BIBLIOGRAPHIC DATA SHEET

1. CONTROL NUMBER	2. SUBJECT CLASSIFICATION (695)
PN-AAK-573	AP10-0000-G732

3. TITLE AND SUBTITLE (240)
Bicol River Basin, comprehensive water resources development study; volume III report

4. PERSONAL AUTHORS (100)

5. CORPORATE AUTHORS (101)
Tippetts-Abbett-McCarthy-Stratton
Trans-Asia Engineering Associates, Inc.

6. DOCUMENT DATE (110)	7. NUMBER OF PAGES (120)	8. ARC NUMBER (170)
1976.	309p.	

9. REFERENCE ORGANIZATION (130)
TAMS

10. SUPPLEMENTARY NOTES (500)
(Volume I: PN-AAG-164)

11. ABSTRACT (950)

12. DESCRIPTORS (920)
Philippines
Bicol River, Philippines
Weather
Water resources
hydrology
hydrological services
Mathematical models
Salinity
Sediments

13. PROJECT NUMBER (150)
4920260 00

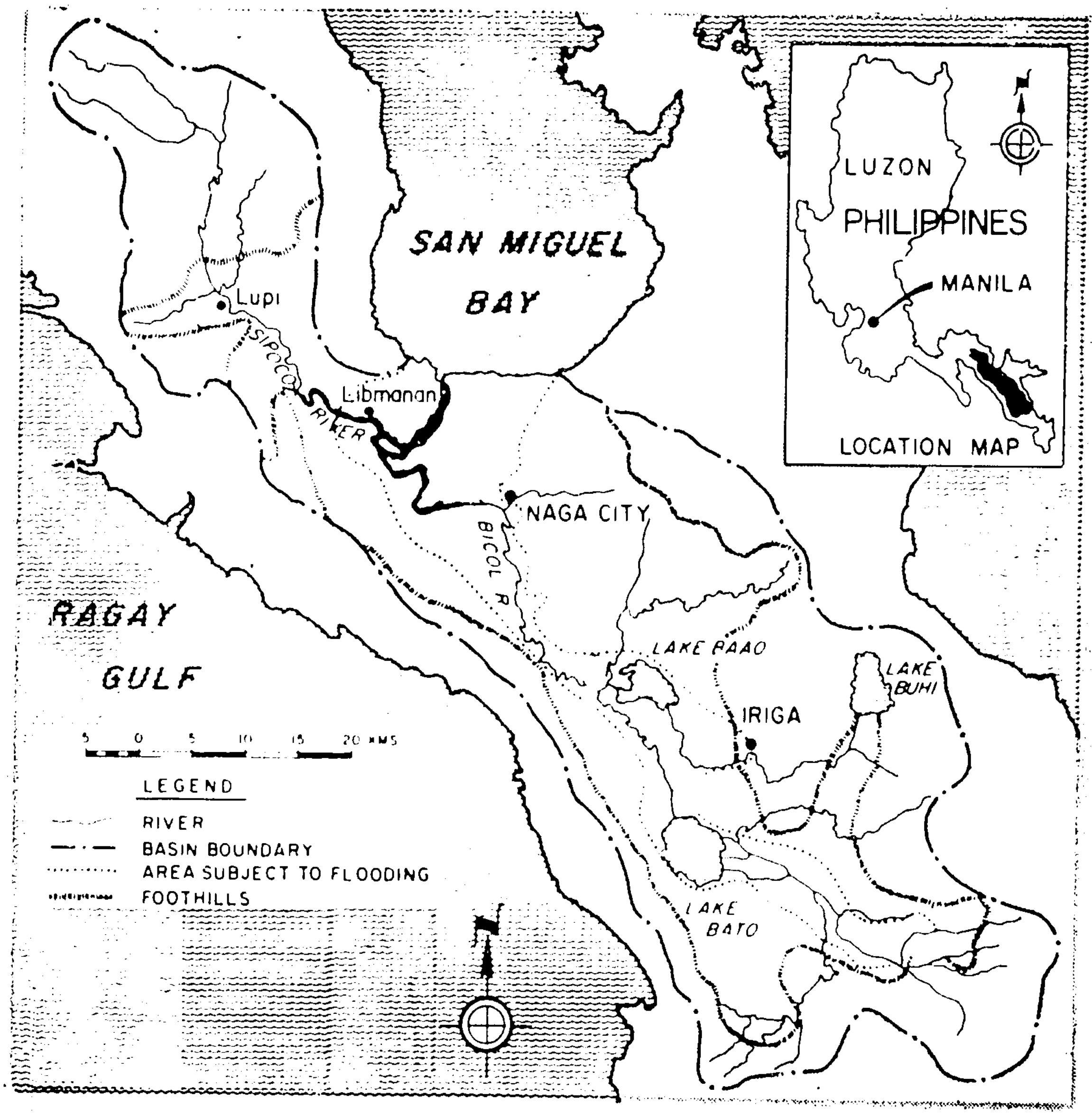
14. CONTRACT NO. (140)	15. CONTRACT TYPE (140)
UNKNOWN	—

16. TYPE OF DOCUMENT (160)
—

AID 590-7 (10-79)

BICOL RIVER BASIN

COMPREHENSIVE WATER RESOURCES DEVELOPMENT STUDY



VOLUME III REPORT
August 1976

TIPPETTS-ABBETT-McCARTHY-STRATTON
TRANS-ASIA ENGINEERING ASSOCIATES, INC. Joint Venture
New York Honolulu

BICOL RIVER BASIN DEVELOPMENT PROGRAM
Baras, Canaman Camarines Sur
PHILIPPINES

COMPREHENSIVE WATER RESOURCES DEVELOPMENT STUDY

VOLUME NO. 3
APPENDIX
TABLE OF CONTENTS

Appendix A
Climate and Hydrology
August 1976

COMPREHENSIVE WATER RESOURCES DEVELOPMENT STUDY

BICOL RIVER BASIN
LUZON ISLAND, PHILIPPINES

APPENDIX A

CLIMATE AND HYDROLOGY

AUGUST 1976

TAMS-TAE JOINT VENTURE
New York Manila

BICOL RIVER BASIN DEVELOPMENT PROGRAM
Baras, Canaman Camarines Sur

APPENDIX A

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

APPENDIX A
CLIMATE AND HYDROLOGY

INTRODUCTION

This study provides information on the areal and seasonal distribution of surface water supply and flood magnitudes. Only minimal efforts, considering the time limitations, were devoted to rectifying the existing information. In most occasions, engineering judgment was employed in making best use of available fragmental data.

PHYSIOGRAPHY

The Bicol River Basin is in southern part of the Luzon Island, located between the latitudes 13°N and 14°N, and longitudes 122°45'E and 123°45'E. See Fig. A-1.

The Eastern Bicol Cordillera, a chain of volcanoes with peaks reaching 2000 meters above mean sea level, forms the northeastern boundary of the basin. The highest point in the area is Mount Mayon, an active volcano reaching a height of 2,420 meters. The Ragay Hills, separating the Bicol Basin from the Ragay Gulf, define the southwestern boundary of the basin. The basin, a lowland of alluvium, lies between the Bicol Cordillera and the Ragay Hills. The northern boundary is San Miguel Bay.

There are three lakes, Bato, Baao and Buhi within the basin. Major drainage is provided by the Sipocot (Libmanan) and Bicol Rivers and their tributaries. These two rivers join about 8 km. from San Miguel Bay, before reaching the sea.

CLIMATE

The climate is tropical. The climatic controls over the area are two air stream systems which produce distinctive variations in the climate. These air stream systems are the monsoons and the Pacific trade winds.

The Northeast Monsoon, associated with the northern hemisphere winter, extends from October to March, bringing significant amounts of rain to the Bicol area. The Southwest Monsoon, originating in the Indian ocean affects the area during the southern hemisphere winter, from May to October. During this period the area is warm and very humid with increasing rates of rainfall.

The north Pacific trade winds prevail during April and May raising the temperature significantly. The south Pacific trade winds coincide with the southwest monsoons from May to July.

Rainfall

There are 17 rainfall gaging stations located within the Basin of which 11 have more than 4 years of record. For this study, 6 stations outside of the basin have also been included. These stations are equipped with collector-type rain gages, observing daily rainfall amounts. Fig. A-2 shows the location of the rainfall stations, and the lengths of records are indicated on Fig. A-3 for the period from 1949 to 1975. At some locations, no rainfall information is available during peak floods due to inaccessibility or flooding of the gaging stations. Recorder gages have been recently established at certain locations within the Basin, but there are still no rainfall intensity data available at present.

The rainfall distribution in the area is influenced by the air streams, tropical cyclones, the Inter-tropical Convergence Zone and the topography.

Within the Bicol region the mean annual rainfall ranges from 2000 to 4000 mm. The period from May to January is generally the rainy season. Figs. A-4 through A-16 show the areal distribution of mean annual and mean monthly rainfalls over the basin. Since there are no stations at the higher elevations, estimates have been made for those areas.

The isohyetal maps indicate a relatively dry area in the Bicol River valley, west of Lake Bato. The lower amounts of rainfall in this area may be due to the sheltering effect of the hills and the mountains surrounding it. The high rainfall over the mountains is caused by orographic effects.

Large amounts of rainfall occur in the project area during the typhoon season. The annual maximum rainfall data for 1, 2 and 3 days duration, for stations with more than 5 years of record, were statistically analyzed by employing Gumbel's extreme value method to determine corresponding rainfall amounts for various return periods for these durations. Table A-1 and Figs. A-17 through A-27 show the results of the statistical analysis. Available data on annual maximum basin rainfall

TABLE A-1

SUMMARY OF RESULTS OF FREQUENCY ANALYSES
FOR 1, 2 AND 3-DAY MAXIMUM RAINFALLS FOR STATIONS IN AND NEAR THE BASIN

Name & Location of Rainfall Station	Period of Record	Length of Record	25-Yrs. 1-Day	25-Yrs. 2-Day	25-Yrs. 3-Day	50-Yrs. 1-Day	50-Yrs. 2-Day	50-Yrs. 3-Day
Daet								
Sabang, Sipocot	1969-75	7	362.5	440.0	472.5	412.0	497.0	533.0
Yabo, Concepcion, Naga	1956-71	15	461.0	538.0	580.0	532.0	610.0	660.0
Inarihan, Calabanga	1969-75	6	235.0	304.0	337.0	266.0	335.0	367.5
BRCES, Pili	1966-75	10	435.0	490.0	530.0	483.0	550.0	588.0
SCP #9, San Jose, Banasi	1956-63	8	380.0	517.0	610.0	435.0	590.0	695.0
SCP #4, Ligao, Albay	1956-72	16	250.0	305.0	327.0	287.0	350.0	372.0
Sto. Domingo, Libog, Albay	1956-74	19	360.0	455.0	515.0	410.0	510.0	575.0
Buhi	1950-75	25	466.0	581.0	630.0	540.0	665.0	719.0
Guinobatan	1954-75	22	389.0	490.0	560.0	422.0	532.0	605.0
Legaspi City	1949-75	27	464.0	562.0	670.0	542.0	652.0	774.0
Joroan, Tiwi	1956-75	20	610.0	722.0	770.0	743.0	855.0	905.0

for two and three-day durations, associated with typhoons were compiled and listed in Tables A-2 and A-3. Attempts were made to obtain the basin rainfall for each year by employing Normal Station and Thiessen methods. However, due to lack of adequate data, the results do not represent the actual flood events in the basin. In recent years 1970 and 1975 were severe flood years, however, the computed basin rainfalls for these years do not indicate this severity.

A relatively dry season occurs from February through April. Dry periods are analyzed and presented under the section on "Droughts and Low Flows."

Temperature

The only temperature recording station within the Bicol River Basin is at Pili where the extreme temperatures range from 17.6°C in February to 34.4°C in June. The mean monthly range is from 23.4°C in December to 27.4°C in June. Fig. A-28 shows the monthly distribution of extreme daily and mean monthly temperature at Pili. The mountainous regions of the basin experience cooler temperatures due to change in altitude, however, there are no available data to quantify these variations.

Evaporation

Data are collected at three evaporation recording stations within the basin. The station at Aliang, Albay, was started in 1975 and the station at Napolidan, Lupi has a very fragmental record from 1966 to 1973. The station with the longest record and reliability is at Naga City. Though discontinuous, there are evaporation recordings available at this location from 1956 to 1973. Since evaporation rates are not expected to vary significantly within the basin, evaporation records of Naga City may be applied in reservoir mass diagram analyses for other locations under study. Observations are made with an open rim type pan with a recommended adjustment coefficient of 0.60. The monthly evaporation rates vary from 5.03 cm. per month in November to 13.64 cm. per month in May. Fig. A-29 shows the monthly distribution of evaporation rates at Naga, after the application of adjustment coefficient.

Wind

Winds are influenced by the monsoon and the Pacific trades systems. However, the highest wind speeds are associated with the typhoons crossing the area. The highest sustained wind velocities recorded have reached a peak of 275 kilometers per hour (150 knots). Extreme high wind speeds frequently damage property and distress people in the basin. A wind rose of wind speeds and frequencies from eight directions of the compass for Southeast Luzon is presented in Fig. A-30.

Humidity

A humidity recording station is located at Pili. The records indicate that the driest period of the year occurs from April through May, and during the rest of the year the relative humidity is high. Mean monthly records varied between 75% in May 1973 and 93% in July 1966 and September 1969. Fig. A-31 shows the monthly distribution of relative humidity at Pili.

Sunshine

The sunshine hours records show a trend inversely related to relative humidity. During May, when the longest sunshine hours are recorded, the observed relative humidity is the lowest. The records at Pili indicate that the mean daily sunshine hours varied from 3.05 hours in December 1969 to 9.71 hours in May 1973. Fig. A-32 shows the monthly distribution of mean daily sunshine hours at Pili.

Tropical Cyclones

The tropical cyclones affecting the Philippines originate in the ocean east of the islands between latitudes 8°N and 11°N, and generally travel on a westerly or northwesterly course over the republic. Fig. A-33 shows typical tropical cyclone tracks affecting the Philippines. The cyclones deposit large amounts of rainfall while passing over the land areas where their energy is gradually dissipated. The tropical cyclones are classified according to the maximum wind velocities (U). They fall into the following categories:

Tropical Depression	=	U < 33 knots (61 kph.)
Tropical Storm	=	33 knots < U < 47 knots (87 kph.)
Severe Tropical Storm	=	47 knots < U < 63 knots (116 kph.)
Typhoon	=	U > 63 knots (116 kph.)

The monthly distribution of frequency of occurrence of tropical depressions and tropical storms which affected the Bicol River Basin from 1948 to 1974 is shown on Fig. A-34. Severe tropical storms and typhoons cause damage to property and lives due to high wind velocities and great amounts of rainfall. Depending on their tracks, typhoons may create storm surges coming from the sea, causing severe flooding. The monthly distribution of frequency of typhoon occurrence is shown in Fig. A-35 which is based on the 1948-1974 data on typhoon passing the proximity of the Bicol River Basin. The names and dates of occurrence of the typhoons, that caused maximum precipitation within the basin, are shown in Tables A-2 and A-3.

Proximity of Typhoon Tracks to Bicol Basin

Rainfall of typhoons is dependent mainly on the intensity of the typhoon as measured by the barometric pressure. Typhoon rainfall at some point on a land surface is further dependent on the topography, which affects orographic rainfall, on the velocity and direction of the typhoon along its track and on the proximity of the track.

Proximity of typhoons can be investigated by a probability analysis of distance of typhoon tracks from a point in the river basin, in this case, Naga City, if the sample is sufficiently long to offset the effects of a possible tendency of cyclic pattern of typhoon occurrences. The probability of proximity for the 27-year period, 1948-1974, is shown in logarithmic probability coordinates in Figure 35a.

The Bicol basin extends about 90 km. in a direction normal to the usual typhoon tracks, with Naga about at the midpoint. From Fig. 35a the probability for a distance of 45 km. is 44 percent, an indication that average recurrence interval for typhoon track crossing the Bicol Basin is about one year in two. The eye of a typhoon is said by Shih-Liang Wong in his master's thesis to be usually 19 to 24 km. in a diameter, with enlargement as much as 64 km. in large typhoons. For a radius

TABLE A-2

MAXIMUM TWO-DAY ACCUMULATED RAINFALL DEPTH
(Millimeters)

Year	Station Number	Date of Two-Day Storm	Typhoon	BASIN RAINFALL Arithmetic Average	BASIN RAINFALL Thiessen Method	Daet*	Napo-lidan	Sabang Sipocot	Pasacao*	Inarihan Calabanga
1950	3	Dec. 29-30	Fran	212.5	278.6	273.4	-	-	-	-
1951	3	Nov. 20-21	Wanda	186.9	248.6	123.2	-	-	-	-
1952	2	Oct. 20-21	Trix	395.6	473.3	243.2	-	-	-	-
1953	3	Nov. 15-16	Cora	147.1	151.6	166.7	-	-	-	-
1954	3	Nov. 7- 8	Ruby	317.5	367.9	366.9	-	-	-	-
1955	3	Nov. 27-28	Patsy	303.1	277.3	264.9	-	-	-	-
1956	6	Dec. 9-10	Polly	235.5	266.9	178.1	-	-	-	-
1957	6	Nov. 10-11	Kit	215.9	211.4	413.9	-	-	-	-
1958	6	Oct. 28-29	Lorna	328.9	366.2	333.6	-	-	-	-
1959	6	Nov. 15-16	Freda	277.8	295.7	285.1	-	-	-	-
1960	6	Oct. 5- 6	Kit	306.5	321.1	183.4	-	-	-	-
1961	6	Sept.21-22	Ruby	145.3	186.5	210.4	-	-	-	-
1962	6	May 17-18	Hope	158.4	150.3	244.0	-	-	-	-
1963	6	Aug. 12-13	Luding	205.5	222.6	252.1	-	-	-	-
1964	5	June 28-29	Dading	227.4	243.3	388.1	-	-	-	-
1965	6	July 12-13		163.9	140.5	63.3	-	-	-	-
1966	6	Dec. 26-27	Aning	215.9	226.1	189.6	-	-	-	-
1967	7	Nov. 2- 3	Welming	268.9	246.4	244.5	227.3	-	-	-
1968	6	Sept.26-27		177.7	205.2	92.2	-	-	-	-
1969	8	Dec. 10-11		101.9	105.8	142.8	-	133.0	72.4	38.1
1970	8	Oct. 12-13	Sening	303.9	300.2	193.1	220.7	327.7	518.1	206.7
1971	10	Dec. 28-29		128.5	134.5	239.1	88.4	166.9	167.9	-
1972	11	June 24-25	Conching	129.6	152.1	75.9	-	118.4	204.2	-
1973	11	Oct. 14-15	Ruth	203.9	206.5	242.8	118.1	200.2	-	160.0
1974	9	June 8- 9	Dinah	357.5	382.8	220.9	-	317.8	-	-
1975	11	Dec. 24-25	- - -	219.9	228.6	271.8	-	288.0	151.0	245.4

* Stations Outside of Basin

TABLE A-2 (Cont)

MAXIMUM TWO-DAY ACCUMULATED RAINFALL DEPTH
(Millimeters)

Year	Station Number	Date of Two-Day Storm		Typhoon	Yabo Farm	Naga City	BRCES	CRIS* San Jose	SCP #9 Banasi Bula	Sta. Cruz Baao Cams. Sur	Buhi
1950	3	Dec.	29-30	Fran	-	-	-	-	-	-	298.8
1951	3	Nov.	20-21	Wanda	-	-	-	-	-	-	300.1
1952	2	Oct.	20-21	Trix	-	-	-	-	-	-	548.0
1953	3	Nov.	15-16	Cora	-	-	-	-	-	-	148.7
1954	3	Nov.	7- 8	Ruby	-	-	-	-	-	-	390.8
1955	3	Nov.	27-28	Patsy	-	-	-	-	-	-	290.0
1956	6	Dec.	9-10	Polly	312.0	-	-	-	182.4	-	372.1
1957	6	Nov.	10-11	Kit	180.3	-	-	-	119.8	-	290.6
1958	6	Oct.	28-29	Lorna	388.6	-	-	-	397.4	-	333.3
1959	6	Nov.	15-16	Freda	344.0	-	-	-	279.8	-	216.5
1960	6	Oct.	28-29	Lorna	302.0	-	-	-	380.1	-	359.4
1961	6	Sept.	21-22	Ruby	365.9	-	-	-	123.2	-	61.5
1962	6	May	17-18	Hope	66.0	-	-	135.4	173.3	-	198.1
1963	6	Aug.	12-13	Luding	241.6	-	-	-	223.6	-	177.3
1964	5	June	28-29	Dading	256.4	-	-	-	-	-	223.5
1965	6	July	12-13		123.2	154.3	-	238.5	-	-	137.7
1966	6	Dec.	26-27	Aning	-	119.4	354.4	-	-	-	244.1
1967	7	Nov.	2- 3	Welming	-	105.4	417.8	439.0	-	-	142.6
1968	6	Sept.	26-27		-	138.4	227.1	-	-	-	335.0
1969	8	Dec.	10-11		-	-	88.0	39.0	-	100.3	89.2
1970	8	Oct.	12-13	Sening	-	-	336.1	-	-	-	360.7
1971	10	Dec.	28-29		-	-	151.0	149.6	-	98.0	120.4
1972	11	June	24-25	Conching	-	-	213.0	169.8	-	126.8	173.2
1973	11	Oct.	14-15	Ruth	-	-	225.7	-	-	281.7	207.3
1974	9	June	8- 9	Dinah	-	-	443.5	507.1	-	-	620.3
1975	11	Dec.	24-25	- - -	-	-	182.1	268.7	-	182.7	175.0

* Stations Outside of Basin

TABLE A-2 (Cont)

MAXIMUM TWO-DAY ACCUMULATED RAINFALL DEPTH
(Millimeters)

Year	Station Number	Date of Two-Day Storm	Typhoon	Bato Central School	Libon Central School	SCP #4* Pio Duran Albay	Guino-batan	Malama Ligao Albay	Pantao* Libon	Legaspi*
1950	3	Dec. 29-30	Fran	-	-	-	-	-	-	65.4
1951	3	Nov. 20-21	Wanda	-	-	-	-	-	-	137.4
1952	2	Oct. 20-21	Trix	-	-	-	-	-	-	-
1953	3	Nov. 15-16	Cora	-	-	-	-	-	-	126.0
1954	3	Nov. 7- 8	Ruby	-	-	-	294.4	-	-	217.7
1955	3	Nov. 27-28	Patsy	-	-	-	251.7	-	-	405.6
1956	6	Dec. 9-10	Polly	-	-	89.2	279.4	-	-	169.4
1957	6	Nov. 10-11	Kit	-	-	138.4	152.5	-	-	148.8
1958	6	Oct. 28-29	Lorna	-	-	88.7	428.9	-	-	330.7
1959	6	Nov. 15-16	Freda	-	-	185.4	355.7	-	-	250.4
1960	6	Oct. 5- 6	Kit	-	-	237.2	376.6	-	-	254.5
1961	6	Sept. 21-22	Ruby	-	-	52.3	58.2	-	-	44.4
1962	6	May 17-18	Hope	-	-	86.6	182.1	-	-	201.1
1963	6	Aug. 12-13	Luding	-	-	84.3	254.1	-	-	303.3
1964	5	June 28-29	Dading	-	-	112.3	156.6	-	-	115.8
1965	6	July 12-13		-	-	172.5	248.0	-	-	202.5
1966	6	Dec. 26-27	Aning	-	-	101.6	286.0	-	-	217.5
1967	7	Nov. 2- 3	Welming	-	-	80.0	469.9	-	-	542.9
1968	6	Sept. 26-27		-	-	72.4	200.9	-	-	137.9
1969	8	Dec. 10-11		-	-	-	151.2	-	-	200.2
1970	8	Oct. 12-13	Sening	-	-	148.6	313.1	-	-	199.7
1971	10	Dec. 28-29		-	131.8	36.3	194.1	-	-	232.0
1972	11	June 24-25	Conching	204.5	19.3	71.6	199.7	109.5	76.2	239.7
1973	11	Oct. 14-15	Ruth	207.8	306.8	-	250.3	78.3	12.5	147.9
1974	9	June 8- 9	Dinah	-	273.5	-	379.4	102.9	182.2	338.4
1975	11	Dec. 24-25	- - -	127.0	261.3	-	380.0	70.3	181.8	580.3

Note: in the Malama Ligao Albay and Pantao Libon columns the printed values for 1972–1975 are, top to bottom: Malama 109.5, 78.3, 102.9, 70.3, -; Pantao 76.2, 12.5, 182.2, 181.8, 154.4.

* Stations Outside of Basin

TABLE A-3

MAXIMUM THREE-DAY ACCUMULATED RAINFALL DEPTH
(Millimeters)

Year	Station Number	Date of Three-Day Storm	Typhoon	BASIN RAINFALL Arithmetic Average	Thiessen Method	Daet*	Napo-lidan	Sabang Sipocot	Pasacao*	Inarihan Calabanga
1949										
1950	3	Dec. 28-30	Fran	218.4	283.5	283.5	-	-	-	-
1951	3	Nov. 20-22	Wanda	195.6	256.9	133.4	-	-	-	-
1952	2	Oct. 19-21	Trix	398.1	477.8	247.6	-	-	-	-
1953	3	Nov. 13-15	Cora	157.4	157.2	188.0	-	-	-	-
1954	3	Nov. 6- 8	Ruby	359.8	377.7	368.0	-	-	-	-
1955	3	Nov. 27-29	Patsy	383.6	366.4	327.4	-	-	-	-
1956	6	Dec. 7- 9	Polly	254.3	289.6	209.3	-	-	-	-
1957	6	Nov. 10-12	Kit	220.3	215.7	425.2	-	-	-	-
1958	6	Oct. 27-29	Lorna	407.4	428.3	350.3	-	-	-	-
1959	6	Nov. 14-16	Freda	290.9	309.4	299.5	-	-	-	-
1960	6	Oct. 4- 6	Kit	358.9	377.3	226.3	-	-	-	-
1961	6	Sept. 20-22	Ruby	154.1	191.9	211.3	-	-	-	-
1962	6	May 16-18	Hope	173.9	161.7	300.5	-	-	-	-
1963	6	Aug. 12-14	Luding	214.4	231.9	252.5	-	-	-	-
1964	5	June 27-29	Dading	239.3	258.2	405.4	-	-	-	-
1965	6	July 11-13	- - -	173.5	156.6	72.5	-	-	-	-
1966	6	Dec. 26-28	Aning	220.1	230.8	191.1	-	-	-	-
1967	6	Nov. 2- 4	Welming	257.6	253.6	251.8	251.0	-	-	-
1968	6	Sept. 25-27	- - - -	200.3	225.7	95.3	-	-	-	-
1969	7	Dec. 9-11	- - - -	133.1	133.2	188.8	-	142.6	94.5	91.4
1970	8	Oct. 12-14	Sening	319.4	328.8	226.7	245.1	337.9	527.0	250.0
1971	8	Dec. 28-30	- - -	137.5	147.2	259.7	95.8	195.1	171.2	-
1972	9	June 23-25	Conching	160.1	174.1	75.9	-	118.4	228.8	-
1973	10	Oct. 13-15	Ruth	213.7	223.0	251.1	129.5	200.2	-	160.0
1974	9	June 8-10	Dinah	367.6	405.5	234.9	-	335.1	-	-
1975	11	Dec. 23-25	- - -	267.1	261.5	464.0	-	* 314.5	192.5	262.9

* Stations Outside of Basin

TABLE A-3 (Cont)

MAXIMUM THREE-DAY ACCUMULATED RAINFALL DEPTH
(Millimeters)

Year	Station Number	Date of Three-Day Storm	Typhoon	Yabo Farm	Naga City	BRCES	CRIS* San Jose	WMP San Jose	SCP #9 San Jose Banasi	Sta. Cruz Baao Cams. Sur
1949					-		-			
1950	3	Dec. 28-30	Fran	-	-	-	-	-	-	-
1951	3	Nov. 20-22	Wanda	-	-	-	-	-	-	-
1952	2	Oct. 19-21	Trix	-	-	-	-	-	-	-
1953	3	Nov. 13-15	Cora	-	-	-	-	-	-	-
1954	3	Nov. 6- 8	Ruby	-	-	-	-	-	-	-
1955	3	Nov. 27-29	Patsy	-	-	-	-	-	-	-
1956	6	Dec. 7- 9	Polly	335.5	-	-	-	-	189.2	-
1957	6	Nov. 10-12	Kit	183.6	-	-	-	-	122.4	-
1958	6	Oct. 27-29	Lorna	455.2	-	-	-	-	433.0	-
1959	6	Nov. 14-16	Freda	358.4	-	-	-	-	284.4	-
1960	6	Oct. 4- 6	Kit	349.5	-	-	-	-	464.7	-
1961	6	Sept. 20-22	Ruby	372.9	-	-	-	-	130.3	-
1962	6	May 16-18	Hope	66.0	-	-	135.4	-	177.0	-
1963	6	Aug. 12-14	Luding	246.6	-	-	-	-	250.7	-
1964	5	June 27-29	Dading	284.2	-	-	-	-	-	-
1965	6	July 11-13	- - -	136.9	-	-	238.5	-	-	-
1966	6	Dec. 26-28	Aning	167.1	131.6	354.3	-	-	-	-
1967	6	Nov. 2- 4	Welming	462.3	105.4	429.8	446.8	-	-	-
1968	6	Sept. 25-27	- - - -	-	153.7	234.2	-	-	-	-
1969	7	Dec, 9-11	- - - -	-	-	107.0	53.2	-	-	106.7
1970	8	Oct. 12-14	Sening	-	-	347.5	-	-	-	-
1971	8	Dec. 28-30	- - -	-	-	162.8	155.9	-	-	111.4
1972	9	June 23-25	Conching	-	-	214.4	169.8	93.2	-	142.0
1973	10	Oct. 13-15	Ruth	-	-	227.8	-	-	-	305.3
1974	9	June 8-10	Dinah	-	-	474.7	720.2	614.4	-	-
1975	11	Dec. 23-25	- - -	-	-	208.8	-	299.2	-	207.4

* Stations Outside of Basin

TABLE A-3 (Cont)

MAXIMUM THREE-DAY ACCUMULATED RAINFALL DEPTH
(Millimeters)

Year	Station Number	Date of Three-Day Storm	Typhoon	Buhi	Bato Central School	Libon Central School	SCP #4* Pio Duran Albay	Guino-batan	Malama Ligao Albay	Pantao* Libon, Albay	Legaspi*
1949											
1950	3	Dec. 28-30	Fran	302.0	-	-	-	-	-	-	69.6
1951	3	Nov. 20-22	Wanda	307.8	-	-	-	-	-	-	145.6
1952	2	Oct. 19-21	Trix	548.6	-	-	-	-	-	-	-
1953	3	Nov. 13-15	Cora	148.8	-	-	-	-	-	-	135.4
1954	3	Nov. 6- 8	Ruby	402.6	-	-	-	308.9	-	-	233.2
1955	3	Nov. 27-29	Patsy	463.0	-	-	-	360.4	-	-	443.7
1956	6	Dec. 7- 9	Polly	397.5	-	-	112.0	282.4	-	-	175.5
1957	6	Nov. 10-12	Kit	292.9	-	-	138.4	159.3	-	-	149.1
1958	6	Oct. 27-29	Lorna	414.3	-	-	306.3	485.1	-	-	388.9
1959	6	Nov. 14-16	Freda	244.3	-	-	195.6	363.0	-	-	270.8
1960	6	Oct. 4- 6	Kit	420.6	-	-	265.7	426.5	-	-	288.3
1961	6	Sept. 20-22	Ruby	67.6	-	-	71.6	70.9	-	-	65.8
1962	6	May 16-18	Hope	201.7	-	-	97.8	200.7	-	-	207.5
1963	6	Aug. 12-14	Luding	177.3	-	-	89 .4	270.0	-	-	313.4
1964	5	June 27-29	Dading	224.8	-	-	122.4	159.8	-	-	115.1
1965	6	July 11-13	- - -	148.9	-	-	185.2	258.8	-	-	217.0
1966	6	Dec. 26-28	Aning	246.6	-	-	108.8	288.0	-	-	229.0
1967	6	Nov. 2- 4	Welming	150.2	-	-	80.0	528.3	-	-	578.0
1968	6	Sept. 25-27	- - - -	362.4	-	-	109.3	246.7	-	-	145.3
1969	7	Dec. 9-11	- - - -	117.7	-	-	-	195.7	-	-	244.3
1970	8	Oct. 12-14	Sening	360.7	-	-	158.0	329.3	-	-	232.4
1971	8	Dec. 28-30	- - -	120.7	-	-	36.3	206.3	-	-	237.3
1972	9	June 23-25	Conching	173.2	210.8	-	78.0	199.7	-	-	268.9
1973	10	Oct. 13-15	Ruth	241.9	-	319.8	-	263.5	107.0	182.4	161.9
1974	9	June 8-10	Dinah	647.0	-	294.6	-	400.5	70.3	183.6	422.5
1975	11	Dec. 23-25	- - -	197.1	166.3	285.0	-	433.6	-	206.0	744.9

* Stations Outside of Basin

distance of 10 km. Figure 35a indicates there is a 10 percent chance or average recurrence interval of 10 years, that an eye of a typhoon would traverse Naga. For practical purposes, it can be said that any point in the basin would have an average recurrence interval of 10 years that it would experience passage of an eye of a typhoon. Typhoon rainfall is so common and so great that it is the cause of the maximum basin-wide mean rainfall, in an annual series of probability analysis, in about 90 percent of the years of record.

STREAMFLOW

There are 27 stream gaging stations within the Basin. Discharge records are available for 23 stations and gage height data for the other four (4). Fig. A-36 shows the location and the available records and Fig. A-37 indicates the drainage areas of the stations. Table A-4 indicates the degrees of confidence of the stations. The records of the stations under tidal influence should be handled with caution especially for low flows. In this study, along the length of the Bicol River only the records of the station at Sto. Domingo, very close to Lake Bato and with slight tidal influence, were used directly in the streamflow analyses. Monthly flows for the station on the Bicol River at Ombao, Bula were constructed synthetically. Similarly, monthly flow rates for the Pulantuna River, Pulantuna Creek, Sipocot River and Talisay River were adjusted to give more realistic results at stations and at nearby project sites.

The regimes of the Bicol Basin rivers can be studied within three regions:

a. Rivers flowing into Lake Bato: Streamflow originating in the Albay region is affected by irrigation diversions before the water enters Lake Bato. The major rivers with control structures are:

Quinale River	-	Dam downstream of gage;
Irraya River	-	Dam upstream of gage.

There are other structures on their tributaries.

b. The Bicol River and tributaries down to the confluence with the

TABLE A-4

ACCURACY OF STREAMFLOW RECORDS WITHIN THE BICOL RIVER BASIN

Streamflow Gaging Station	Remarks*	
San Francisco River, Bobongsuran	Good.	Above 20 cms, fair.
Cabilogan River, Bobongsuran	Fair	
Ugsong River Benanuan	Fair.	Above 3 cms, poor. Diversion upstream
Nasisi River	Fair.	Upstream irrigation canal.
Irraya River	Good.	Above 15 cms, fair (Dam upstream)
Talisay River	Fair.	
Quinali River	Good.	Above 19 cms, fair, (Dam downstream)
San Agustin River	Good.	Above 20 cms, fair.
Agus River	Fair	
Aslong River	Fair	
Libmanan River		Station affected by tide.
Lake Bato	Fair.	Station slightly affected by tide at low flows
Bicol River, Sto. Domingo	Fair.	Station affected by tide at low flows
Pawili River, San Vicente	Fair	
Pawili River, San Roque	Fair	
Bicol River, Ombao	Fair.	Above 220 cms, poor. Station affected by tide at low flows.
Anayan River, San Roque	Good.	Above 10 cms, fair.
Bicol River, Baliwag Nuevo	Fair.	Station affected by tide at low flows.
Bicol River, Mabulo, Naga	Fair.	Station affected by tide.
Yabo River, San Isidro, Naga	Fair	
Pulantuna River		Above 40 cms, fair.
Culacling River		Above 10 cms, fair.
Pulantuna (Yabu) Creek		Above 10ccms, fair.
Sipocot River	Fair	
Bicol River, Cuyapi	Fair.	Station affected by tide.
Barit River, Sto. Niño	Fair.	Dam upstream

* Water Supply Bulletins, BPW.

Libmanan River: The Bicol River originates at the outlet of the Lake Bato. The total contributing drainage area at this location is 874 km^2. Due to storage effect of the lake, the flow into the Bicol River channel can not be directly correlated with any of the streams flowing into the Lake Bato. Major tributaries draining the mountain slopes of Eastern Bicol range are:

(1) Barit (Iriga) River - Originates at the outlet of Lake Buhi with some branches flowing into Lake Baao and others into the Bicol River before the Pawili River confluence.

(2) Pawili River - Joins the Bicol River before Ombao, Bula.

The high discharges of this river are responsible for substantial flooding both upstream and downstream of its confluence with the Bicol.

c. The Libmanan (Sipocot) River: This river originates on the humid slopes of the Bicol National Park, a thickly covered rain-forest area, under the name of the Napolidan River. Further downstreams, joined by other tributaries, this river takes the names of Sipocot and, further downstream Libmanan, with a drainage area of 596 km^2 at the gaging station at Libmanan.

During the rainy season the Libmanan (Sipocot) River discharges high peaks compared with other rivers of equal drainage areas within the region.

Rating curves, compiled from the records and slope-area calculations of the non-tidal streams within the Basin, are presented in Figs. A-38 through A-58. Although there are discharge records of the Bicol River at Ombao (Bula), and Baliwag Nuevo, the rating curves are excluded from this report. The rating curve for Sipocot River at Sabang, Sipocot was revised on the basis of a Manning's n = 0.035. There were a number of good checks between these stage-discharge curves and the results of the LATIS model for comparable locations.

The gage observations are taken on a daily basis and therefore, unit hydrographs of the rivers within the basin are not available. However, for the rivers which are not under the influence of tides, daily maximum discharge versus flood volume relationships have been established for 1, 2 and 3-day floods and presented in Figs. A-59 through A-77. The base flows, computed from Fig. A-78 were subtracted from the flood volume in establishing these relationships.

The mean flow conditions of the river Basin have been previously analyzed and presented in AIT Research Report No. 54 "Surface Water Supply Study, Bicol River Basin". Therefore, this effort has not been duplicated here.

The distribution of runoff coefficients within the basin have also been studied by AIT and presented in Report No. 48. The runoff coefficients, as shown in Fig. A-79 adopted from the AIT report, are considered adequate within the quality of available data.

HYDROLOGIC EXTREMES IN THE BASIN

Floods

Floods are produced by typhoons and tropical storms frequenting the area every year. Rainfall over the basin, especially at higher ground elevations, in durations from one day to more than a week, and the topographic characteristics of the basin cause extensive and extended flooding in the lowlands.

The flooded areas can be studied within the same three regions described in the section on streamflow and in the areas subject to tidal surge flooding.

On rivers flowing into Lake Bato, the flash floods coming down from the mountains have been somewhat controlled in recent years by construction of dike system. However, due to failure of dikes during the December 1975 floods, the Albay region of the basin was flooded. These streams, especially the ones originating at Mount Mayon, carry a large sediment load which they deposit along the lowlands as the flow velocities subside. There is a well defined delta formation at the mouth of Naporog. Most of the coarse sediment load is deposited in this and other deltaic areas around the lake.

In the Bicol River and tributaries down to the confluence with the Libmanan, Lake Bato serves as a reservoir, where substantial flood peak reduction occur naturally. According to records, the peak discharge into the Bicol River channel from the lake has not reached 450 cms. However, due to the storage effect, the surface area of the lake is more than doubled, flooding the adjacent areas, and forming a very large lake after combining with Lake Baao at peak elevations.

In the stretch between Ombao and Baliwag Nuevo, the bankful capacity of the Bicol River is 350 cms. The tributaries, especially the Pawili River, with an observed maximum peak discharge of 69 cms. (observed at San Roque, Bula) cause flooding of the low areas of the Bicol Basin, down to the vicinity of Naga City, augmented by flows from other tributaries along the route of the Bicol Basin. In addition, part of the Pawili flows contribute to flooding upstream of its confluence, in the area of Lake Baao.

The Libmanan (Sipocot) River starts flooding upstream of Sipocot down through Libmanan during extreme floods. The towns of Sipocot and Libmanan have been flooded more than once. Due to overbank flow in the vicinity of Libmanan, flood waters from this river have reached the lower areas towards Pamplona.

Tidal surges become progressively more important in the flooding of low areas toward the mouth of the estuary, with a corresponding decrease in the benefits derived from fluvial flood control.

The flood peaks of the Bicol River and its tributaries and the flood peak of the Libmanan River reach their confluence only hours apart. The Libmanan River has a much larger flow (with an estimated peak of more than 2000 cms).

The discharge records of the gaging stations were statistically analyzed by employing Gumbel's Extreme Values Analysis, and relationships between peak and daily maximum flows and corresponding return periods were established. Figs. A-80 through A-95 show these relationships. Similarly, water surface elevations (above msl) for stations under tidal influence, or for stations without flow records but with only gage heights, are presented in Figs. A-96 through A-104 for various return periods. The indicated peaks of record are the highest of two or three observations taken during the day. Actual instantaneous flood peak could be somewhat higher.

Droughts and Low Flows

The distribution of rainfall within the Basin throughout the year is not even. Generally, the period of February through May, sometimes extending well into September, is the dry season. Typical variation in monthly basin rainfall at Pili is shown on Fig. A-105.

Low rainfall amounts within the basin were analyzed for seven (7) gaging stations located in agricultural areas. Effective precipitation was estimated at or below 80 mm per 10 calendar days; any depth of precipitation in excess of this value was considered wasted. The records of the seven stations were studied and for every year, available rainfall amounts for consecutive 10, 20, 30, 60, 90, and 120 days were tabulated. Two methods were employed:

a. Year/Severity Analysis: Every year on record was arranged according to the severity of drought, considering no rainfall as 100% severity. Relative severities were established using the frequencies of rainfall lower than the designated amounts during periods of 20 to 120 consecutive days. Thus 83% severity means that once every 6 years (1/0.17) the effective rainfall is lower than the amount given by the corresponding curve. Figs. A-106 through A-111 show the result of these analyses.

b. Weibull's Extreme Value Analysis: At each station the available rainfall amounts were arranged in ascending order and assigned return periods for each duration. Then these values were plotted on Weibull's Probability paper, establishing a relationship between return periods and available rainfall amounts for each duration at every station. Figs. A-112 through A-123 show the results of these analyses.

