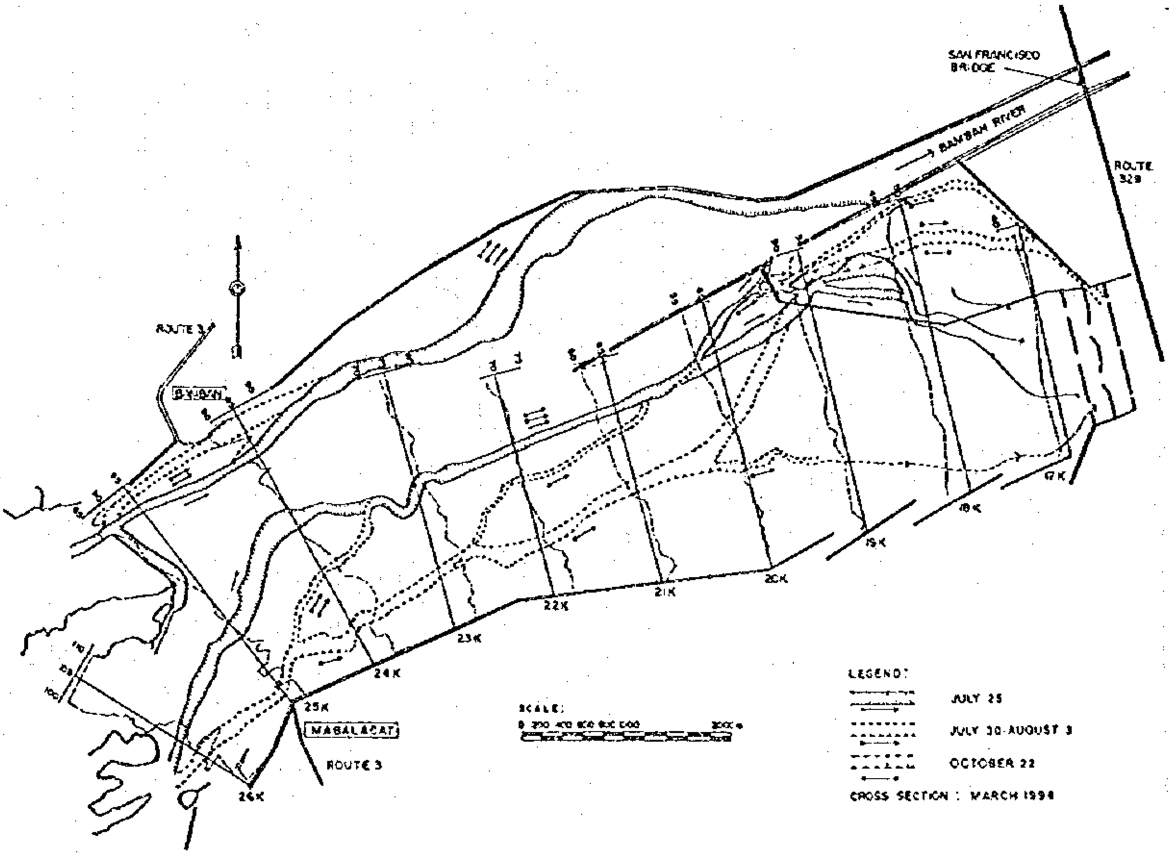

Figure C.28 Chronological Changes of Sacobia-Bamban Watercourse in 1994

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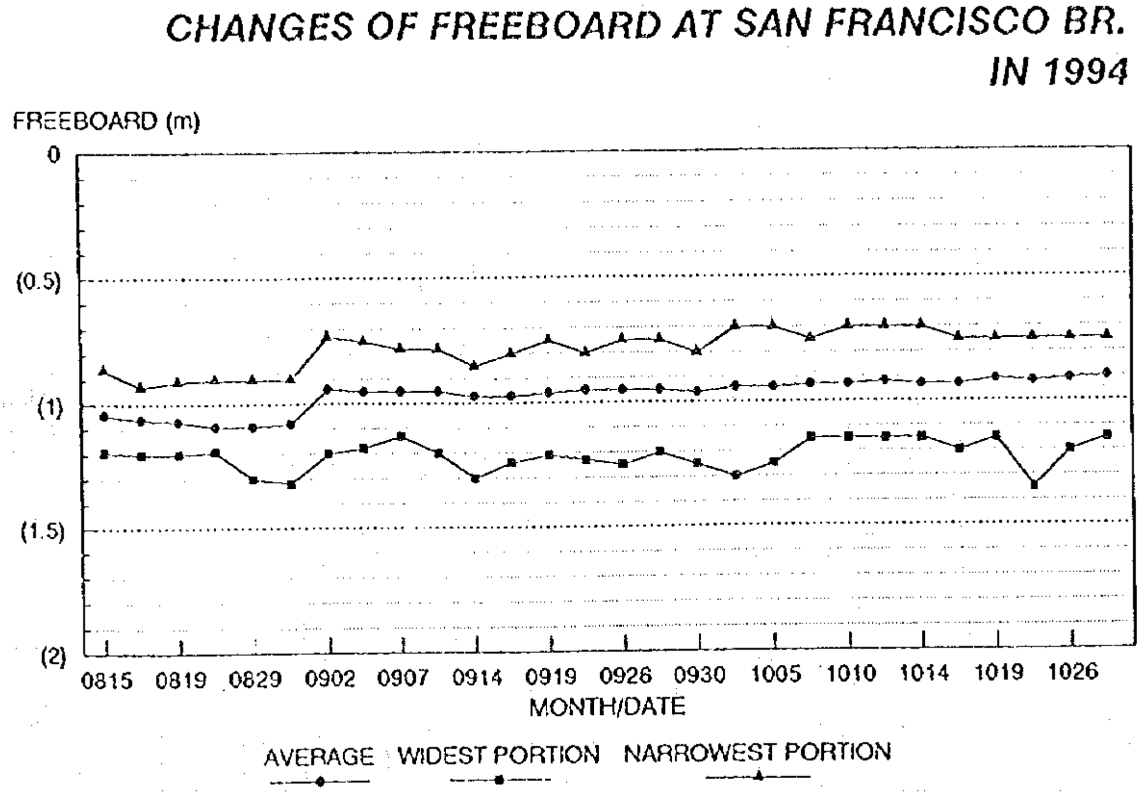

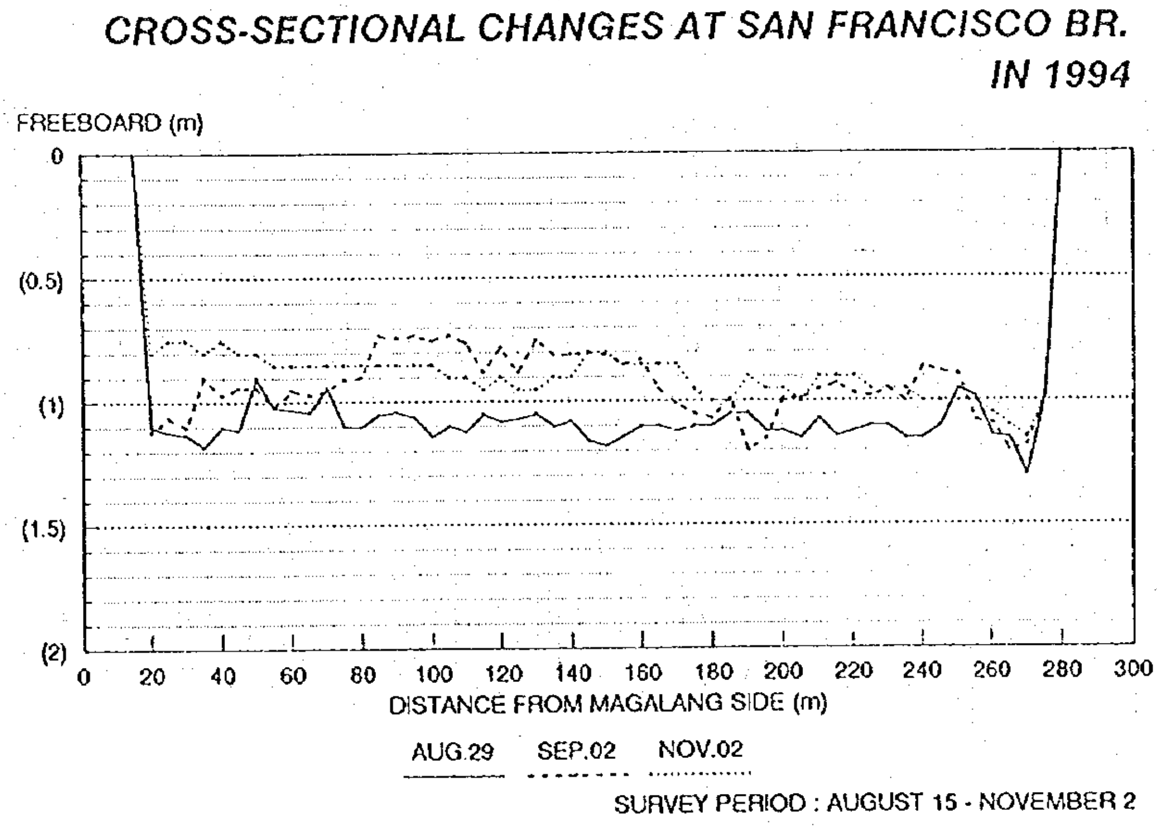

Figure C.29 **Changes of Freeboard and Cross-Section of San Francisco Bridge in 1994**

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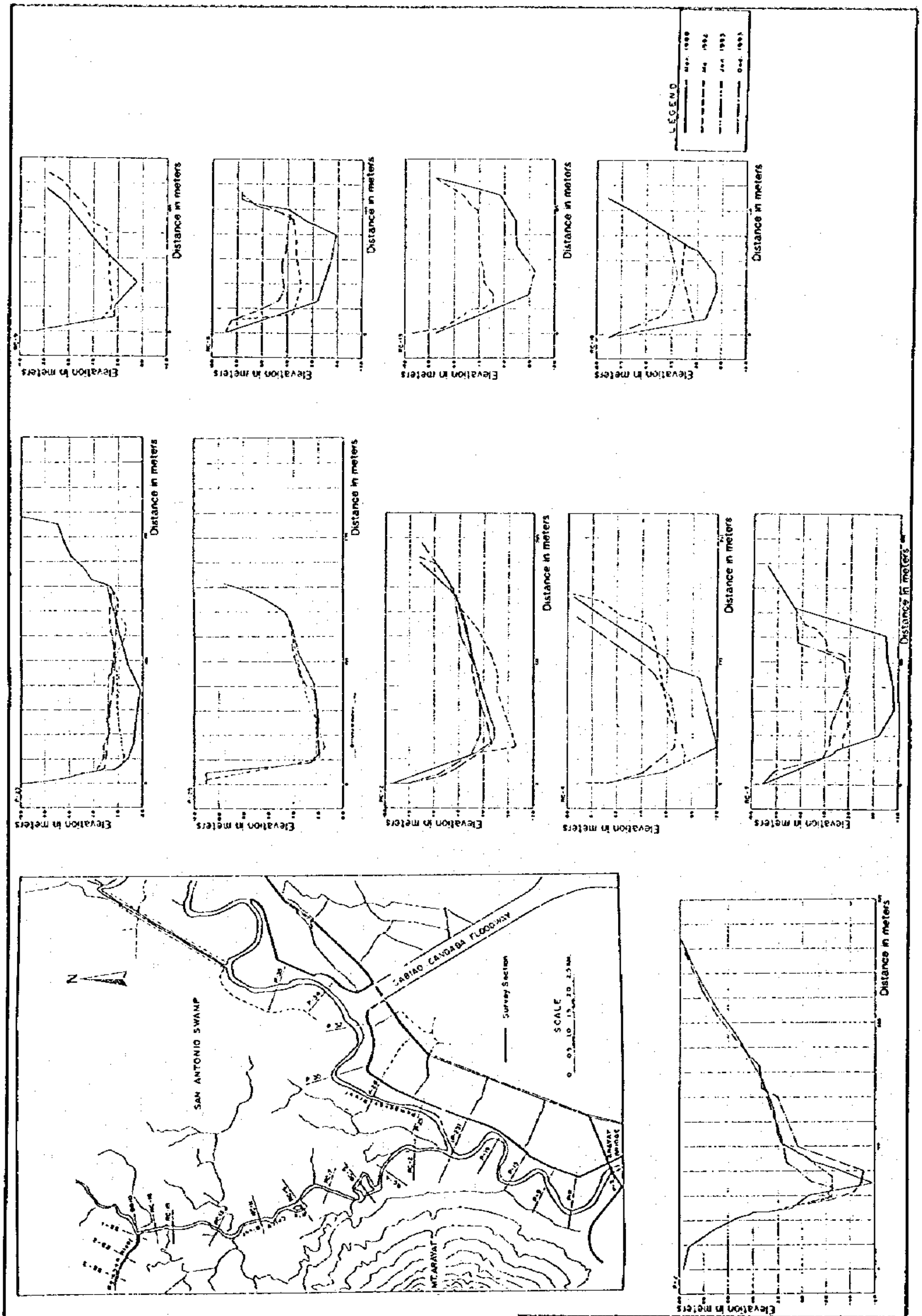

Figure C.30

Cross-Sectional Changes of Rio Chico and Pampanga Rivers

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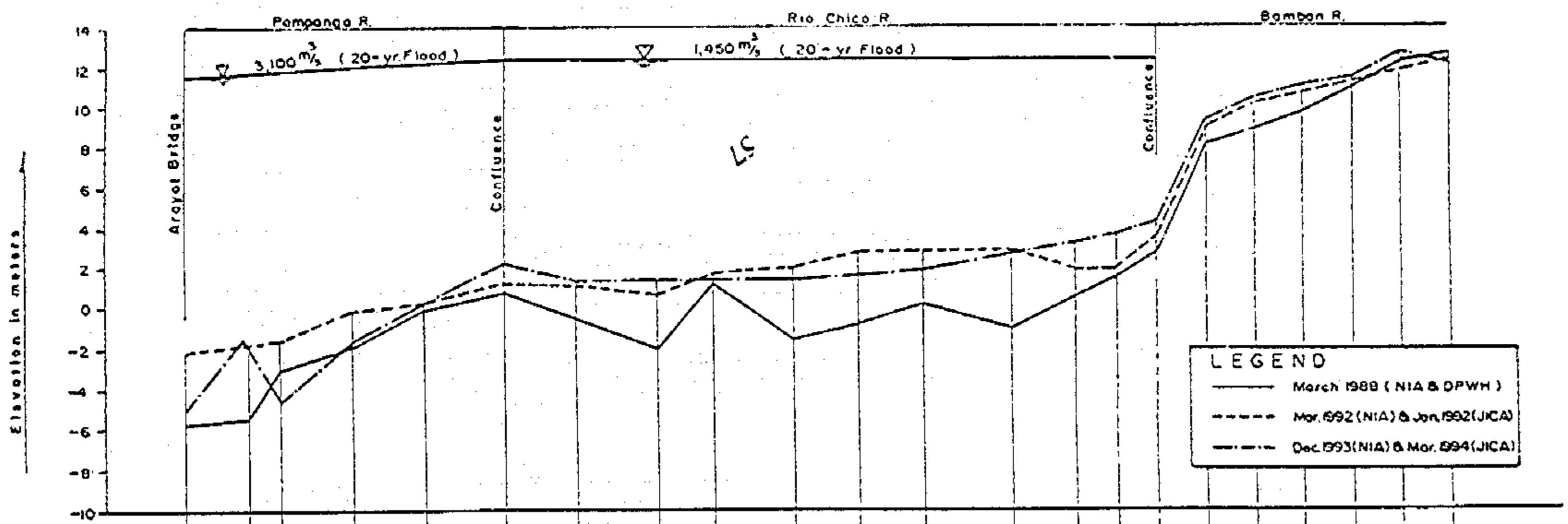

Section No.	Accum. Distance (m)	Lowest Riverbed Elevation (El. m) Mar. 1988	Mar. 1992	Jan. 1993	Dec. 1993
P-2	0	-5.80	-2.20	-2.70	-5.15
P-8	820	-5.50	-1.80		-1.55
P-9	1,200	-3.00	-1.60		-4.71
P-15	2,200	-2.00	-0.20		-1.83
P-19	3,000	-0.20	0.20		
P-23	4,000	0.70	1.20	2.17	2.22
RC-2	4,900	-0.60	1.09	2.28	1.33
RC-4	5,900	-2.00	0.63		1.32
RC-5	6,600	1.20	1.70		
RC-7	7,600	-1.60	2.04		1.37
RC-9	8,400	-0.90	2.80		
RC-11	9,200	0.10	2.94		3.83
RC-13	10,300	-1.00	2.90		
RC-15	11,100		1.90		3.27
RC-16	11,600	1.50	3.48		3.68
BB-0	12,100	2.78	5.05		4.33
BB-1	12,700	8.07	9.20		9.28
BB-2	13,300	8.93	10.25		10.49
BB-3	13,900	9.79	10.75		11.01
BB-4	14,500	11.00	11.25		11.49
BB-5	15,100	12.32	11.75		12.73
BB-6	15,700	12.95	12.05		12.08

Figure C.31 Longitudinal Profile of Lowest Riverbed Elevation

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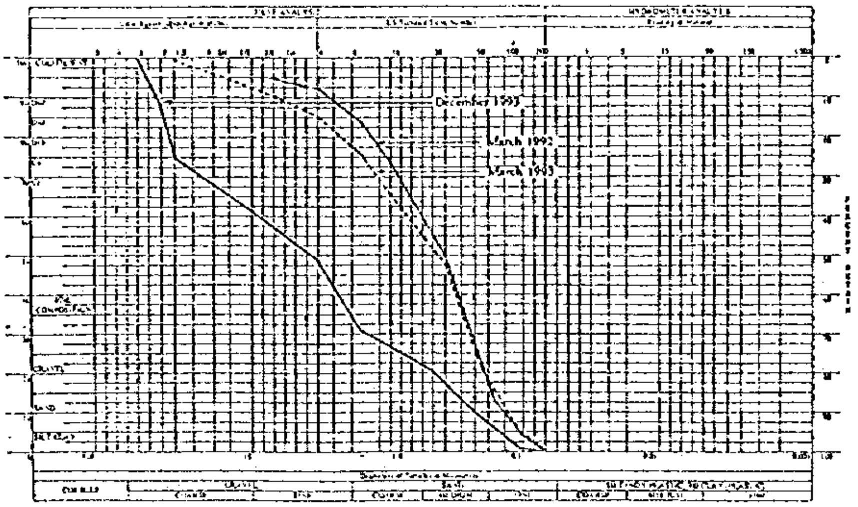
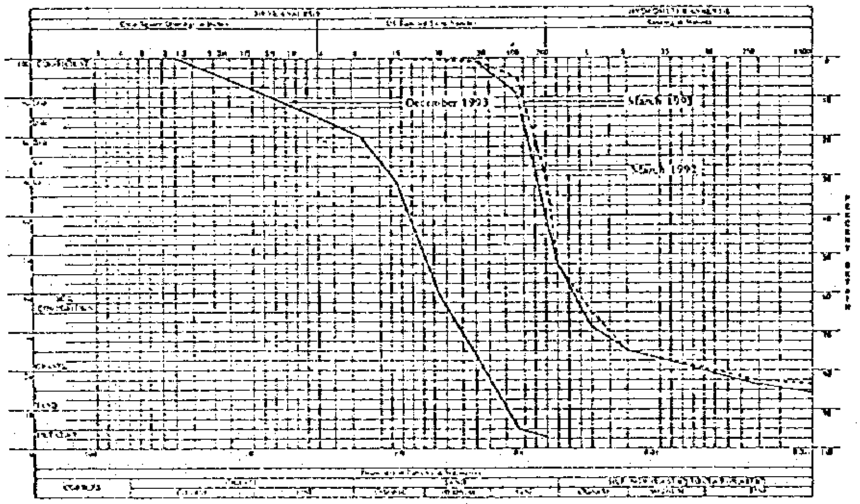
SAMPLE NO.: RC-16 CENTER



SAMPLE NO.: RC-2 CENTER



SAMPLE NO.: P-23 CENTER

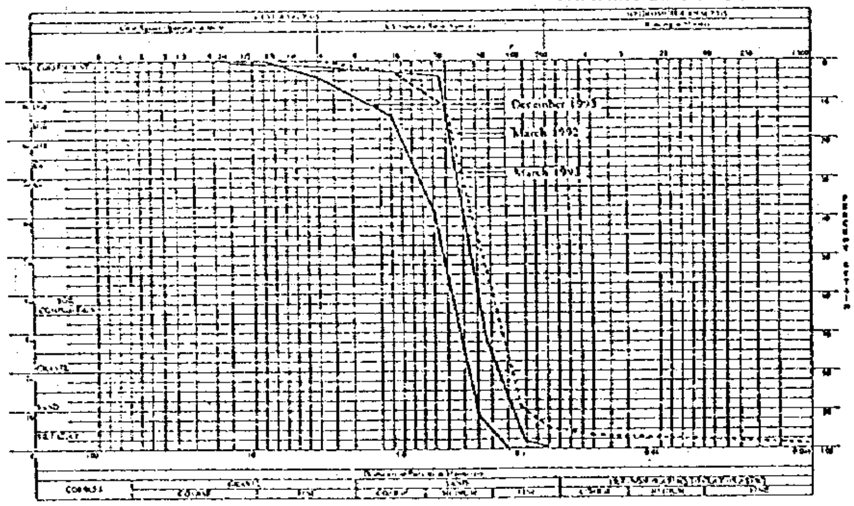


Figure C.32 Grain Size Distribution in Rio Chico and Pampanga Rivers

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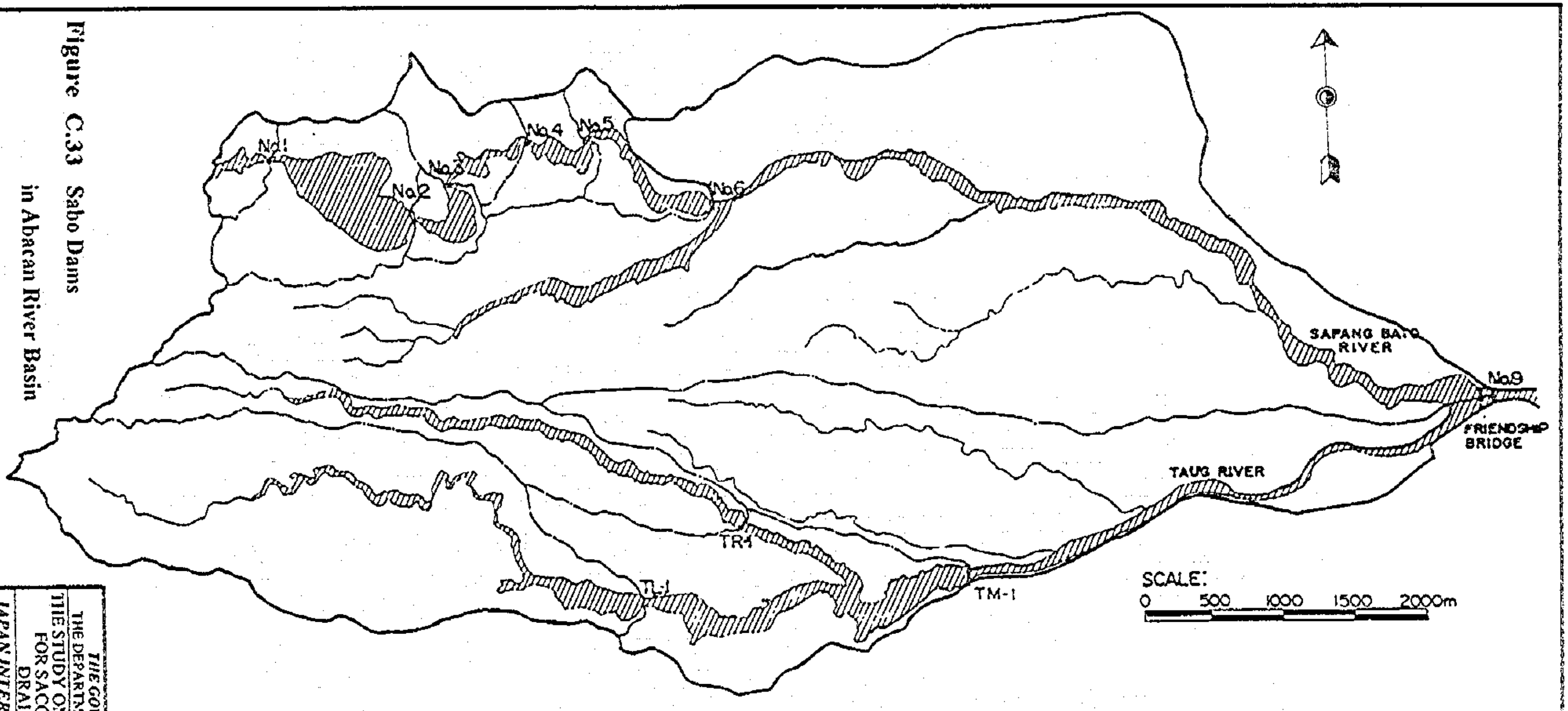

Figure C.33 Sabo Dams in Abacan River Basin

Existing Sabo Dams in Abacan River

As of November 1994

Description		Unit	Sapang Bato River							Taug River		
			No 1	No 2	No 3	No 4	No 5	No 6	No 9	TR-1	TL-1	TM-1
Location	latitude		N15°10'23"	N15°10'10"	N15°10'16"	N15°10'26"	N15°10'30"	N15°10'12"	N15°09'28"	N15°08'57"	N15°08'42"	N15°08'47"
	longitude		E120°28'21"	E120°29'07"	E120°29'17"	E120°29'40"	E120°29'54"	E120°30'26"	E120°33'39"	E120°30'33"	E120°30'12"	E120°31'27"
Catchment Area		km^2	0.3	1.5	1.8	2.4	2.8	3.5	33.3	1.8	4.7	8.3
Main Dam												
1) Structure			Sand Bags	Sand Bags	Sand Bags	Gabions	Gabions	Gabions	Gabions	Gabions	Gabions	Gabions
2) Dam Height		m	10.5	4.0	4.0	10.0	5.0	3.0	4.0	6.0	6.0	5.0
3) Crest Length		m	11.0	68.0	29.0	25.0	67.0	50.0	106.00	79.0	79.0	124.00
4) Volume of Dam Body		m^3	4,300	2,000	2,400	2,300	2,800	1,100	2,800	3,200	4,400	3,200
Sediment Containment		m^3	35,000	83,000	-	104,000	48,000	71,000	405,000	140,000	173,000	456,000
Construction Period			1991. 11-12	1991. 11-12	1991. 11-12	1992. 3 - 4	1993. 4 - 6	1992. 3 - 4	1992. 4 - 5	1992. 5 - 6	1992. 5 - 8	1992. 5 - 11
Present Effective Dam Height		m	7.5	(Collapsed in 1994)	(Silted in 1992)	10.0	5.0	3.0	5.0	(Partially Collapsed in 1994)	(Collapsed in 1994)	3.0
Date of Restoration			1992 Jul.			1993 Mar 1993 Nov	1993 Sep.	1993 Mar. 1993 Oct	1993 Apr. 1993 Oct	1993 Jul.		1993 Sep.