Streamflows in the basin reach their minimum values during the low rainfall season. Monthly distribution of mean flows are shown on Figs. A-124 and A-125 for the Sipocot River (adjusted flow), and the Bicol River at Ombao (synthetic flow) considered as typical.

Low flows within the Basin were analyzed by employing the monthly discharge records of the streams unaffected by tides. In the study, synthetic flows for the Bicol River at Ombao, Pulantuna River (at the damsite), Pulantuna Creek (at the damsite) and adjusted flows for the Sipocot River at Sabang, Talisay River (at the damsite) were employed. The low water levels at Lake Bato were also included in the analysis. At each station, minimum 1 month, 2-month and 3-month average discharges in each year were taken into the study. After plotting each value with the corresponding return period on Weibull's Paper, similar to the procedure employed in low rainfall analysis, a relationship between flow and return period was established for all three durations at each station. Figs. A-126 through A-148 show these relationships. Table A-5 presents the 5-year and 10-year flow values for 1, 2 and 3-month durations at each station.

TIDES AND TIDAL STORM SURGES

The tides at the mouth of the Bicol Estuary are of a semi-diurnal type. High water stage varies from .46 m to 1.47 m msl and low water stage varies from - 0.1 to - 1.13 m msl over the period of a year for neap and spring tide, respectively. There is some inequality but the principal variations follow the moon changing phases.

Tidal effects on the Bicol reach Minalabac, where backwater effect is observed. The thalweg of the Bicol River rises one meter above mean sea level at Barrio Payogpoyan, Bula, Camarines Sur, some 70 km. upland of the mouth. Theoretically, if there were no freshwater discharge, this would be the maximum upstream location of tidal effects. The high tide at Mabulo Bridge, Naga City occurs 2 hours after the time of high tide at the mouth. Tidal observations at Balongay show that high tide occurs 10 minutes after the predicted high tide of Cabgan Island, according to the "Tide and Current Tables, Philippines, 1976".

No field measurements exist of the actual occurrence of tidal storm surges induced by typhoons. Model studies by AIT indicate that the magnitude of storm surge is on the order of 2.0 m; rising from 0.0 m to 2.0 m over a period of three (3) hours and then subsiding to 0.0 m over a three-hour period. The AIT model assumed that the typhoon passed across the mouth of San Miguel Bay, which is reasonable. The storm surge is added to the astronomic tide and as a consequence, the total storm tide can be as large as 3.47 m or as low as .87 m, corresponding to the highest spring tide and lowest spring tide. No theoretical method exists for predicting the return period of these tidal-storm surges.

The tidal stage at Pasacao exhibits an inequality at both high and low water; highest spring tide is 1.24 m while lowest spring tide is

TABLE A-5

SUMMARY OF LOW FLOW ANALYSIS FOR RETURN PERIODS OF 5 & 10 YEARS

River & Location of Station	5 Years 1-Mo.	5 Years 2-Mo.	5 Years 3-Mo.	10 Years 1-Mo.	10 Years 2-Mo.	10 Years 3-Mo.	Remarks
Quinali R. @ Busac, Oas	2.50	2.90	3.25	1.90	2.15	2.45	Dam Downstream
Irraya R. @ Obaliw, Oas	2.80	3.25	3.70	2.40	2.95	3.25	Dam Upstream
Nasisi R. @ Nasisi, Ligao	0.83	0.90	0.95	0.70	0.75	0.80	Dam Downstream
Ugsong R. @ Benanuan, Ligao			See Curves				Dam Upstream
San Francisco R. @ Bobongsuran	1.70	2.10	2.45	1.00	1.45	1.85	
Cabilogan R. @ Bobongsuran	2.60	3.00	3.50	2.20	2.60	3.00	
Talisay R. @ Damsite	0.01	0.02	0.02	0.01	0.01	0.02	
San Agustin R. @ Libon	1.80	2.20	2.50	1.05	1.35	1.70	
Agus R. @ Agus, Polangui	1.90	2.05	2.10	1.55	1.70	1.85	
Lallo (Naporog) R. @ Antipolo, Buhi	0.43	0.48	0.53	0.70	1.00	1.30	
Barit R. @ Sto. Niño, Iriga	2.45	2.95	3.15	2.00	2.30	2.65	Dam Upstream
Pawili R. @ San Roque, Bula	0.17	0.20	0.23	0.15	0.18	0.21	
Pawili R. @ San Vicente, Ocampo	0.11	0.12	0.13	0.08	0.09	0.10	
Anayan R. @ San Roque, Pili	0.20	0.21	0.22	0.09	0.10	0.20	
Yabo R. San Isidro, Naga City	0.31	0.33	0.35	0.22	0.24	0.26	
Bicol R. @ Sto. Domingo, Nabua	7.20	8.20	9.00	3.20	3.90	4.50	
Bicol R. @ Ombao, Bula	6.70	7.50	8.60	3.30	3.80	4.40	
Pulantuna R. @ Damsite	3.10	3.40	3.70	2.00	2.20	2.40	
Pulantuna Creek @ Damsite	1.15	1.35	1.50	1.10	1.30	1.45	
Sipocot R. @ Sabang Sipocot	6.85	7.85	9.00	5.00	5.80	6.80	
Culacling R. @ Rosario, Lupi	0.18	0.20	0.22	0.25	0.50	0.80	
Aslong R. @ San Isidro, Libmanan	0.37	0.42	0.50	0.23	0.28	0.32	
WATER LEVEL, MSL LAKE BATO	4.80	4.90	5.00	4.40	4.50	4.60	

- 1.14 m msl. The tide varies occasionally from a semi-diurnal type to a fully diurnal type. The occurrence of high and low tides is 90° out of phase with the tides on San Miguel Bay.

AIT conducted a model study of storm surge at this site, but unfortunately, the results are probably exaggerated because the fetch selected for wind set-up was considerably longer than would exist during a storm. Since the Ragay Gulf is deeper than San Miguel Bay, the storm surge should be significantly lower than the one calculated for San Miguel Bay.

LAKE BUHI HYDROLOGY

Introduction

Lake Buhi is a natural lake situated between Mt. Iriga to the west and a ridge, at the eastern divide of the Bicol River Basin, east of the lake. The lake has a surface area of 18 sq. km. and a drainage area, upstream from the lake outlet, of 105 sq. km. The lake is drained by the Barit River, a tributary of the Bicol River via Lake Baao. According to the manager of the Barit Hydroelectric plant, located 6 km. south of the lake, the Barit River was deepened in 1952, and with a dam constructed to form a forebay and with penstocks to turbines, generation of hydroelectric power started in 1957. The turbines discharge into the Barada River, a tributary of the Barit River. The forebay is served also by a siphon which starts to discharge when the forebay reaches water surface elevation 94.88 m. msl. Also, a flat sill overflow is available as a spillway for large floods. It has an elevation of 95 m. msl and is surmounted by hinged wooden gates, each 1 m by 1 m, held upright by chains or wires. When lowered, they form a crest at about elevation 95.3 m. msl. The plan of operation is to lower about 20 at a No. 3 alert, a plan that in effect, augments the flooding of the lower Bicol River Basin by any water in Lake Buhi initially above the normal operating level. The gates were not lowered, a workman has informed employees of the BRBC Office, during the 1970 typhoon and flood, but 6 gates opened as a result of hydrostatic and debris-pressure exerted on the gate's upstream face.

The turbines have a discharge capacity of 12.6 cms. The mean discharge through the power plant for the dry period 1961-1966, computed from kilowatt hours of generation, a head of 20 m, and an efficiency of 80 percent, was 5.3 cms. The monthly maximum was 8.2 cms and the monthly minimum was 2.5 cms. No records are kept of siphon and spillway operation, but a staff gage in the forebay is observed usually every hour.

The hydroelectric plant may not be operated when the geothermal plant at Tiwi starts operation in 1977. None the less, the plant could be used as a hydropower peaking plant in support of a base-load geothermal plant.

Rainfall

Rainfall has been observed within the drainage area of Lake Buhi only at the town of Buhi. A standard raingage has been located successively at various sites within the town, the present location being near the lake. A record exists from 1951 to date, the data of daily rainfall being that for a 24-hour period beginning at hour 8. Frequency of observation has varied, sometimes once a day, sometimes four times a day and in recent years twice a day. The mean annual rainfall is about 2630 mm.

Intense rainfall of periods from one to about four days is due mainly to typhoons, in their various stages of growth and decay, and to tropical depressions. The Bicol River Basin receives an average of about two typhoons a year. Sometimes, as in October 1952 and November 1954, the basin may experience three typhoons in a month. Because typhoons tend to have a cyclical pattern, only a long period of record should be used for statistical analyses. Rainfall of periods from one to five days plotted on log-normal probability coordinates from the period 1951-1974 indicate that median rainfall and rainfall of 50-year average recurrence intervals would be as follows:

Intense Rains at Buhi, Annual Water Year Series

Days starting 8 am:	1	2	3	4	5
Median rainfall, mm:	175	240	280	300	310
50-year rainfall, mm:	510	630	710	720	740

The greatest rainfall resulted from Typhoon Dinah, June 7-10, 1974. Rainfall of Typhoon Sening, October 12-15, had an average recurrence interval of about 3 years.

Buhi is in the lee of a ridge with respect to the usual westerly of northwesterly tracks of typhoons. Because the drainage area on Mt. Iriga lies exposed to the typhoon tracks it experiences a combination of typhoon and orographical rainfall and probably has a much greater storm rainfall than Buhi.

Runoff

Discharges have not been recorded on streams tributary to Lake Buhi, at the outlet of the lake, or at structure at the periphery of the Barit forebay. Stations on the Barit River have been operated intermittently from 1910 to 1956 at Santiago, drainage area 126 sq. km, by the National Power Corporation and intermittently from 1951 to date at Sto. Niño, drainage area 142 sq. km. (including the Barada River), by the Bureau of Public Works. The NPC records are more easily used for an analysis of runoff into and out of Lake Buhi. Monthly and annual discharges and annual yield of the Santiago station are shown in Table A-7. The yield from the basin derived from discharge data at the NPC station at Santiago seems unreasonably high, but with no proof that it is and without a basis for revising the information, no change is attempted herein. There is need before and during any period of a feasibility study of the project to review the runoff records of the Barit River Basin, and if need be to revise discharges not only of the Santiago but also the Sto. Niño station.

Runoff is usually low in April, May and June and high in November, December and January.

The water levels of Lake Buhi and the Barit forebay are observed but unfortunately during most years of observation, the Lake Buhi gage has sufficed only for low, normal and moderately high levels, with no gage installed to observe high lake levels.

Floods

Residents of Buhi hold memories of five high levels of Lake Buhi. The highest occurred in 1943, with the level up to the main street of town, estimated roughly as elevation 100 m. Subsequently, the outlet channel was excavated so that a repetition of the flood event would result in a lesser level of flooding. The remaining events, according to recollection in 1975 of high water marks, which then were surveyed by BRBC, were as follows: .

Year	Typhoon	Approximate Maximum Water Level in Lake Buhi
December, 1956	Polly	98.7
October, 1952	Trix	98.6
October, 1970	Sening	97.54
January, 1972	Aliang	97.05

On the basis of this information, the maximum water level of typhoon Sening, October 1970, was one of about 10-year recurrence interval.

The probability of water-year annual floods of the Barit River, Santiago, is shown in Fig. A-149. Again it seems that discharges are overstated, particularly events in 1952, 1955 and 1956.

Flood Discharges

Engr. Veloso prepared and sent to the General Manager, the National Power Corporation, a discharge rating curve for the outlet of Lake Buhi using lake levels versus discharges of the Barit River, Santiago. The rating is based on data of the period 1950-1955 and was applied to lake levels of the period 1954 to 1963 for studies to determine whether the lake could be used to better advantage in generation of power. The rating was as follows:

Discharge Rating of Outlet of Lake Buhi

Surface M.MSL.	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
95		3.4	4.0	5.1	6.2	8.7	9.5	11.6	14.6	17.9
96	21.5	25.6	31.0	37.1	44.0	51.5	60.0	69.0	80.0	97.5
97	100.0	130.0	150.0	176.0	203	239.0	274.0	319.0	360.0	410.0
98	470.0									

The rating, as for that at Santiago, may overstate the true discharge. The manager of the Barit power plant has stated that the channel from the lake to the Barit forebay was not enlarged in the period of 1953 to 1975. The rating is used herein, in lieu of anything better, to analyze some of the great flood events.

Flood of October 1970 - Typhoon Sening

The flood of October 1970 is of interest because it is the event used to calibrate the computer models of the Bicol River Basin. At the time of the AIT Study, discharges of the Barit River were not used as inputs into the computer network, and instead the Barit River Basin, like many other tributaries of the Bicol River, was assigned rainfall according to Thiessen polygons together with generalized runoff coefficients. An attempt will be made to derive discharge hydrographs of lake outflow and basin-wide runoff into the lake. Inflow will be compared with rainfall as observed at Buhi.

For the October 1970 flood, gage height data are not available for the Barit River, Sto. Niño, or for the Barit forebay. (The Santiago station had ceased to be operated on December 31, 1956, before the power plant started to operate and divert water into the Barada River.) Levels of Lake Buhi are available for October 1-13 and October 17-31. The gage was submerged on October 14 to 16. Rainfall, normally observed twice daily is given as a single reading and assigned - wrongly - to 5 pm, October 12. The observer may well have been hampered by typhoon winds and rain and thereafter by high lake levels, so it seem appropriate to assume he observed the gage at 5 pm, October 15 or 16. The observer reported beginning of rain as hour 2330 October 12 and end as hour 24 October 13. If rain occurred at other times, as it did at most other Bicol Stations, it paled in comparison with that of the typhoon rain, and the observer reported "no rain". A high water mark - or rather a recollection in 1975 of high water in 1970 - was surveyed in September 1975 by BRBC as 97.54 m msl.

Given the meager data, much has had to be estimated. The levels of lake Buhi, the outflow, the inflow to the lake, the accretion and depletion of groundwater storage in the drainage basin, the direct surface runoff expressed as yield in millimeters, the mass curve of rainfall at Buhi, as developed for the typhoon Sening storm and flood, are shown in Fig. A-150. Tabulation of events is shown in Table A-8.

An outcome of the estimate - whatever its degree of validity may be - is that direct surface runoff of the flood is a total of 462 mm. The accretion of groundwater storage from the storm, according to the assumed line in Fig. A-150 in excess of uniform base flow, is 160 mm. Assuming say 40 mm as the evapotranspiration loss during the period of surface runoff, there would be a total of 662 mm as average rainfall on the basin. Such an amount is about 80 percent greater than the observed rainfall 360.7 mm at Buhi. An amount greater than Buhi is expected but whether 80 percent is reliable is open to question. In addition to the differences with respect to topography there is the feature that rain gages will understate rainfall when rains are accompanied by stormy winds. In any case, further analyses should be made during feasibility studies, based on discharge measurements at the outlet of the lake.

The inflow and outflow hydrographs of Table A-8 and Figure A-150 may be used for the LATIS Computer Study.

Flood of December 1956 - Typhoon Polly

The flood of December 9, 1956 was the greatest flood of record on the Barit River. At the NPC station near Santiago (drainage area 126 sq. km.) a daily mean discharge, based on twice - daily staff gage observations, is reported as 360 cms. At the B.P.W. station ear Sto. Niño (drainage area 142 sq. km.), the daily mean discharge and the momentary peak discharge are reported as 555.5 and 859 cms., respectively. The rainfall for the rain gage at Buhi is reported as follows:

Rainfall for 24 Hours Starting at Hour (08.mm)

December, 1956	6	7	8	9	10	11	12	13
Rainfall, mm:	119.4	25.4	116.3	255.9	24.9	0.0	2.8	0.0
Accumulation, mm:	0.0	119.4	144.8	261.1	516.9	541.8	544.6	544.6

Records are not available of water levels of Lake Buhi. The residents of Buhi recollect that the lake was higher in 1956 than at any time in the last 25 years and that it was exceeded in 1943 before the Barit River Channel was deepened. Survey in 1975 of the 1956 high-water mark recalled by Buhi residents placed the water level at Elev. 98.7. If this level is reliable and if the rating curve also is reliable, the outflow hydrographs from the lake must have been very great.

Records, if any exist, of the water-level elevations of Barit forebay, are not at the Barit Power House Office.

An analysis of runoff into and out of Lake Buhi has not been attempted, despite the magnitude and importance of this flood event.

Flood of November 1955- Typhoon Patsy

The flood of November 1955 is the second ranked flood of record of the Barit River. The daily mean discharge of the NPC station near Santiago is reported as 310 cms. The daily mean and momentary maximum discharges of the Barit River near Sto Niño are reported as 199.6 and 280 cms, respectively.

An analysis of this flood with respect to the drainage basin, 105 sq. km. in area of Lake Buhi is shown in Table A-9 and Fig. A-151. By use of the NPC rating table for the outlet channel of the lake, the peak outflow is found to be 350 cms. By use of the outflow hydrographs and changes in storage in the lake, the inflow hydrograph is estimated to be 390 cms. During this event, the staff gage in the lake was submerged November 29 and 30, but NPC reports a maximum lake elevations as 97.76 m. With an initial lake level at the onset of the flood at elevation 95.53 m., the rise of level was 2.23 m., equivalent to a volume of 40.1 million cubic meters. The yield from the basin of direct surface runoff is estimated roughly at 975 mm. With storm rainfall loss to groundwater storage at 295 mm. and evapotranspiration loss assumed as 40 mm, the mean rainfall over the basin would have been 1310 mm, an amount comparable to the mean rainfall, 1313 mm, of typhoon Gloria on the 763.4 sq. km. drainage area upstream from Shihman dam in Taiwan, hereto held to be a world record. If the analysis of runoff is reliable, then some place in the drainage basin is likely to have had a rainfall greater than the 24-hour Philippine rainfall record, 1169 mm, at Baguio.

Flood of October 1952 - Typhoon Trix

Residents of Buhi hold this flood to be second to that of 1956, with reference to height of Lake Buhi water levels. By recollection of high water marks, the level would have been 98.6 m. Either the recollection is faulty or the NPC zeros of their staff gages in the lakes are inconsistent. By the NPC staff gage observations, the maximum water elevation could only be a few centimeters over the observations, 97.36 m, at hour 18, October 22. The latter amount would place the 1952 event at about the same magnitude as the 1970 event.

At the NPC hydrographic station on the Barit River near Santiago, the 1952 flood was the third greatest of record, with daily mean discharges of 250 cms. on October 22. No record is available for the BPW station near Sto. Niño.

An analysis of runoff into and out of Lake Buhi is shown in Table A-10 and Fig. A-152. The maximum discharge at the lake outlet was about 200 cms. The lake level rose about 1.4 m, equivalent to storage of 25 million cubic meters.

Flood of June 1974 - Typhoon Dinah

More rainfall occurred at Buhi - for periods from one to over five days - than in any previously recorded period. Maximum discharge from the lake, from the analysis shown in Table A-11 was less than for floods previously mentioned, that is about 110 cms, one reason being that the lake level at the onset of the flood was at a low elevation. Another reason results from uncertainty of the maximum water level, the gage having become submerged at water surface elevation 96.8 m. An estimate of maximum level is shown in Fig. A-153 as elevation 97.0 m, the pattern of gage levels being taken to simulate that of the other floods. The 1974 runoff utilized Lake Buhi storage between elevations 95.4 and 97.0, or 28.9 million cubic meters.

Discharge data for the BPW station, Barit River near Sto. Niño, are not yet available for 1974.

Flood of January 1972 - Typhoon Asiang

The flood of 1972 was memorable to the residents of Buhi as being the fourth ranked in 25 years with respect to levels of Lake Buhi. By their recollection of high water levels, the elevation would be at 97.05.m.

The high lake level occurred because the lake level at the onset of the flood was high. The storm and runoff were not otherwise of importance to project planning. The analysis of the event is shown in Table A-12 and Fig. A-154.

RECOMMENDATIONS

The existing hydrologic information on the Bicol Basin must be improved through refinement of basic data. The existing data gathering network also should be improved. An outline of recommendations for future data collection is presented in Table A-6.

The quality of the available data is nevertheless, adequate for a pre-feasibility study, and little effort was devoted to refine the data at this stage. As the studies progress into following stages, the hydrologic work presented here should be reviewed and improved according to the requirements of future work.

TABLE A-6

BICOL RIVER BASIN HYDROLOGIC DATA

Data	Existing	Required	Suggestions	Remarks
Precipitation	1. Daily records 2. Intensity Data (only very recent)	1. Extend daily rain-fall collection network 2. Install more intensity recorders 3. Install weekly/ monthly collector gages in mountains	1. Daily rainfall gages a. Schools b. Villagers or farmers 2. Intensity re-corders a. Universities Colleges b. Cities, large towns 3. Long term col-lectors a. Mobile team b. Farmers	1. Proximity to potential project sites 2. Easy access 3. Intensive control 4. Sharing data
Evaporation	Daily records	1. Extend the exist-ing network 2. Install long term data collectors near rainfall collectors on mountains	1. Daily gages a. Universities/ Colleges b. Cities, large towns 2. Long term gages a. Mobile team b. Farmers	1. Same as above

TABLE A-6 (Cont)

BICOL RIVER BASIN HYDROLOGIC DATA

Data	Existing	Required	Suggestions	Remarks
Stream Stages Stream Flows	Daily Records	1. Rehabilitate or improve existing gages 2. Extend existing network 3. Install recorders 4. Topographic establishment of datum for each gage.	1. Stream staff gages a. Gages extending above possible flood levels 2. Stream flows a. Mobile team	1. Easy access 2. Conscientious observers 3. Intensive control 4. Simultaneous flow measurements and tide observations at various flow levels in tidal reaches. 5. Continuous recording-Unit hydrographs 6. Hourly flood observations.
Flood Wave Profiles	Water surface elevations at various locations along rivers		Mobile team	Obtain from stream stage data
Tide Levels	1. Predicted astromomic tide levels 2. Tide levels at Balongay (short term)			Continuous observations during typhoons

TABLE A-6 (Cont)

BICOL RIVER BASIN HYDROLOGIC DATA

Data	Existing	Required	Suggestions	Remarks
Flood Duration	Daily Stream Stage Records	Same as for stream stages	1. Short duration (less than 24 hours) floods: hourly observations	1. Easy access 2. Intensive control 3. Conscientious gage keepers
Low Water Duration	Daily Stream Stage Records			
Sediment Transport	Individual observations	Sampling during various periods of the year	Simultaneous with flow measurement at streams	1. Bottom sampling 2. Suspended sediment sampling with depth-integrating samples. 3. Source surveys.
Water Quality	Individual observations	Sampling during various periods of the year	1. Same as current measurements 2. Additional samples at ungaged locations	Provide adequate lab. and expertise
Groundwater				Please refer to report prepared by Mr. L. Nonini.

TABLE A-6 (Cont)

BICOL RIVER BASIN HYDROLOGIC DATA

Data	Existing	Required	Suggestions	Remarks
Temperature	Daily records	1. Extend existing network 2. Install shorter interval (6 or 12 hrs.) system 3. Install wet bulb, dry bulb temperature reading system	1. Daily readings a. Schools b. Villagers and farmers 2. Other readings a. Universities/ Colleges b. Cities, large towns	1. Intensive control 2. Conscientious observers
Humidity	N o n e	Install daily humidity reading network	Universities/ Colleges Cities, large towns	Same as for temperature
Wind Speed/ Direction	Daily mean speed and directions records	Install wind speed/ direction recording stations	Pili Airport	Continuous hourly readings during typhoons
Barometric Pressures	N o n e (Outside the basin)	1. Install daily reading system 2. Short duration readings	1. Daily reading a. Universities/ Colleges b. Cities, large towns 2. Short duration readings a. Pili Airport	Same as for winds

TABLE A-6 (Cont)

BICOL RIVER BASIN HYDROLOGIC DATA

Data	Existing	Required	Suggestions	Remarks
Cloudiness Sunshine Hours	None (Outside the Basin)	1. Install daily clouding recording system 2. Install sunshine hours recorder.	1. Daily cloudiness Same as pressure 2. Sunshine hours Pili Airport	1. Intensive control 2. Conscientious observer

APPENDIX A

REFERENCES

Asian Institute of Technology: Surface Water Supply Study BRB.; USAID/Philippines; Oct. 1975.

Bureau of Public Works: Surface Water Supply, Bull. #2 Vol. I - 1945-'56 Manila, Philippines; Water Resources Survey Division: 1973.

Bureau of Public Works: Surface Water Supply; Bull. #2 Vol. II - 1945-'46 Manila, Philippines; Water Resources Research Division, 1946.

Hess, W.N., ed.: Waather and Climate Modification; John Wiley & Sons; 1974.

Howell, Wallace E. and Lopez, Manuel E.: Cloud Seeding in Southern Puerto Rico; Lexington, Mass.; W. E. Howell and Asso., Inc. 1966. (Leaflets).

Murty V.R. and Biswas, K.R.: Weather Modification in India, Institute of Tropical Meteorology; India.

Bureau of Reclamation: Project Skywater; Atmospheric Water Resources Management Program; 1973. (Xerox Leaflets).

Table A — 6a

Monthly and Annual Rainfall at Buhi, Camarines Sur
(Millimeters)

YEAR	J	F	M	A	M	J	J	A	S	O	N	D	CALENDAR YEAR	WATER YEAR
1950														
1951														
1952	246.5	145.5	108.7	11.7	114.80	206.50	290.8	669.0	185.7	899.4	375.1	509.0	3762.8	
1953	146.5	200.4	80.5	29.9	168.6	181.3	175.5	257.0	231.9	169.1	282.4	351.8	2272.9	
1954	73.9	74.4	205.2	18.0	82.3	186.9	139.2	320.8	223.5	218.2	623.8	546.3	2711.5	
1955														
1956	131.1	75.9	153.7	313.7	142.7	124.7	288.3	199.1	579.3	161.7	451.6	1231.1	3859.9	
1957	315.4	65.5	100.0	135.8	35.8	197.6	303.7	159.5	161.0	395.2	402.3	98.2	2350.0	
1958	211.1	76.5	121.4	190.8	52.6	253.2	183.4	279.4	187.2	746.3	244.3	43.2	2583.4	
1959	228.8	83.0	238.7	38.6	210.8	102.6	253.4	241.5	82.5	152.4	445.5	575.5	2653.3	
1960	85.9	105.4	48.0	142.7	333.8		164.1	185.9	173.2	597.7	236.5	172.7		
1961	129.5	12.2	42.7	38.4	124.9	129.5	256.3	290.1	333.8	246.4	222.8	356.4	2183.0	
1962	175.5	106.7	128.0	42.4	339.3	105.7	364.2	148.8	203.5	74.7	299.2	291.8	2279.8	
1963	77.5	101.1	11.9	30.2	49.3	252.5	94.9	404.4	250.2	116.3	219.2	224.8	1832.3	
1964	130.8	158.8	20.6	85.1	62.7	244.9	90.2	151.1	388.4	131.3	293.4	320.3	2077.3	
1965	197.6	40.6		20.6	1970.4	266.7	371.1	227.8	406.7	178.8	280.7	317.3		
1966	257.1	16.0	61.0	41.2	208.3	210.3	381.2	353.4	235.9	191.6	437.6	602.1	2995.7	
1967	218.5	124.7	138.3	100.6	176.1	157.7	379.8	440.9	285.0	186.1	232.1	139.3	2679.1	
1968						159.2	186.5	353.2	427.5	54.2	148.9	65.3	1608.4	
1969						190.4	307.0	175.4	144.6		309.03			
1970	98		89	32.7	23.3	91.3	298.4	283.4				313.4		
1971	187.3	313.3	148.1	43.9	295.5			49.6	165.9	237.3	207.9	441.5		
1972	355.4	33.1	58.9	31.6	173.9	350.8	197.4	524.4	204.5	154.18	359.31	221.9	2665.39	
1973	55.8	55.9	36.0	27.7	91.9	128.9	226.5	254.4	322.0	583.4	471.8	625.2	2879.53	
1974	65.4	117.4	54.3	29.3	102.0	730.2	357.7	181.1	174.9	465.7	492.7	543.2	3313.9	
Mean														
Max														
Min														

SOURCE: ANNUAL CLIMATOLOGICAL REVIEW (1952-1968) and FILES, (1950-1, 1953, 1969-74) WEATHER BUREAU

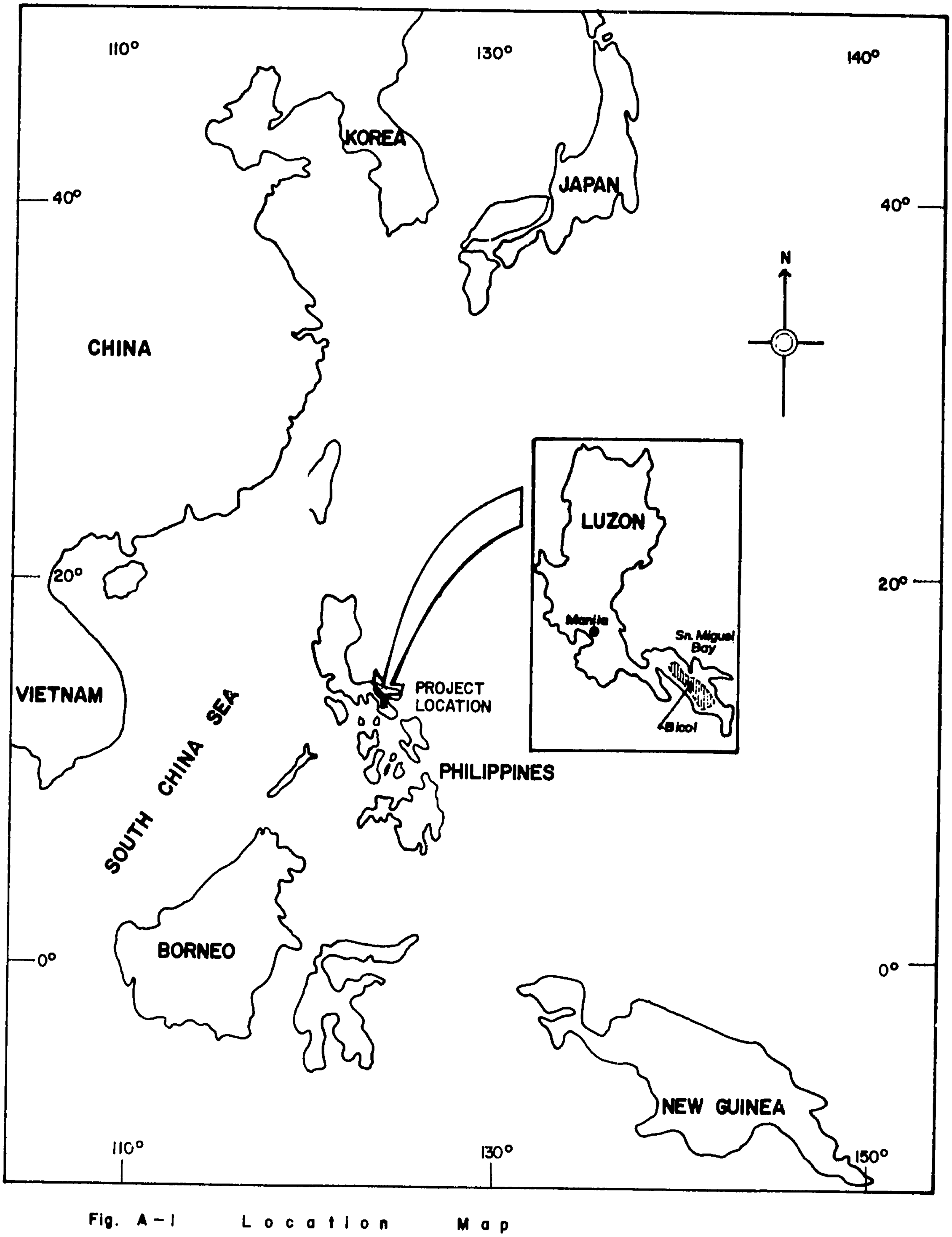


Fig. A-I Location Map

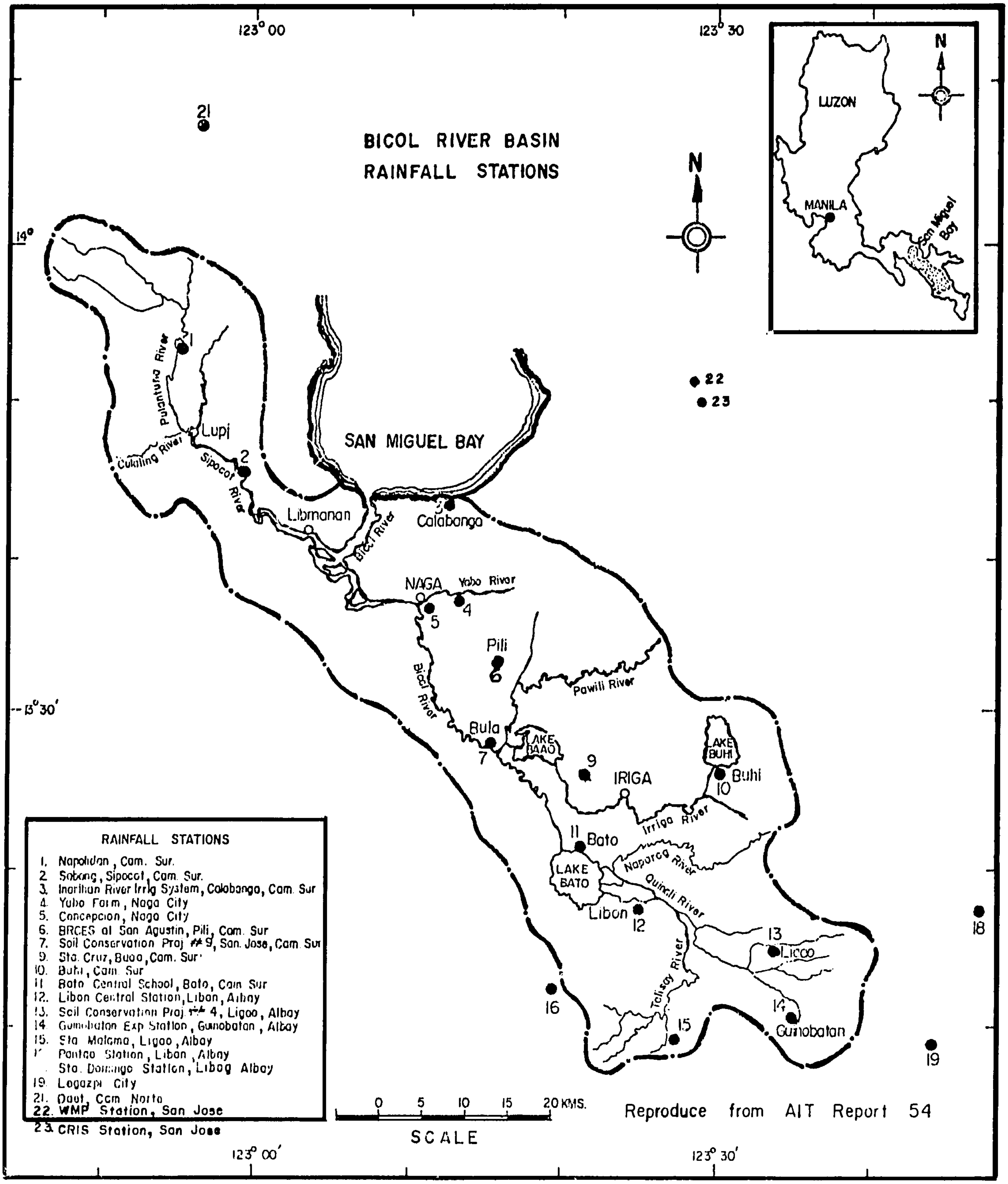


Fig. A-2 Locations of Rainfall Stations in Bicol River Basin and Its Vicinity

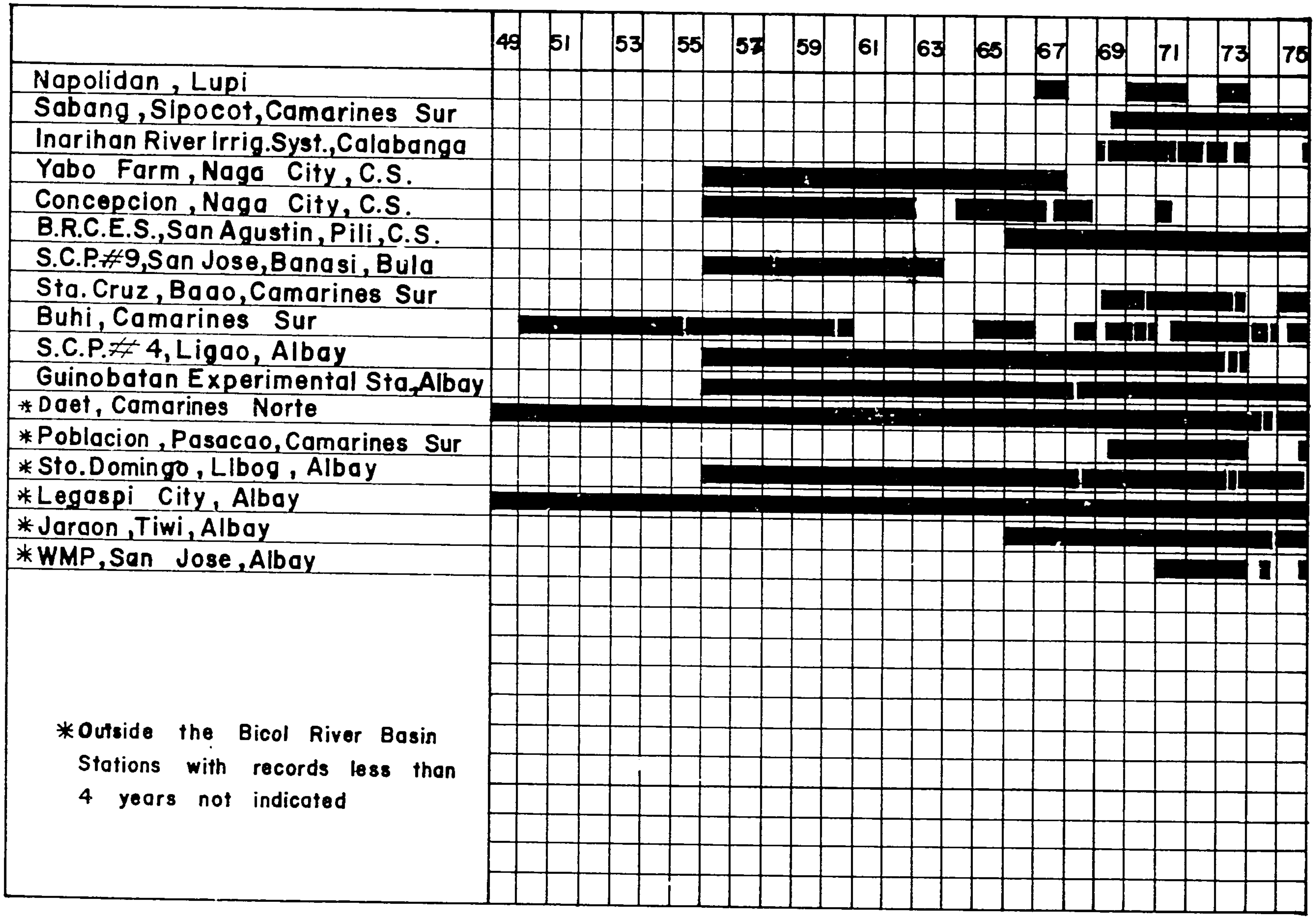


Fig A-3 Length of Record for Rainfall Stations in the Bicol River Basin and its Vicinity

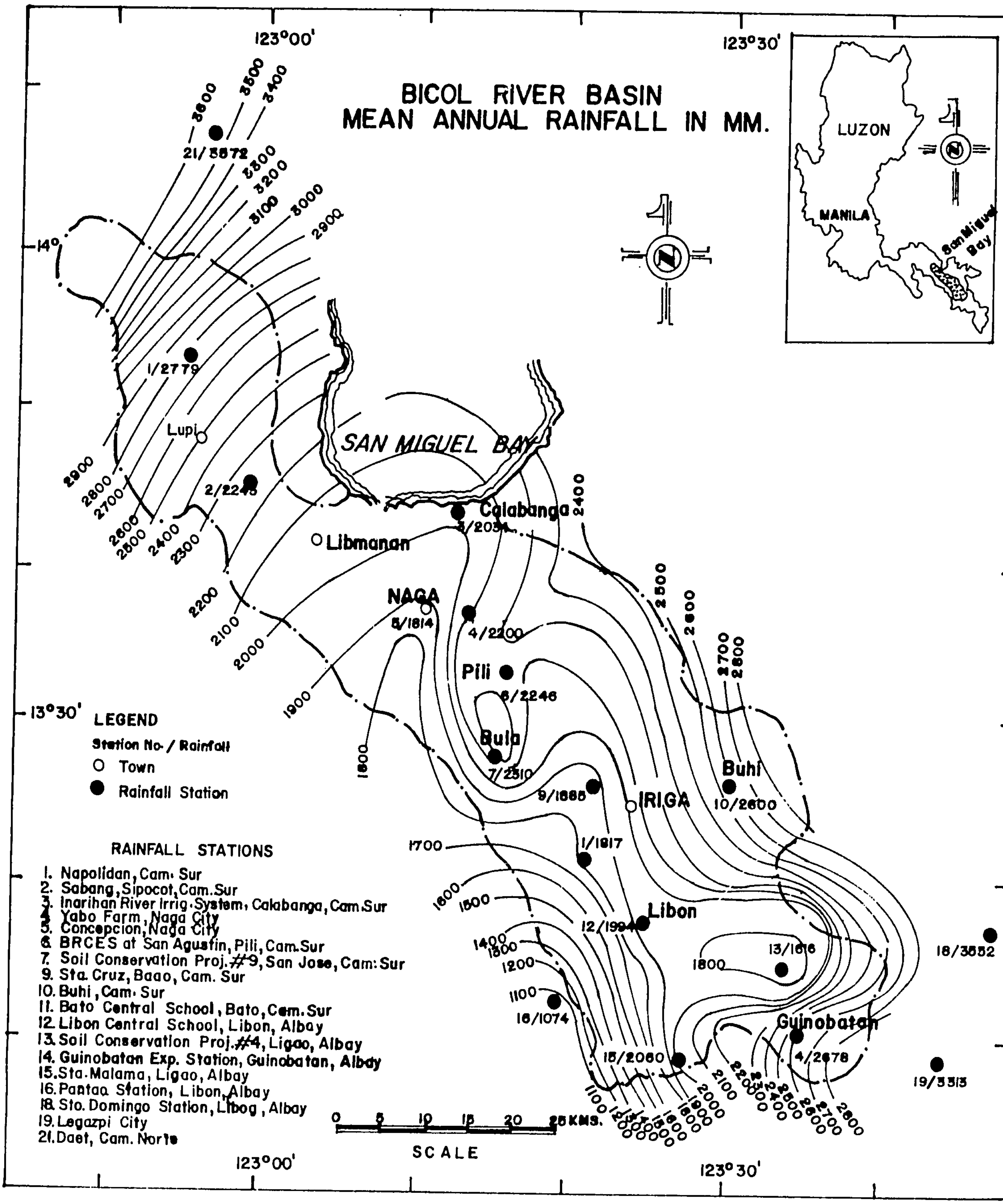


Fig. A-4 Isohyets for Mean Annual Rainfall, Bicol River Basin

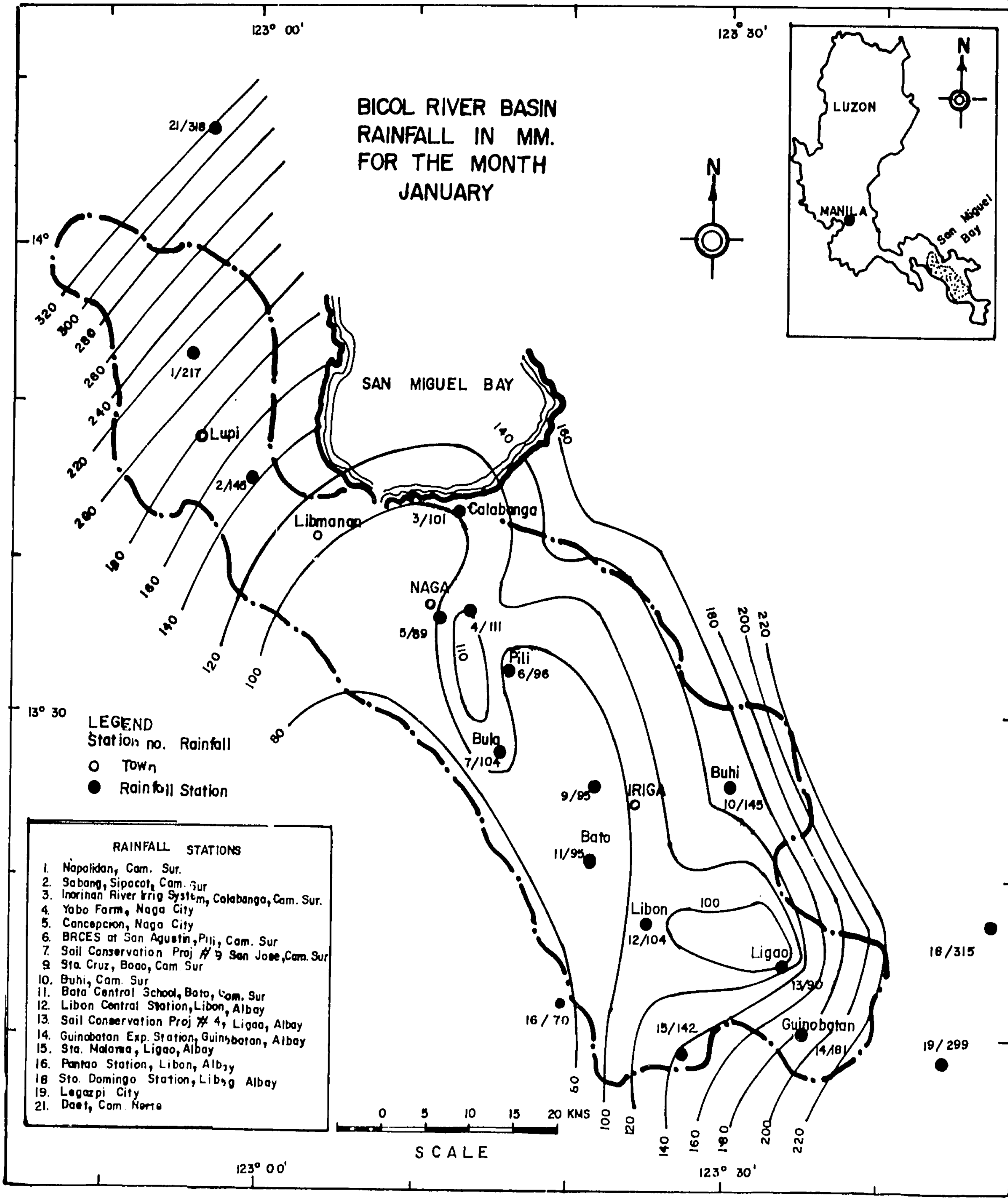


Fig. A-5 Isohyets for Mean Monthly Rainfall, for the Month of January, Bicol River Basin.