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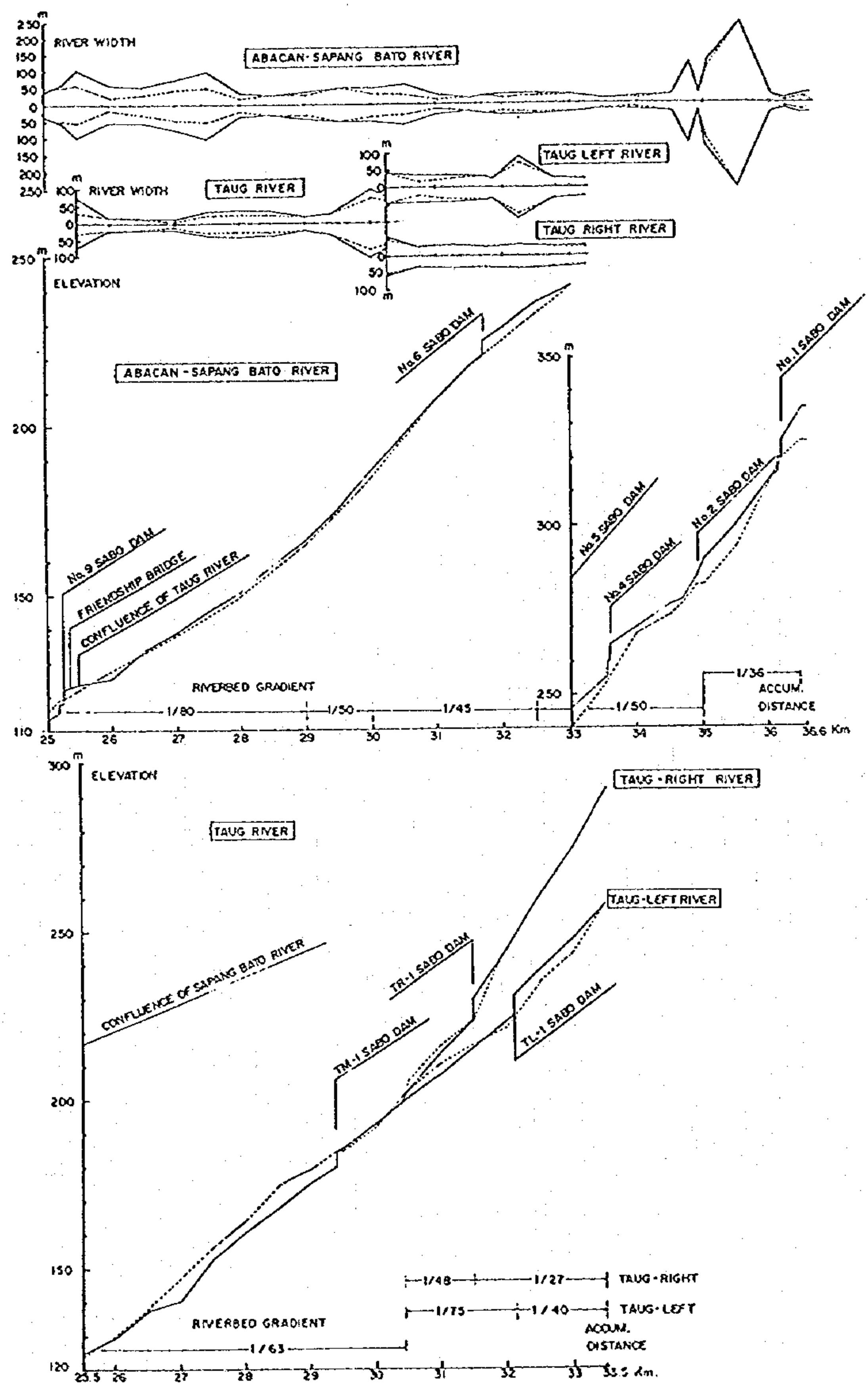

Figure C.34 Longitudinal Profile and River Width in Upper-Abacan River

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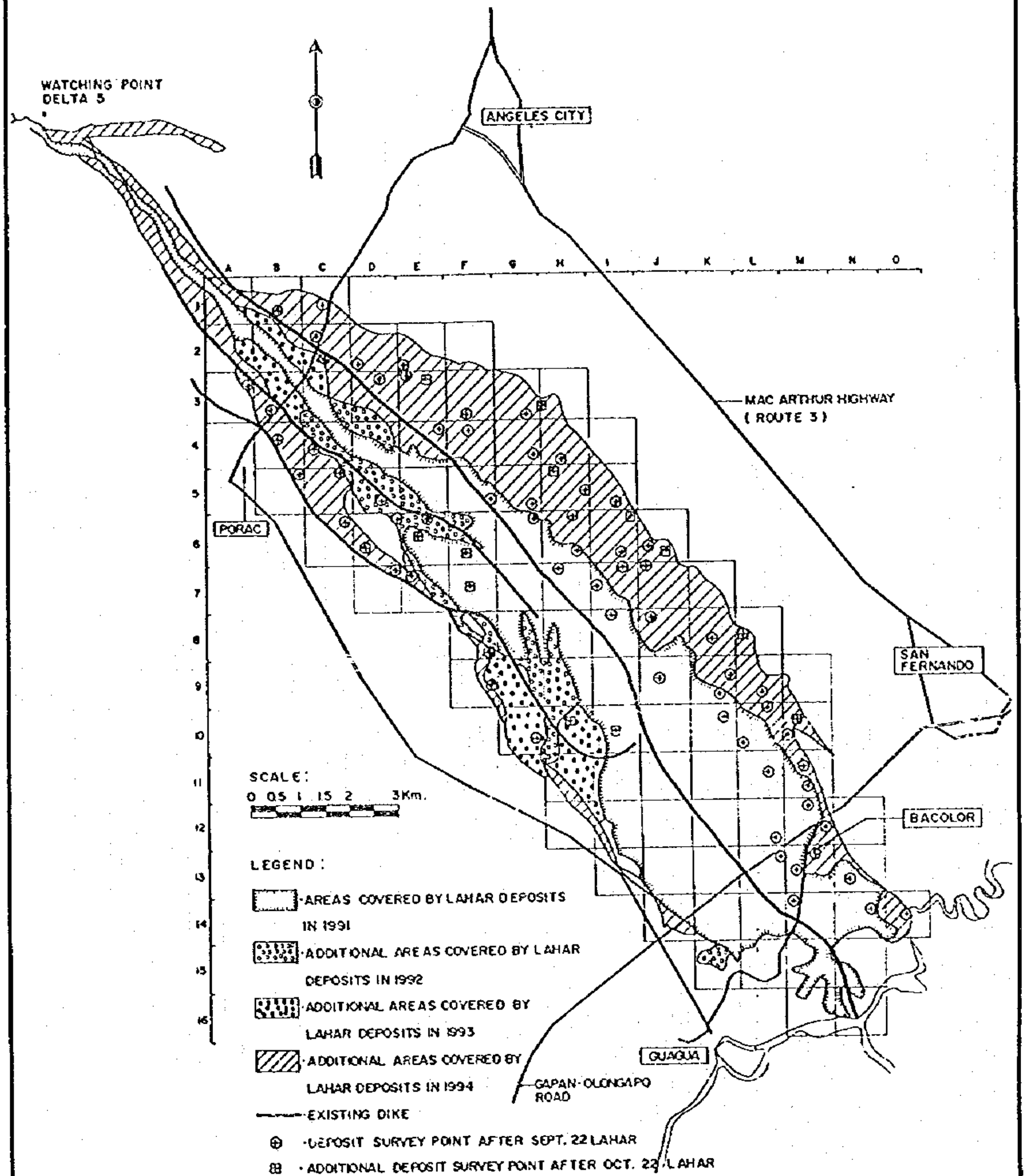

Figure C.35 Sediment Deposition Survey Area in Pasig-Potrero River

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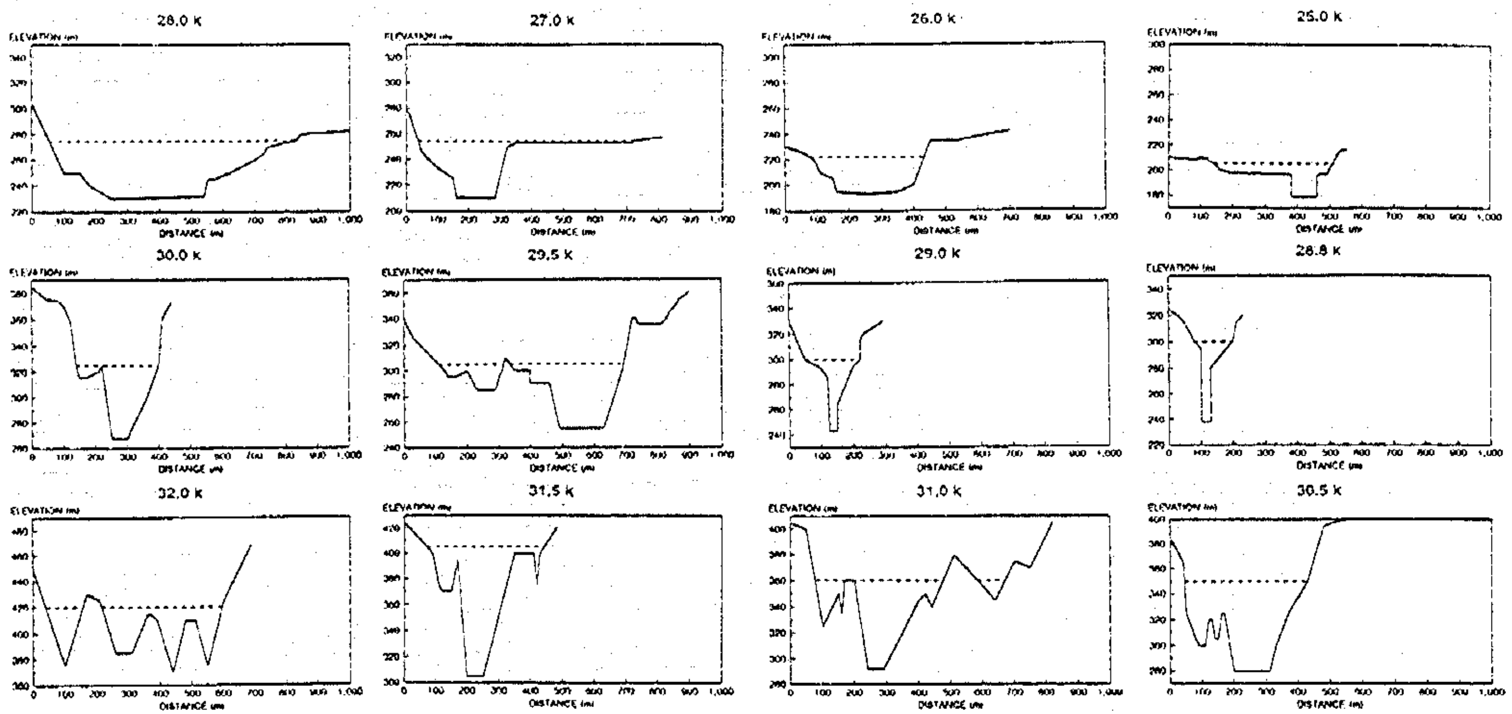

ESTIMATE OF LAHAR DEPOSITS

Cross Section	Distance (m)	Deposited Area (10^3m^2)	Accumulated Sediment Volume (10^3m^3)
25.0k		4.2	
26.0k	1,000	7.8	6,030
27.0k	1,000	9.4	8,635
28.0k	1,000	22.9	16,160
28.8k	800	2.6	10,192
29.0k	200	3.0	562
29.5k	500	13.3	4,073
30.0k	500	7.2	5,113
30.5k	500	17.3	6,123
31.0k	500	12.7	7,500
31.5k	500	14.8	6,875
32.0k	500	11.5	6,568
	Sub-Total	25.0k-28.8k :	41,017
		28.8k-32.0k :	36,812
	Total		77,829

(As of Nov. 1, 1994)

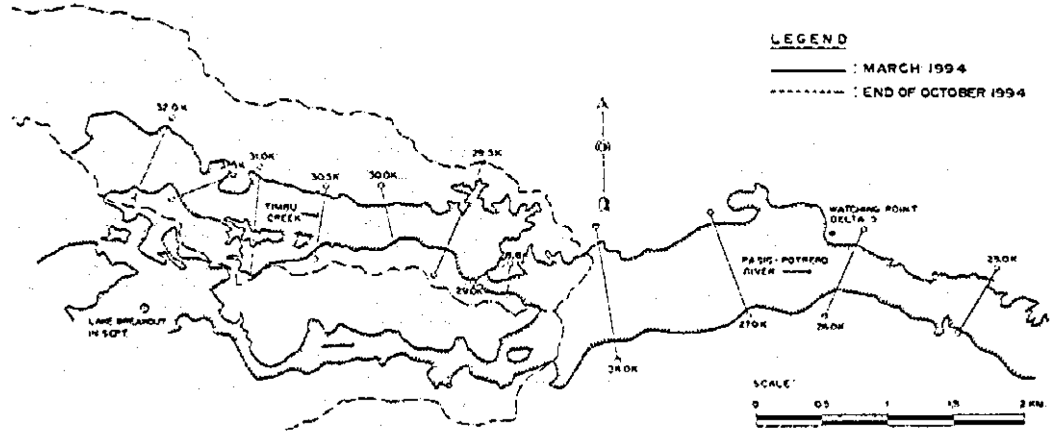

Figure C.36 Sediment Deposition in Upper Reach from Watching Point Delta 5 in Pasig-Potrero River

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Pyrocrastic Flow Deposits in SPFF

Eruption in 1991 : 1,398

Volume of PFD
Sacobia : 968
Pasig : 430

Rainy Season in 1991 & 1992

Volume of Erosion : 370

Remaining Volume of PFD
Sacobia : 688
Pasig : 340

November in 1992 : 1,028

Volume of Erosion : 120

Rainy Season in 1993

Sacobia Headwaters were Annexed to Pasig Basin in October 1994.