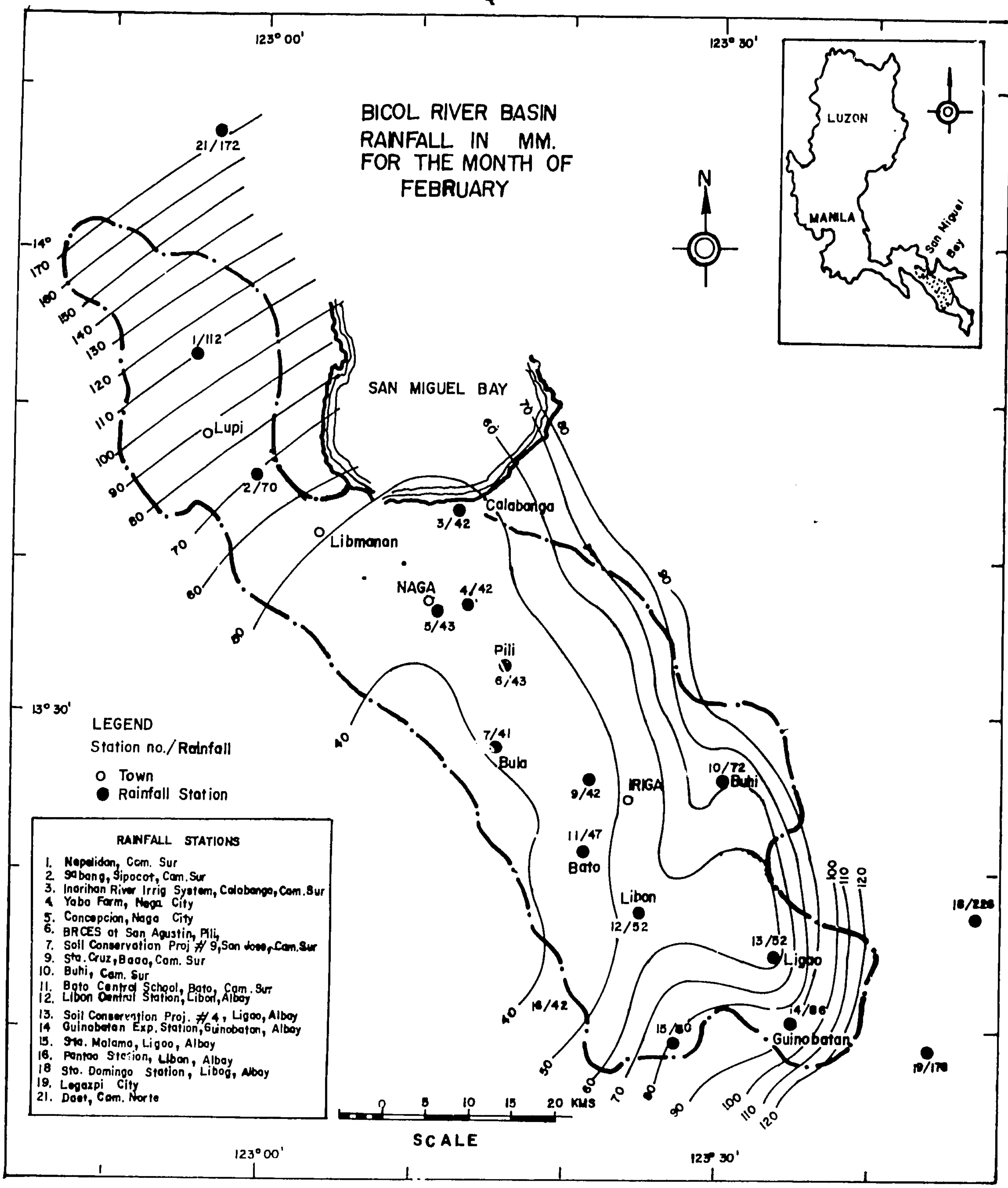


Fig. A-6 Isohyets for Mean Monthly Rainfall, for the Month of February, Bicol River Basin.

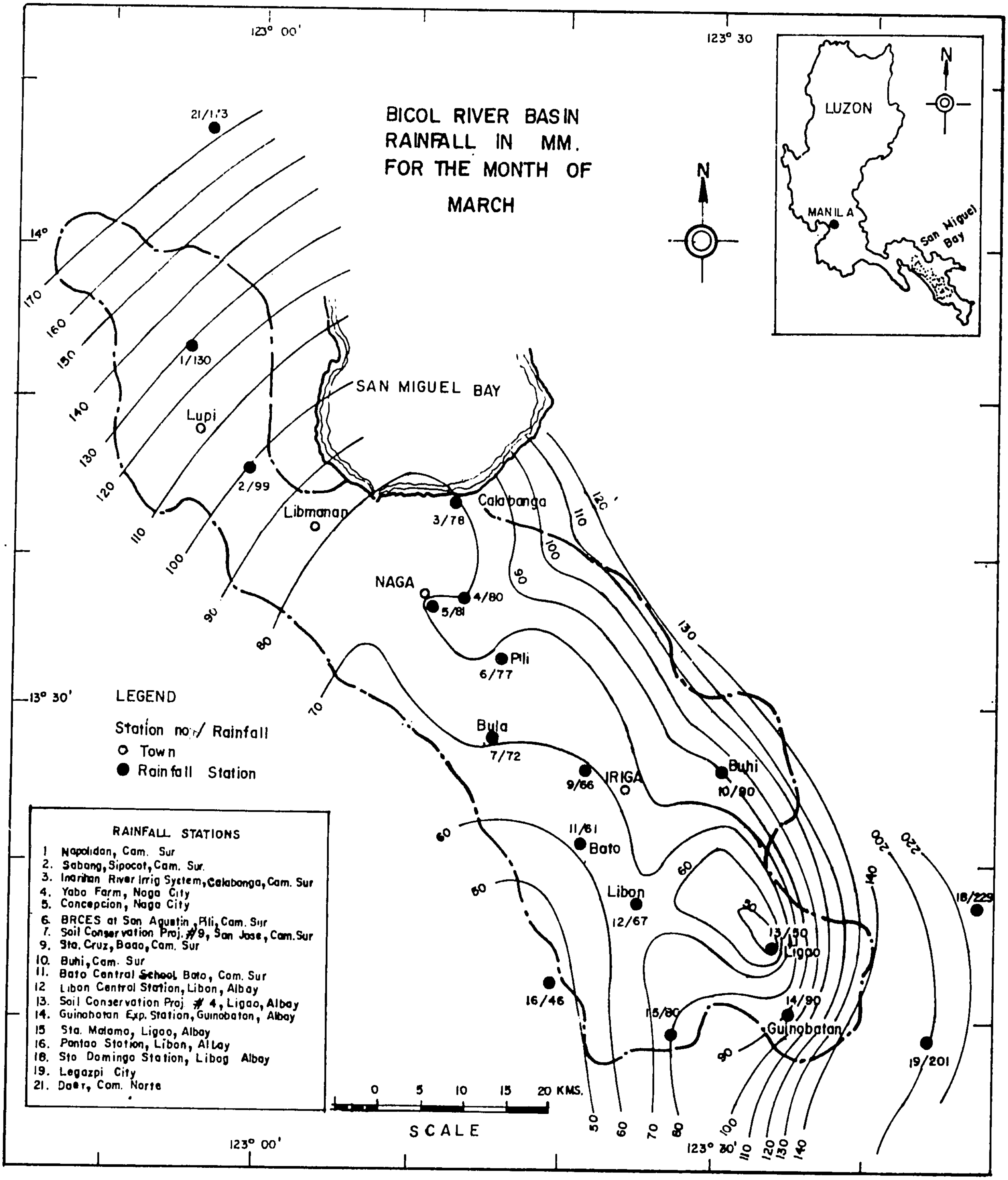


Fig.A-7 Isohyets for Mean Monthly Rainfall, for the Month of March, Bicol River Basin

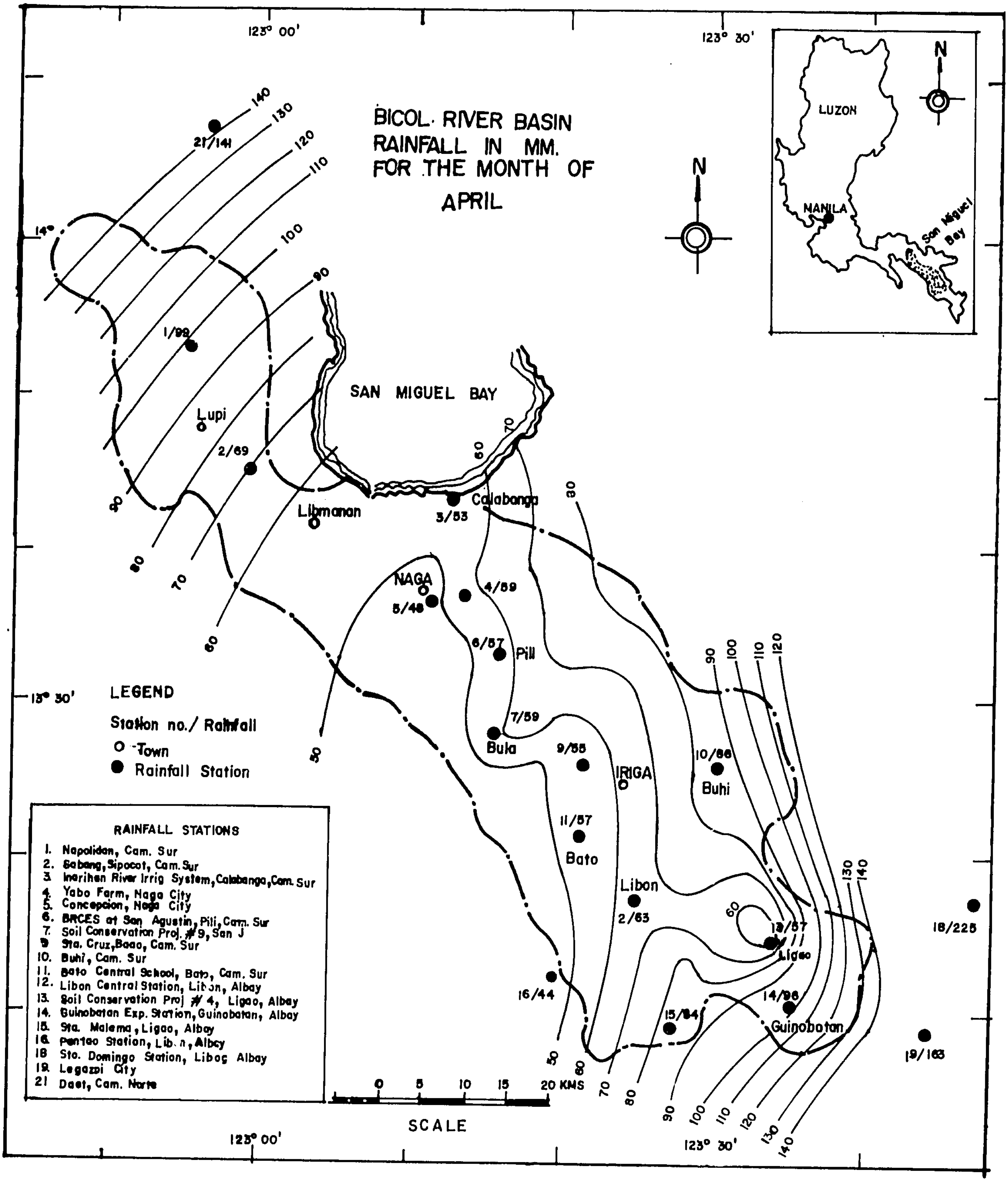


Fig A-8- Isohyets for Mean Monthly Rainfall, for the Month of April, Bicol River Basin

9

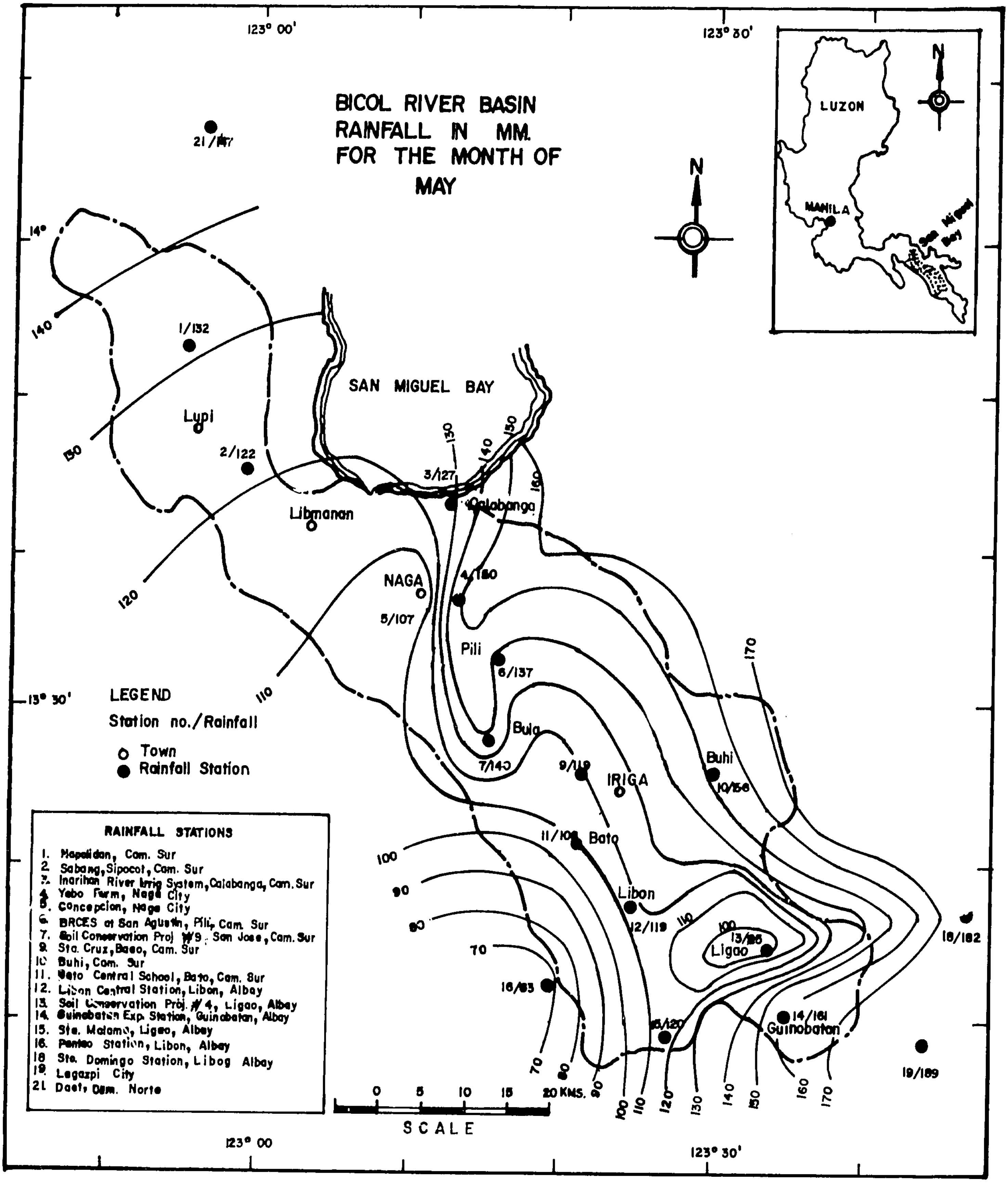


Fig. A-9 Isohyets for Mean Monthly Rainfall, for the Month of May, Bicol River Basin

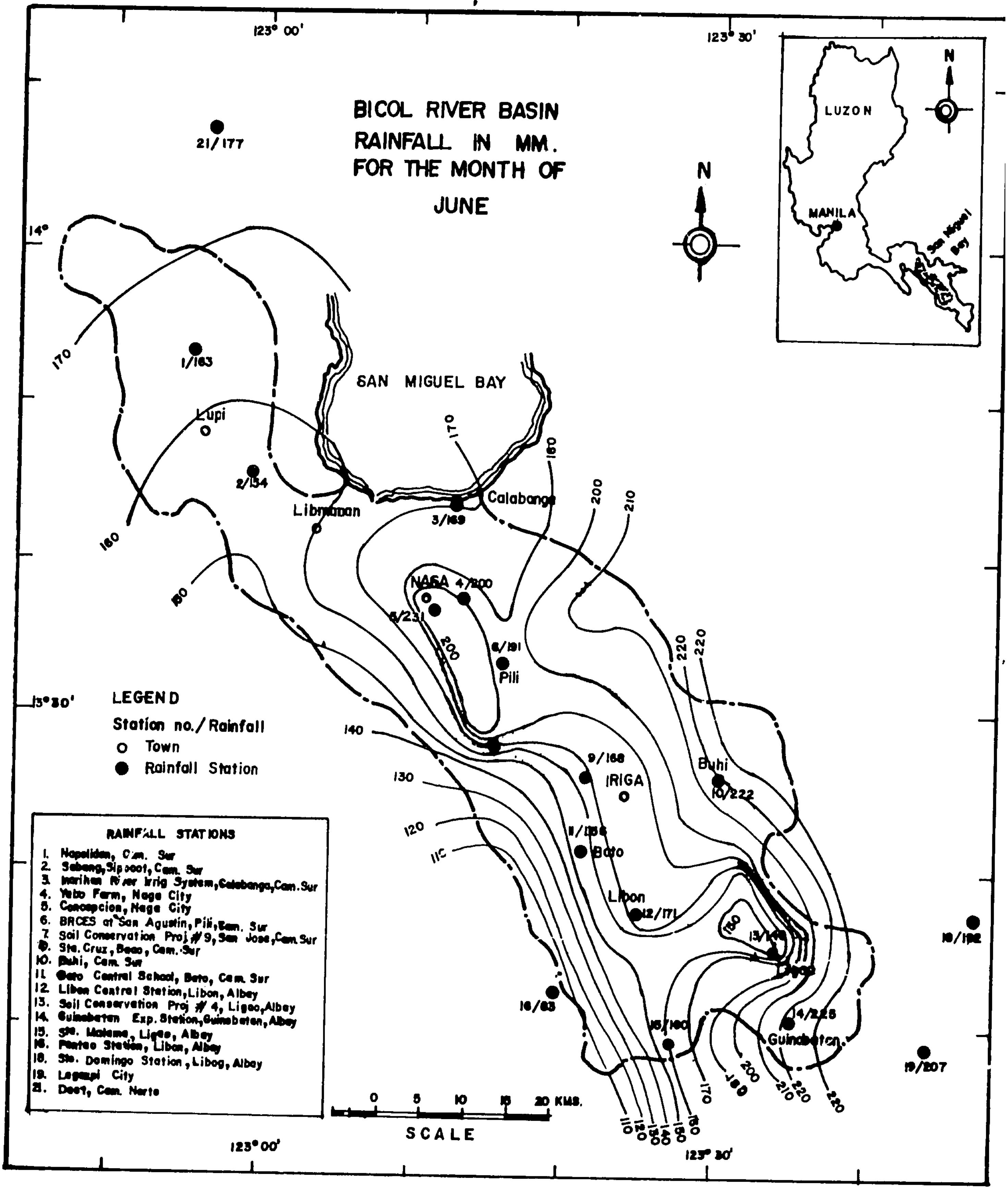


Fig. A-10 Isohyets for Mean Monthly Rainfall, for the Month of June, Bicol River Basin

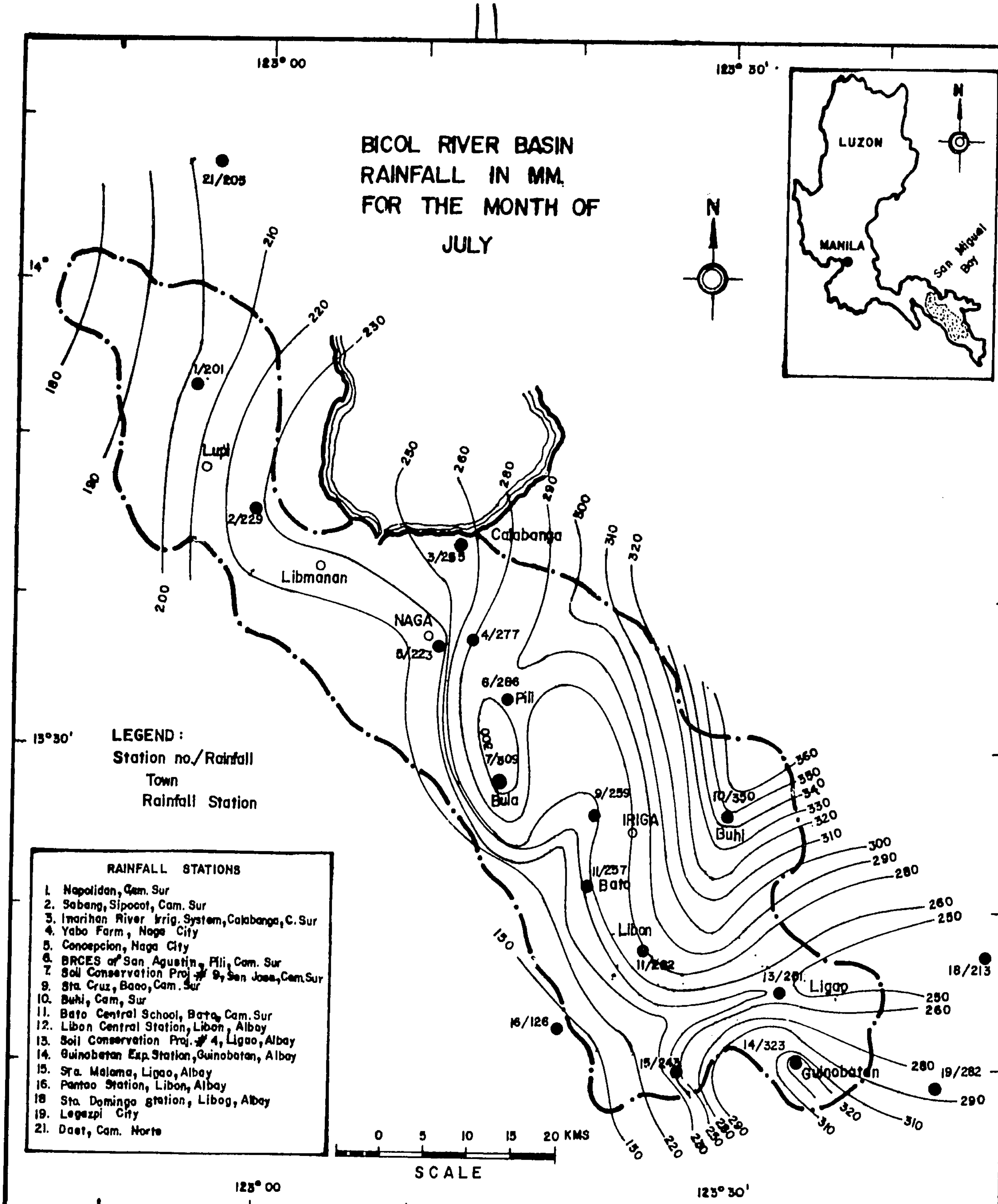


Fig. A-11 Isohyets for Mean Monthly Rainfall, for the Month of July, Bicol River Basin

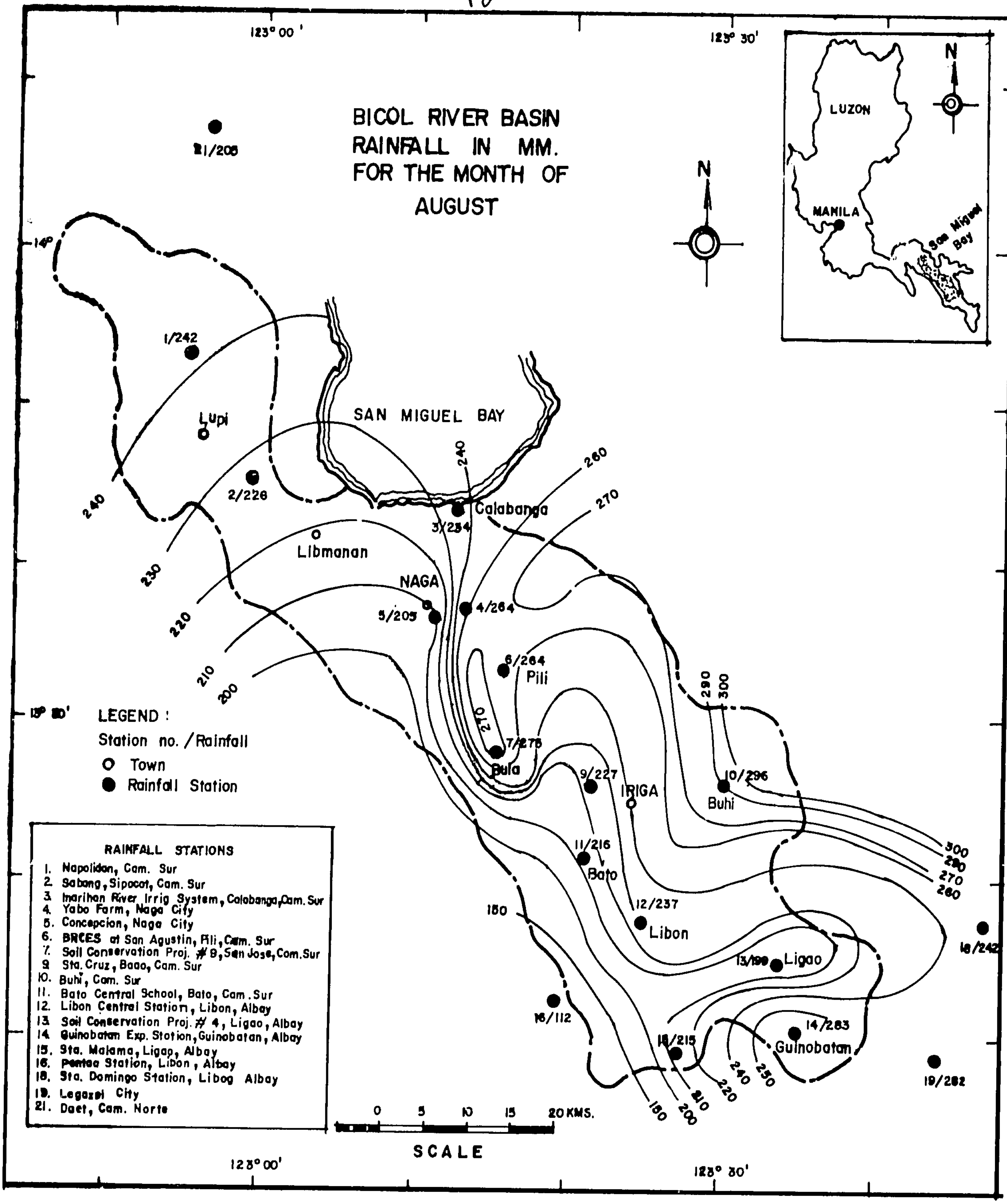


Fig. A-12 Isohyets for Mean Monthly Rainfall, for the Month of August, Bicol River Basin

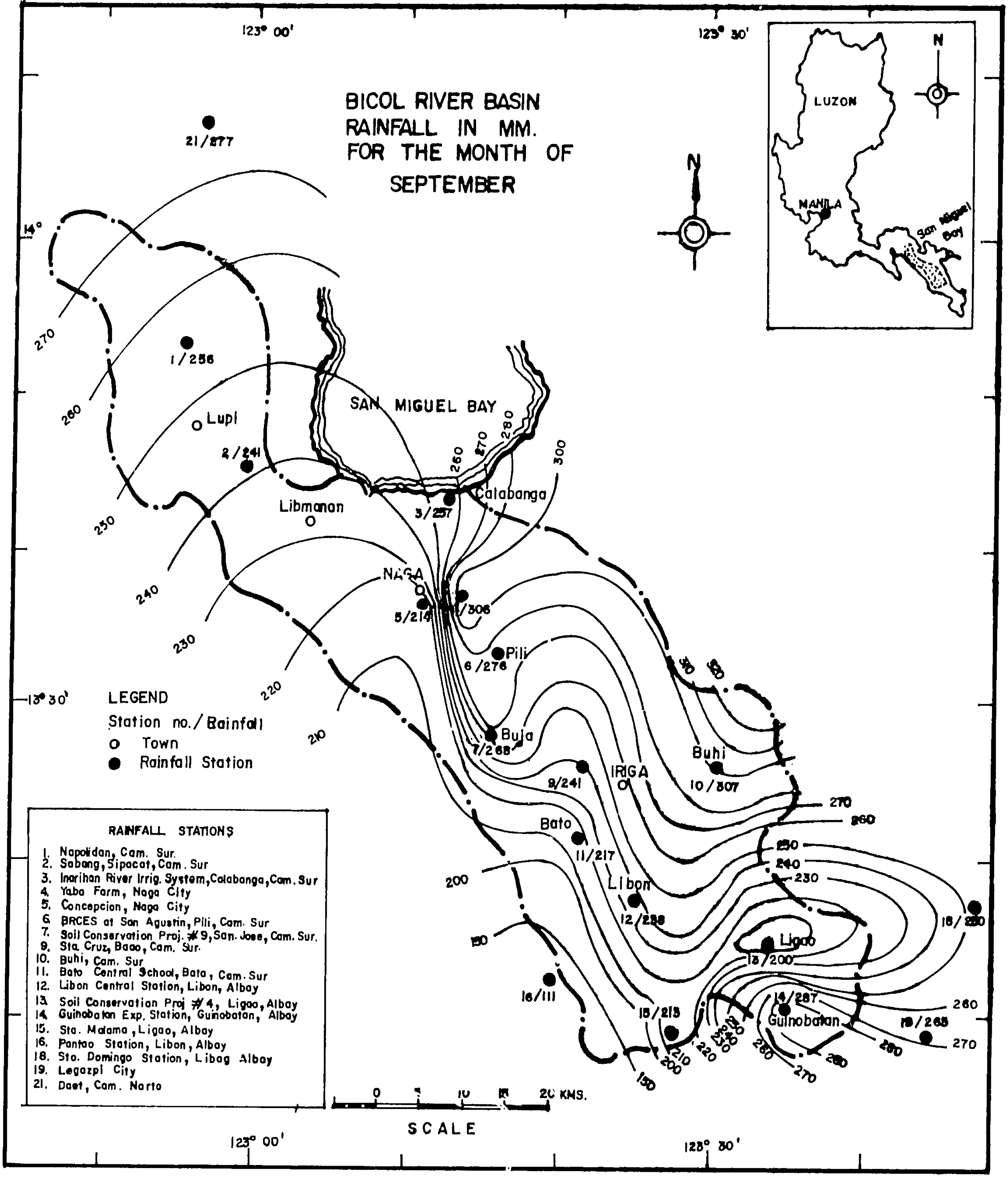


Fig. A-13 Isohyets for Mean Monthly Rainfall, for the Month of September, Bicol River Basin

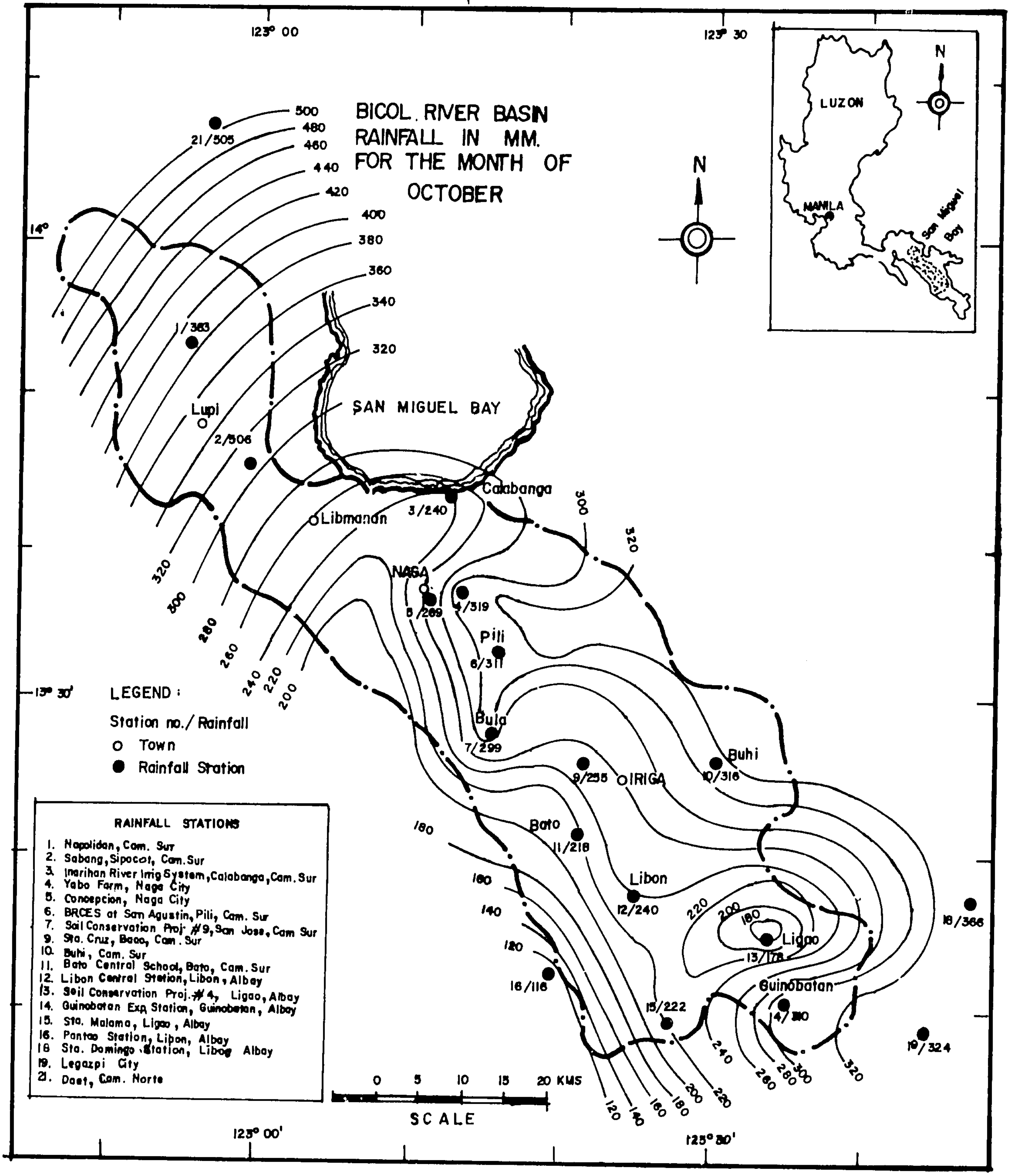


Fig. A-14 Isohyets for Mean Monthly Rainfall, for the Month of October, Bicol River Basin