Remaining Volume of PFD
Sacobia : 303
Pasig : 605

March in 1994 : 908

Volume of Erosion : 138

Rainy Season in 1994

Remaining Volume of PFD
Sacobia : 295
Pasig : 475

October in 1994 : 770

Lahar Deposits

Rainy Season in 1991 & 1992

Sacobia-Bamban		
1. Mactan to Maskup	:	55
2. Maskup to Route 329	:	125
3.Downstream Areas	:	50
Total	:	230
Abacan	:	50 [1]
Pasig-Potrero	:	90 [1]

Rainy Season in 1993

Sacobia-Bamban		
1. Mactan to Maskup	:	28
2. Maskup to Route 329	:	35
3. Downstream Areas	:	2
Total	:	65
Abacan	:	0
Pasig-Potrero	:	55 [1]

Rainy Season in 1994

Sacobia-Bamban		
1. Mactan to Maskup	:	-3
2. Maskup to Route 329	:	10
3. Downstream Areas	:	1
Total	:	8
Abacan	:	0
Pasig-Potrero		
1. to Delta 5	:	42
- Channel Erosion	:	-20 [1]
2. Inner Area between Levees	:	38 [2]
- Channel Erosion	:	-1
3. Inundated Areas	:	72
- Channel Erosion	:	-1
Total	:	130

Footnotes :
1) PHIVOLCS,USGS data
2) DPWH data

Figure C.37 Volumes of Source Material, Erosion, and Lahar Deposition, 1991-1994

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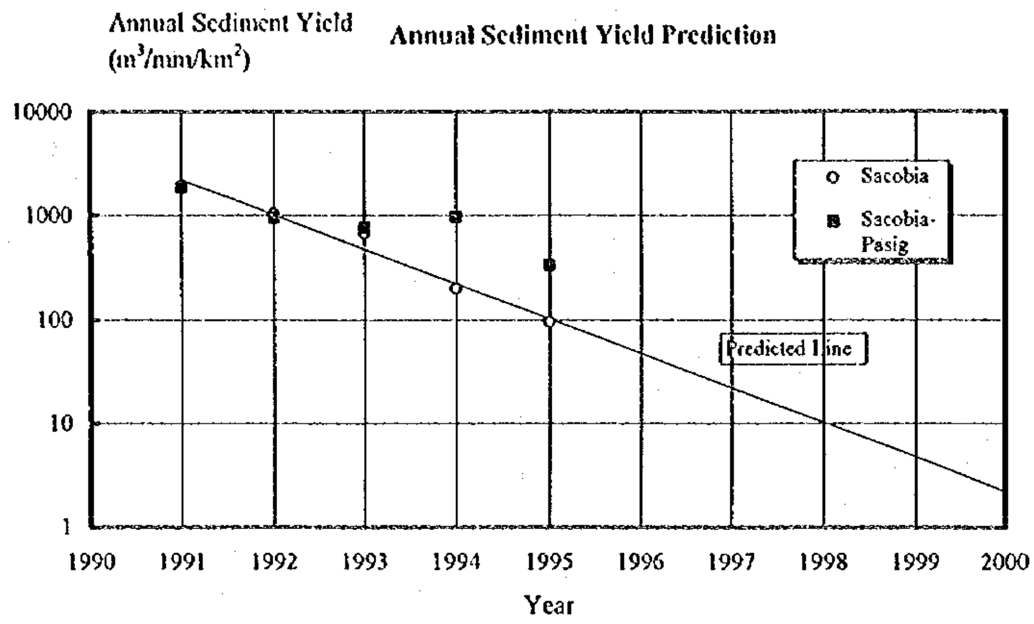

Volume of Source Material, Lahar Deposition, Rainfall and Catchment Area

Year	Volume of Pyroclastic Flow Deposits ($10^6 m^3$)			Volume of Lahar Deposits ($10^6 m^3$)				Annual Rainfall	Catchment Area of Headwaters (km^2)			Normalized Sediment Yields ($m^3/mm/km^2$)		
	Sacobia-Abacan	Pasig	Total	Sacobia	Abacan	Pasig	Total	(mm)	Sacobia	Pasig	Total	Sacobia	Pasig	Total
1991	968	430	1,398	150	50	50	250	2,250	35.3	24.5	59.8	1,889	907	1,858
1992	-	-	-	80	0	40	120	2,000	38.8	24.2	63.0	1,031	826	952
1993	688	340	1,028	65	0	55	120	2,500	38.8	24.2	63.0	670	909	762
1994	303	605	908	8	0	129	137	2,270	18.0	45.0	63.0	196	1,263	958
1995	295	476	771	4	0	45	49	2,360	18.0	45.0	63.0	94	424	330

Note 1) Volume of pyroclastic flow deposits and lahar deposits is obtained by combination of PHIVOLCS-USGS & DPWH data and the results of the Study.
2) Annual rainfall from 1991 to 1993 is refered to PHIVOLCS-USGS data, the value from 1994 to 1995 is refered to PHIVOLCS observation data at Upper-Sacobia gauge.

Prediction of Sediment Yield from EPPFF into Sacobia River

Year	Volume of Sediment Yield ($10^6 m^3$)	Accumulated Volume ($10^6 m^3$)
1996	2.0	2.0
1997	0.9	2.9
1998	0.4	3.3
1999	0.4	3.7
2000	0.4	4.1

Figure C.38
Prediction of Annual Sediment Yield from EPPFF

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APPENDIX D

METEO - HYDROLOGY

APPENDIX D

METEO-HYDROLOGY

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D.1 CLIMATE

In the Philippines, the tropical climate is dominated by several air masses throughout a year. The most dominant air mass around Mt. Pinatubo is the southwest monsoon that typically begins in late May or early June and lasts until September or October, while a northeast monsoon dominates during the dry months from November to March. The distinctive wet and dry seasons are brought about by these reversal monsoons. The air mass of southwest monsoon is classified into equatorial maritime and is warm and very humid, having an average temperature of 26°C and a vapor pressure of about 30 mb (Ref.D.1).

Frequency of typhoons increases gradually through April and May, and it becomes high from June through November. Among 16 tropical cyclones per annum which affect weather condition in the Luzon Island for the period from 1948 to 1991, five (5) tropical cyclones on an annual average passed through in the Central Luzon.

D.2 METEOROLOGY

2.1 RAINFALL

The annual rainfall data at representative rainfall gauging stations (Manila International Airport, Dagupan Meteorological Station and Clark Air Base) which have rainfall records of more than 30 years were discussed about the fluctuation of annual rainfall. Figure D.1 shows that a series of annual rainfall and 5-yr moving average for the above three stations. The data shows that the remarkable volume of rainfall occurred in 1972. In fact, it was reported that a temporary Central Luzon Lake was formed due to prolonged and heavy monsoon rains which fell over several weeks, and flooded Pampanga and Agno river basins were joined together in one inland sea extending from Manila Bay to Lingayen Bay (Ref.D.2). The monthly rainfall of 2,580 mm was recorded in July 1992 at Apalit, Pampanga. The annual rainfall had receded gradually for the period from 1972 to 1983 and the drought in 1983 caused a serious problems in economic activities in Central Luzon, such as shortage of drinking water and reduction of hydropower generation and low agricultural productivity. Those after 1983 has been restored by the level of long-term annual average rainfall. After the eruption of Mt. Pinatubo for the period from 1991 to 1993, the annual rainfall was almost equivalent to the long-term annual average rainfall.

Isohyetal map of annual rainfall in Central Luzon is shown in Figure D.2. It is indicated that the annual rainfall of more than 4,000 mm are experienced over Mt. Sto.Tomas of Benguet, west coast of Zambales and Mt. Angilo of Quezon. The reason for these large rainfall variations is partly topographical contrasts with the great altitudinal range, and partly the presence of large water bodies such as Pacific Ocean and South China Sea.

The variation of monthly rainfall at representative rainfall gauging stations in Central Luzon is shown in Figure D.3. The data clearly shows that the Luzon Island receives two main types of rainfall patterns. Eastern part of Luzon Island receives no really driest month but wetter months in November/December, while in the western part, there is a distinctive wettest month in August and driest months in January/February. About 90% annual rainfall occurs for the period from June to October in the western part of Luzon Island.

An important feature that can describe the rainfall distribution is the number of rainy days. The PAGASA defined a rainy day as a day having a rainfall of 0.1 mm or more. The mean monthly number of rainy days at various stations in Luzon Island is shown in Figure D.4.

2.2 *TEMPERATURE*

The variation of monthly average temperature at representative stations is shown in Figure D.5. The monthly average temperature in Luzon Island varies for the range from 24.8 °C in January to 28.3°C in May. The diurnal variation of temperature is about 10°C in the eastern part of Mt. Pinatubo as shown in Figure D.6. The maximum temperatures for most places occur generally between 1:00 p.m. and 3:00 p.m. while the minimum temperatures occur between 5:00 a.m. and 7:00 a.m. The absolute maximum temperature recorded in Luzon Island was 42.2°C at Tuguegarao in April 1912, and the absolute minimum temperature of 3.0°C was recorded at Baguio in January 1903.

2.3 *RELATIVE HUMIDITY*

The variation of monthly mean relative humidity shows the great difference between the western part of Luzon Island and eastern part as shown in Figure D.7. The monthly relative humidity in western part varies for about 15%, generally for the range from 70% in April to 85% in August. While, those in the eastern part is rather stable throughout a year at about 85%.

2.4 *EVAPORATION*

Open pan evaporation data in Floridablanca (1986-1987) varies for the range from 119.6 mm in November to 204.2 in March. The annual evaporation amount is recorded at 1,736 mm on an average.

2.5 *RAINFALL-RUNOFF RELATIONSHIP*

The ratio of runoff to rainfall volume was estimated on the basis of the monthly rainfall data at Basa Air Base station (1958-1972) and concurrent monthly average discharge data at Del Carmen (CA=111km^2). While the evaporation data at Floridablanca (1985-1987) were referred. All the stations are located in the Porac river basin which originates at southern slope of Mt. Pinatubo and has similar characteristics to the Study Area. Figure D.8 shows that the rainfall volume exceeds runoff for the months from May to October and the ratio of annual runoff to annual rainfall volume is estimated at 61.6% annual rainfall volume on an average.

2.6 *TROPICAL CYCLONE*

2.6.1 Tropical Cyclones in 1991, 1992 and 1993

The Philippines is one of the countries which experience tropical cyclones with the greatest frequency in the world. In 1991, 1992 and 1993, the number of tropical cyclones which entered or occurred in the Philippine Area of Responsibility (PAR) was 19, 16 and 32, respectively.

The tracks of tropical cyclones which entered or occurred in the Philippine Area of Responsibility in 1991, 1992 and 1993 are indicated in Figures in D.9, D.10 and D.11, respectively in which tropical cyclones are classified into (a) Tropical Depression (T.D.) with maximum wind speed less than 61 kph, (b) Tropical Storm (T.S.) with wind speed equal to or more than 61 kph and less than 118 kph and (c) Typhoon (T) with wind speed equal to or more than 118 kph.

2.6.2 Daily Rainfall and Cause of Rainfall

In the years of 1991, 1992 and 1993, six (6), four (4) and ten (10) tropical cyclones hit directly the Luzon Island, respectively. Table D.1 tabulates daily rainfall at the PIE2, Sacobia, Zaragoza and Arayat rainfall gauging stations during these tropical cyclones. In

Table D.2 which shows point and basin mean rainfall during major floods, name of related tropical cyclones are also indicated.

In order to grasp the cause of serious rainfall, the cause of rainfall of more than 100 mm/day at Sacobia Station was studied. During three (3) years from 1991 to 1993, daily rainfall with more than 100 mm was observed eight (8) days (times) at the Sacobia Station.

Out of these days with serious rainfall, rainfall of four (4) days was induced by tropical cyclones such as T.S. Yayang (November 17 1991), T. Goring (June 26 1993) and T.S. Kading (October 4 and 5 1993). However, for two (2) days, namely July 2 1993 and August 28 1993, there were no tropical cyclones in the PAR as can be understood from Figure D.11, while for two (2) days of August 28 and 29 1992, there existed a tropical cyclone T.S. Isang, but the cyclone was located neat Taiwan and almost 900 km far from Mt. Pinatubo.

The cause of heavy rainfall in the study area is not only tropical cyclones as can be understood from the above and more detailed study will be required for the cause of rainfall which may cause heavy rainfall, especially the rainfall like on August 28 1992 which recorded annual maximum daily rainfall in this year.

2.6.3 Hourly Rainfall Distribution and Tropical Cyclone Track

In order to serve as one of the basic information for flood/mudflow warning in the study area, the relation of typhoon track/location and the rainfall at the Sacobia Rainfall Station under the PHIVOLCS was studied. Figure D.12 indicates hourly rainfall distribution at Sacobia Station and tropical cyclone tracks which directly hit the Luzon Island in 1991, 1992 and 1993. Figure D.13 shows the track/location of tropical cyclone with or without rainfall at the Sacobia Station.

These figures indicate in general that rainfall at Sacobia Station starts when the tropical cyclones arrives at long 122.5 E when tropical cyclones cross the Luzon Island from the east and rainfall continues even though tropical cyclones moves to the northwest direction.

D.3 HYDROLOGY

3.1 HYDROLOGICAL DATA

3.1.1 Rainfall Data

In and around the study area, 19 rainfall gauges equipped with an automatic recorder or a telemeter equipment have been installed. These stations, which can provide hourly or much shorter rainfall information, are or were operated by the PAGASA, the PHIVOLCS and the OCD as given in Tables D.3 and D.4. Their locations are shown in Figure D.14. The observation period is also shown in Figure D.15 for rainfall record and Figure D.16 for water level record.

The PAGASA stations can be classified into Pampanga Flood Forecasting and Warning System (Pampanga FFWS) and Hydromet Stations. Five (5) stations included in the Pampanga FFWS are located along the Pampanga River and the Rio Chico River which the Bamban River joins into. T hese stations commenced their observation from 1973. Judging from their location, some of the stations may represent the rainfall characteristics of lower basins of the Bamban River and the Abacan River. However, since the equipment became superannuated, recorders and telemeters did not function well and important data are not available before rehabilitation which was made in 1993.

The four (4) of the PAGASA hydromet stations are located in the south or the east of the study area. The automatic recorders were used since the beginning of 1970s in most stations. However, these had been abandoned by the beginning of 1980s and at present manual measurement of rainfall is undertaken by gauge keepers.

The PHIVOLCS maintains five (5) telemetered rainfall gauging stations in and around the study area as given in Table D.3 and moreover two (2) stations of the PHIVOLCS are located in the western slope of Mt. Pinatubo. These stations composes the lahar monitoring system of the PHIVOLCS together with acoustic flow monitors which were established in 1991 after eruption of Mt. Pinatubo. All the station are located in high land, the elevation of which is higher than 500 m. The equipment are maintained in good condition and the telemetered data are mostly available.

The OCD operates three (3) rainfall stations at present, which are used for lahar warning operation together with lahar information sent through radio from observers who stay in watch points situated at top of hills from which occurrence of lahar can be directly observed. The data sent to the OCD are not printed out regularly after using the warning operation and hard to be used for analysis.

In addition to the above, daily rainfall data are available in six (6) stations under the PAGASA, namely two (2) hydromet stations and four (4) climate stations.

3.1.2 Water Level and Discharge Data

The DPWH has water level/discharge data which are obtained by staff reading at 13 stations located in rivers in and around the study area, such as the Bamban, the Abacan, the Pasig-Potrero, the O'Donnell, the Bangut, the Tarlac, the Porac and the Gumain rivers, while the PAGASA has data of the Tarlac River. The location of these stations is indicated in Table D.4 and Figure D.14. The availability of data are tabulated in Figure D.16 except the Pabanlag Station at the Gumain River for which only annual maximum data have been obtained.

As for the six (6) stations under the DPWH, the observation was terminated by 1972, but two (2) stations, namely Cabetican Station in the Pasig-Potrero River and Valdez Station in the Porac River, continued the observation up to 1979.

After 1979, the DPWH stopped stream flow observation but in 1985 resumed observation at only one (1) station, Nasudeco Station in the Porac River. In addition, after the eruption of Mt. Pinatubo, the DPWH undertakes observation at several points including San Francisco Bridge of the Bamban River and Ninoy Aquino Bridge of the Abacan River.

The data kept by the DPWH for the observation before 1972 are daily mean water level and discharge which are summarized in "Surface Water Supply Bulletin". For the observation from 1972 to 79, raw data such as staff reading which was conducted three (3) times a day and discharge measurement are available at Bureau of Research and Standard (BRS), DPWH but cross-sections with bank height are missing. Regarding the observation after 1985, all kinds of the data mentioned above are available also at BRS.

The PAGASA operates telemetered Tibag water level gauging station in the Tarlac River which is equipped with a sensing pole type gauge and an automatic recorder since 1982. However, at this section, river bed fluctuation is serious even before the eruption of Mt. Pinatubo and therefore discharge data is not available in most years also due to the trouble of the automatic recorder and the telemeter equipment.

3.2 *RAINFALL ANALYSIS*

3.2.1 Rainfall Characteristics

(1) Monthly and Annual Rainfall

Monthly and annual rainfall amount was estimated at two (2) PAGASA Stations, namely, San Julian and Becuran Stations as tabulated in Table D.5. The annual rainfall amount is around 1800 mm. The rainy season is from May to October and 90 % of total annual rainfall occurs in the rainy season.

(2) Probable Daily Rainfall

To estimate probable daily rainfall, three (3) stations which are near to the Sacobia-Bamban and the Abacan river basins are selected. These are BAI Magalang, Arayat and Zaragoza stations, all of which have been operated/maintained by the PAGASA.

Figure D.17 indicates probability graphs of exceedance and the following table tabulates the probable daily point rainfall at these stations.

(Unit : mm)

Return Period	Station		
(year)	BAI Magalang	Arayat	Zaragoza
100	257.3	276.4	280.9
50	217.5	253.6	257.6
20	168.9	222.8	226.1
10	134.9	198.6	201.4
5	102.8	172.8	175.1
2	61.1	132.4	133.9

Numbers of data : BAI Magalang : 17 years, Arayat : 13 years, Zaragoza : 14 years

(3) Rainfall Duration Intensity Curve for Long Duration

Out of Arayat and Zaragoza stations, which are equipped with automatic recorders, Zaragoza Station is selected to analyze rainfall duration intensity curve because of availability of longer data. Figure D.18 shows probability graphs of exceedance for 1-hr, 2-hr, 3-hr, 6-hr and 12-hr rainfall at Zaragoza Station. The following table indicates probable rainfall for this duration of rainfall.

(Unit: mm)

Return Period	Duration				
(Yr.)	1-hr	2-hr	3-hr	6-hr	12-hr
100	97.2	121.9	128.7	172.1	198.5
50	89.8	112.4	118.9	156.6	181.7
25	82.3	102.7	108.9	141.1	164.8
10	71.8	89.3	95.0	119.9	141.6
5	59.7	73.8	78.9	96.1	115.1
2	49.6	61.0	65.5	77.0	93.5

Remarks : Number of data is 11 years.

Figure D.19 indicates rainfall intensity duration curves which were selected from three (3) types of equations explained below in consideration of deviation from the data.

Type I $I = a / (t + b)$ .... (Eq.D.1)

Type II $I = a / t^{n}$ .... (Eq.D.2)

Type III $I = a / (t^{0.5}\ b)$ .... (Eq.D.3)

Where; I : Rainfall intensity (mm/hr)

t : Rainfall duration

a,b and n : Constant

(4) Probable Point Rainfall and Rainfall Duration Intensity Curve for Short Duration

From the last half of the 1960's to the end of 1980, the PAGASA operated some automatic rainfall gauges and recorded rainfall data of short duration in detail. In and around the study area, those stations were Becuran, Cansinala, San Agustin and Sta. Cruz. However, in the data records of these stations, many missing data are found and only San Augustin Station has records of ten (10) years as tabulated in Table D.6. Therefore, using the data of San Agustin Station, probable point rainfall and rainfall intensity curves for short duration were obtained. Figure D.20 shows probability graphs of exceedance for 5 min., 10 min., 15 min., 30 min., 1 hr. rainfall and Table D.7 indicates probable rainfall obtained from these graphs.

Figure D.21 indicates rainfall intensity duration curves which are also selected from three (3) types of equations, which are explained in duration curves for long duration, after evaluation of deviation. To establish these curves, the probable rainfall for 10 min. in Table D.7 was excluded, since these for 10 min. show large deviations from probable rainfall for shorter duration. The following table indicates probable rainfall for short duration which is obtained from rainfall intensity duration curve indicated in Figure D.21.

(Unit: mm)

Return Period	Duration				
(Yr.)	5-min	10-min	15-min	30-min	1-hr
100	22.9	37.9	50.3	79.7	123.3
50	21.5	35.4	46.7	73.5	113.0
20	19.7	31.9	41.9	65.2	99.3
10	18.1	29.1	37.9	58.5	88.5
5	16.4	26.0	33.7	51.4	77.0
2	13.7	21.0	26.8	40.1	59.0

Remarks : Number of data is 10 years.

(5) Relation of Rainfall Amount and Elevation

Rainfall of various duration from 5-min to 24-hr with 100-yr and 10-yr return period at three (3) rainfall stations, namely Cabanatuan City (El. 3.2 m MSL), Sta. Cruz (El. 100 m MSL) and Baguio City (El. 1500 m) are indicated in Figure D.22 (Ref.D.3). From this figure, it may be concluded that rainfall amount with duration less than or equal to one (1) hr is not influenced by the elevation, while the rainfall amount for much longer duration is influence by the elevation.

3.2.2 Model Hyetograph

Model hyetograph with probability of 100-yr, 50-yr, 20-yr, 10-yr, 5-yr, and 2-yr was established from the rainfall at the Arayat, Zaragoza, PIE2 and Sacobia rainfall stations in consideration of rainfall characteristics as well as data quality in order to be used in flood runoff calculation.

(1) Selection of Rainfall Gauging Station

To establish model hydrograph, rainfall stations which are equipped with an automatic recorder or a telemeter equipment are preferable since the rainfall data with short duration are available. And if the existing rainfall stations are used for the establishment of model hydrograph, the results can be easily applied for the analysis of lahar/flood events in the near future. Such stations located in or near to the Sacobia-Bamban and the Abacan river basins are PIE2, Sacobia and Summit Rim stations under the PHIVOLCS and Arayat and Zaragoza stations under the PAGASA. The three (3) PHIVOLCS's rainfall gauges are located in sites elevation of which are more than 600 m and therefore these stations are expected to represent rainfall characteristics of higher river basin, while the rainfall stations of the PAGASA is for the lower river basin. Out of these stations, however, it is judged from the analysis of the data quality that Summit Rim Station gives smaller rainfall amount compared with other stations and thus remaining four (4) stations were decided to be used to establish the model hydrograph.

(2) Compensation of Missing Data

Some missing data were found in observation record of four (4) stations. Moreover, the PIE2 and Sacobia stations under the PHIVOLCS commenced its observation after the eruption of Mt. Pinatubo. Therefore, the missing data were compensated at first.

Regarding Arayat and Zaragoza stations, correlation and the regression coefficients were obtained using the data from 1974 to 1993. The same coefficients among PIE2, Sacobia, Zaragoza and Arayat were computed from the data during three (3) years from 1991 to 1993. The correlation and regression coefficient thus obtained are tabulated in Table D.8.

Table D.2 represents observed and estimated point daily rainfall during major floods which is defined as a flood daily rainfall of which exceeds 75 mm at least at one of the four (4) rainfall stations. Estimation of the missing data in this table was made from stations with higher correlation coefficient using the corresponding regression coefficient in Table D.8.

(3) Basin Mean Rainfall

From the point rainfall at four (4) stations, basin mean rainfall of the Sacobia-Bamban and the Abacan river basins were estimated applying Thiessen Polygon Method. Figure D.23 shows the Thiessen Polygon made from the four (4) stations. Thiessen coefficient to calculate basin mean rainfall are tabulated in the following table.

River Basin	Catchment Area (km2)	Station			
		PIE2	Sacobia	Zaragoza	Arayat
Sacobia-Bamban(*)	224.7	0.35	0.42	0.03	0.20
Abacan	77.2	0.00	0.70	0.00	0.30

Note : (*) Residual basin of 20.4 km2 in the downstream reach is not included. Total catchment area was reduced to 200.6 km2 in October 1993.

The obtained basin mean rainfall for the Sacobia-Bamban and the Abacan river basins during major floods are also indicated in Table D.2.

(4) Probable Basin Mean Daily and 24-hr. Rainfall

The annual maximum basin mean rainfall was obtained from Table D.2 and probable basin mean daily rainfall was computed from the annual maximum basin mean rainfall. Figure D.24 indicates probability graphs of exceedance for the two (2) basins. The following table tabulates probable basin mean daily rainfall together with 24-hr. rainfall which is computed assuming coefficient of 1.13 to convert daily rainfall into 24-hr. rainfall.

(unit : mm)

Return Period (year)	Sacobia-Bamban		Abacan	
	Daily	24-hr	Daily	24-hr
100	440	497	443	501
50	397	448	404	457
20	353	399	365	412
10	295	333	311	351
5	231	260	251	283
2	180	203	202	228

Remarks : Number of data is 19 years.

(5) Model Hyetograph

The model hyetographs for the basin mean rainfall with probability of 100-yr, 50-yr, 20-yr, 10-yr, 5-yr and 2-yr were developed taking the factors mentioned below into consideration.