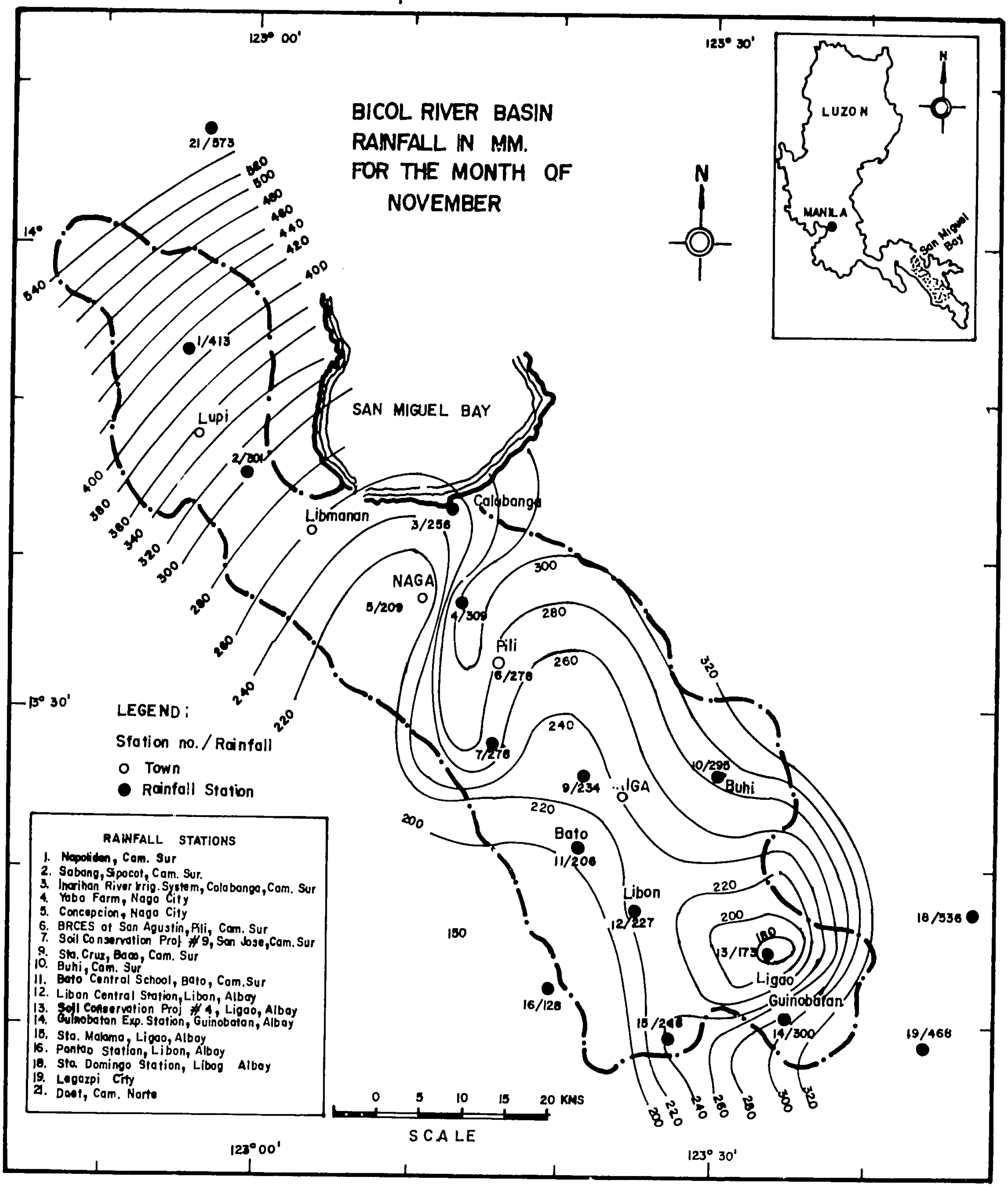


Fig. A-15 Isohyets for Mean Monthly Rainfall, for the Month of November, Bicol River Basin

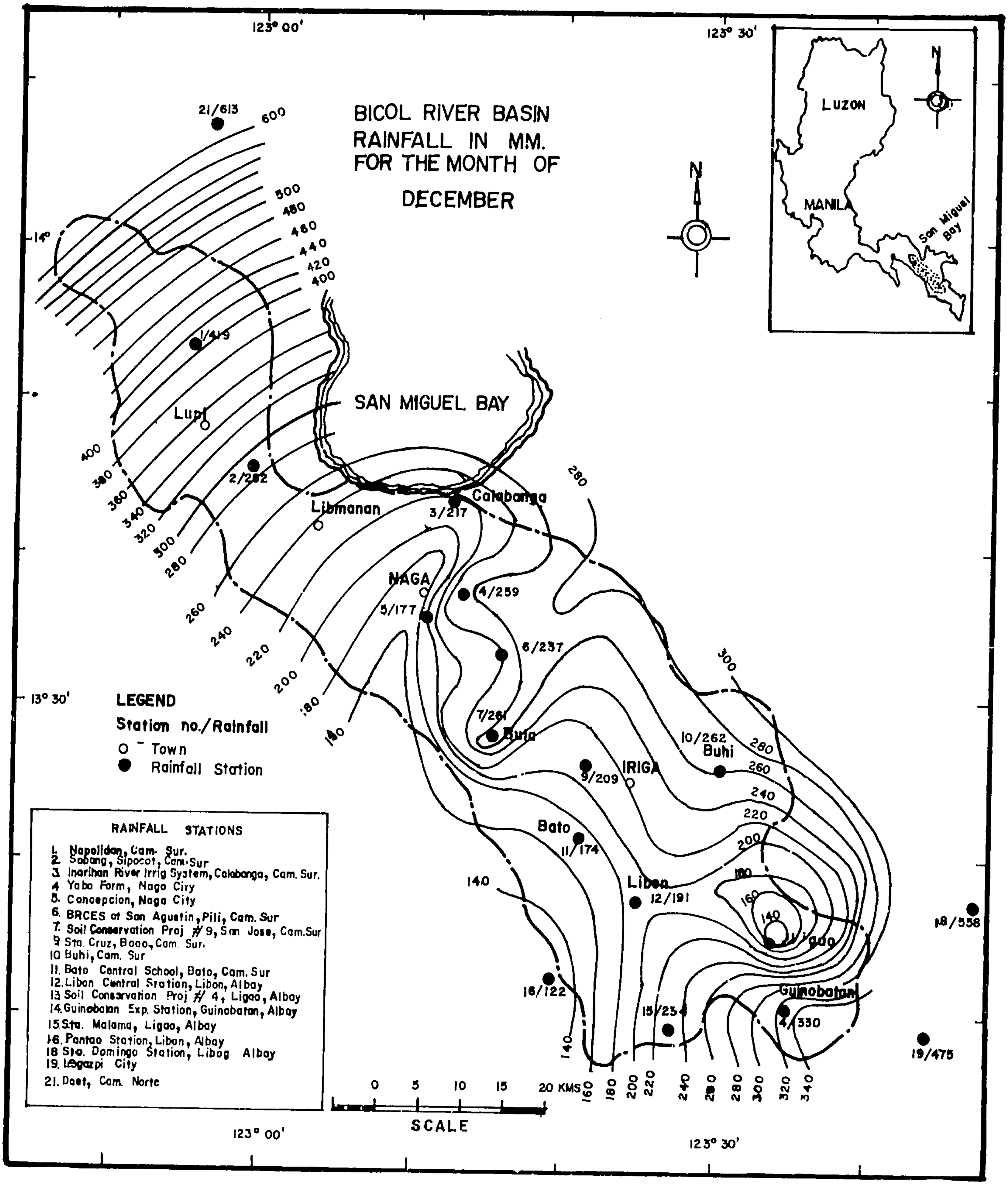
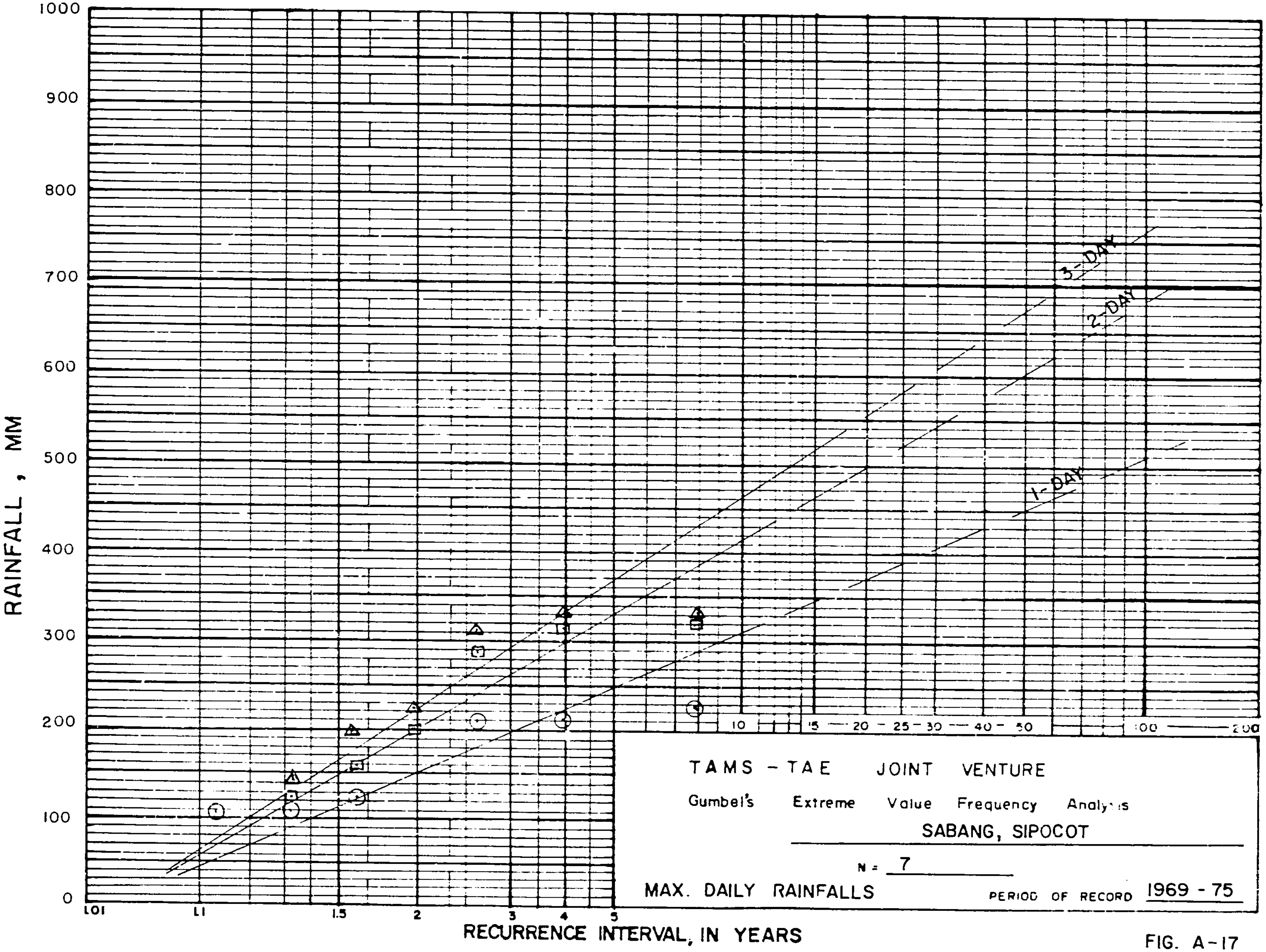


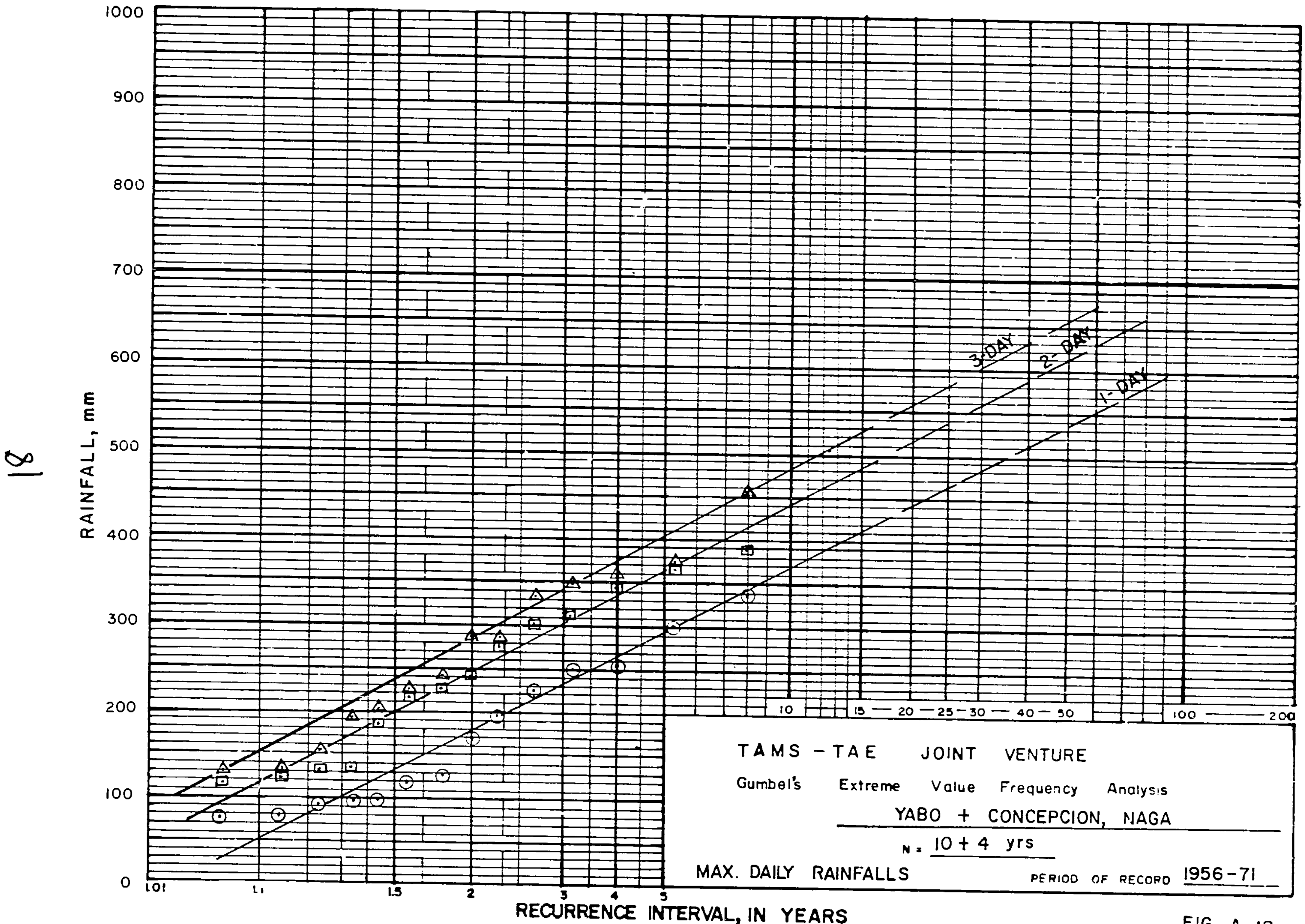
Fig. A-16 Isohyets for Mean Monthly Rainfall, for the Month of December, Bicol River Basin.

17



RAINFALL , MM
1000
900
800
700
600
500
400
300
200
100
0
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
3-DAY
2-DAY
1-DAY
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
SABANG, SIPOCOT
N = 7
MAX. DAILY RAINFALLS
PERIOD OF RECORD 1969 - 75

FIG. A-17



18
RAINFALL, mm
1000
900
800
700
600
500
400
300
200
100
0
3-DAY
2-DAY
1-DAY
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
RECURRENCE INTERVAL, IN YEARS
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
YABO + CONCEPCION, NAGA
N = 10 + 4 yrs
MAX. DAILY RAINFALLS
PERIOD OF RECORD 1956-71

FIG. A-18

19

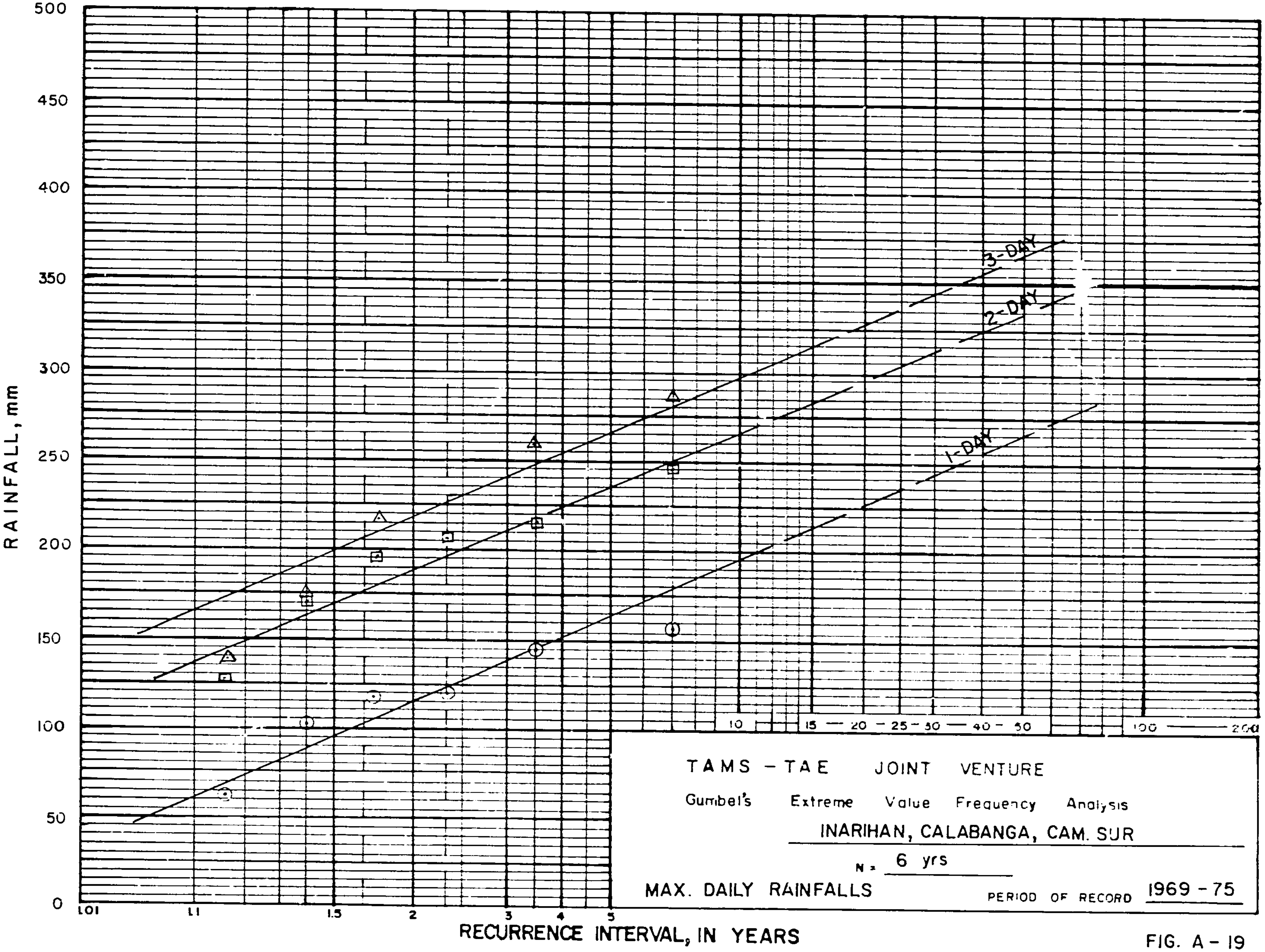
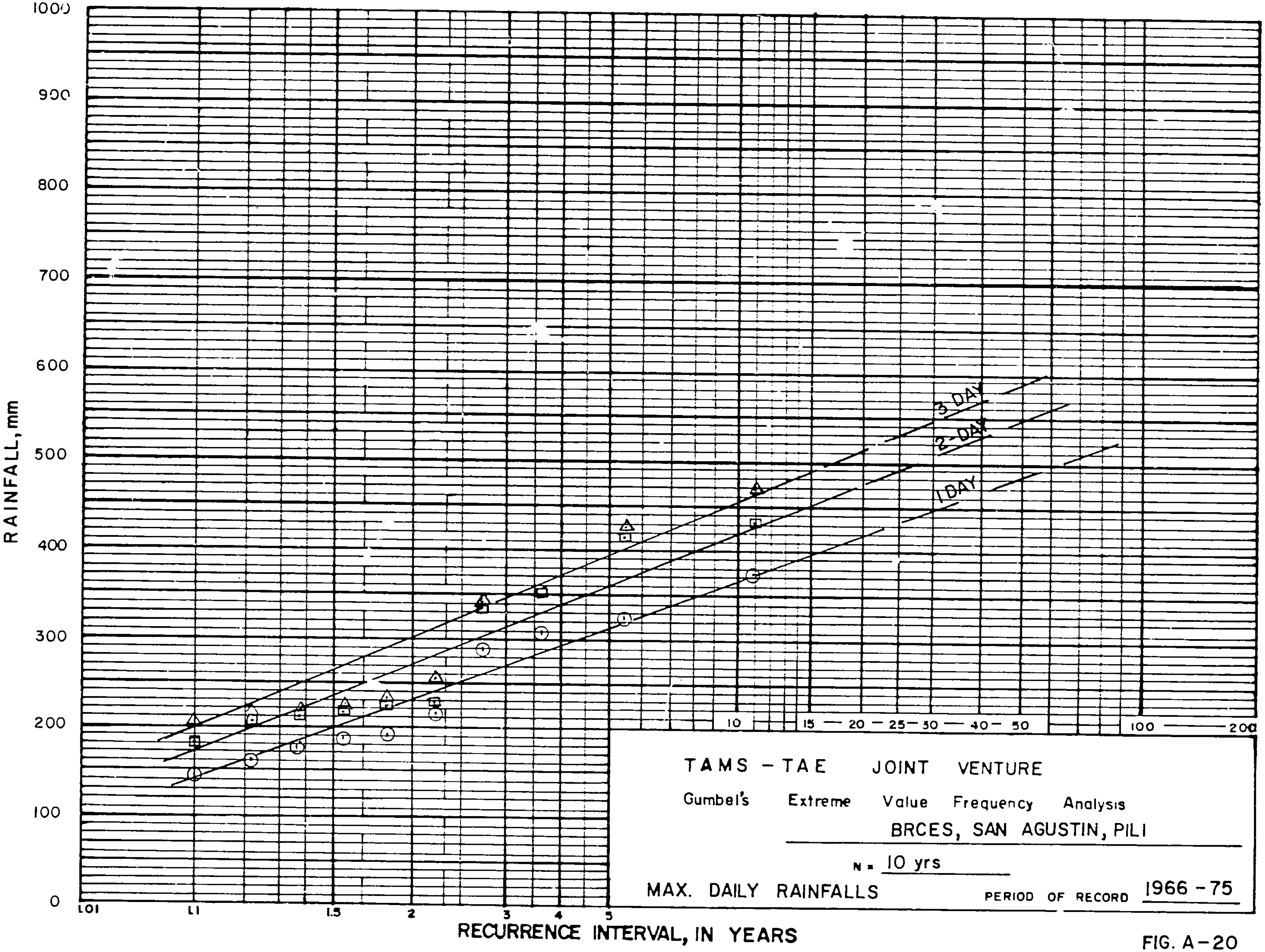

500
450
400
350
300
250
200
150
100
50
0
RAINFALL, mm
3-DAY
2-DAY
1-DAY
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
TAMS – TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
INARIHAN, CALABANGA, CAM. SUR
N = 6 yrs
MAX. DAILY RAINFALLS
PERIOD OF RECORD 1969 – 75
RECURRENCE INTERVAL, IN YEARS

FIG. A – 19

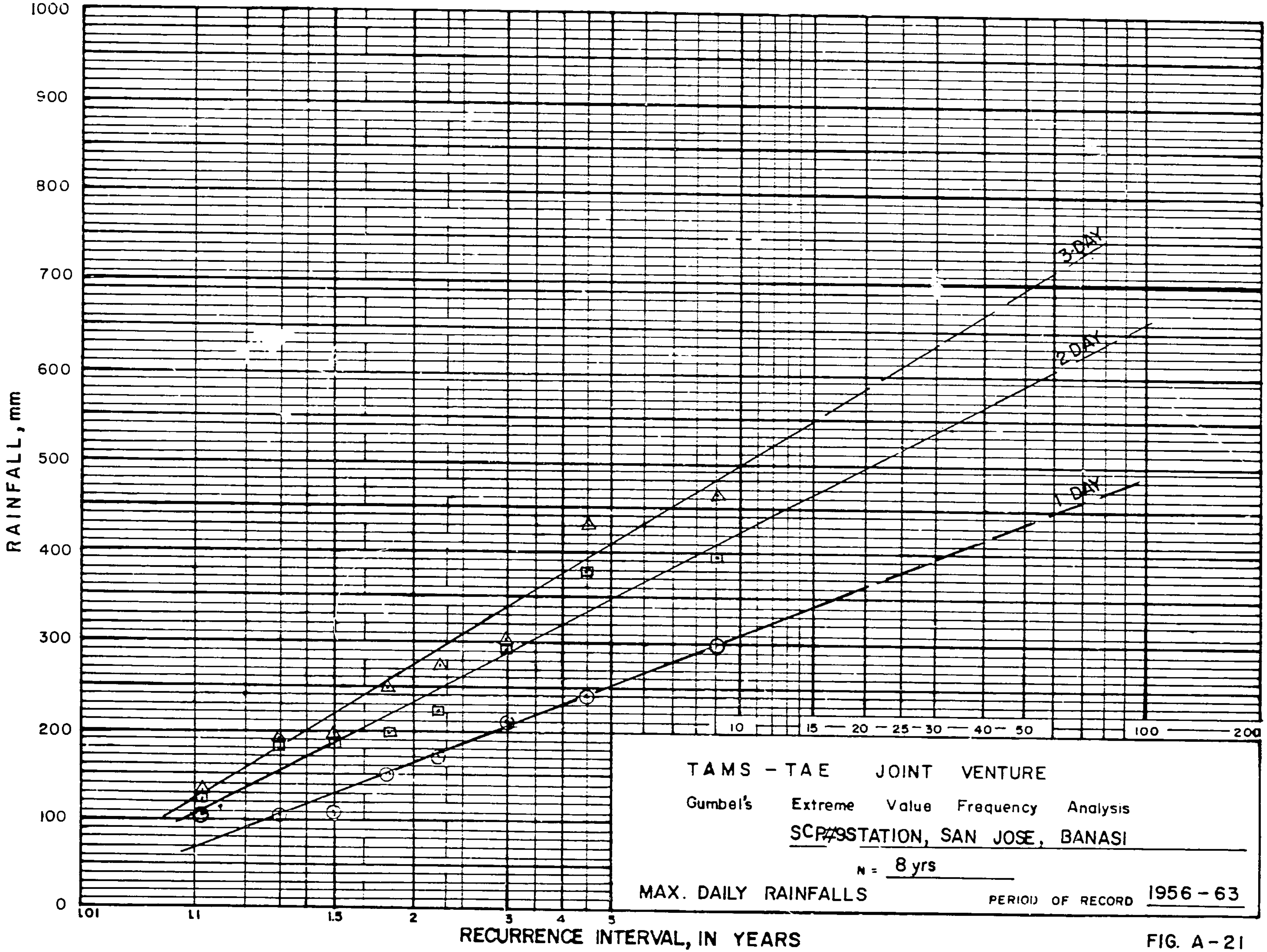
20



RAINFALL, mm
RECURRENCE INTERVAL, IN YEARS
3 DAY
2-DAY
1 DAY
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
BRCES, SAN AGUSTIN, PILI
N = 10 yrs
MAX. DAILY RAINFALLS
PERIOD OF RECORD 1966 - 75

FIG. A-20

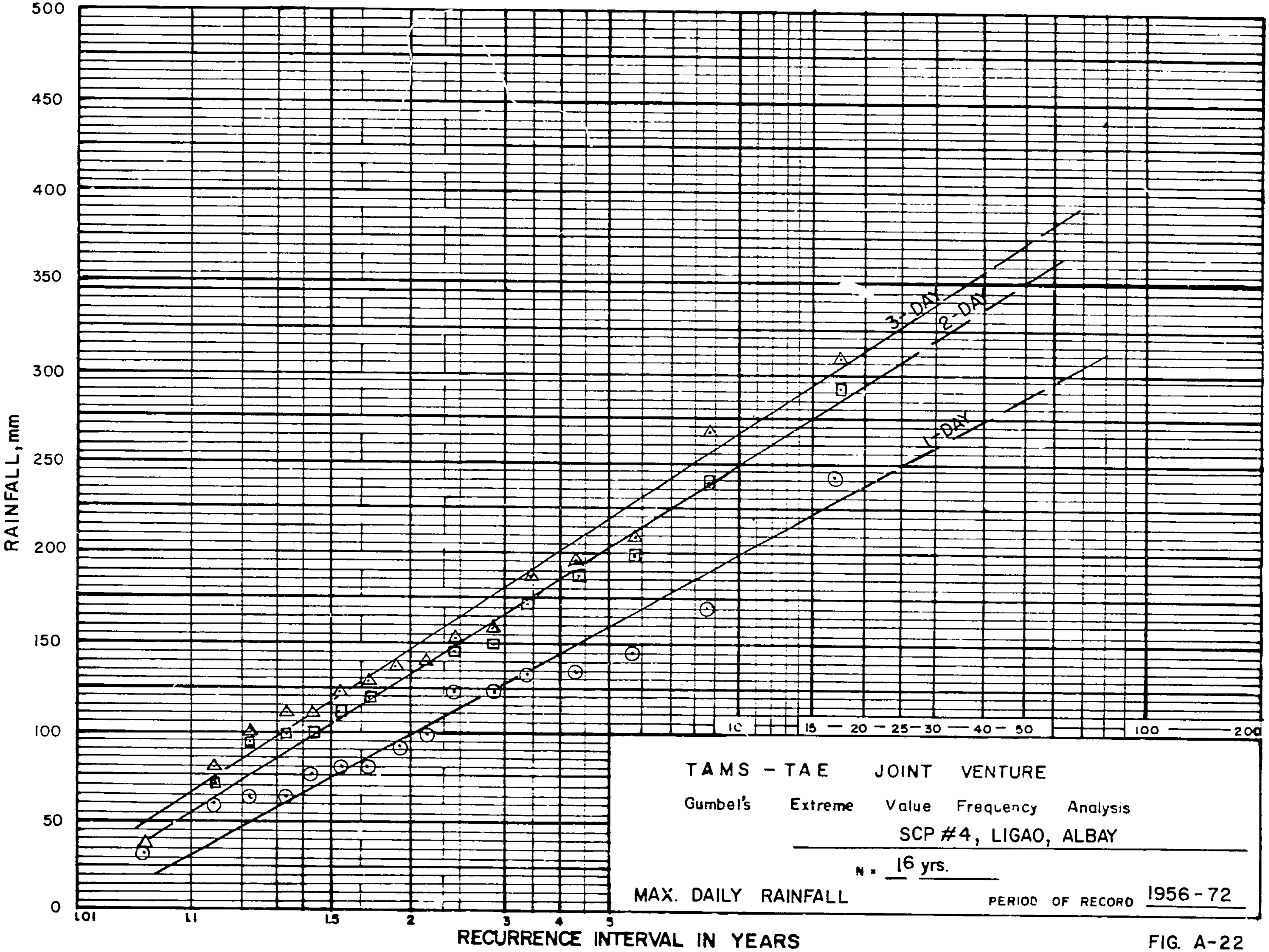
21



RAINFALL, mm
1000
900
800
700
600
500
400
300
200
100
0
3-DAY
2-DAY
1 DAY
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
RECURRENCE INTERVAL, IN YEARS
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
SCP#9 STATION, SAN JOSE, BANASI
N = 8 yrs
MAX. DAILY RAINFALLS
PERIOD OF RECORD 1956 - 63

FIG. A-21

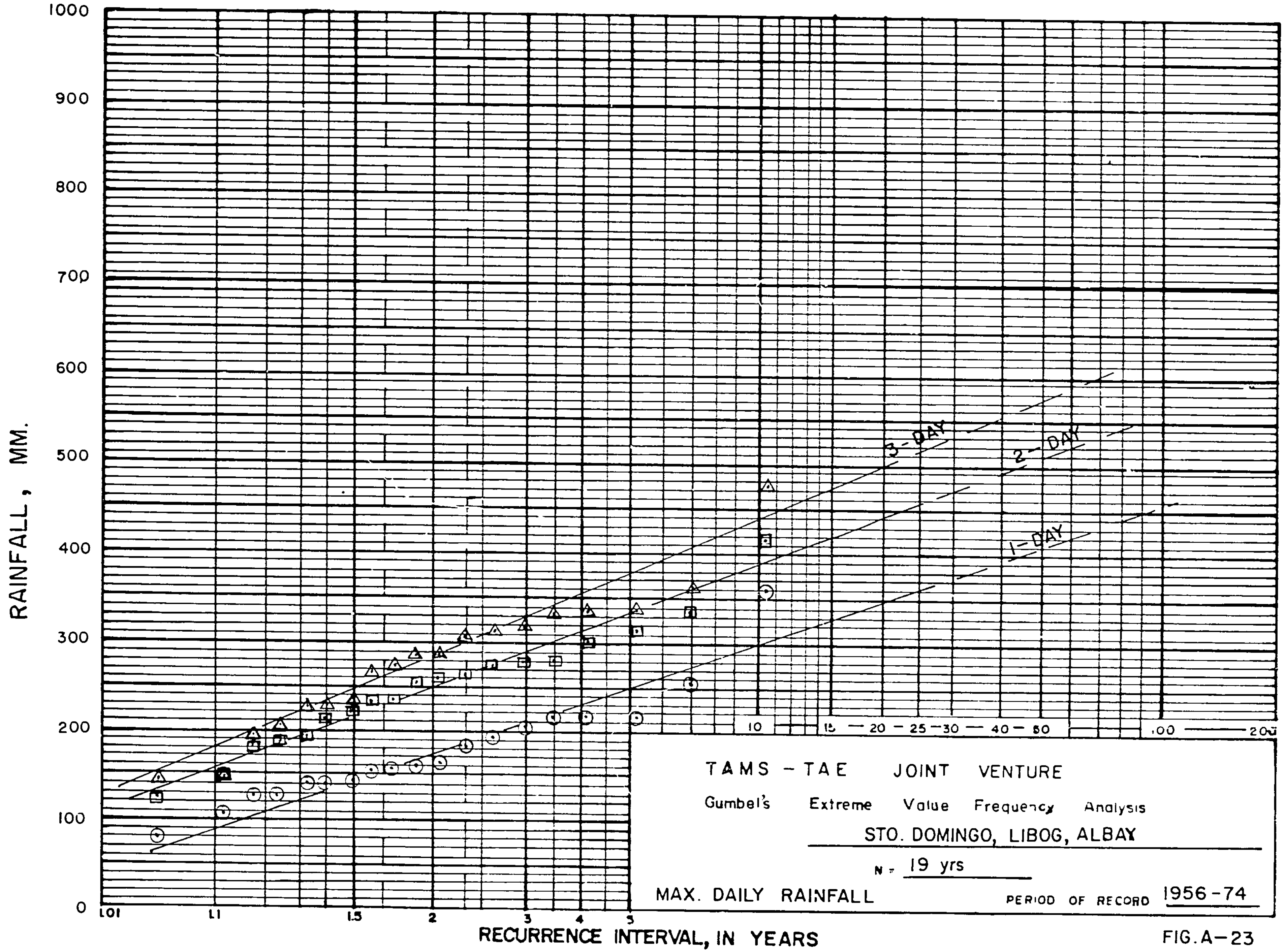
22



RAINFALL, mm
RECURRENCE INTERVAL IN YEARS
3-DAY
2-DAY
1-DAY
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
SCP #4, LIGAO, ALBAY
N = 16 yrs.
MAX. DAILY RAINFALL
PERIOD OF RECORD 1956-72

FIG. A-22

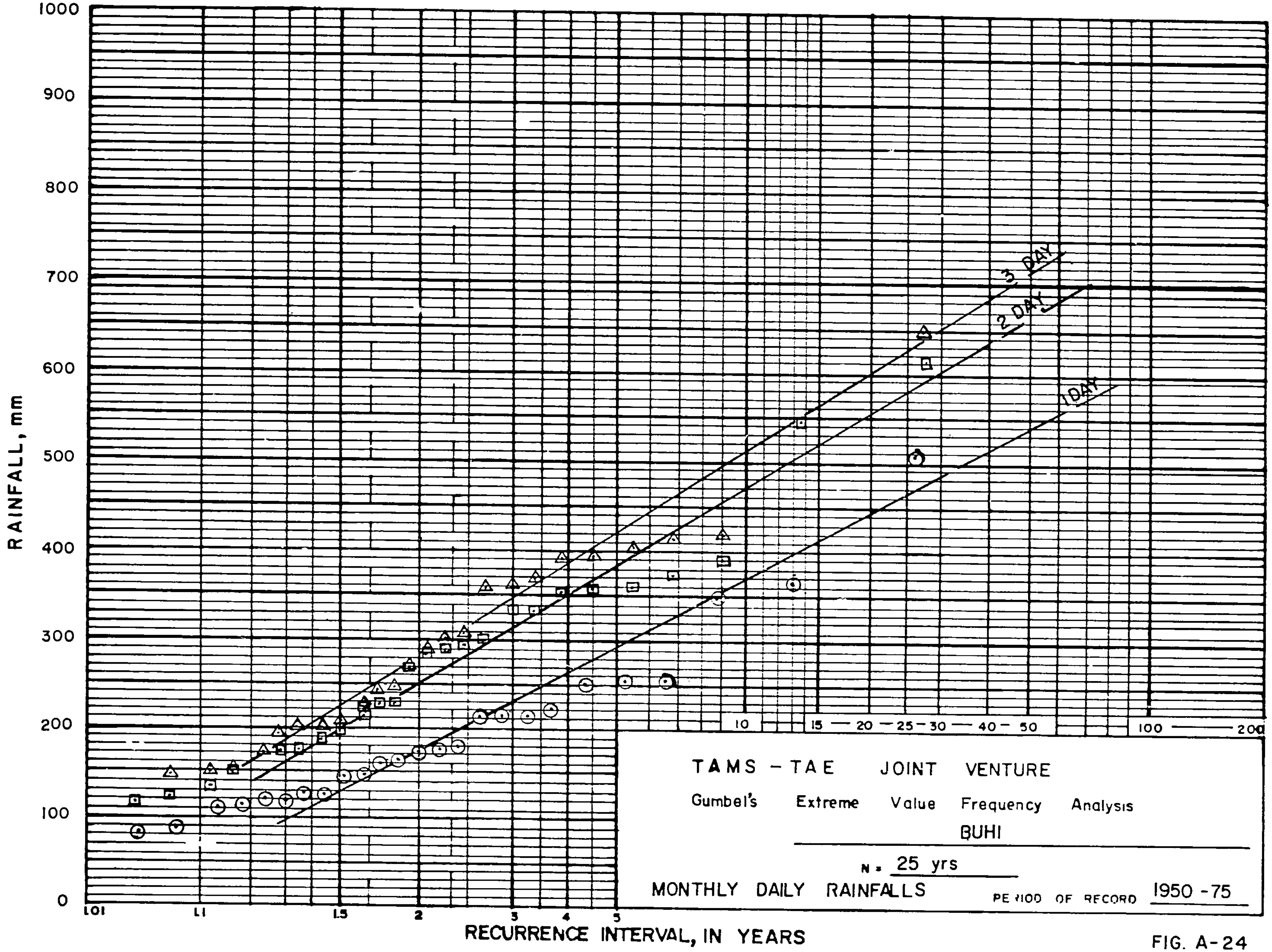
23



RAINFALL, MM.
1000
900
800
700
600
500
400
300
200
100
0
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
3-DAY
2-DAY
1-DAY
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
STO. DOMINGO, LIBOG, ALBAY
N = 19 yrs
MAX. DAILY RAINFALL
PERIOD OF RECORD 1956-74
RECURRENCE INTERVAL, IN YEARS

FIG. A-23

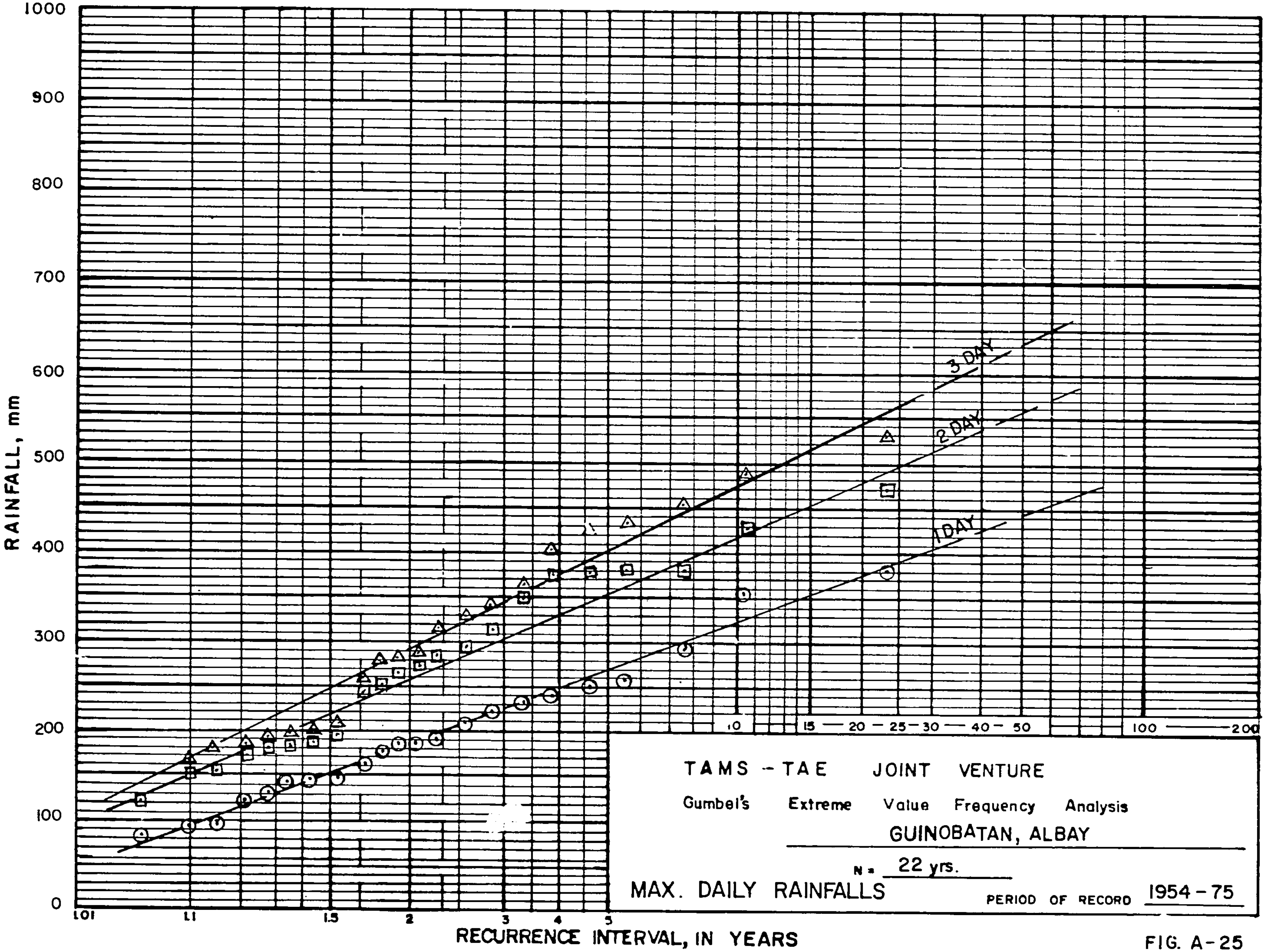
24



1000
900
800
700
600
500
400
300
200
100
0
RAINFALL, mm
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
3 DAY
2 DAY
1 DAY
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
BUHI
N = 25 yrs
MONTHLY DAILY RAINFALLS
PERIOD OF RECORD 1950 -75

FIG. A-24

25



TAMS – TAE JOINT VENTURE

Gumbel's Extreme Value Frequency Analysis

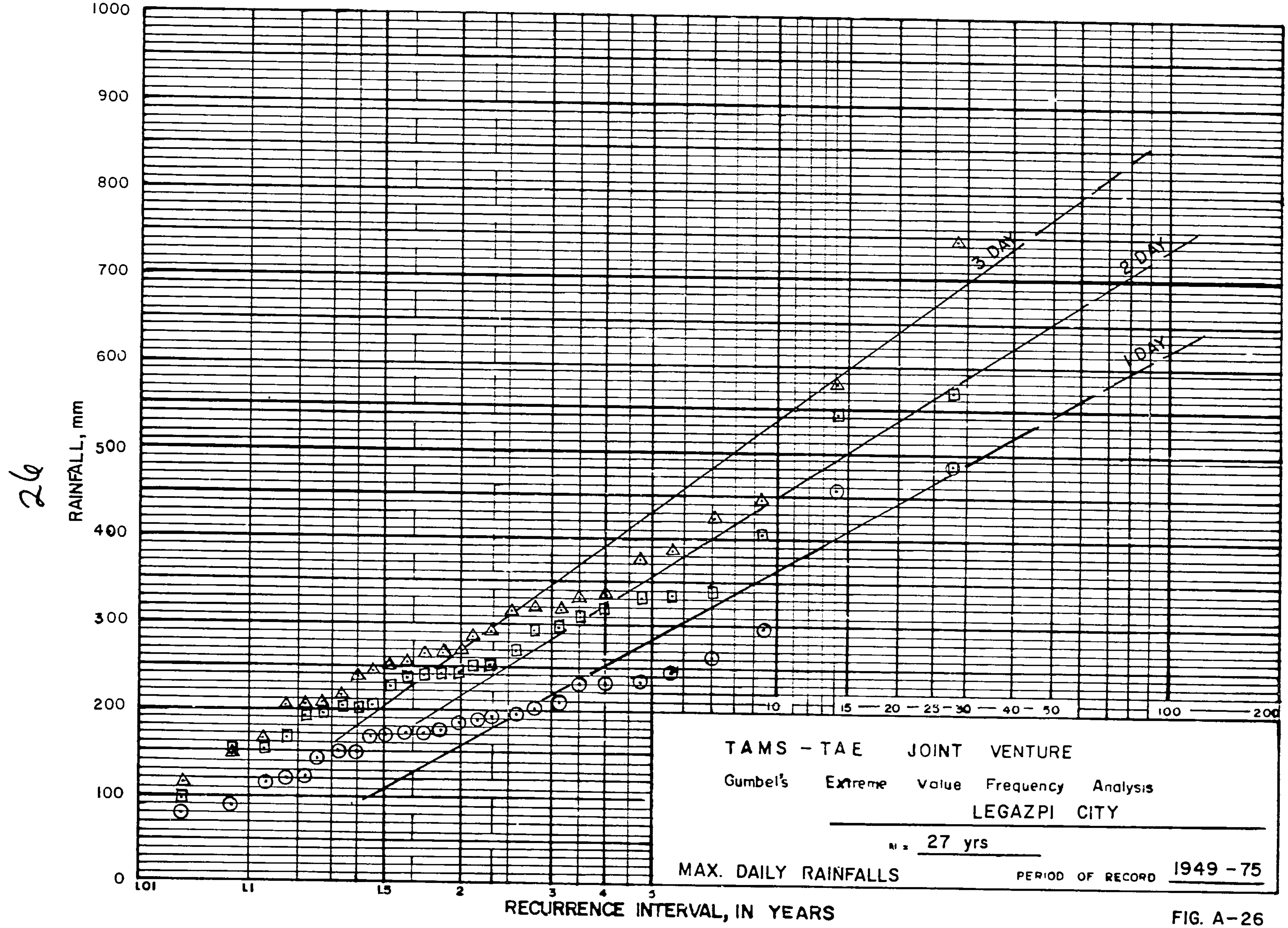
GUINOBATAN, ALBAY

N = 22 yrs.

MAX. DAILY RAINFALLS

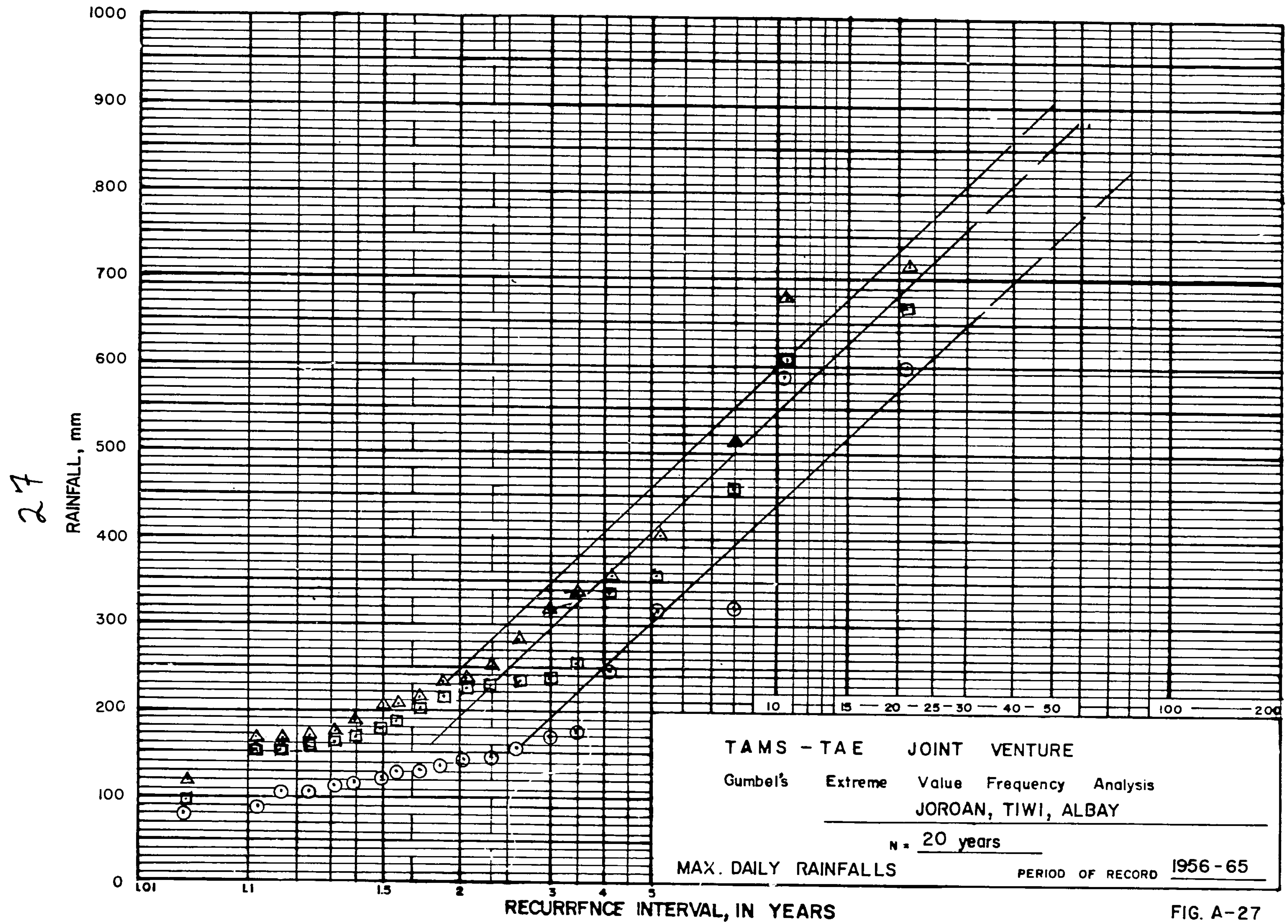
PERIOD OF RECORD 1954 – 75

FIG. A-25



26
RAINFALL, mm
1000
900
800
700
600
500
400
300
200
100
0
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
3 DAY
2 DAY
1 DAY
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
LEGAZPI CITY
N = 27 yrs
MAX. DAILY RAINFALLS
PERIOD OF RECORD 1949 - 75
RECURRENCE INTERVAL, IN YEARS

FIG. A-26



RAINFALL, mm
1000
900
800
700
600
500
400
300
200
100
0
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
RECURRFNCE INTERVAL, IN YEARS
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
JOROAN, TIWI, ALBAY
N = 20 years
MAX. DAILY RAINFALLS
PERIOD OF RECORD 1956-65

FIG. A-27

Job No. BRBC
Project. BICOL
Subject. HYDROLOGY

28

BICOL RIVER BASIN
COMPREHENSIVE WATER RESOURCES STUDY
BRBC TAMS-TAE

Date . . . Jan. '76
By . . . C. E.
Ch'k by . C. Ertuna

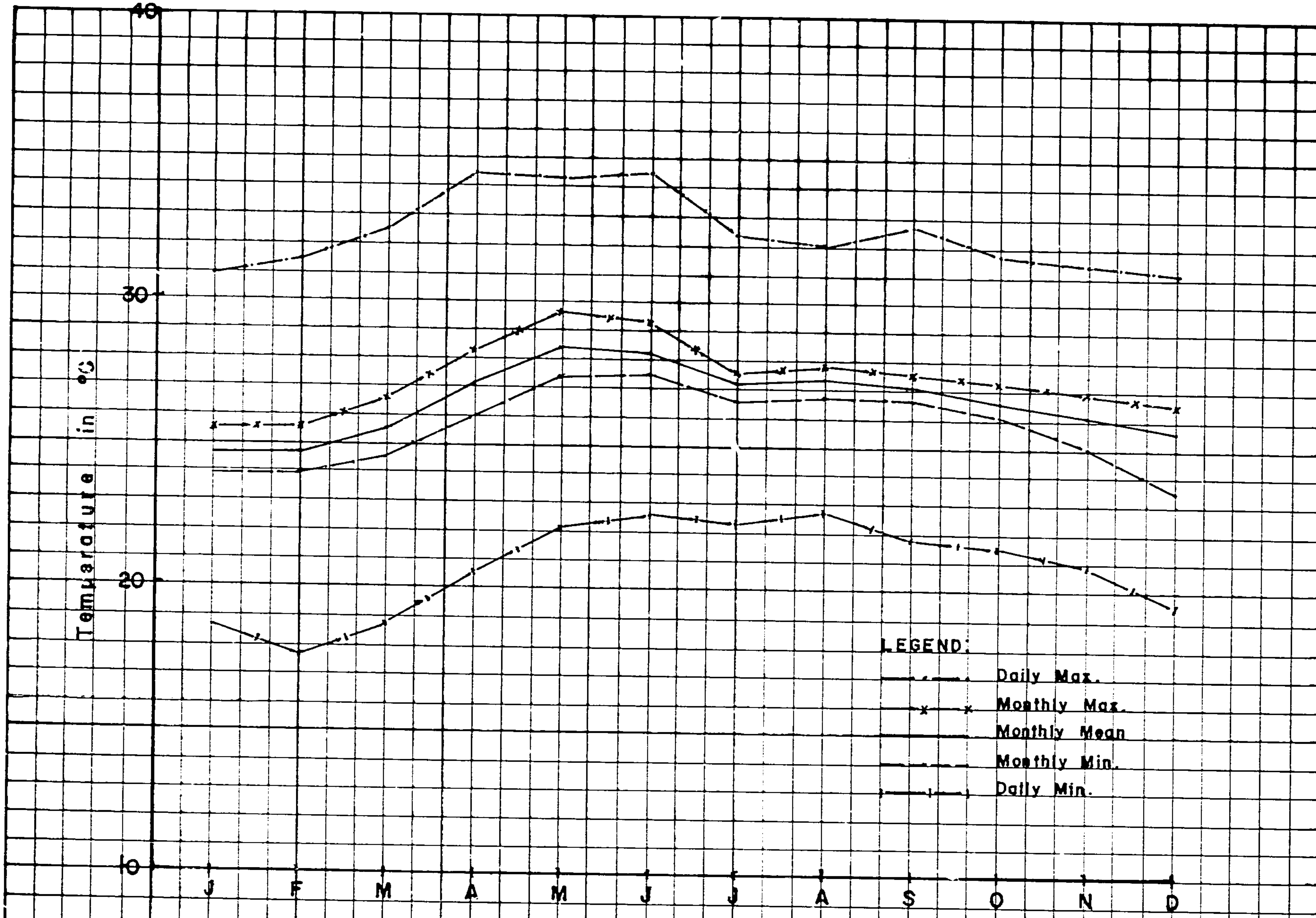


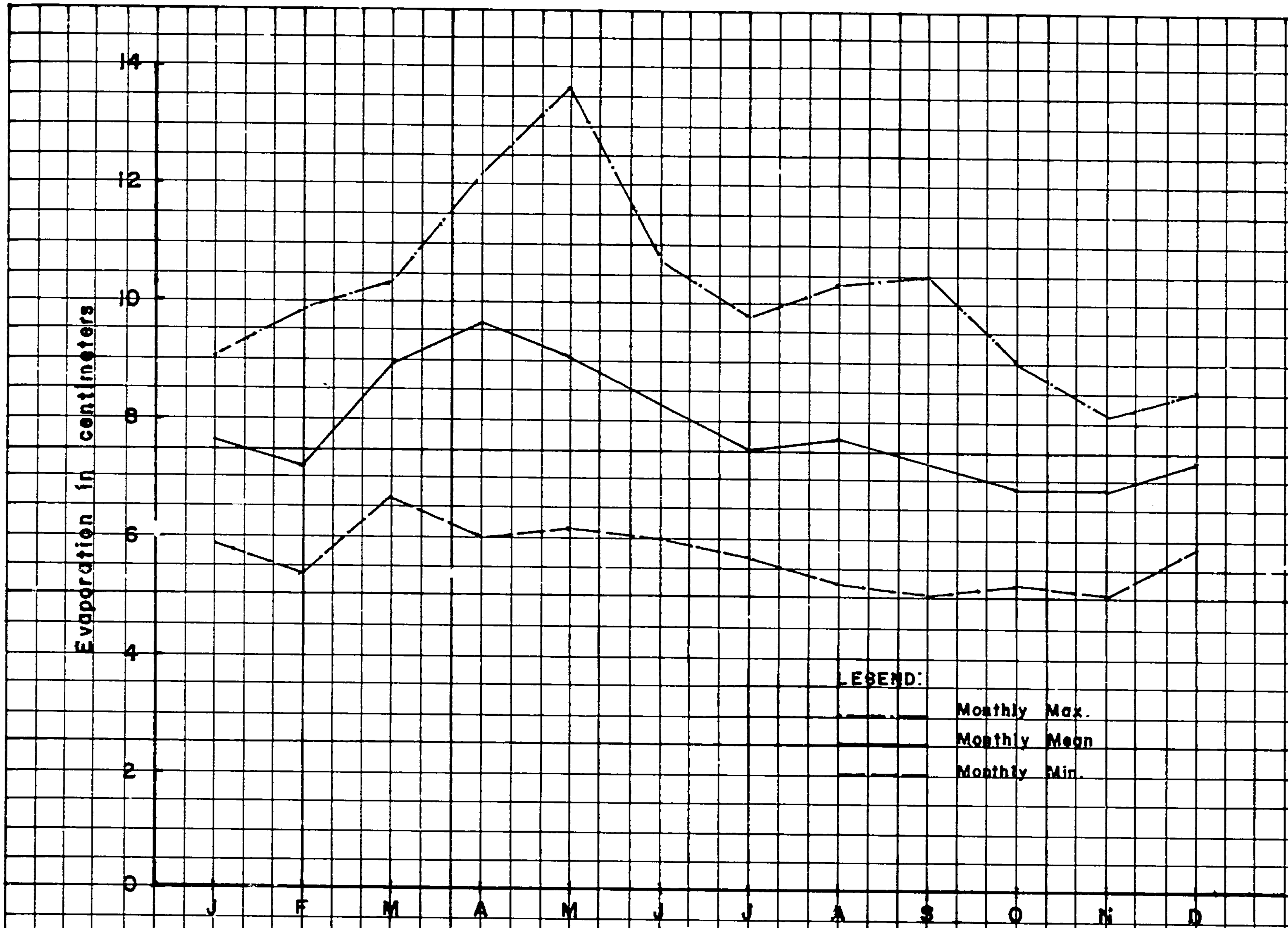
Fig A-28- MONTHLY DISTRIBUTION OF MEAN MONTHLY AND EXTREME DAILY TEMPERATURES, PILI, THE BICOL RIVER BASIN (1966-73)

29

BICOL RIVER BASIN
COMPREHENSIVE WATER RESOURCES STUDY
BRBC TAMS-TAE

Job No. BRBC
Project. BICOL
Subject. HYDROLOGY

Date Feb.'76
By C.E.
Ch'k by C. Ertuna



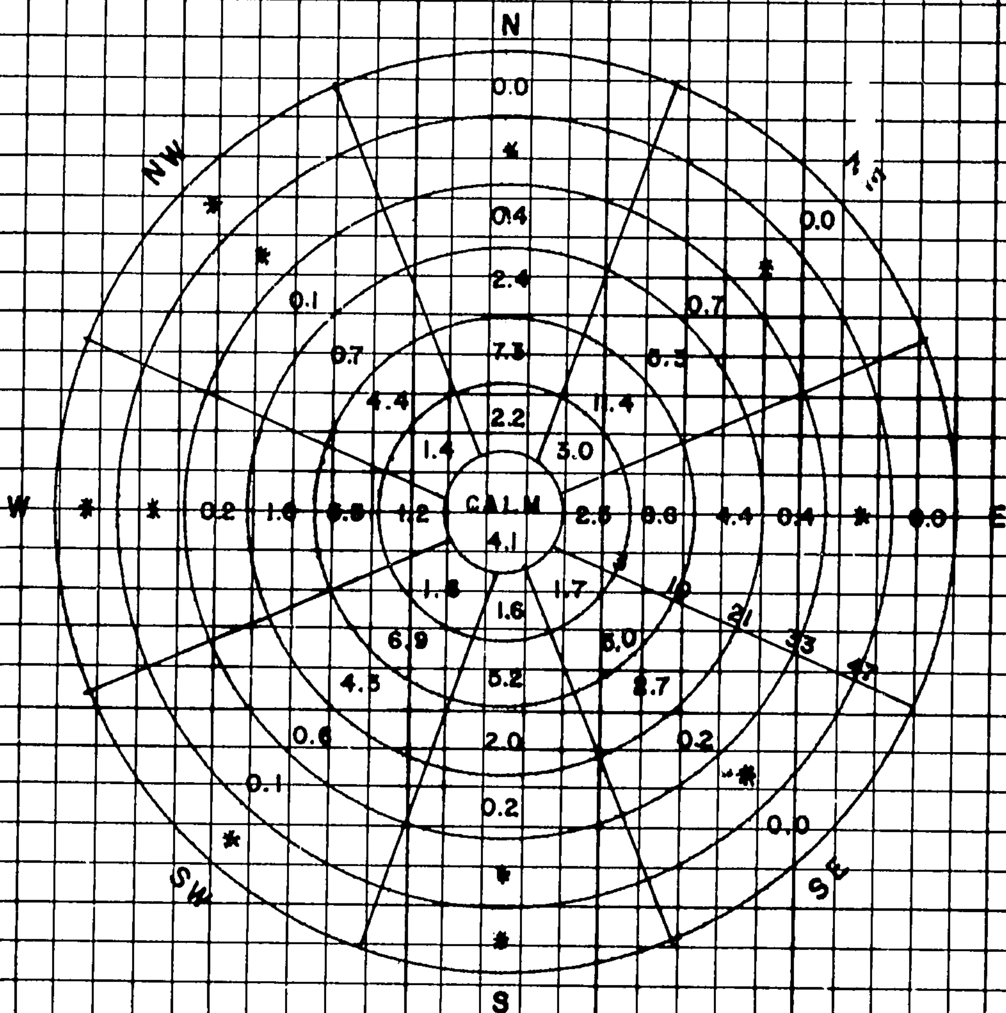
MONTHLY EVAPORATION RATES AT NAGA CITY (1956 - 1973)

Fig A-29

BICOL RIVER BASIN

COMPREHENSIVE WATER RESOURCES STUDY
BRBC TAMS-TAE

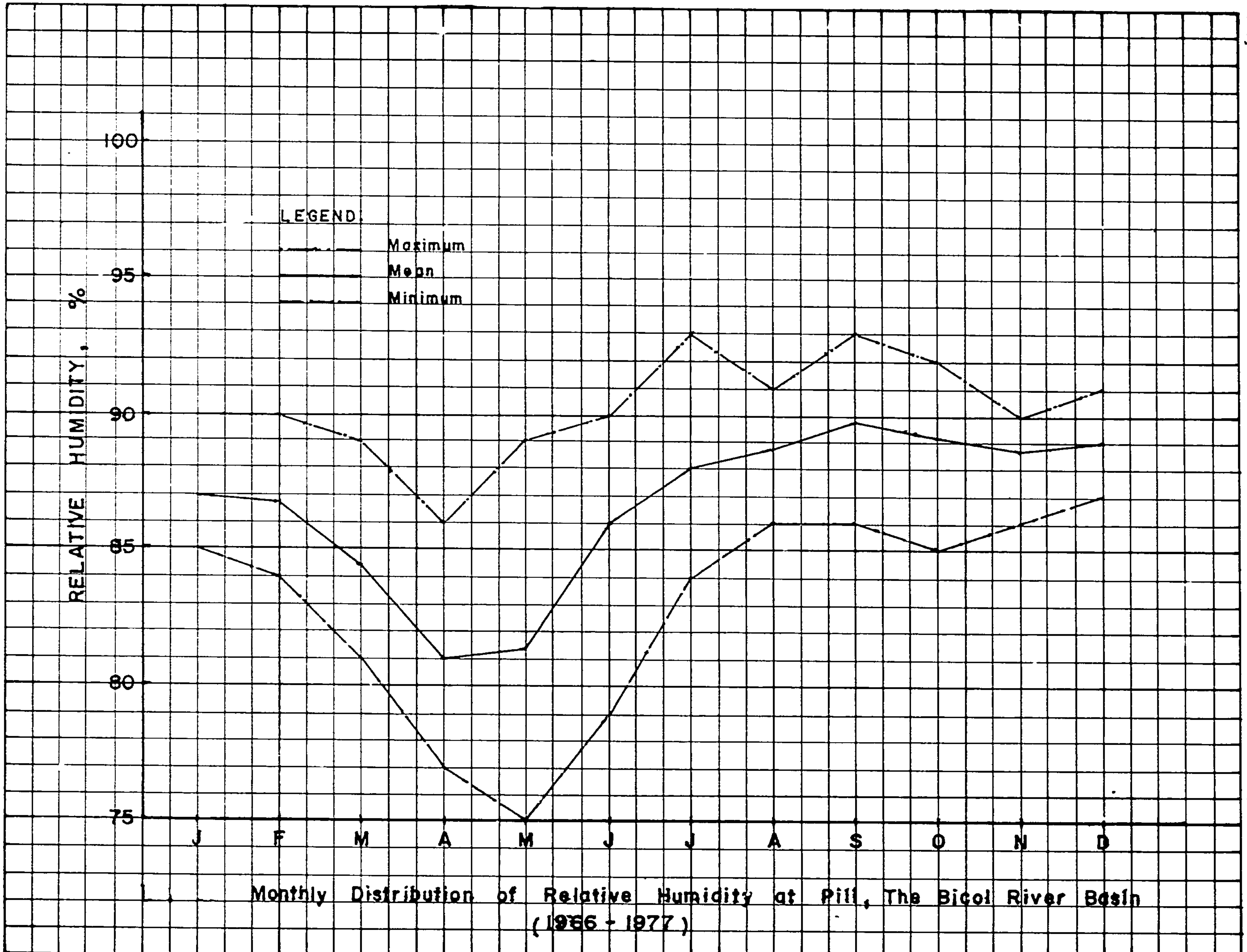
Job No BRBC
Project BICOL
Subject HYDROLOGY
Date Feb. '76
By C. E
Ch'k by C. Ertuna



PERCENTAGES ARE SHOWN FOR INTERVALS IN KNOTS
* DENOTES LESS THAN 1.0 %
PERIOD OF RECORD: 1860-1971
No. OF OBSERVATIONS = 20345
SOURCE: U.S. NAVAL WEATHER SERVICE COMMAND PUBLICATION

ANNUAL WIND ROSE FOR SOUTHEAST LUZON

Fig. A-30



Monthly Distribution of Relative Humidity at Pili, The Bicol River Basin
(1966 - 1977)

Fig. A-31

31

Job No BRBC
Project BICOL
Subject HYDROLOGY

BICOL RIVER BASIN
COMPREHENSIVE WATER RESOURCES STUDY
BRBC TAMS-TAE

Date Feb. '78
By C. E.
Ch'k. by C. Ertuna

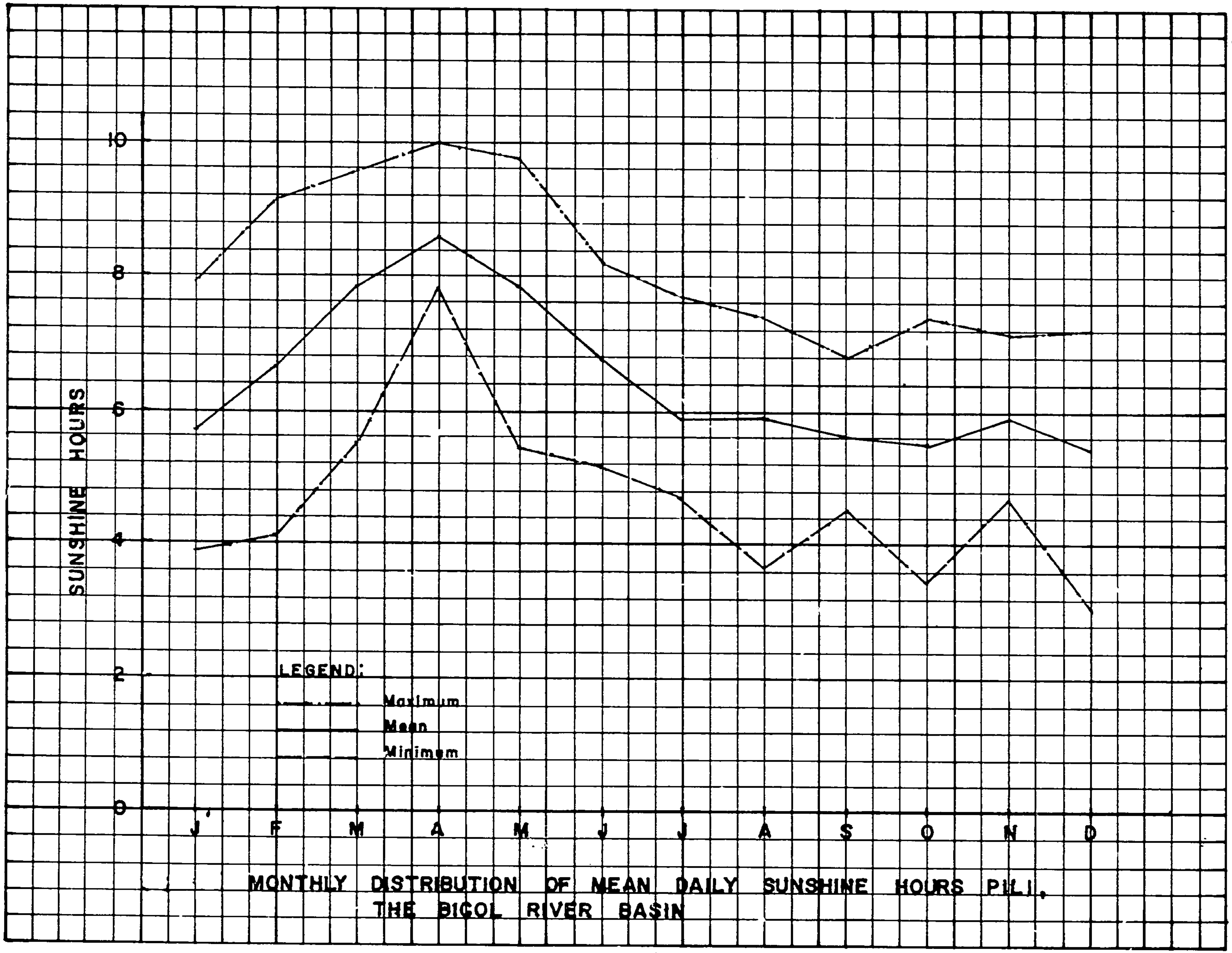


Fig. A-32

Job No. BRBC
Project BICOL
Subject HYDROLOGY

BICOL RIVER BASIN
COMPREHENSIVE WATER RESOURCES STUDY
BRBC TAMS-TAE

Date Feb. '76
By: C. E.
Ch'k. by C. Ertuna

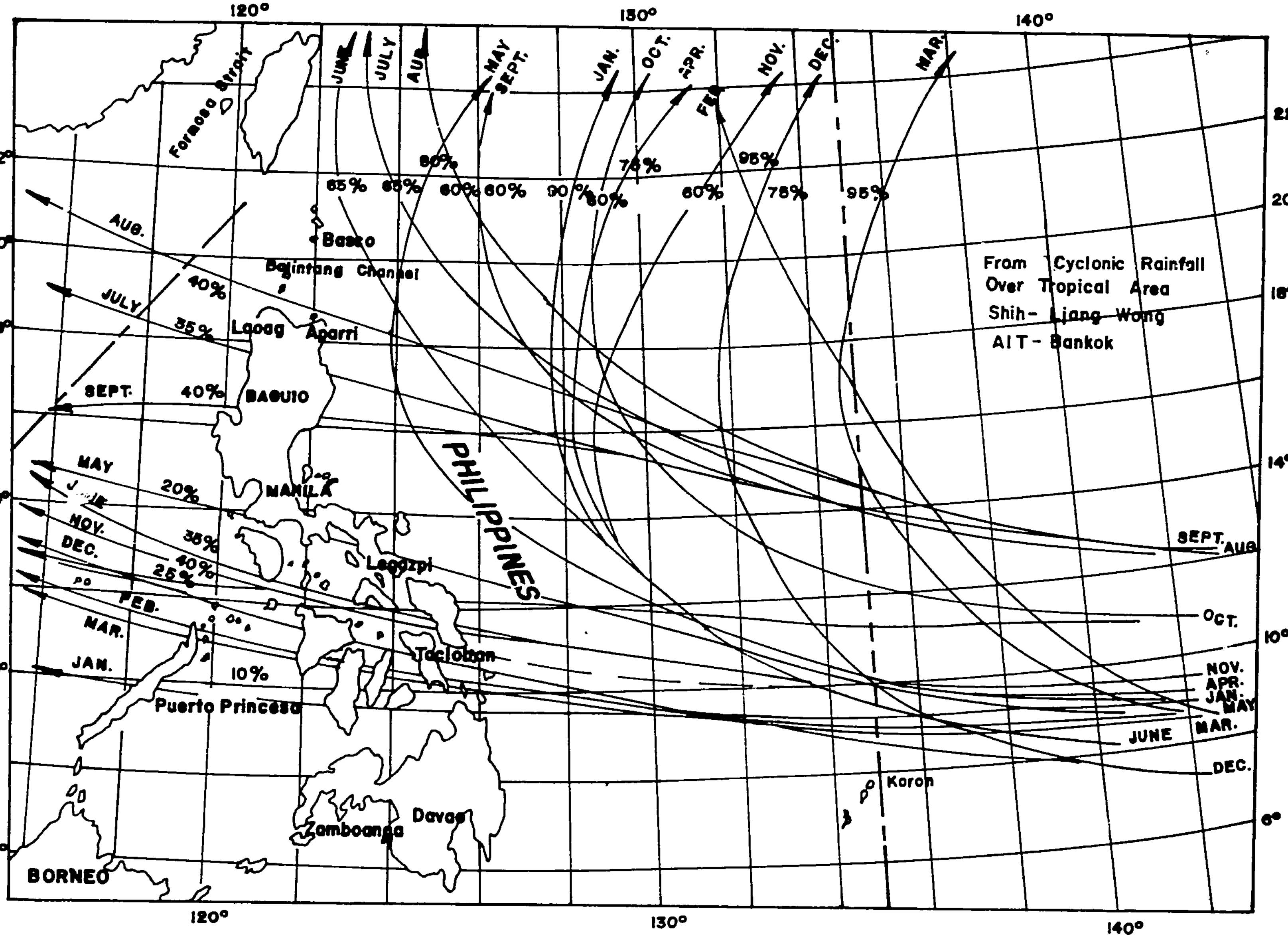


Fig. A—33 Mean Monthly Tracks Of Tropical Cyclones Affecting The Philippines

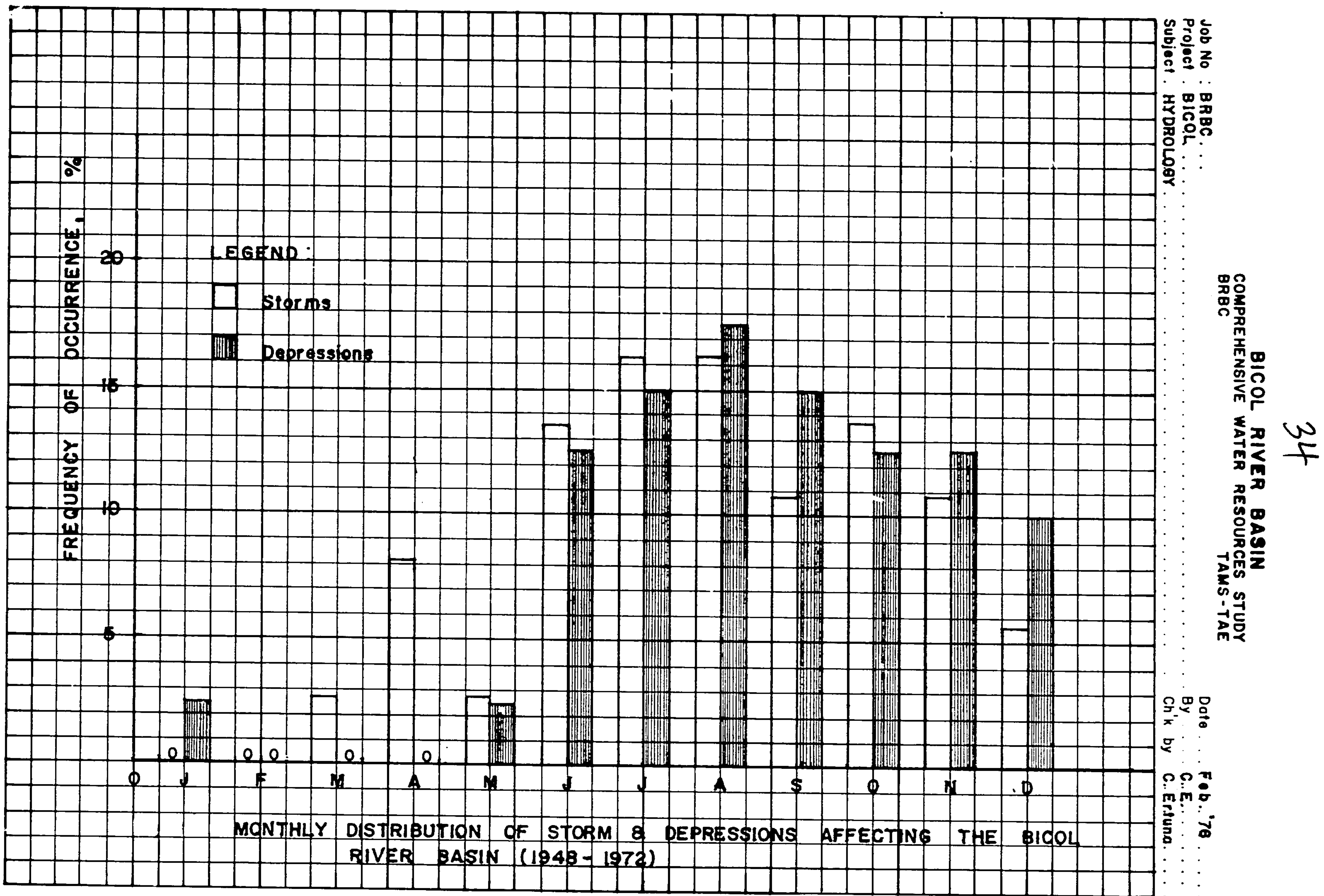
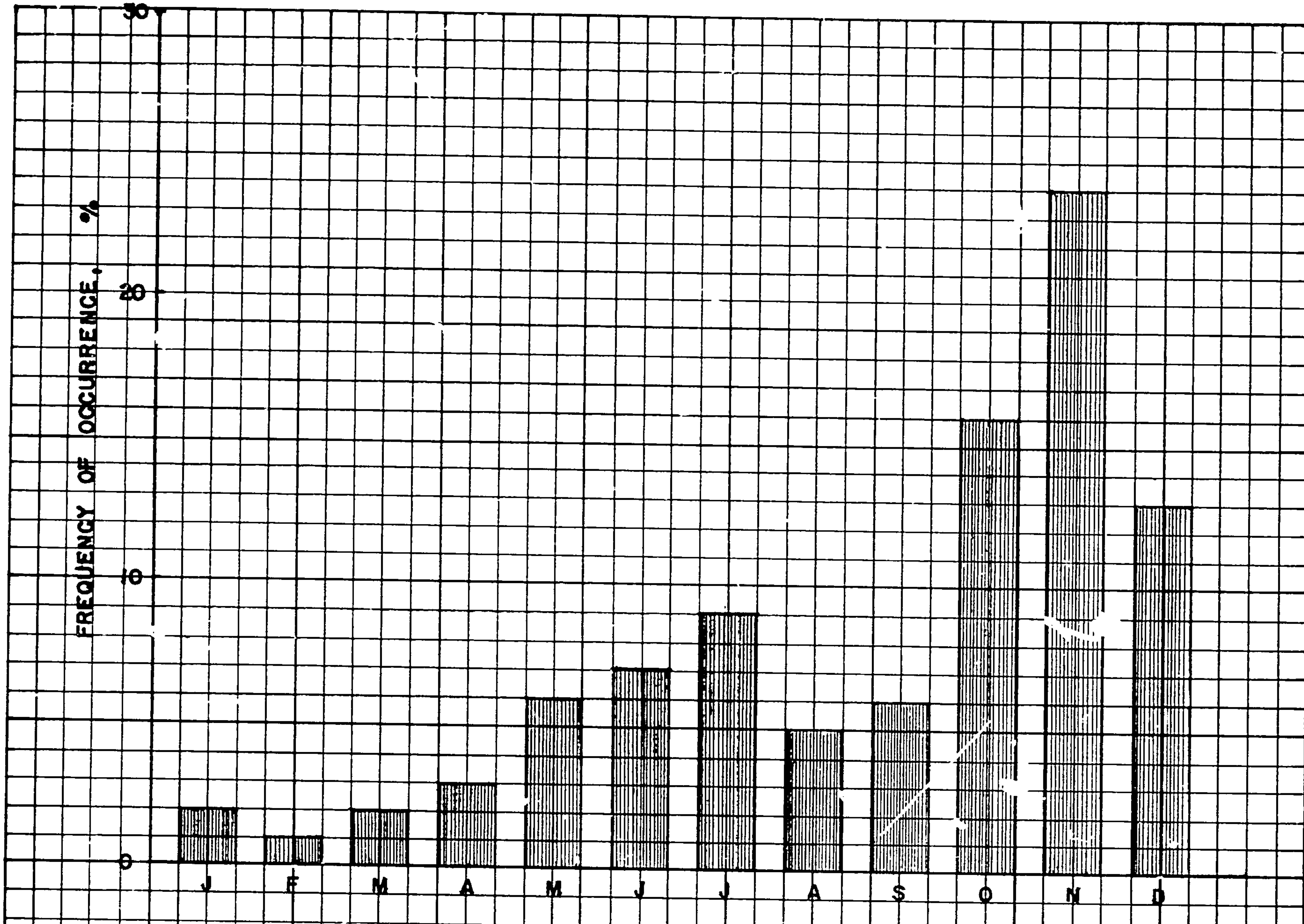

FREQUENCY OF OCCURRENCE, %
20
15
10
5
LEGEND:
Storms
Depressions
0 0 0 0 0 0
O J F M A M J J A S O N D
MONTHLY DISTRIBUTION OF STORM & DEPRESSIONS AFFECTING THE BICOL RIVER BASIN (1948 - 1972)
Job No : BRBC
Project : BICOL
Subject : HYDROLOGY
BICOL RIVER BASIN
COMPREHENSIVE WATER RESOURCES STUDY
BRBC TAMS-TAE
Date Feb. '76
By C.E.
Ch'k by C. Erluna
34

Fig. A-34

Job No. BRBC.
Project BICOL
Subject HYDROLOGY

BICOL RIVER BASIN
COMPREHENSIVE WATER RESOURCES STUDY
BRBC TAMS-TAE

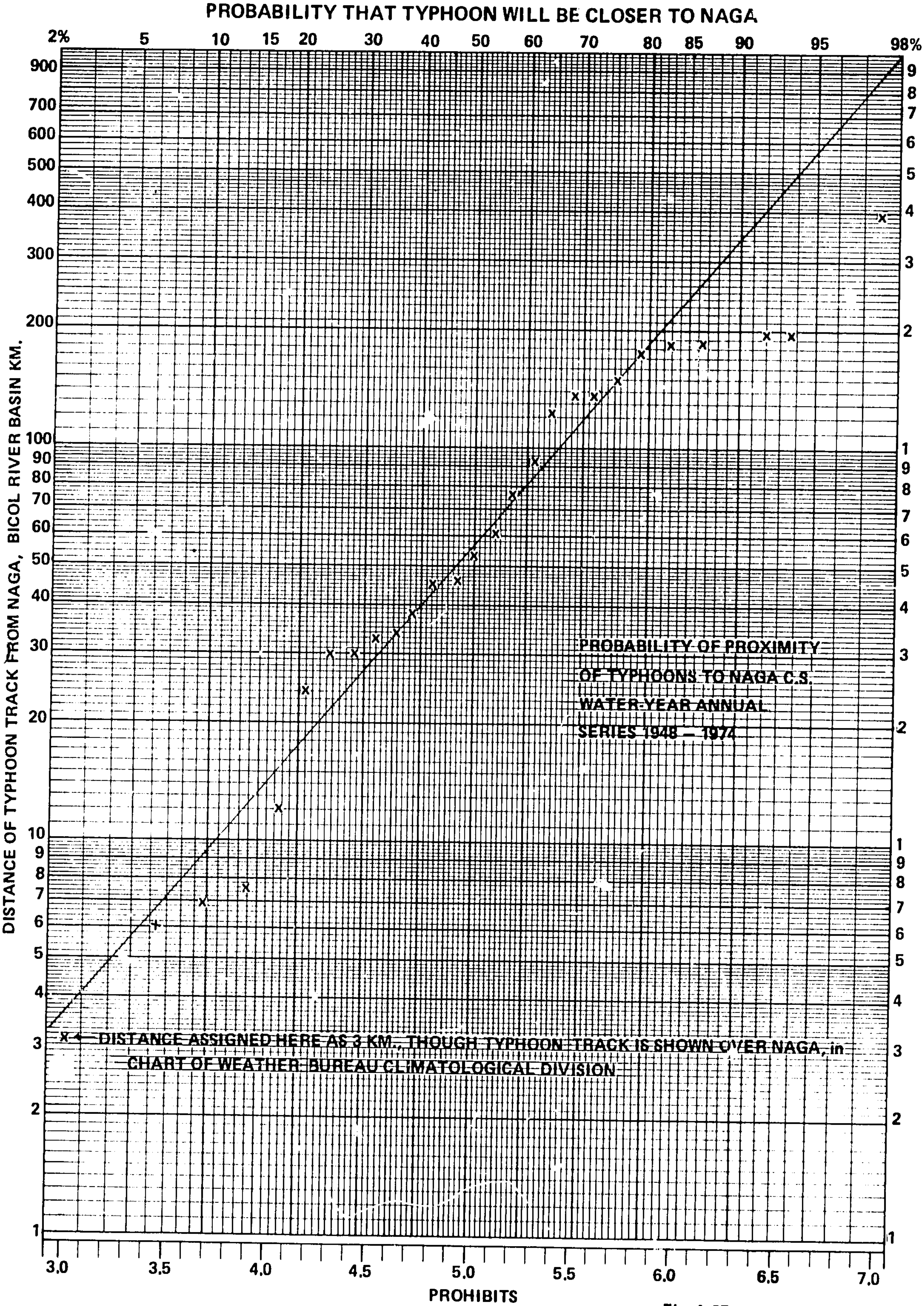
Date Feb. '76
By C.E.
Ch'k by C.Ertuna.