1) Entire Duration of Model Hyetograph

The standard value of the continuation time of one flood is an important factor to determine model hyetograph for runoff analysis of river basins. In this connection, actual rainfall continuation times of the four stations, namely PIE2, Sacobia, Zaragoza and Arayat were analyzed as shown in Figure D.25 using floods in which continuous rain amount exceeds 100 mm. In these stations, no difference are found in as for the rainfall duration. Consequently, the entire duration of the model hyetograph for the basin was set at 24 hours which is average continuation time of one flood of four (4) stations as can be understood from Figure D.25.

2) Time Distribution

Time when the peak rainfall depth occurred in the four (4) stations was also analyzed on the basis of the observed hourly rainfall depth. As a result of the analysis, it is assumed that the model hyetograph has such a pattern that the rainfall depth gradually increases at regular time intervals until it reaches the peak after 11 hours from the start of rainfall and then, gradually decreases at regular intervals up to end of rainfall (24 hours after start of rainfall) as presented in Figure D.25.

3) Peak Hourly Rainfall

As discussed in 3.2.1 (5), hourly peak discharge is almost same even though the elevation becomes higher. In consideration of this characteristics, peak hourly rainfall of the model hyetograph is set almost equal to the probable hourly rainfall at Zaragoza Station in addition that total depth of model hyetograph for 24 hours is equal to the probable rainfall for each basin.

The hourly rainfall distribution for the Sacobia-Bamban and the Abacan river basins which are developed on the basis of factors mentioned above are presented in Figure D.25 in the form of percentage of each hourly rainfall to the accumulated 24-hr rainfall.

3.2.3 Lahar - Rainfall Relationship

(1) Lahar Monitoring System under the PHIVOLCS

The U.S. Geological Survey (USGS) installed a lahar monitoring system in 1991 and then the PHIVOLCS maintains the system with assistance of the Philippine National Police.

The lahar monitoring system is composed of rain gauges and acoustic flow monitors. Data observed by the rain gauges and acoustic flow monitors are radiotransmited and recorded in the computers located at both the Pinatubo Volcano Observatory at Clark Field and the head office of the PHIVOLCS in Manila.

The system installed in 1991 was composed of telemetered six (6) rain gauges and seven (7) acoustic flow monitors as tabulated in Table D.9. At present, the PHIVOLCS maintains seven (7) rain gauges and seven (7) acoustic flow monitors also shown in Table D.9.

(2) Relation between Rainfall and Lahar Volume

During the 1992 lahar season, the PHIVOLCS established a watch point at the Mactan Gate or No.2 Sabo Dam site of the Sacobia River and conducted the observation/ measurement of active lahar events.

The observation/measurement was continued from end of June through the middle of September and several information were recorded for the events of 18 days of this period. The data thus obtained contains information such as flow height, flow velocity, width of active channel, discharge, temperature, diameter of sediment transported in lahar, flow condition and other information related to volcanic activities including time of secondary explosion.

The PHIVOLCS used these data to: (1) correlate the Sacobia acoustic flow monitor data with the observed flow discharge, (2) estimate the cumulative volume of 1992 lahars along the Sacobia River using the calibrated flow monitor data, (3) estimate the minimum intensity and duration of rainfall that triggered lahars along the Sacobia River, and (4) correlate the total amount of rainfall with the magnitude of the associated lahar (Ref.D.4).

Figure D.26 shows the relation between the acoustic flux during one lahar event (AF) and observed lahar volume (LV) in which the correlation can be represented by a linear fit LV=0.014 AV. This relation may be used to estimate the sediment volume transported to down reaches. The lahar volume in 1992 estimated from this equation (including water) by the PHIVOLCS gives 100 mil. m^3, while the lahar deposits estimated from aerial photo and thickness estimates in the field is 70 mil. m^3, thus giving reasonable results, if the water volume contained in the lahar are considered.

Regarding the rainfall which triggers lahar along the Sacobia River, the PHIVOLCS proposed the following equation (threshold curve) also indicated in Figure D.26.

$$I=45.69\ D^{1.47} \qquad \text{(Eq.D.4)}$$

where; I : rainfall intensity (mm/min)
D : rainfall duration (min.)

3.3 *FLOOD ANALYSIS*

3.3.1 Probable Discharge in Neighboring Rivers

As explained in 3.1.2, the DPWH and the PAGASA have water level measurement data in thirteen (13) stations in and around the study area. However, the record period of most stations, including the San Nicolas Station located in the Bamban River, is too short (less than 10 years) and moreover there are too many missing data in most of the stations to undertake probability analysis.

Out of thirteen (13) stations, three (3) stations, namely the Del Carmen (Porac River), Valdez (Porac River) and Pabanlag (Gumain River) have data record of 26 years, 15 years and 31 years, respectively, which may be of enough length to conduct probability analysis.

These rivers run in the eastern/southeastern slope of Mt. Pinatubo and from the location, it can be judged that these rivers have same hydrological characteristics with the Sacobia-Bamban and the Abacan river basins.

Therefore, in order to grasp the specific discharge of the Sacobia-Bamban and the Abacan river basins, the probability discharge and its specific discharge at these three (3) stations were computed. Figure D.27 indicates probability graphs of two (2) stations in the Porac

River and one (1) station in the Gumain River. The following table tabulates probable discharge and its specific discharge at these three (3) stations.

(Unit: m^3/s)

Return Period (year)	Porac River Del Carmen (111 km^2)	Valdez (118 km^2)	Gumain River Pabanlag (128 km^2)
100	961 (8.66)	930 (7.88)	710 (5.55)
50	783 (7.05)	751 (6.36)	604 (4.72)
20	576 (5.19)	546 (4.63)	473 (3.70)
10	438 (3.95)	411 (3.48)	381 (2.98)
5	315 (2.84)	292 (2.47)	294 (2.30)
2	168 (1.51)	151 (1.28)	178 (1.39)

Figures in parenthesis under the name of the station indicates catchment area of the station. Figures in parenthesis on the right of discharge is specific discharge.

3.3.2 Flood Runoff Model

(1) Alternative Cases for Flood Runoff Model

Flood runoff analysis was made for both of the Sacobia-Bamban River Basin and the Abacan River Basin. The calculation was made only one (1) case for the Abacan River, while for the Sacobia-Bamban River Basin, following six (6) cases were calculated in consideration of (1) river course of the Sacobia River and (2) piracy of the East Pinatubo Pyroclastic Flow Field (EPPFF).

1) River Course of the Sacobia River

(a) The Sacobia River which contains too much sediment is designed to be combined to the Bamban River through the Sapang Balen River after sediment deposits in the sand pocket which will cover the same area as existing one.

(b) The Sacobia River is designed to be joined between the Road 3 and the Road 329 in which sand pocket will have smaller area than the existing one.

(c) The Sacobia River is designed to be joined just after the Road 3 which is the condition sediment to be transported to downstream becomes smaller.

2) Piracy Condition of EPPFF

(a) The EPPFF belongs to the catchment area of the Sacobia River which was a condition before the river piracy occurred in October 1993.

(b) The EPPFF is captured to the Pasig River and the Sacobia River reduces its catchment area as can be seen at present.

As the combination of the cases mentioned above, probable discharge of the following six (6) alternative cases was calculated for the Sacobia-Bamban River Basin.

Alternative Case	River Course of Sacobia River	Condition of EPPFF
1 - 1	(a)	(a)
1 - 2	(a)	(b)
2 - 1	(b)	(a)
2 - 2	(b)	(b)
3 - 1	(c)	(a)
3 - 2	(c)	(b)

(2) Modeling by Storage Function Model

The Storage Function Method is employed for the flood runoff analysis because this method can express the non-linearity of rainfall-runoff relation and it has been used widely for a long time to generate hydrographs. A basin runoff is constructed for each river based on the subbasin divisions and the topographic conditions.

The Storage Function Model was developed to express the non-linear characteristics of runoff phenomena by introducing the following function between the storage volume (S) of a basin and the discharge (Q) from the same.

$$S = KQ^P \quad \text{(Eq.D.5)}$$

where; K and P are parameters.

This equation is used with the equation of motion which expresses runoff as proportional to the exponent of storage volume. In this equation, runoff phenomena is considered to be similar to the runoff from the notch of a container filled with water.

Runoff calculation is performed in combination with the following equation of continuity for basin.

$$dS/dt = fr_{ave}A - Q \quad \text{(Eq.D.6)}$$

where;
- S : apparent storage volume in the basin (m3/s/hr)
- f : inflow coefficient
- r_{ave} : basin's average rainfall (mm/hr)
- A : area of the basin (km2)
- $Q(t) = Q(t+T)$: direct runoff height with lag time (m3/s)
- T : lag time (hr)

The Storage Function of the channel is expressed as follows:

$$S = K\,Q^P - T\,Q \quad \text{(Eq.D.7)}$$

where;
- K and P : parameters
- T : lag time for river channel

1) Division of Basin

Each river basin was divided into several subbasins to construct a flood runoff model. The division into subbasins was made in such that a subbasin is approximately 2 to 25 km^2 taking into consideration the catchment of tributaries and the topographic conditions as shown in Figure D.28 for the Sacobia-Bamban River Basin and Figure D.29 for the Abacan River Basin, catchment area of which is tabulated in Table D.10. Based on this division into subbasins, the basin runoff model is developed as shown in Figure D.30. This figure for the Sacobia-Bamban River indicates three (3) cases for the change of river course of the Sacobia River and the EPPFF is attached to the Sacobia River Basin.

2) Constants of Storage Function Model

a) K, p and TL for River Basin

Constants K and p are determined as follows:

$K = 8.6\,A^{0.1}$ .... (Eq.D.8)
$P = 0.6$ .... (Eq.D.9)
$T = 0.95\,A^{0.14}\,r_c^{-0.4}$ .... (Eq.D.10)

where; A : catchment area (km^2)
r_c: height of net supply rainfall calculated from peak discharge volume Qp in which $r_c = 3.6\,Qp / A$

In the above, equations for K and p have been proposed by the Public Works Research Institute, Ministry of Construction, Japan, while that for T has been proposed by Kadoya. Those equations are widely used in Japan as synthetic model. The constants thus, determined are tabulated in Table D.10.

b) Primary Runoff Rate (f1) and Saturation Rainfall Depth (Rsa)

The constants of f1 and Rsa are fixed at 0.65 and 300 mm, respectively, which are used for river basins on volcanic rocks formed in the quaternary era.

c) K, p and TL for River Channel

K and P for river channels are determined assuming the flow as Manning's uniform flow. Constant K is expressed in the form of:

$K = L\,B^{0.4}\,(n / I^{0.5})^{0.6} / 3.6$ .... (Eq.D.11)

where; B : average channel width (m)
L : channel length (km)
n : Manning's roughness coefficient
I : average channel slope

In the channels in which sediment has been widely deposited and erosion is occurring at present, the following equation is applied to obtain the channel width B. Constant 5 is used in the sand pocket.

$B = 3 \sim 5\,Q^{0.5}$ .... (Eq.D.12)

The constant "P" takes the value of 0.6 from the Manning's Formula for Steady Flow. The lag time T is expressed by the following equation:

$T = L\ \ kc\,p_c / I_*^{\,1-Pc}$ .... (Eq.D.13)

where; L : catchment length (km)
kc : $(n / s^{0.5})^{Pc}$
Pc : 0.6
I_* : maximum inflow volume (m3/s)

These constants were decided as shown in Table D.10 after trial calculations.

3.3.3 Probable Peak Discharge and Hydrograph

Probable peak discharge distribution of six (6) cases for the Sacobia-Bamban River Basin is shown in Figure D.31 and that of the Abacan River Basin is indicated in Figure D.32. The probable runoff flood hydrograph at the representative points of the Sacobia-Bamban River (Alternative Case 1-2) and the Abacan River are presented in Figures D.33 and D.34, respectively.

3.3.4 Verification of Obtained Peak Discharge

In general, the flood runoff model should be verified from the view point of conformity of the computed runoff hydrograph with the actual discharge hydrograph, even though the synthetic model is applied. However, as for the Sacobia-Bamban and the Abacan river basins, verification of this method is difficult to be applied due to the following reasons.

1) Before the eruption of Mt. Pinatubo in 1991, there are available discharge data obtained by the DPWH and the PAGASA. However, no rainfall data in high elevation areas are available to establish runoff model for the purpose of verification, though.

2) After the eruption of Mt. Pinatubo, water level measurement is continued at the NASUDECO Stations in Porac River and in addition, new stations have been established in some rivers running on the eastern slope of Mt. Pinatubo including the San Francisco Bridge of the Bamban River and the Ninoy Aquino Bridge of the Abacan River. However, due to the sedimentation and/or dredging of the riverbed, the measured water level is hard to be converted to discharge.

In consideration of the above restraints, the verification was made in the way that the specific discharge of the obtained probable discharge at the representative points are compared with the actual specific discharge at the Del Carmen and Valdez stations in the Porac River and the Pabanlag Station in the Gumain River. These specific discharges are indicated in Figure D.35 together with the regional specific curves (Ref.D.5). From the specific discharge, the runoff model and the obtained peak discharge are appropriate and it is judged that the probable peak discharge distribution and hydrograph can be used for the planning and design for the Sacobia-Bamban and the Abacan rivers.