MONTHLY DISTRIBUTION OF TYPHOONS AFFECTING THE BICOL RIVER BASIN
(1948 - 1974)

Fig. A-35

35a



PROBABILITY THAT TYPHOON WILL BE CLOSER TO NAGA
2% 5 10 15 20 30 40 50 60 70 80 85 90 95 98%
DISTANCE OF TYPHOON TRACK FROM NAGA, BICOL RIVER BASIN KM.
900 700 600 500 400 300 200 100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
PROBABILITY OF PROXIMITY
OF TYPHOONS TO NAGA C.S.
WATER-YEAR ANNUAL
SERIES 1948 – 1974
DISTANCE ASSIGNED HERE AS 3 KM., THOUGH TYPHOON TRACK IS SHOWN OVER NAGA, in
CHART OF WEATHER BUREAU CLIMATOLOGICAL DIVISION
3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0
PROHIBITS

Fig. A 35 – a

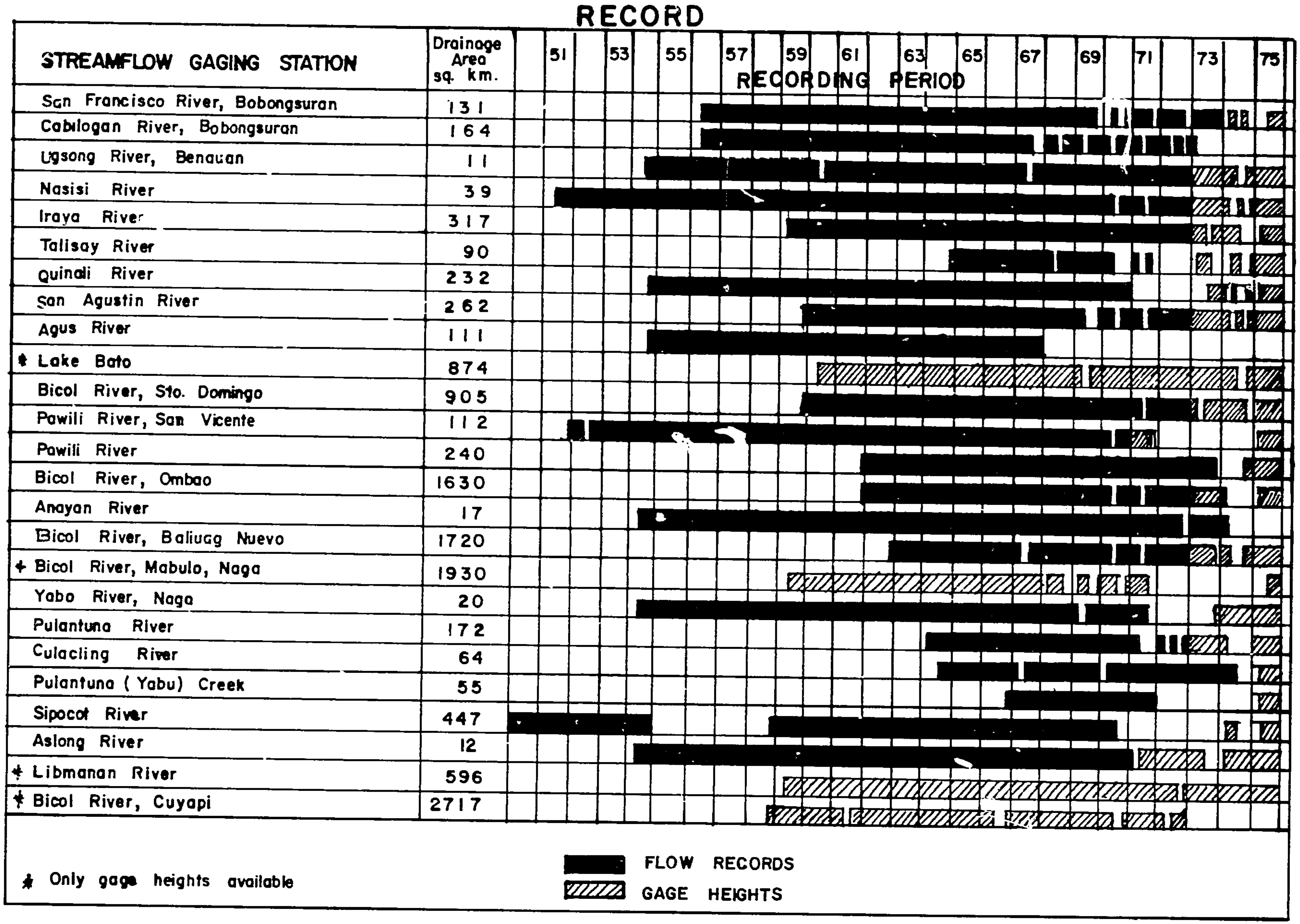


FIG. A-36 STREAMFLOW GAGING STATIONS IN THE BASIN

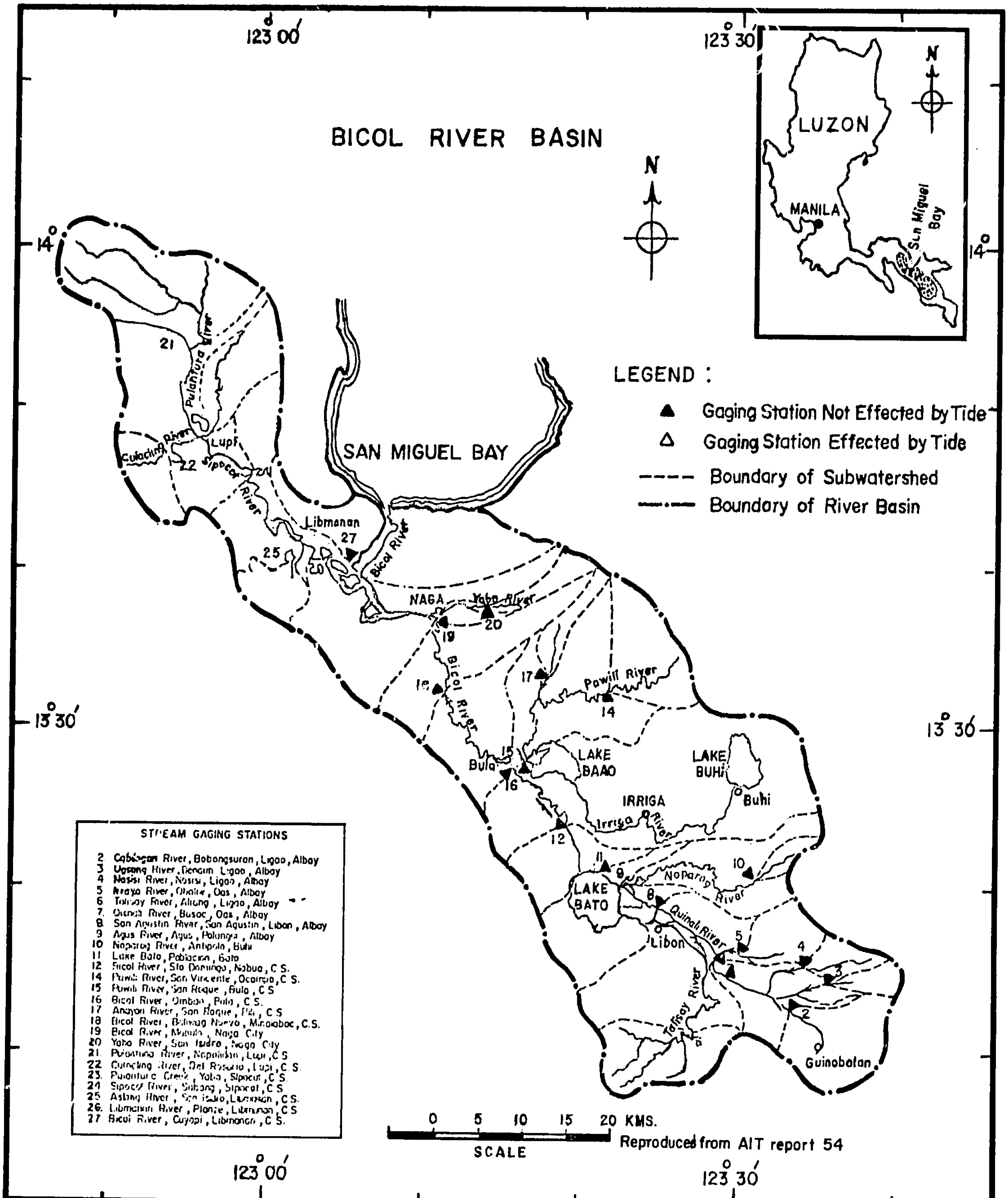


Fig. A-37 Division of Subwatersheds for Bicol River Basin and Locations of Stream Gaging Stations

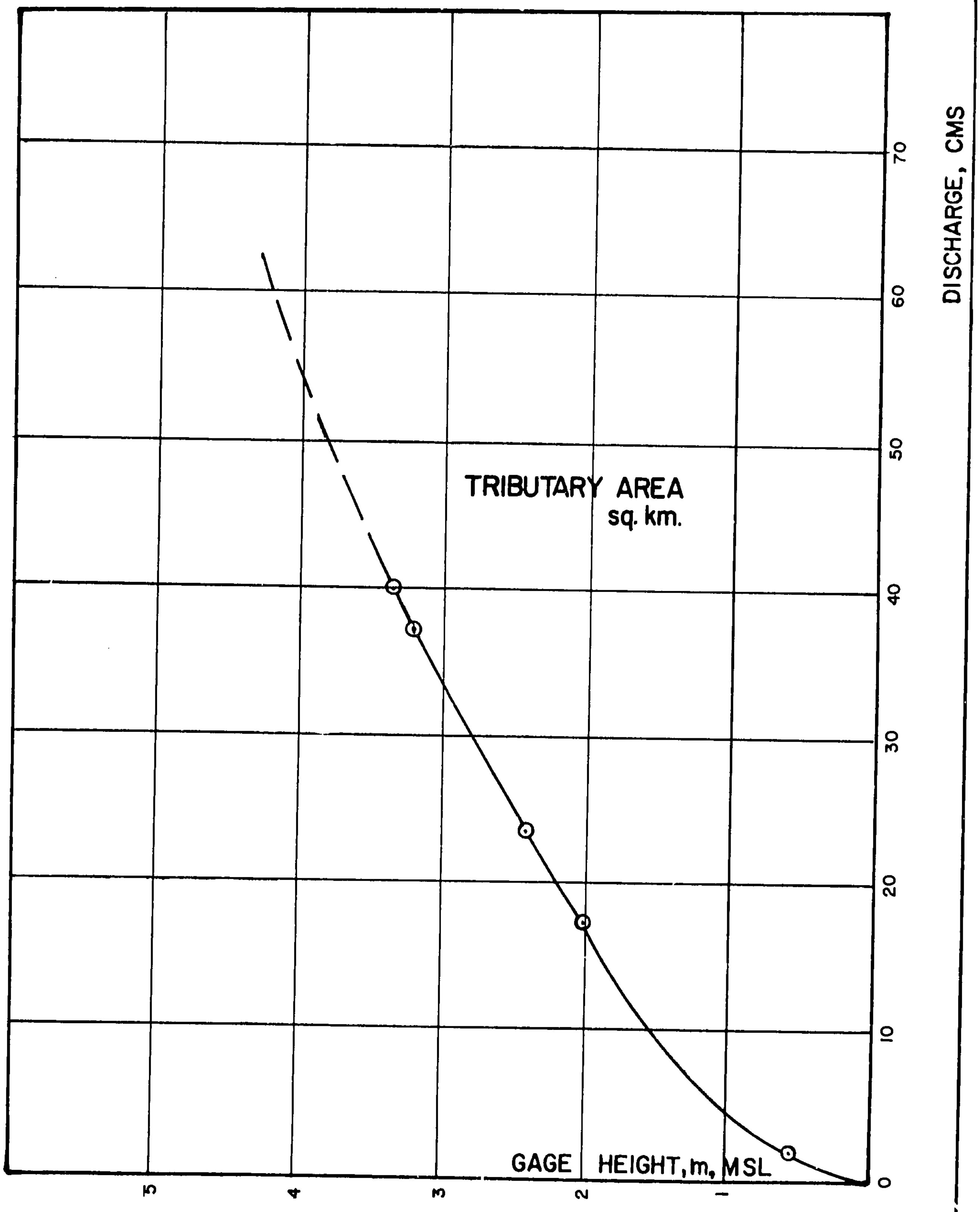


Fig. A-38 Rating Curve for Lalo River, Antipolo, Buhi

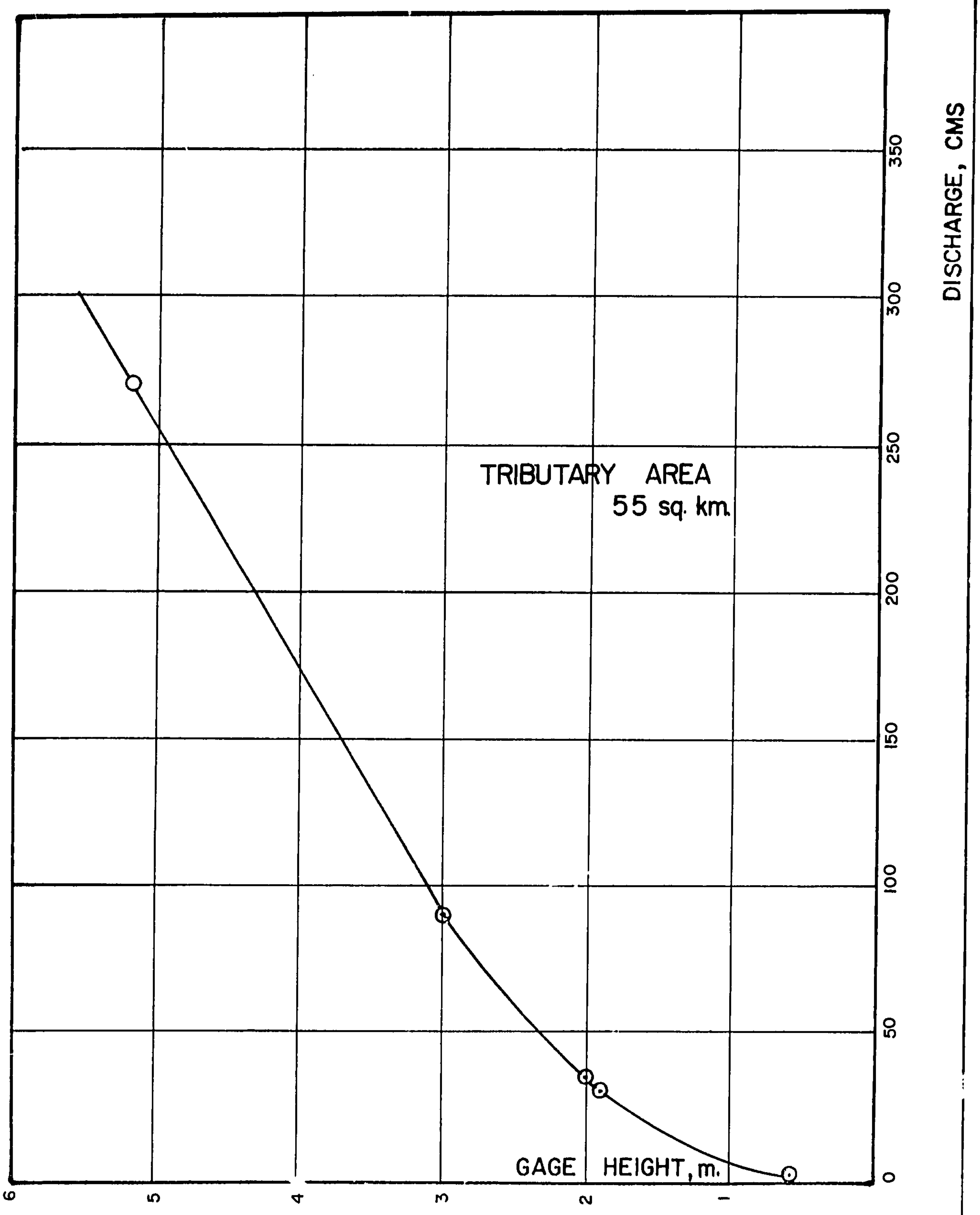


Fig. A–39 Rating Curve for Yabo River (Pulantuna Creek), Yabo, Sipocot, Camarines Sur

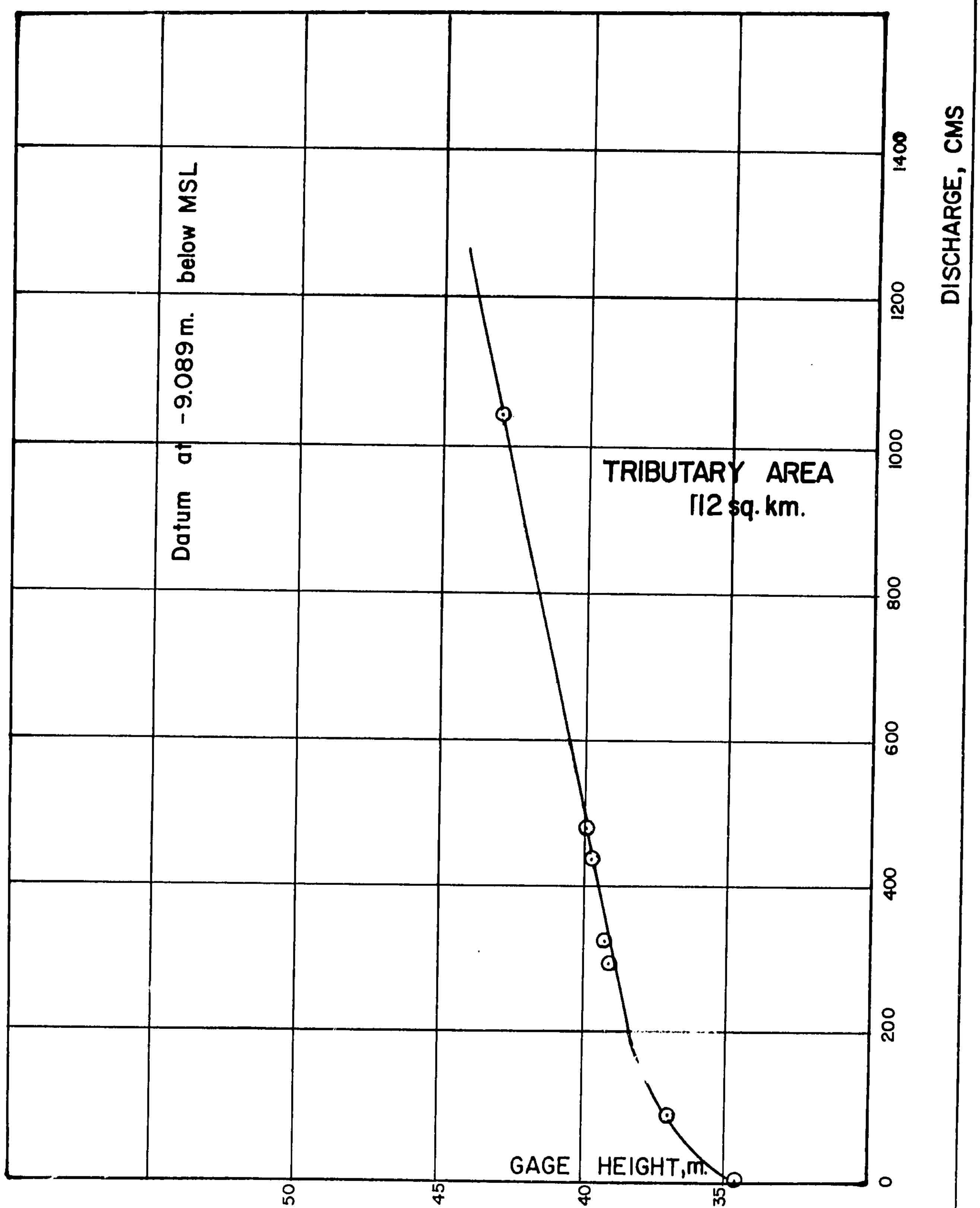


Fig. A-40 Rating Curve for Pawili River, San Vicente, Ocampo, Camarines Sur

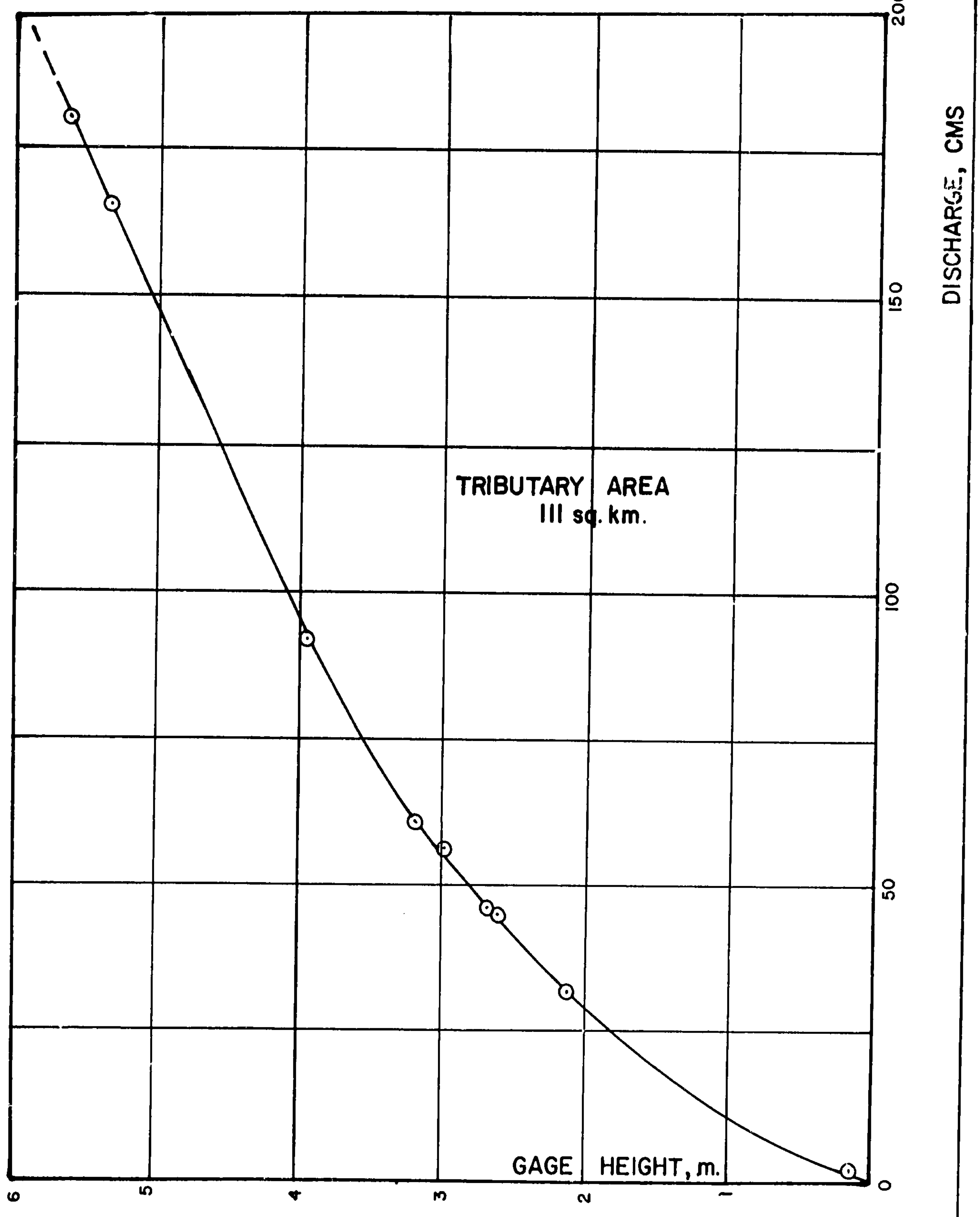


Fig. A-41 Rating Curve for Agus River, Polangui

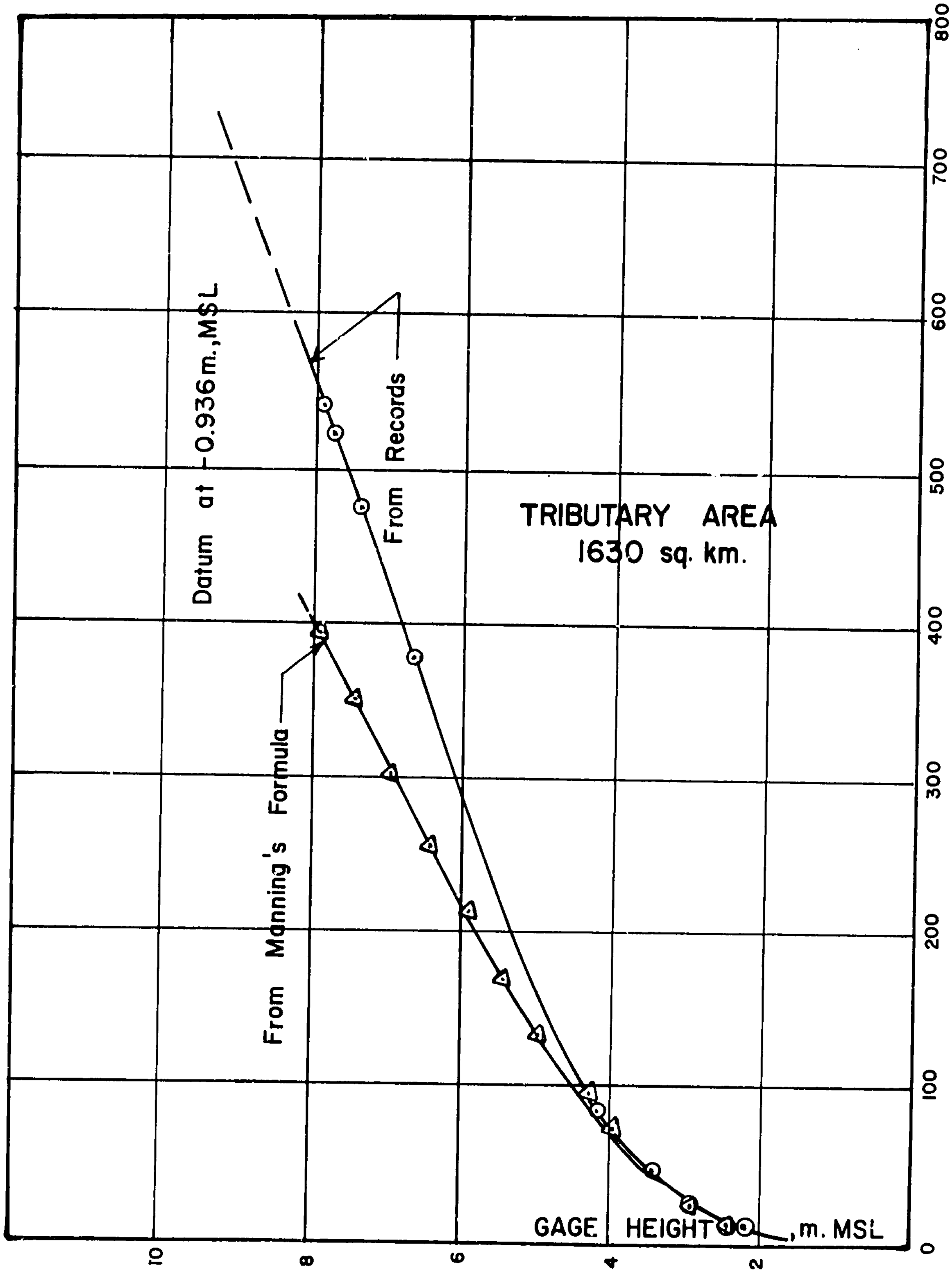


Fig. A-42 Rating Curve for Bicol River, Ombao, Bula.