3.4 LOW FLOW ANALYSIS

3.4.1 Selection of Water Level Gauging Station

At present, only one (1) water level gauging station, namely, Nasudeco Station of the Porac River, is operated continuously for almost ten (10) years in and around the study area. In this station, all the data/records such as cross sections of the station, flow measurement and water level measurement which are conducted three (3) times a day are available and therefore, it is judged that more reliable analysis may be done through review of data including rating curve.

The catchment area of this Nasudeco Station is also located in the eastern slope of Mt. Pinatubo as shown in Figure D.36 and therefore, similar hydrological characteristics to the Sacobia-Bamban and the Abacan river basins is expected.

3.4.2 Review of Rating Curve

In Nasudeco Station, the DPWH has established a rating curve. However, this rating curve was made based on discharge data water depth of which were less than 1.5 m. Therefore, this rating curve, even if extrapolated, is not applicable for most of floods with much higher water level. Hence, new rating curve are prepared by the Study Team to cover up to the bankful discharge, applying the Manning's uniform flow formula to the average cross-sections before the eruption of Mt. Pinatubo. The rating curve which is newly established is presented in Figure D.37.

3.4.3 Flow Duration Curve

Based on the established rating curve mentioned above, daily average flow was estimated for the years of 1986, 1987, 1989 and 1990 using the water level data measured by the DPWH. The other years without complete observation data were excluded from the calculation. Also discharge in the years after eruption of Mt. Pinatubo was not computed since the discharge is hardly to be estimated due to serious riverbed fluctuation in the Porac River. Figure D.38 indicates flow duration curves for the year of 1986, 1987, 1989 and 1990.

Using the discharge data for four (4) years mentioned above and annual average daily discharge of 4.71 m^3/s (Catchment area of the Nasudeco Station: 119.1 km^2), a normalized daily flow duration curve was obtained as indicated in Figure D.39.

As for the Sacobia-Bamban and the Abacan river basins, it may be judged that their hydrological characteristics are similar to that of the Porac River. Therefore, the same average daily discharge per catchment area and normalized daily flow duration curve for the Nasudeco Station may be applied to the Sacobia-Bamban and the Abacan river basins.

3.4.4 Dependable Discharge

Flow pattern estimates at the Sacobia-Bamban and Abacan rivers were performed and the results tabulated in Figure D.40 for the pre-eruption era which respectively shows the daily flow duration curves for the tributaries of the two rivers and the 10-day, 80% reliable daily and monthly flows. Since there are no gauging stations of sufficient record length in the two river systems, the pre-eruption records of the Porac river from 1945 to 1979 were utilized in unadjusted form with the assumption that artificial influences, i.e., (upstream diversions) above the gauging stations are insignificant. There are also no surveyed communal systems in the upstream reaches of the Sacobia-Bamban and Abacan river basins.

The estimate, however, should be considered as preliminary and should be adjusted by a rainfall proportionality factor to account for rainfall variability on the study area. A rainfall ratio of 1.0 was utilized in making the estimates due to the lack of adequately long and reliable rainfall records over the two catchments.

D.4 GROUNDWATER

4.1 PRE-ERUPTION

The assessment of groundwater resources in the project area prior to the Pinatubo eruption was based on the rapid assessment of water supply systems in the Philippines conducted by the then National Water Resources Council (NWRC). Based on NWRC's results for the provinces of Pampanga and Tarlac, the project area is generally a shallow well area, i.e., with the static water level generally within 6 m below the ground surface (mbgs) and wells with depths not greater than 20 m. Difficult areas, i.e., areas where the groundwater depths vary considerably and about 25% of which may yield non-productive boreholes, occur only within the 20 km radius of the Mt. Pinatubo crater and within the areas occupied by Mt. Arayat.

On the basis of about 207 test wells within the project area, the average static water level ranges from 1.8 m in the town of Concepcion to 11.0 m in Angeles City. The average well drilling depth varies from 12.3 m to 82.63 m. The range of the average specific capacity is from 0.65 to 1.05 lps/m. Table D.11 summarizes the average static water level, well depth and specific capacity in the municipalities situated within the study area.

The groundwater mining picture depicting the relationship between groundwater mining withdrawal and the period of exhaustion of the entire influence area of the Pampanga river basin is governed by the following equation

$$Q = (77{,}140 / T) + 3{,}300 \quad \text{(Eq.D.14)}$$

where: Q = mining withdrawal (MCM/yr)
T = period of exhaustion (yr)

The total groundwater storage for the entire Pampanga river basin is estimated to be 77,140 million cubic meters (MCM) with an inflow of 3,300 MCM/yr. For the project area which is about 2% of the entire Pampanga river basin, the groundwater storage is estimated to be 1,638 MCM. The recommended safe yield for the entire Pampanga river basin is set at 3,300 MCM/yr. A total of 4,850 MCM/yr is available for a 50-year mining withdrawal.

4.2 POST-ERUPTION

The assessment of the groundwater resources in the project area during the post-eruption era was based on 1) actual survey and interview of tubewell owners 2) post-eruption groundwater assessment by the Bureau of Mines and Geo-Sciences and 3) geo-resistivity test by the National Water Resources Board.

Result of field survey and interview in Angeles, Mabalacat, Mexico, Bamban and Concepcion show that the project area is still predominantly a shallow well area. The average static water table level ranges from about 1.8 m to 10.4 m below the ground surface (mbgs) while the well drilling depth ranges from 6.0 m to 61.0 m. Table D.12 shows a summary of the essential groundwater and well characteristics in selected sites of the project area.

According to the tubewell owners in the project area, the groundwater yield and static water table level remained practically the same after the Pinatubo eruption. This is proven by the fact that tubewells installed several years before the Pinatubo eruption still yield essentially the same discharge at the present time. Although a reduction in well discharge by about 30 to 50 % during the dry months of April and May is notable, this discharge reduction in the said months was already prevalent even during the pre-eruption era.

Of all sites surveyed, the groundwater wells in the project area are generally of the shallow type, i.e., with the static water level within 6.0 m below the ground surface and drilling depths of not more than 20.0 m except in the municipality of Mexico in Pampanga where the drilling depth goes as deep as 61.0 m. This is attributable to the fact that the soil formation within the groundwater reservoir in Mexico is predominantly of the clayey type and hence, a relatively low transmissibility unlike in the other areas whose soil formations are predominantly the sandy type.

A study conducted by the Bureau of Mines and Geo-Sciences after the Pinatubo eruption similarly indicates that the pre and post-eruption groundwater conditions are essentially the same. A summary of the groundwater and well characteristics in selected sampling points in the project area is presented in Table D.13.

A more meaningful assessment of groundwater resources in the project area was conducted by the NWRB through geo-resistivity survey. Table D.14 summarizes NWRB's geo-resistivity results in the selected sites located within the project area.

It is evident from the geo-resistivity resulted of NWRB that the project area is generally a shallow well area. Productive aquifers in the project area lie within 1.0 to 12.0 m below the ground surface. There are areas, however, that are highly stratified that productive aquifers lie within shallow and deep layers. Examples of this are some of the barangays in Mexico namely; San Jose and Dolores where productive aquifers lie at a depth of 120 m and 61 m, respectively, although another productive aquifer in the former lies within 1.4 mbgs. This stratification partly explains the fact that wells in Mexico are usually of the deepwell type.

An estimate of the potential maximum number of wells that could be developed in the project area are based on NWRB's data is presented in Table D.15.

D.5 WATER QUALITY

5.1 WATER QUALITY : PHYSICO-CHEMICAL

The water quality standards of the Philippines and WHO are presented in Table D.16. Reports about the pre-eruption conditions on surface and ground water around the Mt. Pinatubo area are few. The earliest reports were made by the GIRD (1981) in connection with an environmental assessment of the Sapang Bato Resettlement Project (Table D.17). In the same year, GIRD also examined four rivers, namely; the Mabanglo River, Marimla River, Sapang Cauayan River along with the Bangot River and a spring in San Juan. The same group studied the Abacan River in 1982. Data on these bodies of water are presented in Table D.18. The NWRC and the DPWH are the two government agencies that have gathered information on Central Luzon rivers including those in Pampanga and Tarlac. These data are also found in Table D.19. The rivers examined by the NWRC in 1983 which are closest to the Study Area in Pampanga are those of Sto. Niño and San Jose rivers, both of the town of San Fernando.

(1) Total Dissolved Solids (TDS)

Tables D.20 and D.21 shows that between 1991 and 1994, the TDS in the Rio Chico River stayed below 190 mg/L. In Sacobia River a definitely increasing trend was noted between 1991 and 1994, the amounts in recent determinations being double that earlier ones. Abacan River, however, did not indicate a similar trend.

Results of the present study pertaining to surface water in some areas in Angeles City, Mabalacat, Mexico, and Magalang, all in Pampanga; and Bamban and Concepcion in Tarlac show that a considerable increase in TDS concentration has taken place (Table D.21). The minimum established in the present study is roughly equivalent to the maximum of Sacobia River in 1991-1992 while the maximum is a little less than two-and-a-half times the same.

With respect to groundwaters, Table D.22 shows that places in Pampanga and Tarlac had TDS levels ranging from 322 mg/L to 429 mg/L in 1991. Comparing the presently obtained levels with the above, it can be seen that present minima are slightly higher than the maximum mean above. Furthermore, the present maximum is slightly higher than twice the earlier-reported maximum. Although rising TDS are indicated, the values are still below standard.

(2) pH

The DPWH data on the Rio Chico River indicate that the river developed a minimal decrease in pH between 1991 to 1993 which was equivalent to ca. 0.6 unit (Table D.20). Most of the present determinations indicate that surface waters tend to be on the slightly alkaline side (Table D.21). Three places out of eight sampled showed a slight development acidity. Sapang Bato was found to have changed markedly from its acidic pH of 6.3 in 1982 to a present slightly alkaline pH of 7.8. All levels observed are all within the normal range for bodies of water outside of the influence of Mt. Pinatubo. Unpublished information obtained by Zafaralla and associates in Cauayan River which presently empties into Sacobia Lake ranged from 6.5 to 9.6. The Sto. Tomas River which they likewise sampled have a pH range of 6.5 to 7.5.

In the case of ground water, the 1991 pH levels in various sampling areas in Pampanga and Tarlac varied within the normal range (Table D.22).

(3) Dissolved oxygen

Zafaralla and associates are the only ones engaged in an on-going examination of the behavior of this parameter in various bodies of water in Tarlac and Zambales. They report that there was a generally normal level of DO in the Cauayan River and Sacobia Lake after the eruption, the mean range being fro 5.8 - 9.6 ppm. Unpublished data in Sto. Tomas River of Zambales indicate that DO may become as low as 2.6 mg/L. The minimum amount measured in the present study is more than this minimum. All other levels noted are within normal.

(4) Chlorides

Data on the Sacobia and Abacan rivers gathered by the DPWH indicate a seeming inconsistent trend in the levels of this parameter from 191 to 1994 (Table D.20). Unpublished data of Zafaralla and associates indicate a chloride mean range of 185 to 258 ppm for the Cauayan River - Sacobia Lake system. The present levels (Table D.21) observed in surface and ground waters compare favorably with reports extending from 1983 to 1994 (Tables D.16, D.20 to D.23).

(5) Calcium

Information gathered by the DPWH in surface waters between 1986 to 1994 in Rio Chico River indicate a definite increase of over 70 percent (Tables D.16, D.20 and D.21). Sacobia similarly manifested an increasing trend; but the Abacan River did not. The present minimum of 60 mg/L is lower than the minimum observed by the DPWH but much higher than the levels noted in 1982 by the GIRD. The present maximum of 234 mg/L is lower than the maximum established by the DPWH for Sacobia.

Groundwater calcium in 1991 had a mean range of 17 to 22 mg/L (Table D.22). An evident elevation in calcium content of ground waters from the sampled places indicated. The increase ranges from four to almost six times the maximum in the above cited range (Table D.23).

(6) Magnesium

The IGST findings presented in Table D.23 indicate the mean magnesium range in 1991 to be from around 8 mg/L to 17 mg/L. The present data (Table D.22) indicate that present levels may range from a low of approximately 3 mg/L to 132 mg/L indicative of an elevation of magnesium levels in surface waters.

Present ground water levels range from non-detectable to 47 mg/L (Table D.23). These levels are more closely related to the surface water levels reported by the GIRD in 1982.

(7) Hardness

Hardness levels indicate an increasing trend in Sacobia River (Tables D.20 and D.21) from 1991 to 1994, the highest value of 923 mg/L having been observed in the middle of the current year. Abacan river, however, did not concur this observation.

The Sapang Bato datum of 325 mg/L indicates that past levels have almost doubled in the river, evidence of Mt. Pinatubo's promotive effect on the development of hardness in bodies of water within its vicinity. The upper limits pointed out are close to exceeding the maximum permissible limit set by the WHO (1984) which is 500 ppm for both surface and ground waters. The excessive hardness of river water within the 20-km radius of Mt. Pinatubo is reiterated by the limited sampling done by the Bureau of Research and Standards (BRS, 1993) of the DPWH which report a value of 1,292 ppm.

5.2 *WATER QALITY : BIOLOGICAL*

All of the ground water samples tested had total coliform counts exceeding 1×10^5 CFU (colony forming unit) (Table D.24). Coliforms did not exceed the allowable limit of 50 MPN/100ml for Class GA (ground water source of domestic water supply). However fecal contamination of wells in Culatingan, Concepcion and Sapang Libutad was indicate.

D.6 INSTALLATION OF HYDROLOGICAL GAUGING EQUIPMENT

Under the Mt. Pinatubo JICA Study, three (3) rainfall gauging stations, five (5) stream flow/mudflow gauging stations and twelve (12) ground water level gauging stations have been constructed at the sites indicated in Figure D.41.

6.1 RAINFALL GAUGING STATION

6.1.1 Location

(1) Sacobia Rainfall Gauging Station

Sacobia Rainfall Gauging Station is located at a top of a hill near Mactan Gate of Clark Field (Coordinate: 15°10'56.9"N, 120°29'13.7"E).

(2) Bamban Rainfall Gauging Station

This station is located at Bamban Central Elementary School (Coordinate: 15°16'52.2"N, 120°34'02.8"E).

(3) Angeles Rainfall Gauging Station

This station is located at Teodoro P. Tinio Elementary School near the Abacan Bridge of the Abacan River (Coordinate: 15°09'23.8"N, 120°35'19.9"E).

6.1.2 Configuration of Equipment

(1) Sacobia Rainfall Gauging Station

Automatic rainfall gauge of one unit type (Model Number: B-432-00) which can be operated by one dry battery size C is utilized at this station (Figure D.42). However, serious ash fall at this point is judged to cause clogging of pipe to tipping bucket and therefore, overflow type rainfall collector was made which has similar structure used by the PHIVOLCS as indicated in Figure D.43.

When it rains with ash, ash settles into the settling pipe and rain water overflows into the tipping bucket of the automatic rainfall gauge through a connecting pipe. A drain is made at the bottom of the settling pipe in order to drain the settled ash and make easy to clean the settling pipe.

To protect those equipment, fence with a height of 2.0 m was installed around the equipment as shown in Figure D.44.

(2) Bamban and Angeles Rainfall Gauging Stations

In these stations, a separate type automatic rainfall gauge (BR-12-10-00) is installed. This rainfall gauge is composed of a rainfall collector with tipping bucket (B-011) and an automatic recorder (B-311) as shown in Figure D.42. The rainfall collector is installed on a tower newly constructed with height of 6 m (Figure D.45).

The automatic recorder is installed in the Principal's Office at the Angeles Station and in a small room near the Principal's Office at the Bamban Station. Rainfall data is sent from the collector to the recorder through a connection cable. The electricity is supplied from a dry battery (size C) so as to move recording chart and from a car battery which is also installed in the same room so as to move a recording pen.

6.1.3 Required Maintenance

(1) Sacobia Rainfall Gauging Station

Recording chart (S-001), dry buttery and recording pen (N-015-12) need to be changed every three (3) months. Whenever recording chart is changed, zero point of the recorder should be adjusted and time line of the chart is adjusted to the actual time. Also date and time when the new chart is inserted should be recorded on the new chart for the convenience to read recorded rainfall data.

In order to avoid clogging due to ash fall, rainfall collector and parts mentioned in the Instruction Manual may be cleaned every ten (10) days. In addition to water for cleaning the rainfall collector and other parts, water of about 3 litter will be required to fill the settling pipe up to the outlet to the tipping bucket. Interval for cleaning should be adjusted in consideration of ash fall condition.

(2) Bamban and Angeles Rainfall Gauging Stations

Car battery should be changed to the other recharged battery every one month (Two sets of batteries for both of the Bamban Station and Angeles Station and one battery charger are provided).

Recording chart (S-064) and recording pen (N-016-02) need to be changed every three (3) months. Whenever recording chart is changed, zero point should be adjusted and time line of the chart is adjusted to the actual time. Also date and time when the new chart is inserted should be written on the new chart for the convenience to read recorded rainfall data.

Periodical cleaning especially to avoid clogging due to ash fall will be also required at these stations for the parts explained in the Instruction Manual, possibly one a ten days.

6.2 STREAMFLOW/MUDFLOW GAUGING STATION

6.2.1 Location

(1) Sacobia Stream Flow/Mud Flow Gauging Station

Sensors are installed Sacobia Gorge just upstream of the confluence with the left tributary around 1 km far from the Mactan Gate (Coordinate: 15°11'37.8"N, 120°29'24.9"E), while an electric house which accommodate several equipment is located on a hill just beside the acoustic sensor owned by the PHIVOLCS.

(2) San Francisco Stream Flow/Mud Flow Gauging Station

Sensors are installed on the San Francisco Bridge of the Bamban River (Coordinate: 15°17'42.1"N, 120°38'11.7"E), while the electric house is constructed beside the bridge on the right bank.

(3) Friendship Stream Flow/Mud Flow Gauging Station

Sensors are installed on the Friendship Bridge of the Abacan River (Coordinate: 15°09'30.9"N, 120°33'31.5"E), while the electric house is constructed beside the bridge on the left bank.

(4) Capaya Stream Flow/Mud Flow Gauging Station

Sensors are installed on the PNCC Bridge of the Abacan River (Coordinate: 15°09'04.8"N, 20°37'18.6"E), while the electric house is constructed beside the bridge on the left bank.

(5) San Juan Stream Flow/Mud Flow Gauging Station

Sensors are installed on the Ninoy Aquino Bridge of the Abacan River (Coordinate: 15°07'12.6"N, 120°42'05.8"E), while electric house is constructed beside the bridge on the right bank.

6.2.2 Configuration of Equipment and Initial Setting

(1) Sacobia Stream Flow/Mud Flow Gauging Station

Stream flow/mud flow gauge station has three (3) sensors, namely radio wave current sensor (Figure D.46), ultrasonic wave water level sensor (Figure D.47), and temperature sensor which measures air temperature to adjust the change of propagation speed of ultrasonic wave by air temperature (Figure D.47).

At Sacobia Station, water level and temperature sensors are attached to an arm with a length of 8 m, while velocity sensor is installed on a steel stand with a height of 2 m with 30 degree of depression angle (Figure D.48).

These sensors are connected with three (3) cables with a length of 200 m to the equipment installed in the electric house (Figure D.49). The equipment related to water level measurement are; converter (Figure D.48), IC memory card logger (Figure D.50) and pen recorder with two pens (green and red), while those for velocity measurement are a converter with IC memory card logger (Figure D.47) and pen recorder with one pen.

The zero point of the water level is set at 10 m below the water level sensor. The chart speed is set at 2 cm/hr, the lowest speed of the pen recorder and therefore, the chart with a length of 15 m can record one (1) month data. Recording interval of recording to IC memory card for both the water level and flow velocity is variable and for all the stream flow/mud flow stations in this study, the interval was set to record data every five (5) minutes and the IC memory card can accommodate one (1) month data for this interval.

The power to all the equipment mentioned above is supplied from the Clark Field by extending power line with 3 km inside and 1 km outside the Clark Field. At the electric house, the voltage is dropped from 240V to 100 V through a transformer and the power is stored in the batteries. The power to the equipment is supplied from the batteries through the power supply unit (Figure D.50). The capacity of the batteries for both the water level and flow velocity is determined so as to supply the power at least half day in case of brownout. Figure D.51 indicates wiring diagram of all equipment mentioned above.

(2) Other Four Stream Flow/Mud Flow Gauging Station

Three (3) sensors, namely ultrasonic wave water level sensor, radio wave velocity sensor and temperature sensor, are attached to an arm with a length of 2 m (Figures D.52 and D.53) fixed on the bridge and velocity sensor is installed with 45 degree of depression angle.

Same equipment mentioned in the Sacobia Station are installed in the electric houses of the San Francisco and the San Juan stations. However, for the Friendship and the Capaya Stations, pen recorders are not equipped and therefore, water level and flow velocity data are recorded only on the IC memory card.

The power is supplied from the Angeles Electric Company to the Friendship and Capaya Stations, from the Tarlac Electric Company to the San Francisco Company and from the Anao Cooperative Electric Company to the San Juan Station. The power supplied from these companies is 220/240V and then same power supply system explained in the Sacobia Station is also used to drop it to 100V and to supply DC to all the equipment.

6.2.3 Required Maintenance

IC memory card (M-863-20) for all the stations and recording chart (B 9529AA)/ recording pens for three (3) stations mentioned above should be changed every one (1) month.

When new IC memory card is inserted, the number (file name) listed below is recommended to be entered through the key operation of IC card loggers for identification of data.

Sacobia Station:	Water Level	11yymm
	Flow Velocity	21yymm
San Francisco Station:	Water Level	12yymm
	Flow Velocity	22yymm
Friendship Station:	Water Level	13yymm
	Flow Velocity	23yymm
Capaya Station:	Water Level	14yymm
	Flow Velocity	24yymm
San Juan Station:	Water Level	15yymm
	Flow Velocity	25yymm

When the data of IC memory card is retrieved by a computer with a IC card reader by running software named "ICUTY.EXE" explained in 6.2.4, this number will be used as a file name. The first digit means type of data (1: Water level, 2: Velocity) and the second digit indicates code name of station. Then, "yymm" shows year and month when the IC memory card is inserted .

Regarding the recording pens, following three (3) pens need to be changed, namely a green pen (B9518 CU) for the water level recorder as well as red pens (B9518 CT) for both the water level and flow velocity recorders.

Whenever recording chart is changed, zero point should be adjusted and time line of the chart be adjusted to the actual time. Also date and time when the new chart is inserted should be recorded on the new chart for the convenience to read recorded rainfall data.

For all the stations, adjustment/checking of zero point of water level needs to be conducted once a year, at the beginning of the rainy season by the portable water level gauge which is provided by the manufacturer of the equipment.

At the Sacobia Station, there are many grasses in front of velocity sensor and these should be cut from time to time to avoid disturbance of radio wave propagation from and/or to the velocity sensor.

6.2.4 Data Retrieval from IC Memory Card

Velocity and water level data which are recorded in the IC memory card is retrieved through the following two (2) steps.

(1) Making a file from IC memory card using the program "ICUTY.EXE", and

(2) Making a Lotus file from the file mentioned above using Lotus add-in soft "Memoria"

The water level data is recorded as the change of voltage in the IC memory card and therefore conversion of the voltage into the water level (height from the zero point) will be required using conversion factor 2.0.

For the IC memory card for flow velocity, two (2) kinds of flow velocity is directly recorded in the IC memory card, namely value indicated in a unit of m and a unit of cm.

6.3 GROUNDWATER LEVEL GAUGING STATION

6.3.1 Location

12 stations were constructed inside the school ground of elementary schools.

(1) Angeles Ground Water Gauging Station
Gueco Balibago Elem. School, Angeles
(Coordinate: 15°10'10.1"N, 120°35'42.1"E)

(2) Dau Ground Water Level Gauging Station
Dau Central Elem. School
(Coordinate: 15°10'58.3"N, 120°35'03.3"E)

(3) Mabalacat Ground Water Level Gauging Station
Mabalacat Elem. School
(Coordinate: 15°13'38.1"N, 120°34'13.6'E)

(4) Bamban Ground Water Level Gauging Station
Bamban Central Elem. School
(Coordinate: 15°16'52.2"N, 120°34'02.8"E)

(5) Culubasa Ground Water Level Gauging Station
Culubasa Elem. School
(Coordinate: 15°08'41.6"N, 120°39'06.9"E)

(6) San Jose Ground Water Level Gauging Station
San Jose Elem. School
(Coordinate: 15°11'27.6"N, 120°38'04.7"E)

(7) Santo Rosario Ground Water Level Gauging Station
Santo Rosario Elem. School
(Coordinate: 15°14'48.3"N, 120°38'13.9"E)

(8) San Francisco Ground Water Level Gauging Station
San Francisco Elem. School
(Coordinate: 15°18'46.0"N, 120°38'11.1"E)

(9)San Juan Ground Water Level Gauging Station
San Juan Elem. School
(Coordinate: 15°07'06.9"N, 120°42'06.1"E)

(10) Magalang Ground Water Level Gauging Station
Magalang Elem. School
(Coordinate: 15°13'05.2"N, 120°39'31.6"E)

(11) Telapayung Ground Water Level Gauging Station
Telapayung Elem. School
(Coordinate: 15°11'13.1"N, 120°40'26.5"E)

(12) San Bartolome Ground Water Level Gauging Station
San Bartolome Elem. School
(Coordinate: 15°17'02.5"N, 120°40'35.8"E)

6.3.2 Equipment Configuration and Initial Setting

The station consist of observation well with a diameter of 150 mm and depth of 10 m as well as a pen recorder with two pens (green and red) to record water level as shown in Figure D.54 which is installed in a station house shown in Figure D.55. The pen recorder (W-761-03-00) is operated by four (4) dry batteries of size A. The zero point of the gauge is set at the ground level and ground water level is measured from this point.

6.3.3 Required Maintenance

The recording chart (S-115), the recording pens of green and red (N-015-11) as well as four (4) dry batteries should be changed every three (3) months. Whenever chart is changed newly, the zero point adjustment of recorder will be required. Accuracy of water level indication should be checked one a year at the beginning of the rainy season and necessary adjustment will be required based on the Instruction Manual.

6.4 OBSERVED HYDROLOGICAL DATA

Hydrological data observed from the installation of the equipment until the end of November 1994 were collected and data reading was made by the Abacan Office of MPR-PMO, DPWH together with the JICA Study Team. Daily rainfall data of three (3) rainfall gauging stations are tabulated in Table D.25. Water level and current velocity of five (5) streamflow/mudflow gauging stations are shown in Figures D.56 and D.57, respectively together with hourly rainfall of related rainfall station. In Table D.26, groundwater level of twelve (12) stations are indicated.

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Ref.No.	Title
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D.5	USACE, "Mount Pinatubo Interim Action Report", 1992