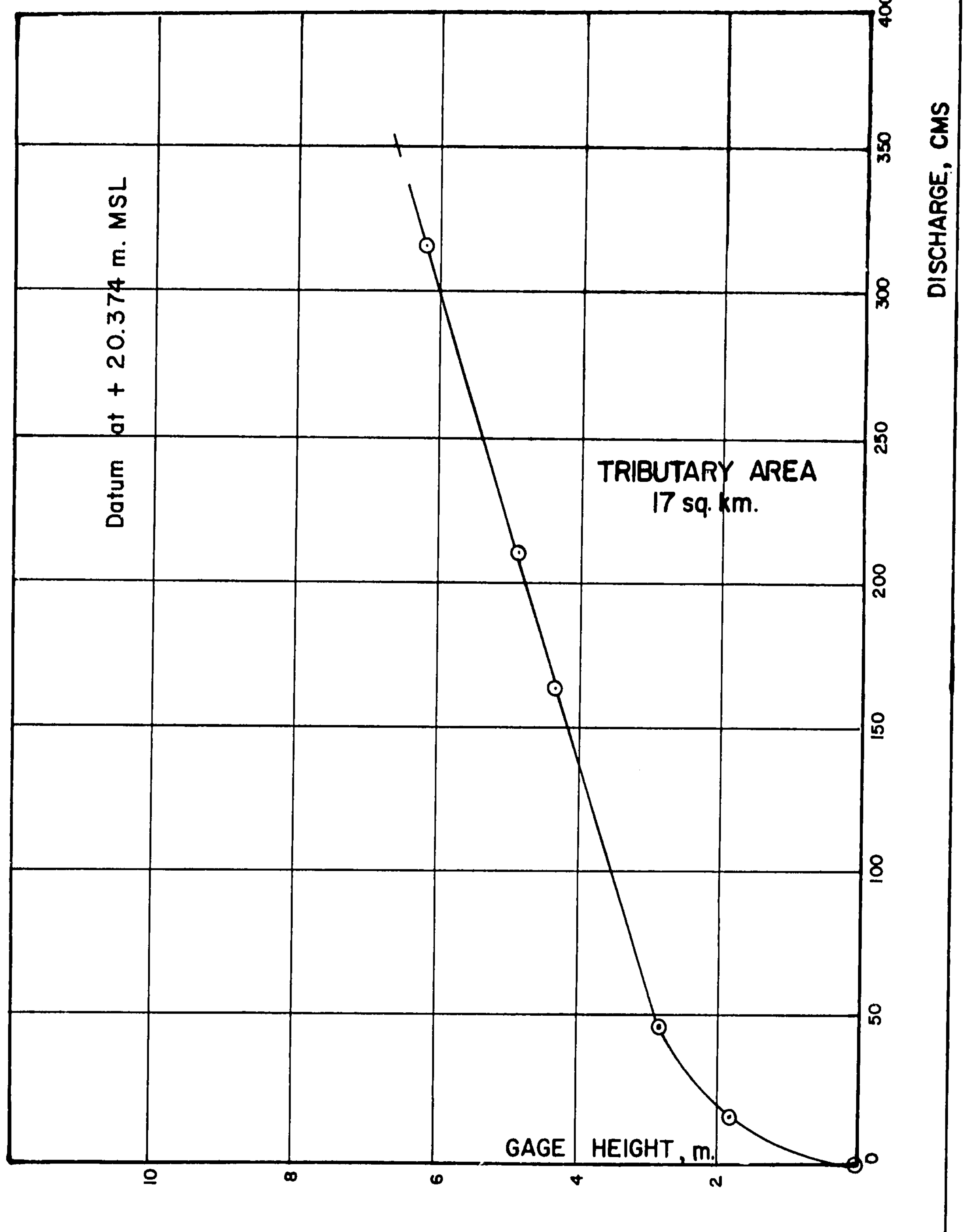


Fig. A-43 Rating Curve for Anayan River, San Roque, Pili

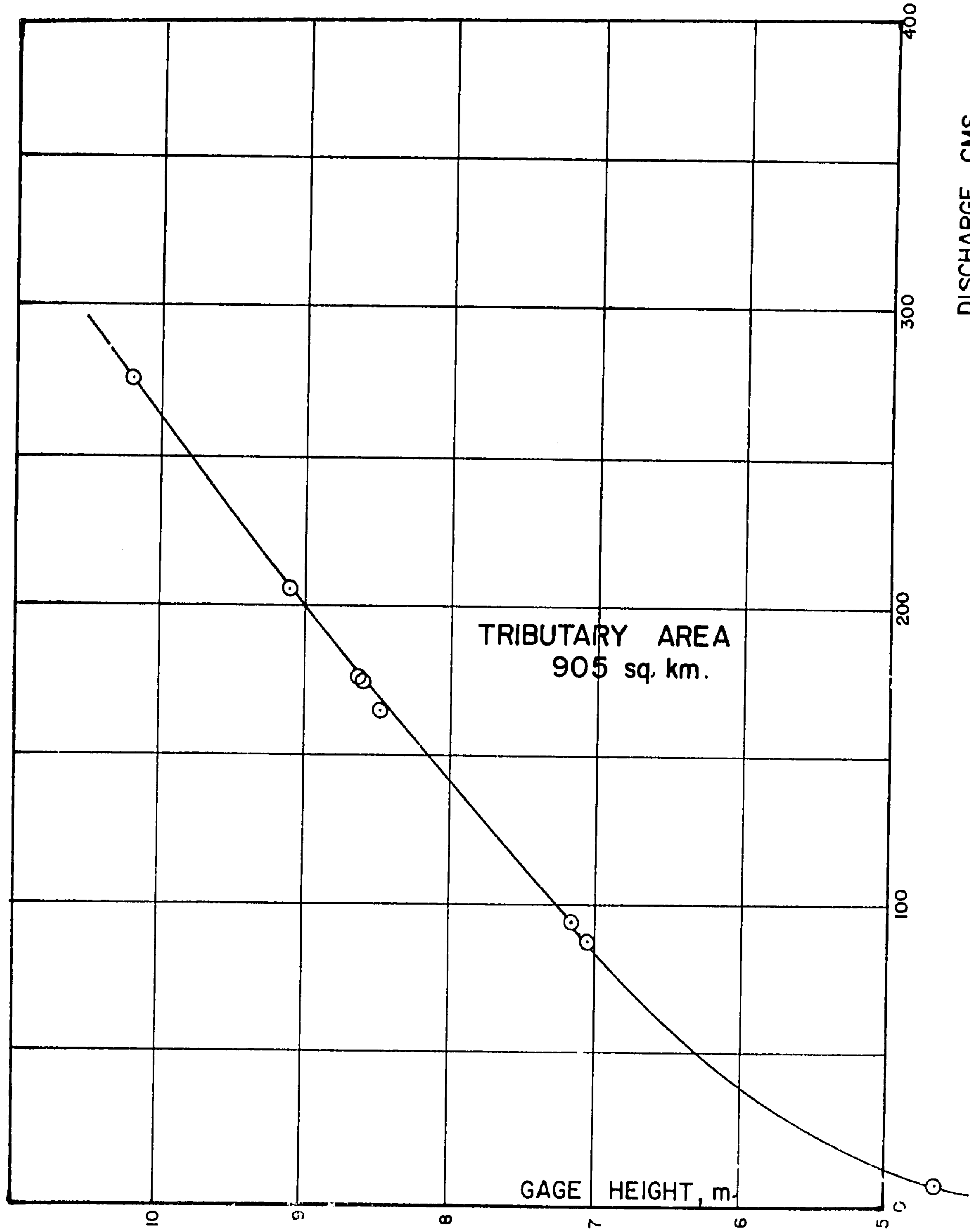


Fig. A-44 Rating Curve for Bicol River, Sto. Domingo

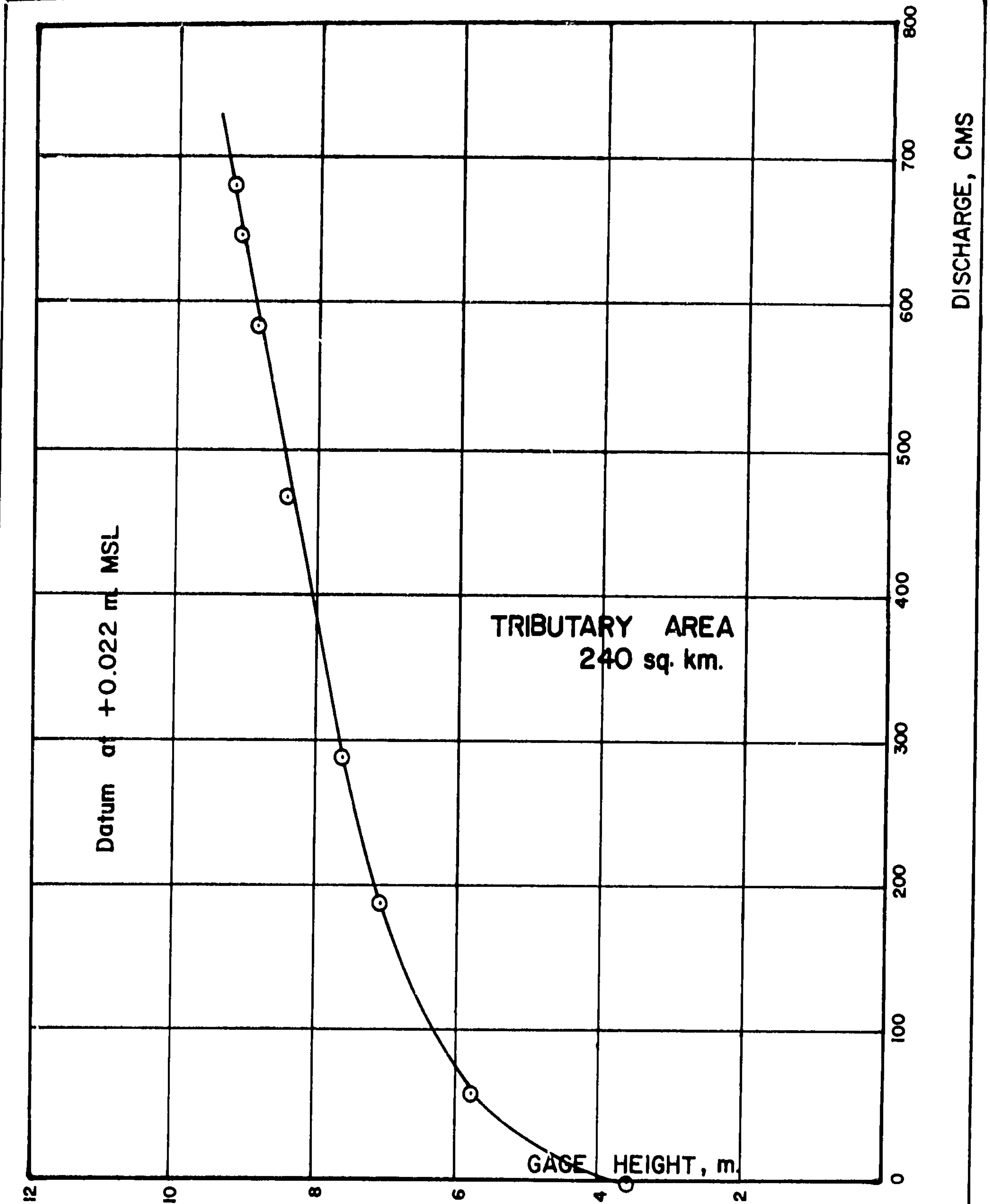


Fig. A-45 Rating Curve for Pawili River, San Roque Bula

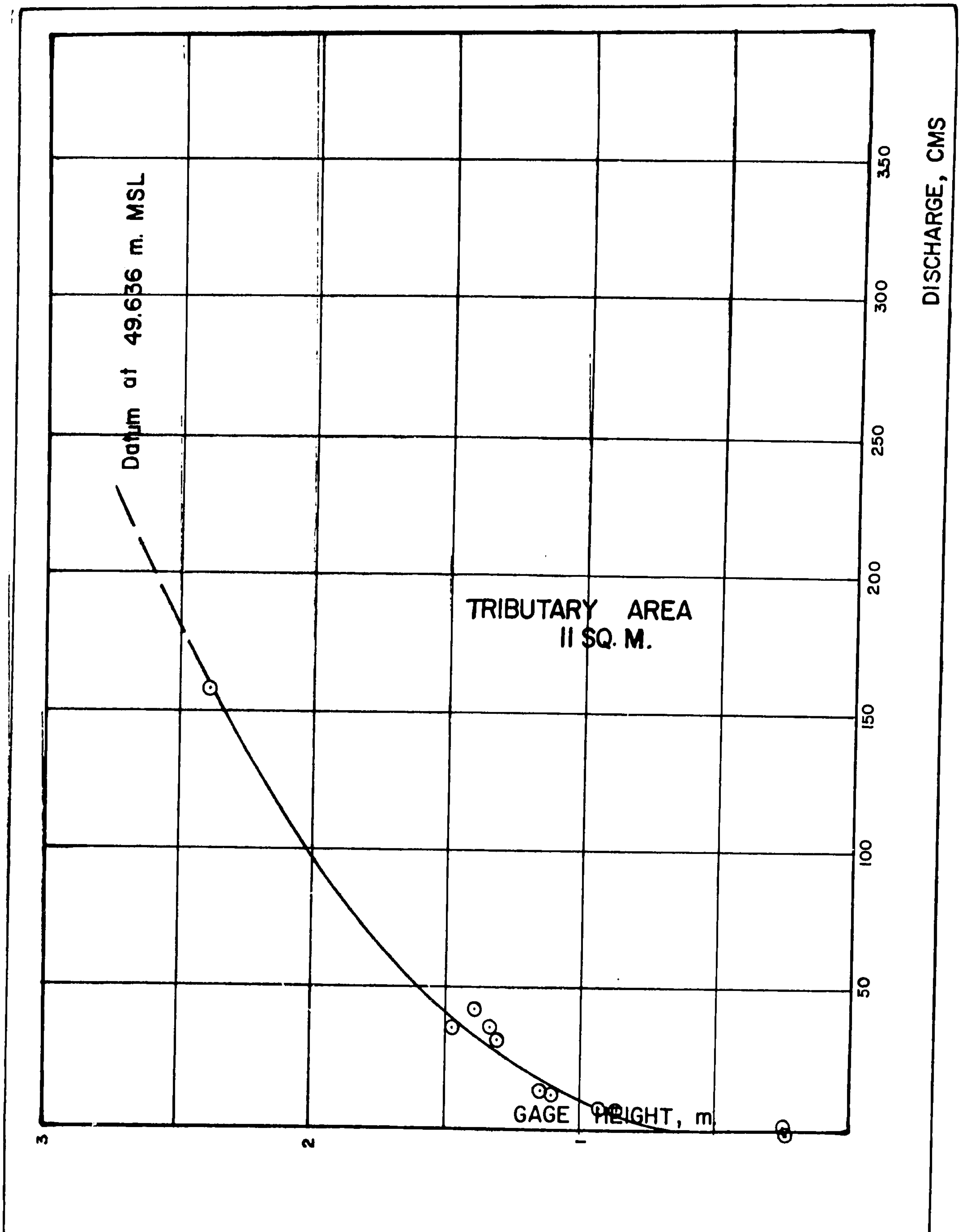


Fig. A-46 Rating Curve for Ugsong River, Binanuanan, Ligao

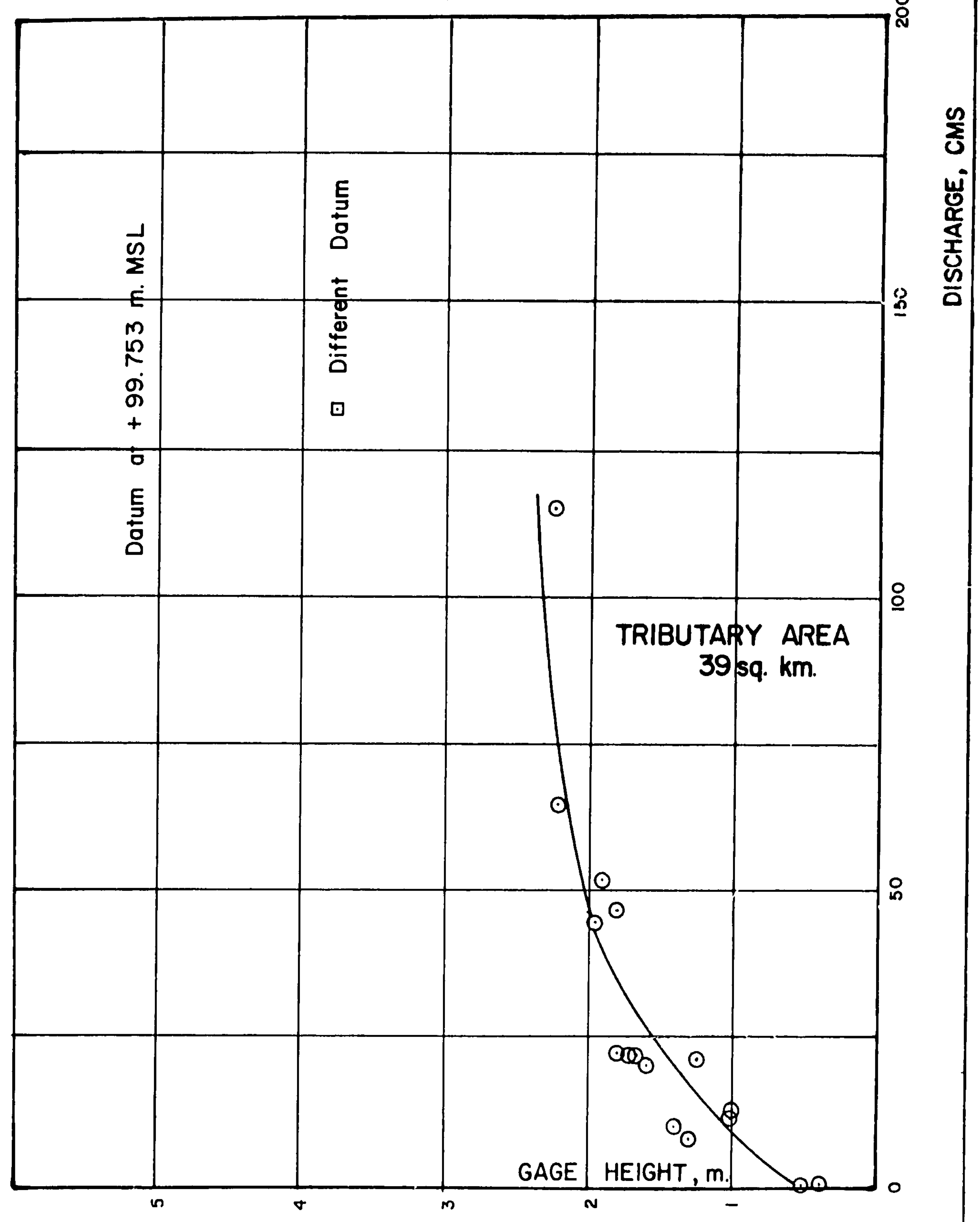


Fig. A-47 Rating Curve for Nasisi River, Nasisi, Ligao

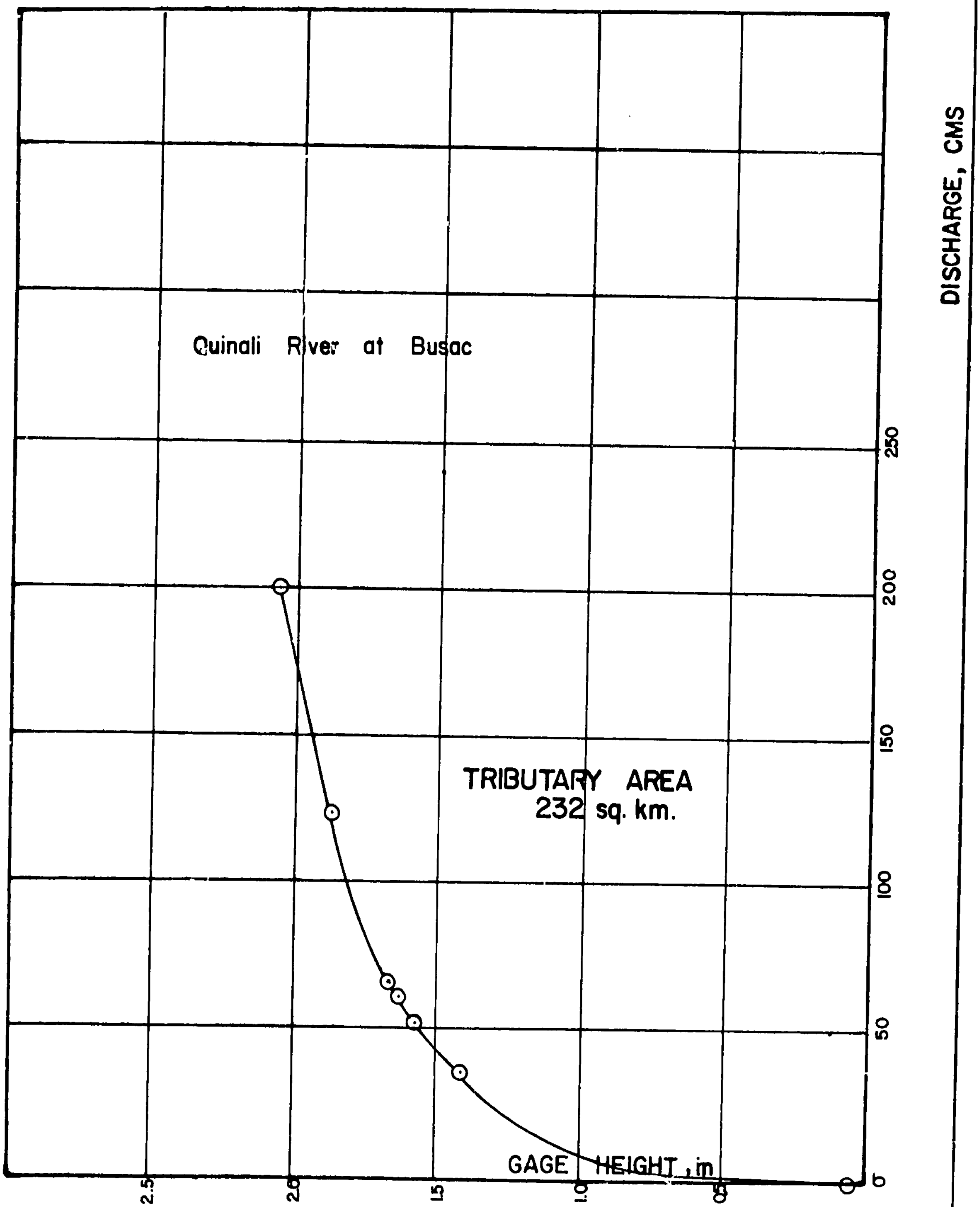


Fig.A-48 Rating Curve for Quinali River, Busac

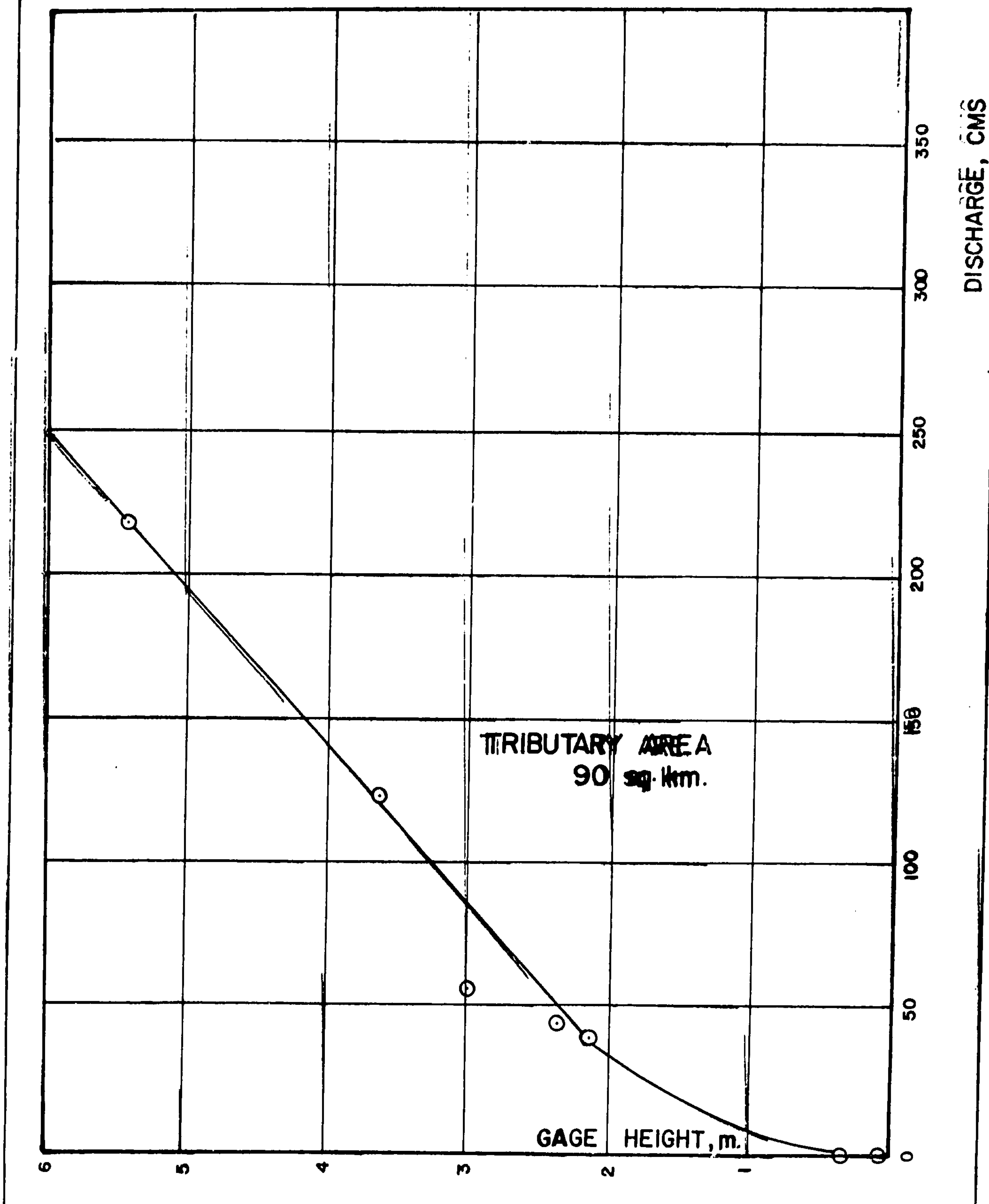


Fig. A-49 Rating Curve for Talisay River, Aliang, Ligao

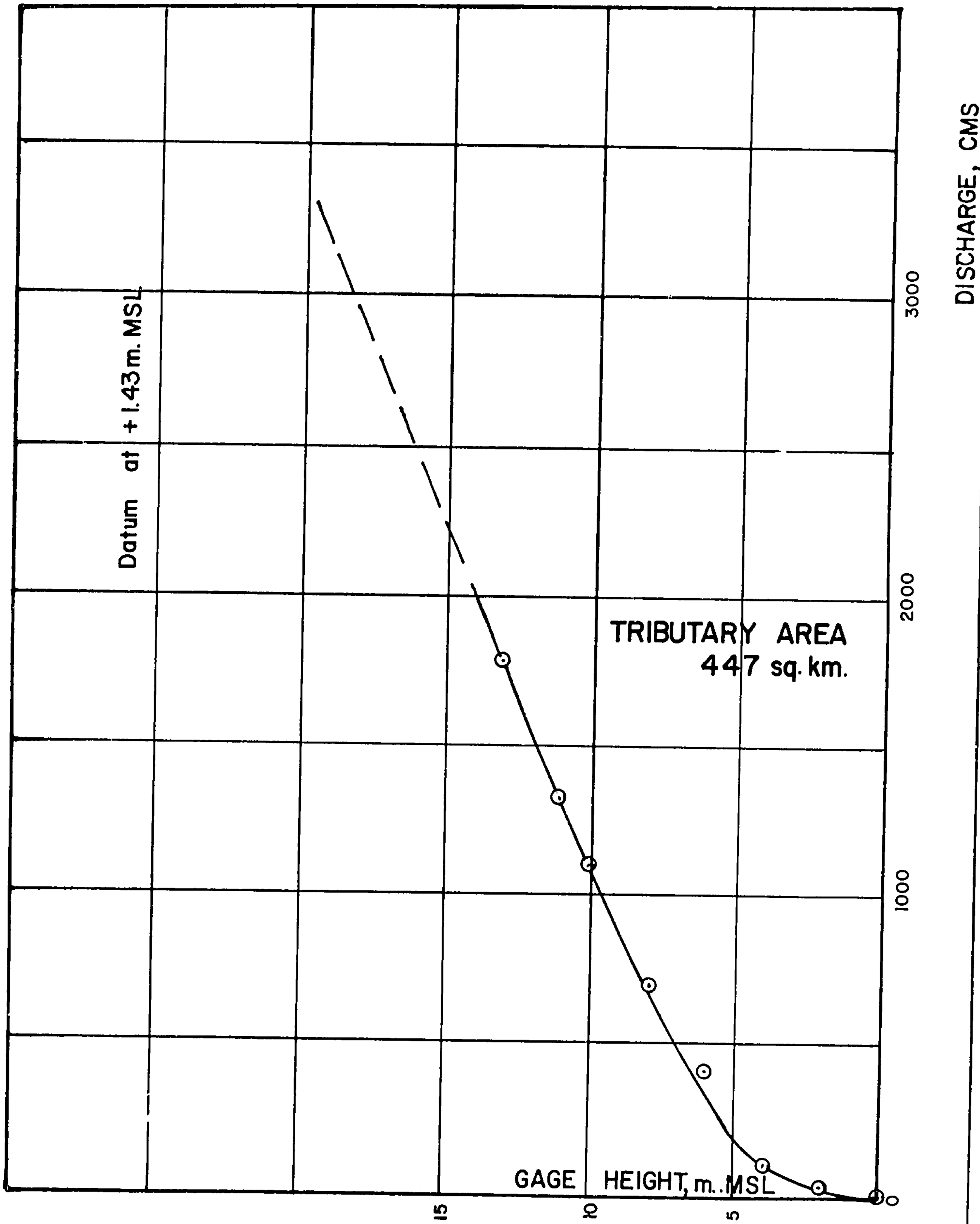


Fig. A-50 Rating Curve for Sipocot River, Sabang (Revised)

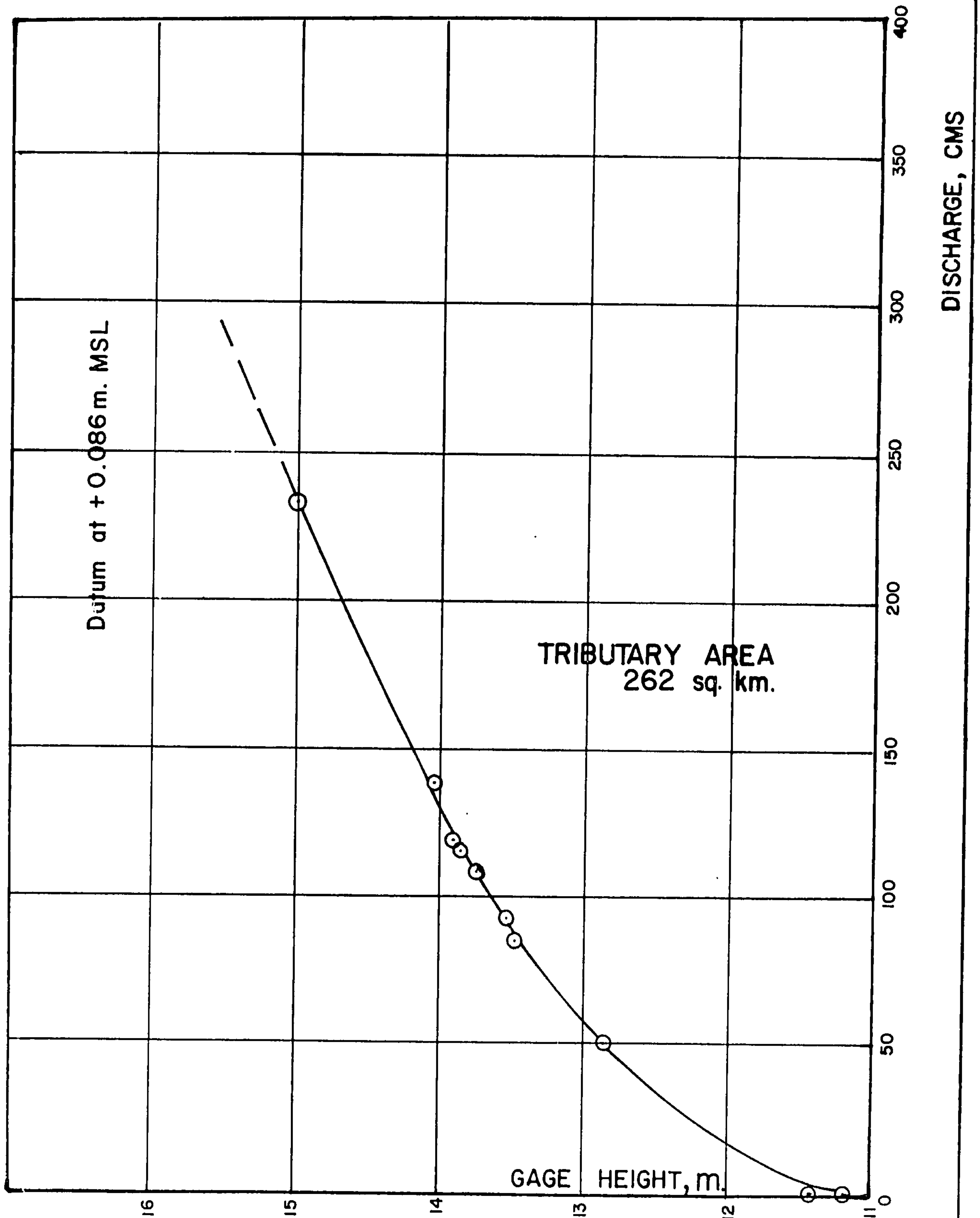


Fig. A-51 Rating Curve for San Agustin River, San Agustin, Libon, Albay

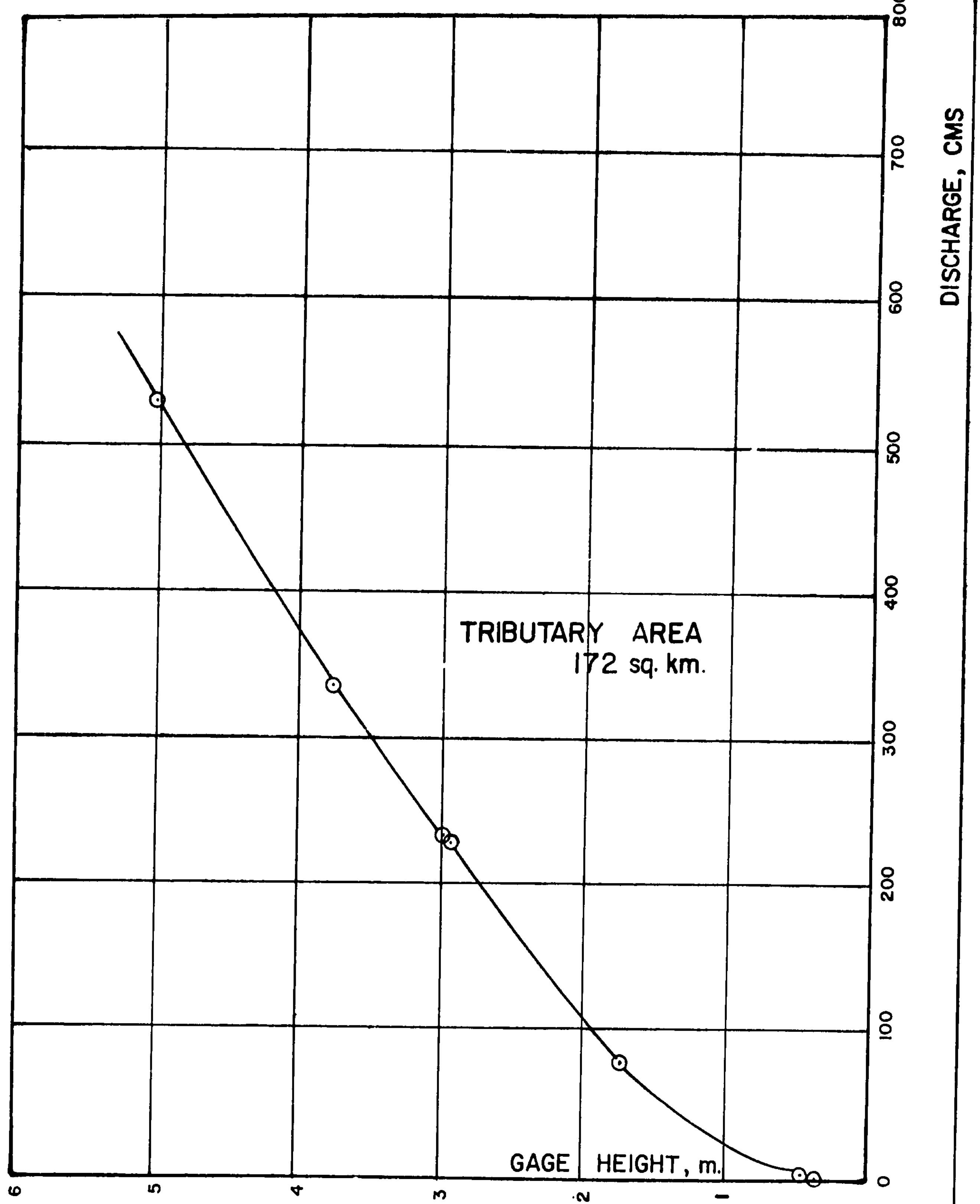


Fig. A-52 Rating Curve for Pulantuna River, Napolidan, Lupi, Camarines Sur

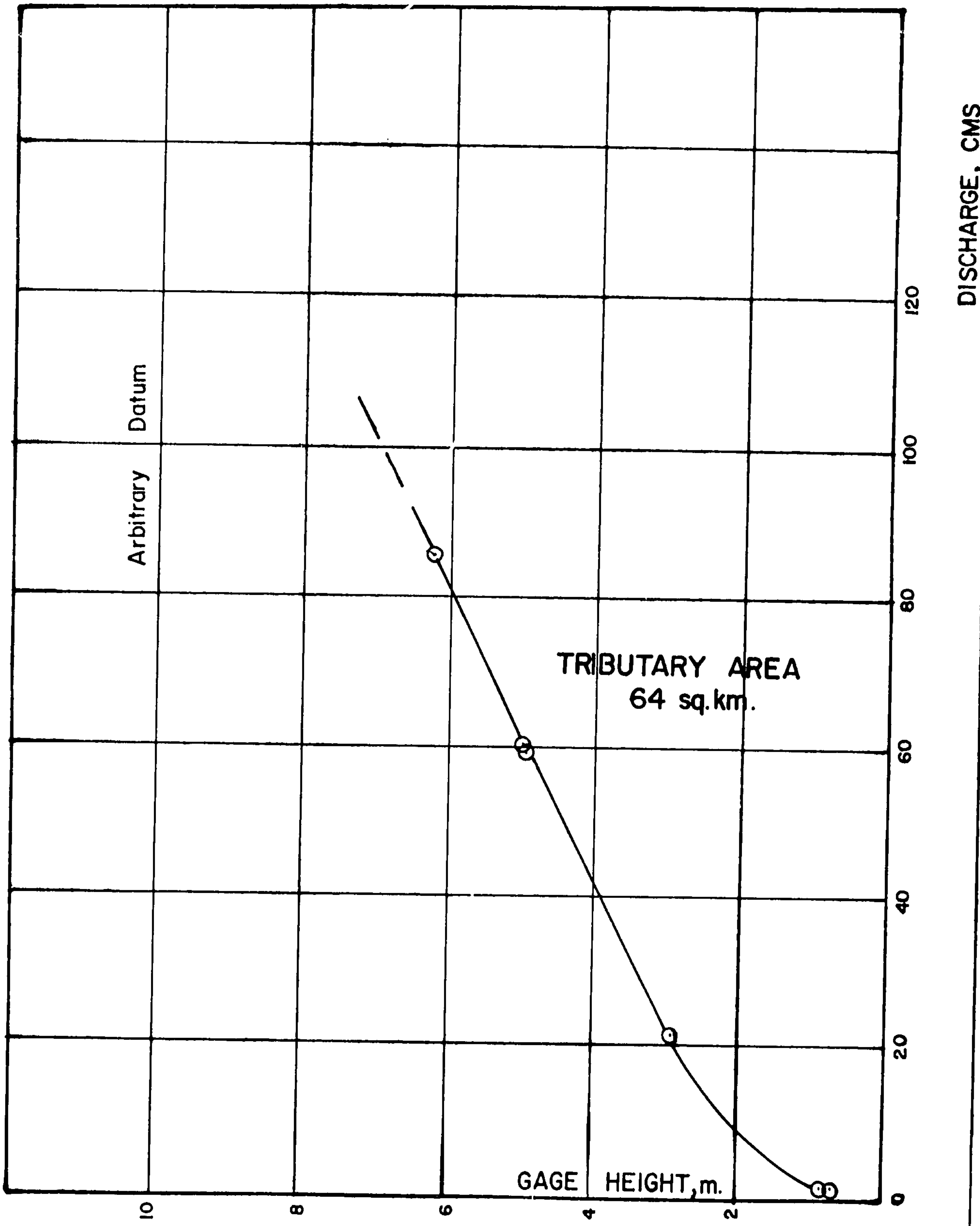


Fig. A-53 Rating Curve for Culacling River, Del Rosario, Lupi

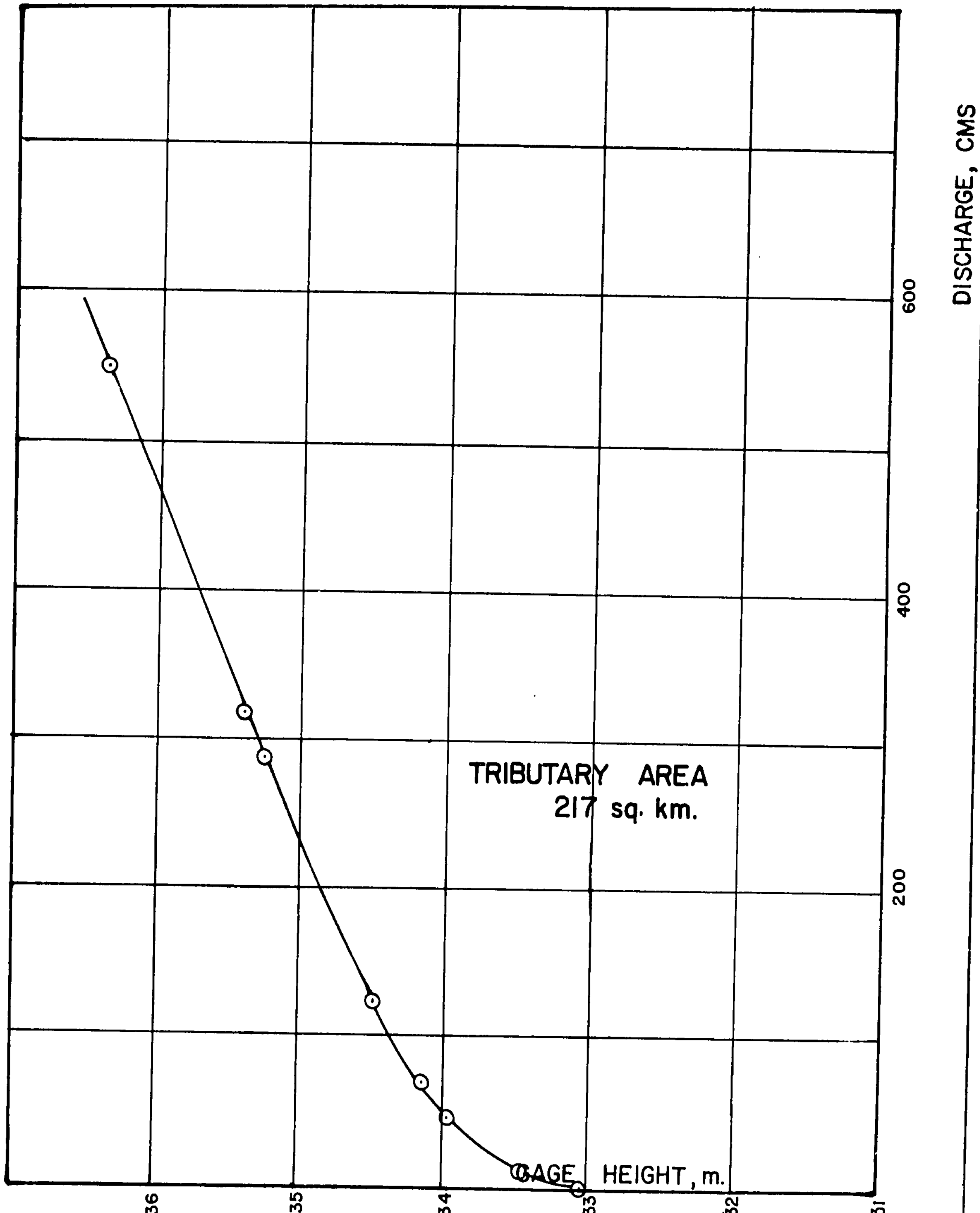


Fig. A-54 Rating Curve for Irraya River, Obaliw, Oas

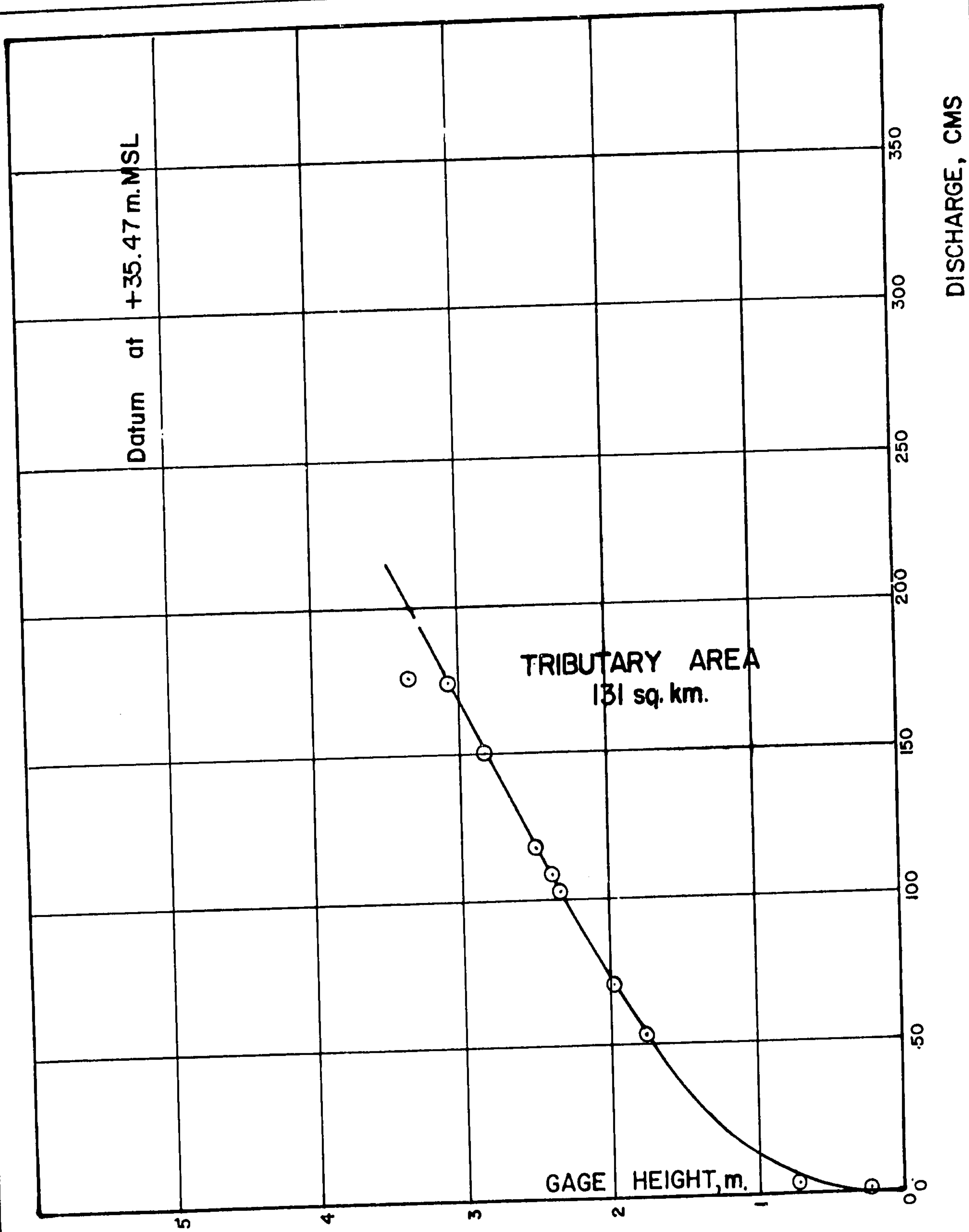


Fig. A-55 Rating Curve for San Francisco River, Bobongsuran, Ligao

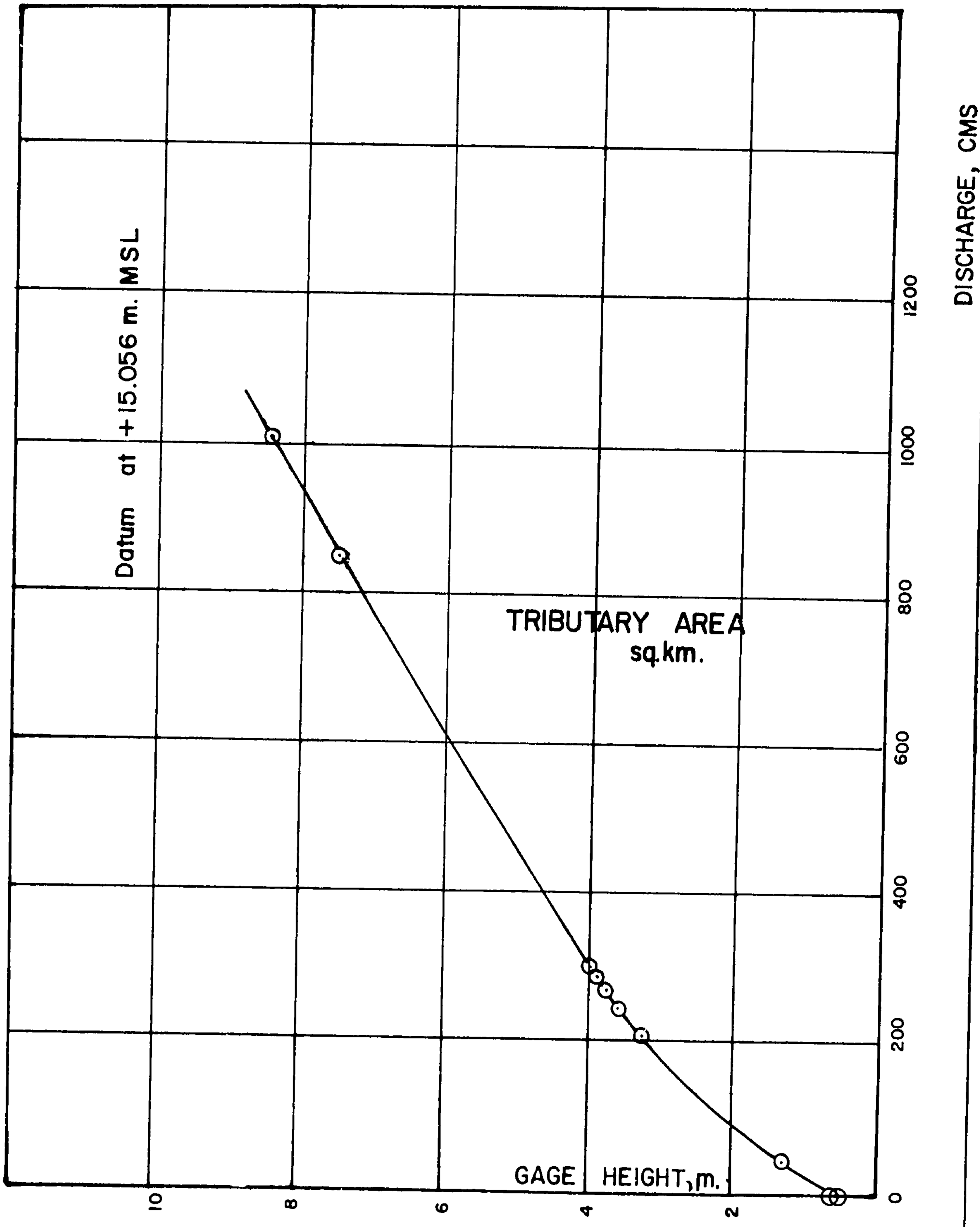


Fig. A-56 Rating Curve for Barit River, Sto. Nino, Iriga

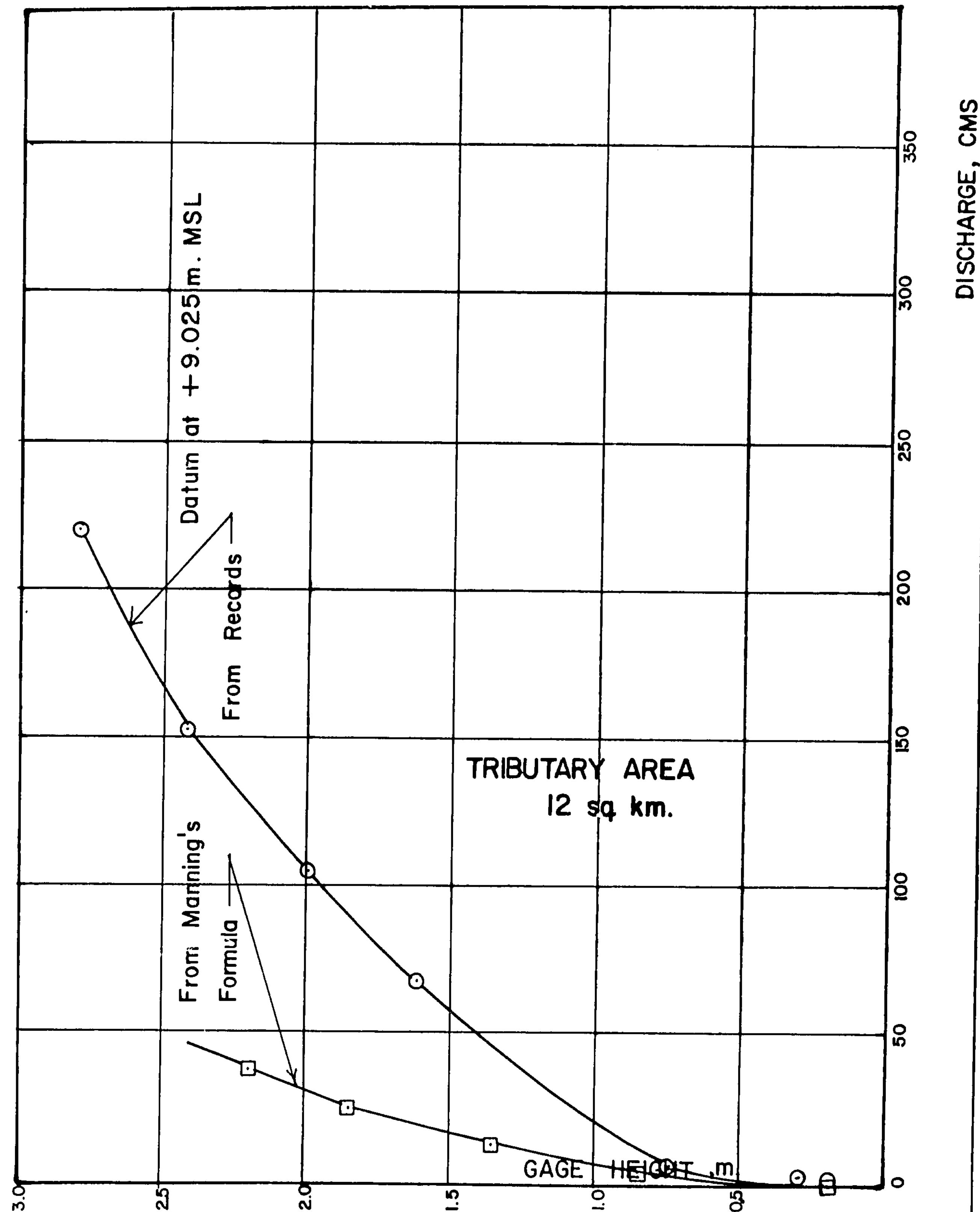


Fig. A-57 Rating Curve for Aslong River, San Isidro, Libmanan, Camarines Sur

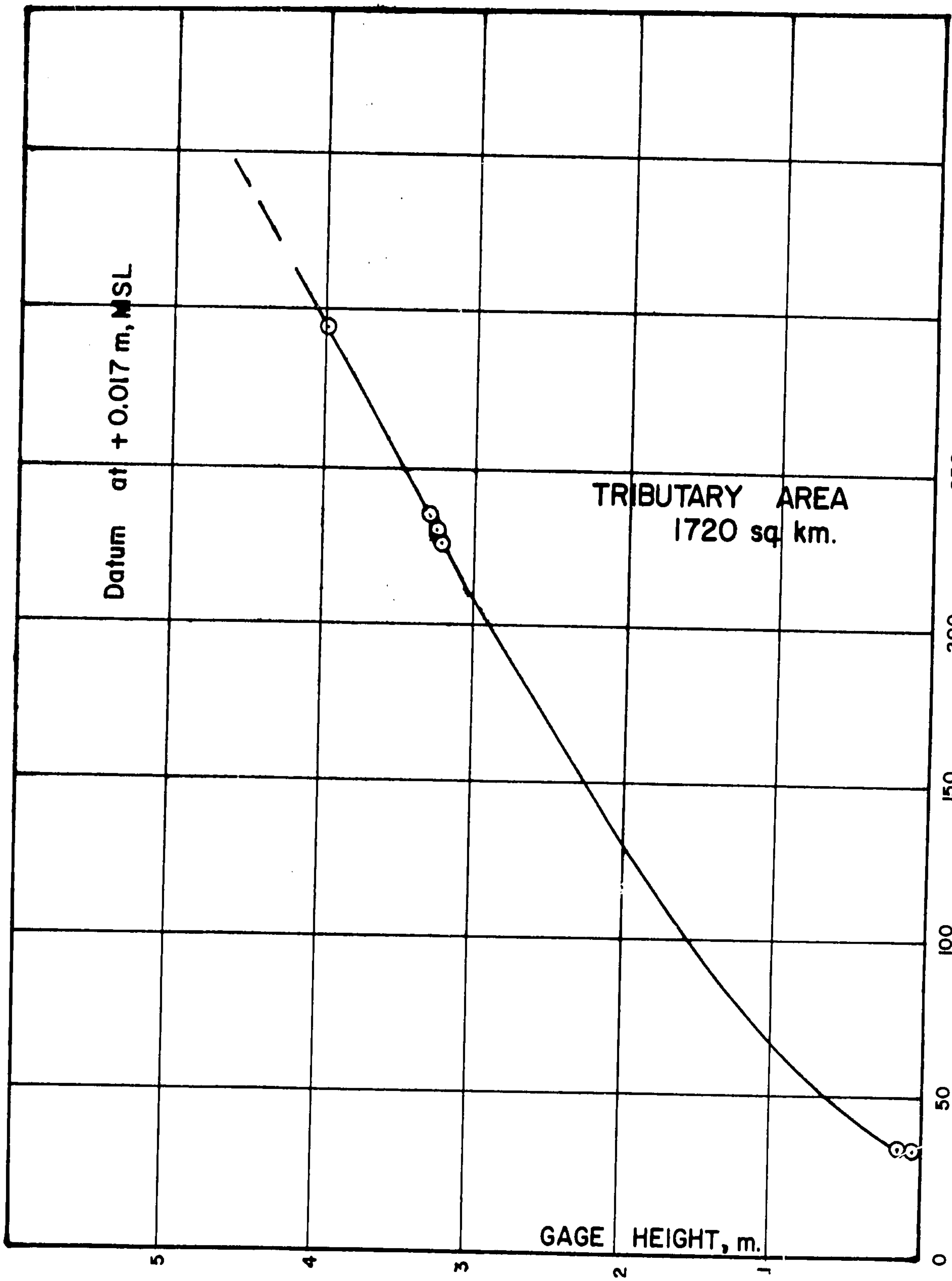


Fig. A-58 Rating Curve for Bícol River, Baliwag Nuevo, Minalabac

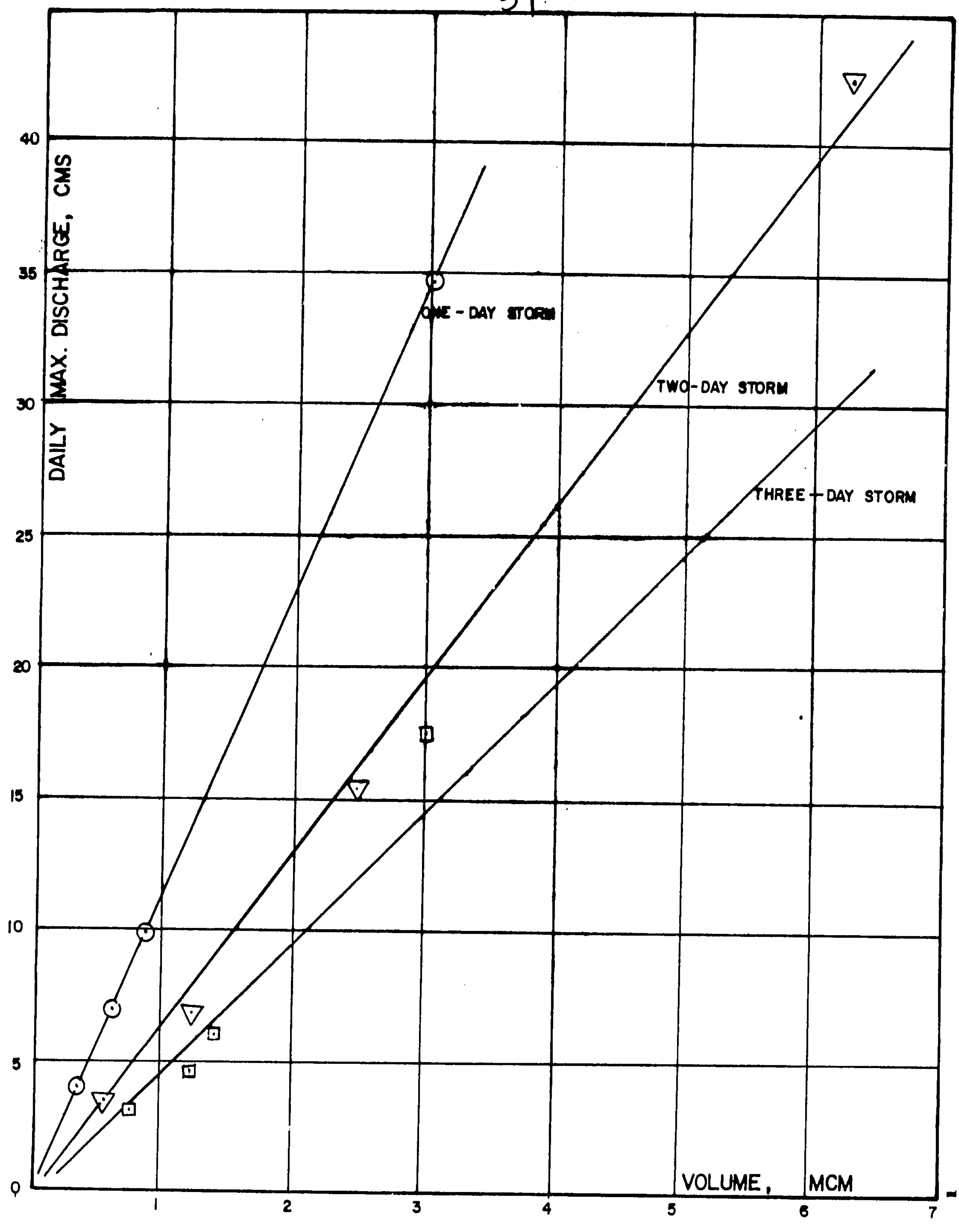


FIG.A-59 Daily Maximum Discharge-Volume Relationship, YABO RIVER, San Isidro, Naga City

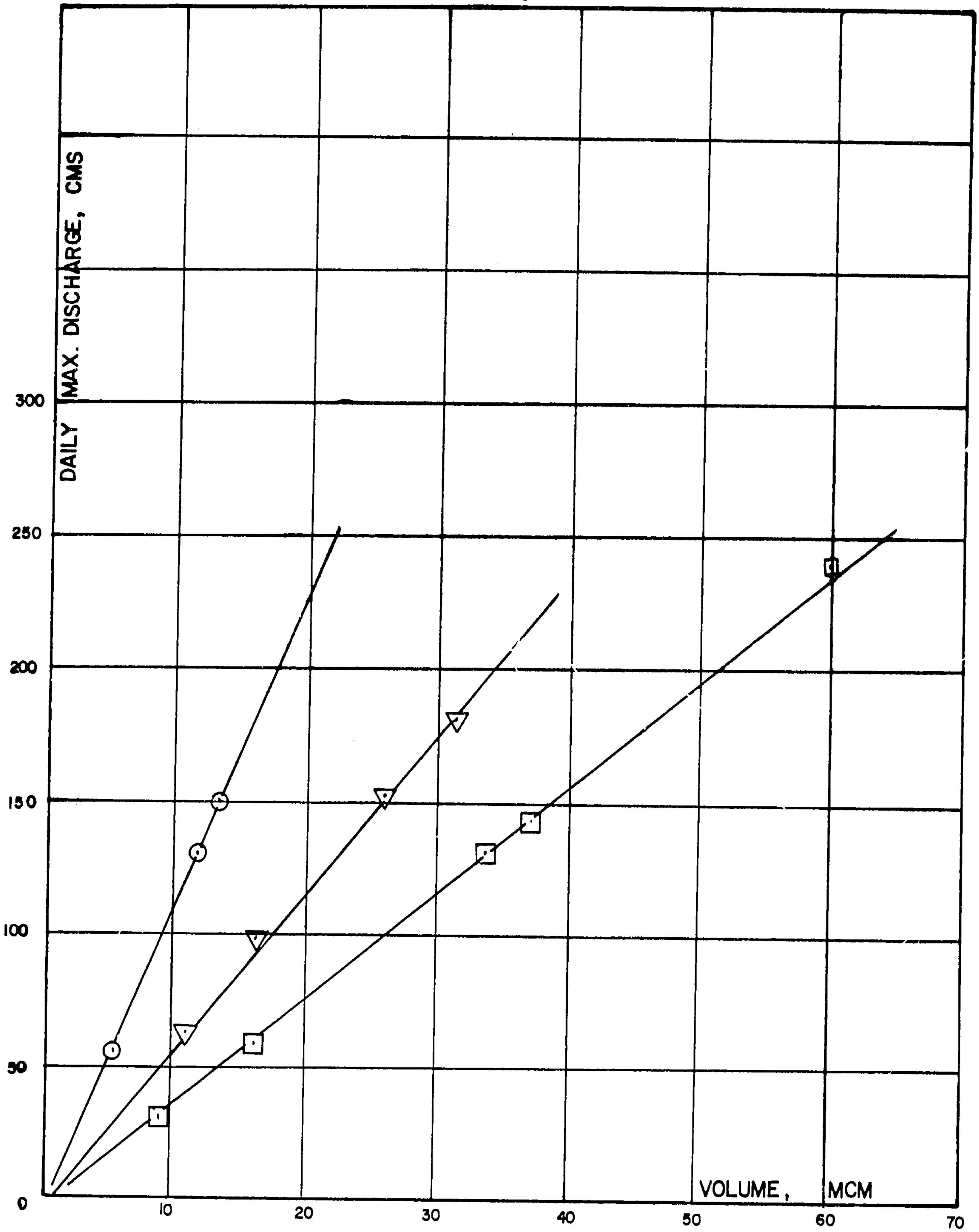


FIG. A-60 Daily Maximum Discharge-Volume Relationship, BICOL RIVER, Sto. Domingo, Nabua, Cam. Sur

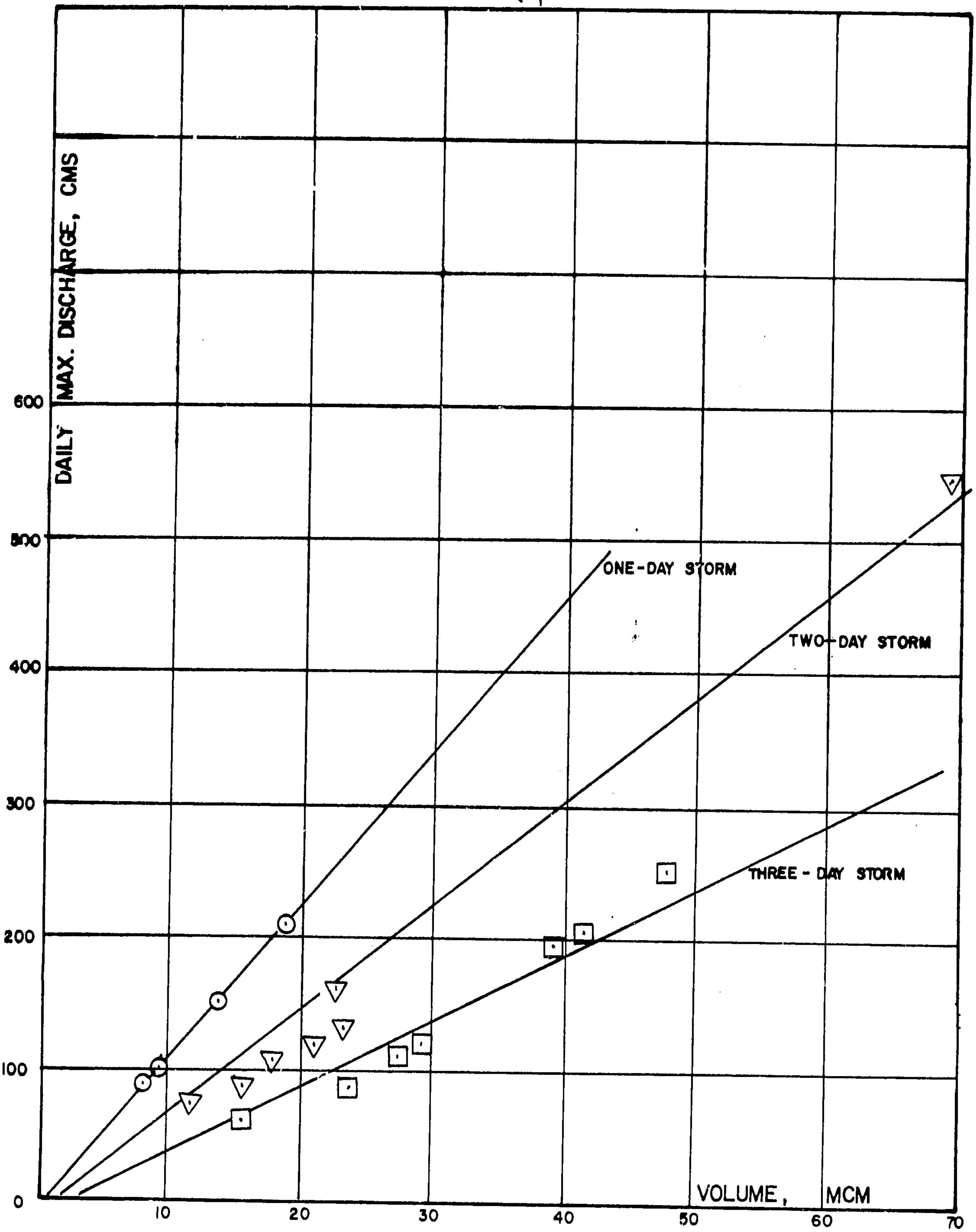


FIG. A-61 Daily Maximum Discharge-Volume Relationship, BARIT RIVER, Sto. Niño, Iriga City

62

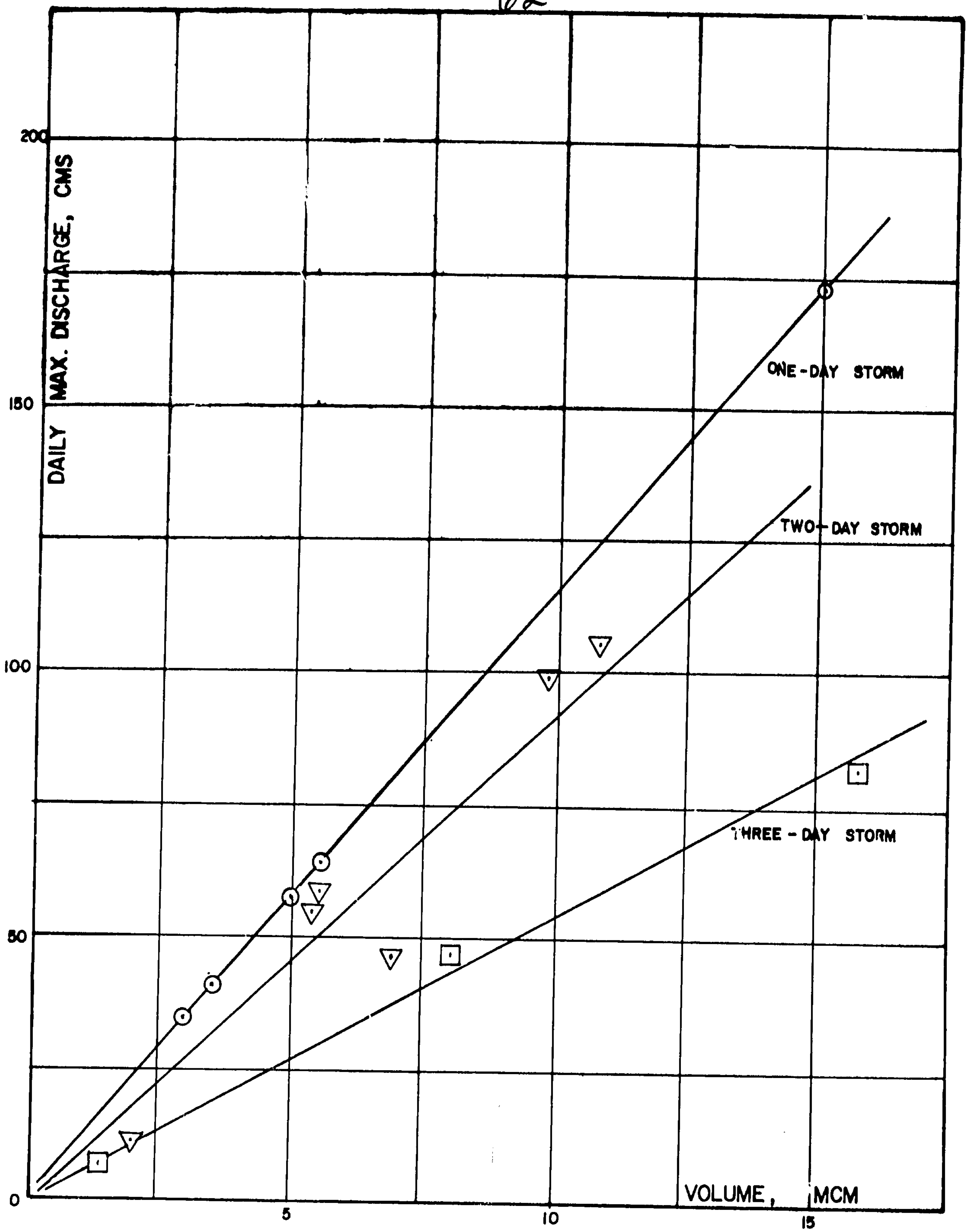


FIG.A-62 Daily Maximum Discharge-Volume Relationship,
ANAYAN RIVER, San Roque, Pili, Cam. Sur

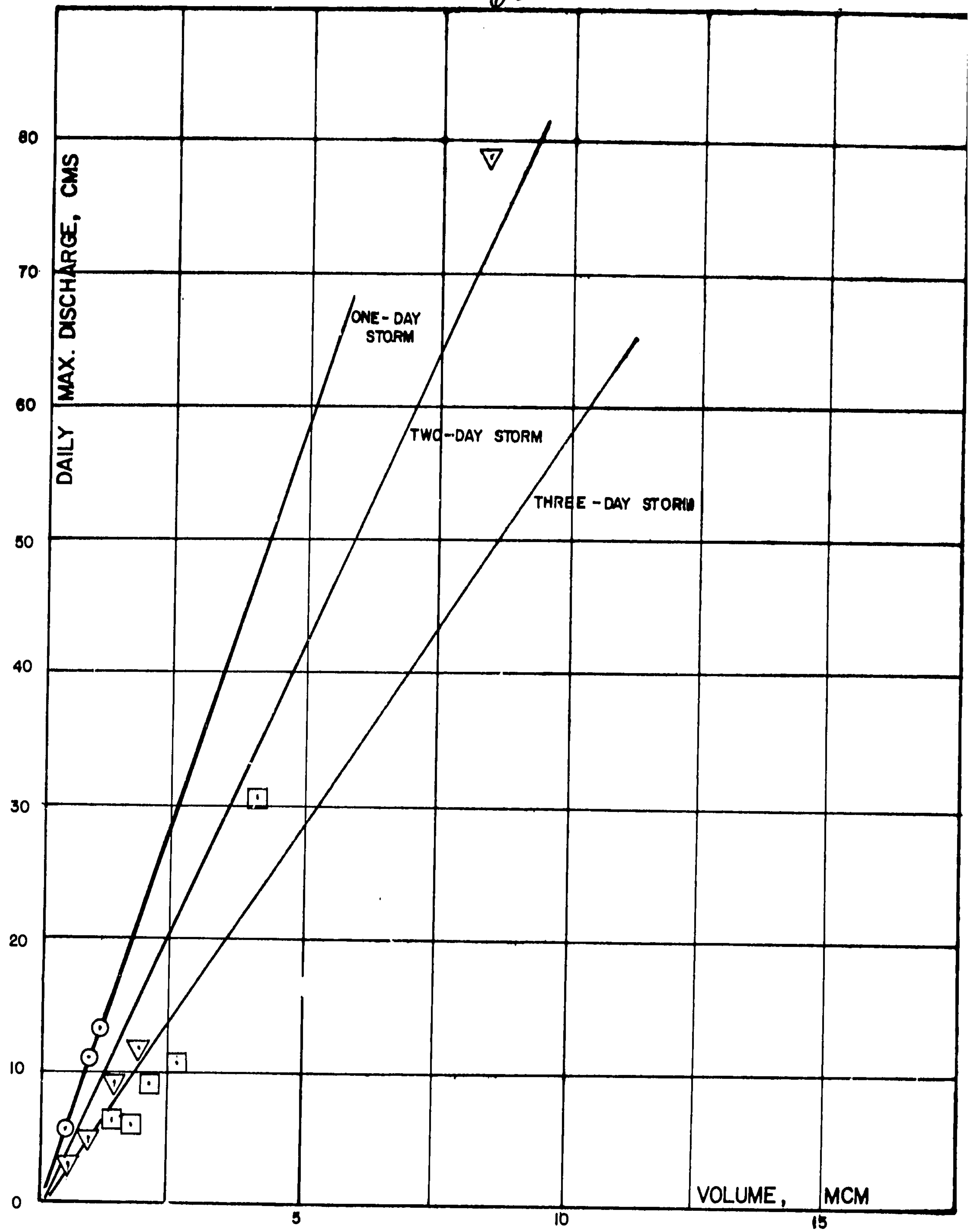


FIG.A-63 Daily Maximum Discharge - Volume Relationship, UGSONG RIVER, BINANUAANAN, LIGAO, ALBAY

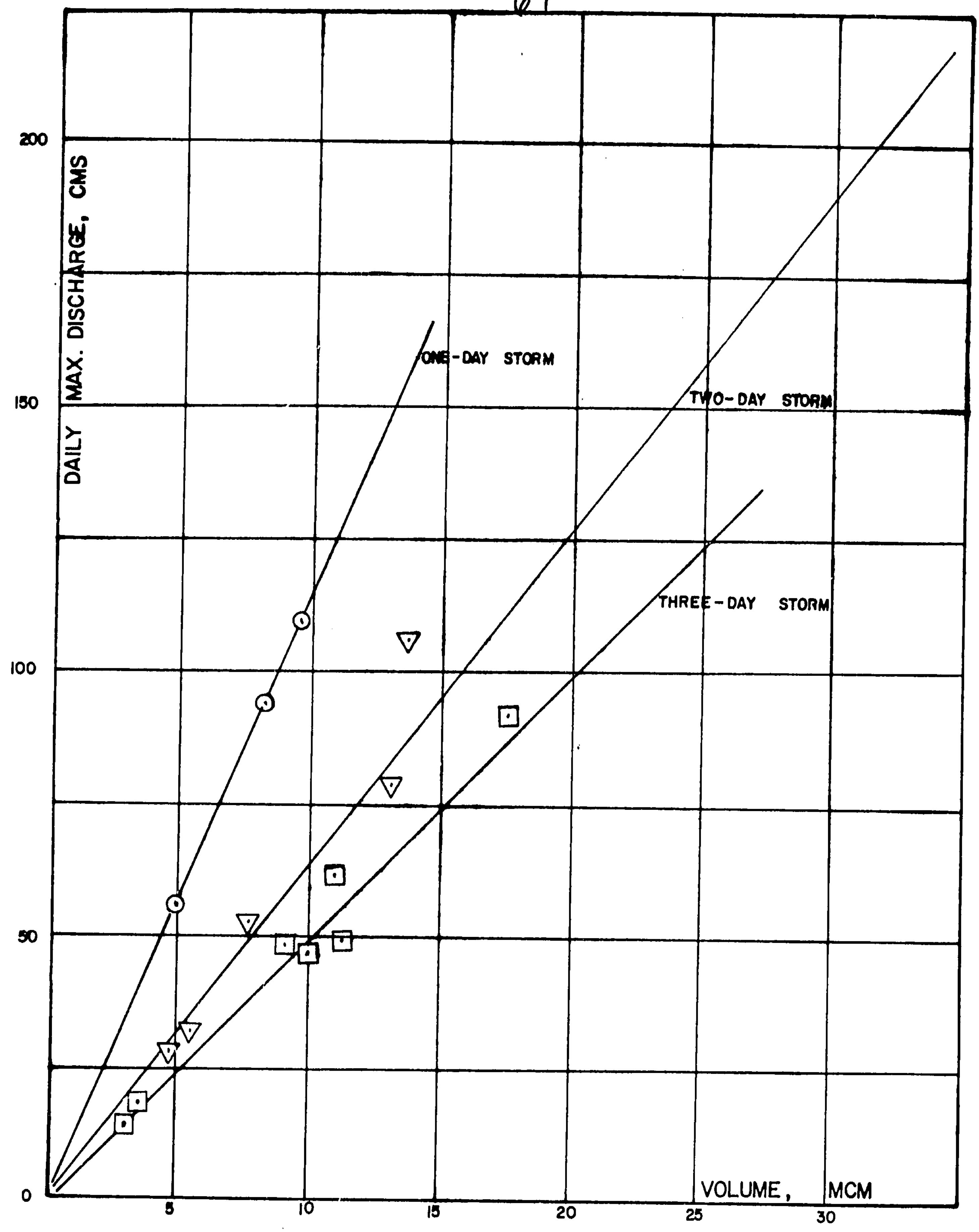


FIG.A-64 Daily Maximum Discharge-Volume Relationship,
SAN AGUSTIN RIVER, San Agustin, Libon, Albay

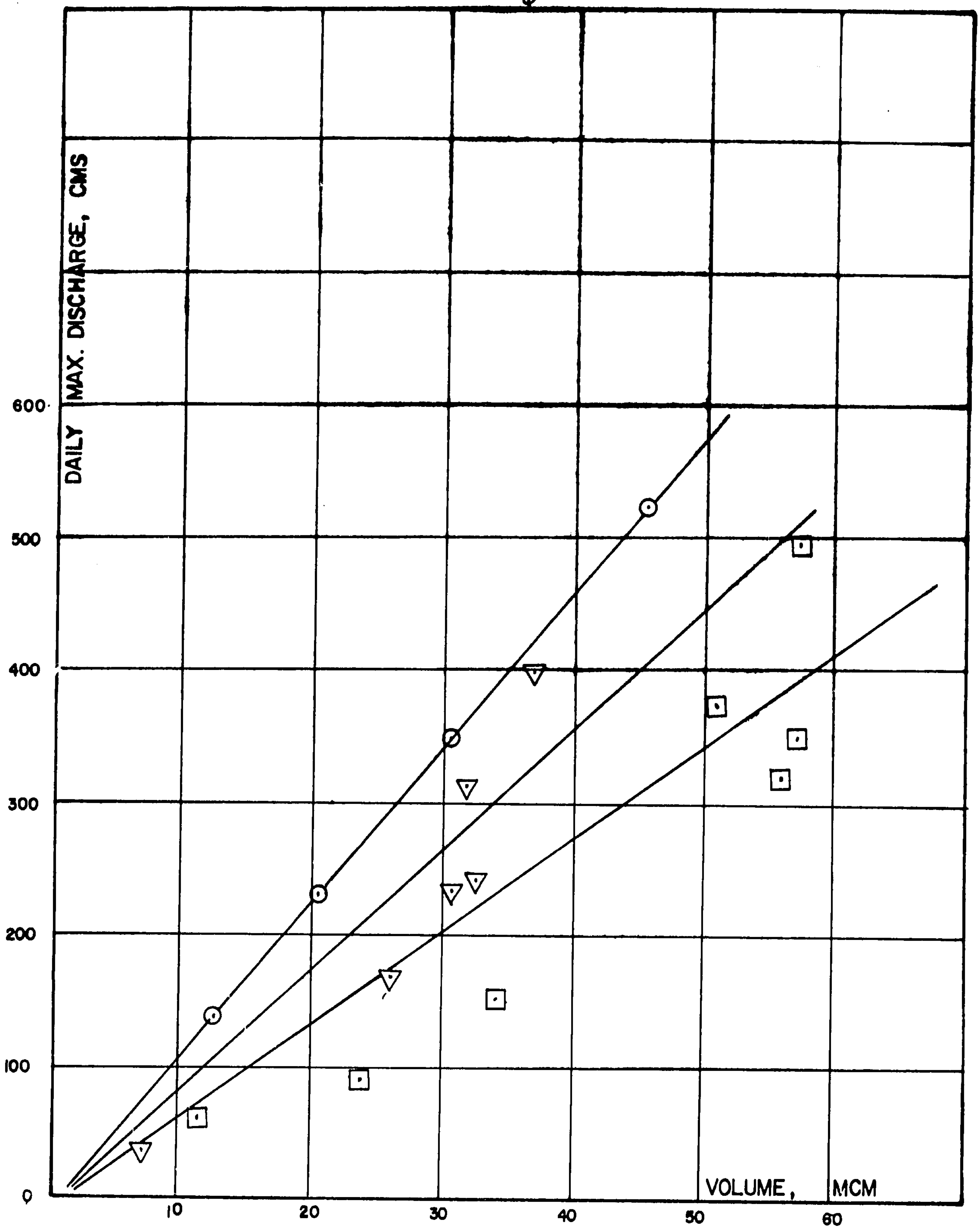


FIG. A-65 Daily Maximum Discharge-Volume Relationship, PAWILI RIVER, San Vicente, Ocampo, Cam. Sur

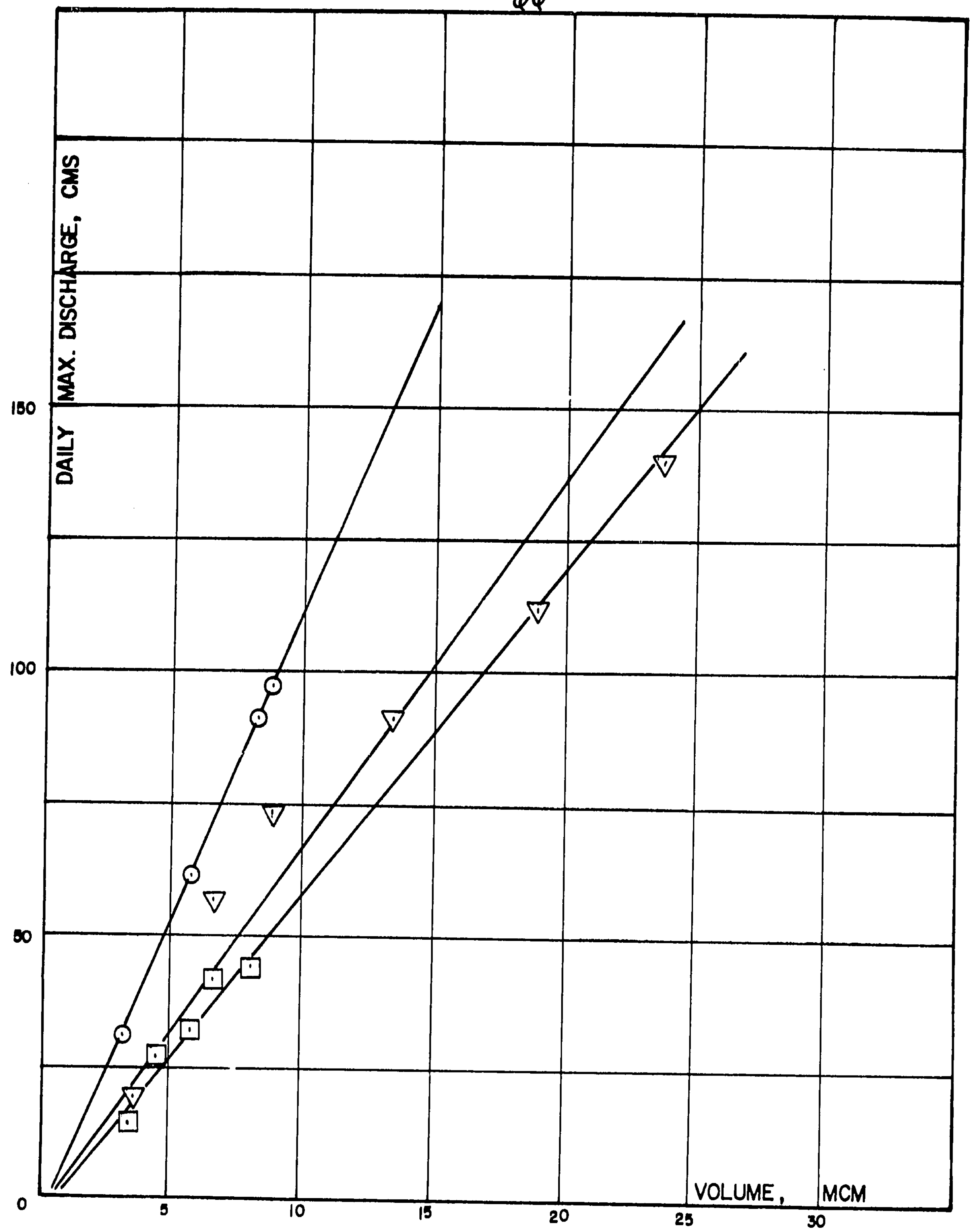


FIG.A-66 Daily Maximum Discharge-Volume Relationship,
SAN FRANCISCO RIVER, Bobongsuran, Ligao, Albay

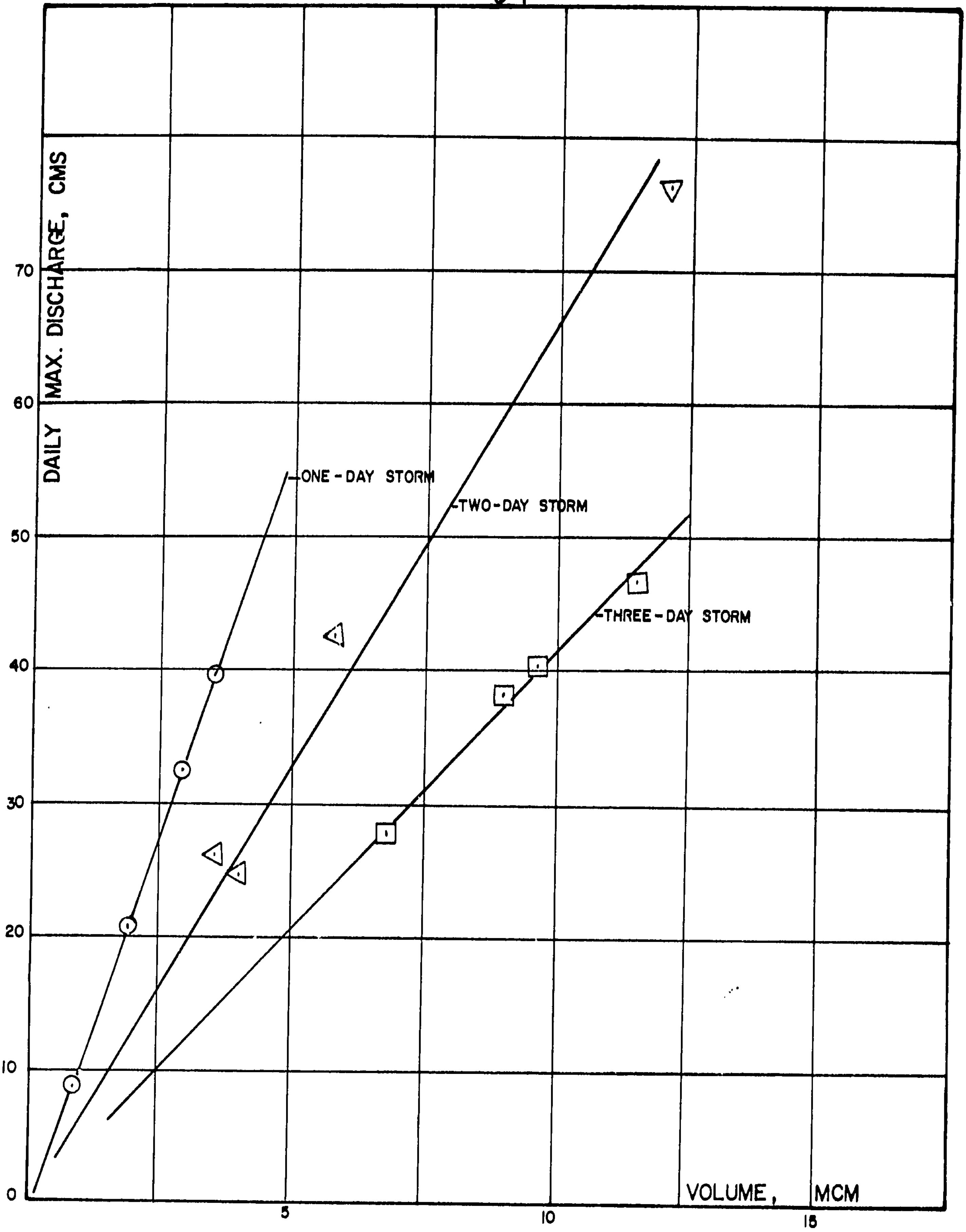


FIG. A-67 Daily Maximum Discharge - Volume Relationship, QUINALI RIVER, Busac, Oas, Albay

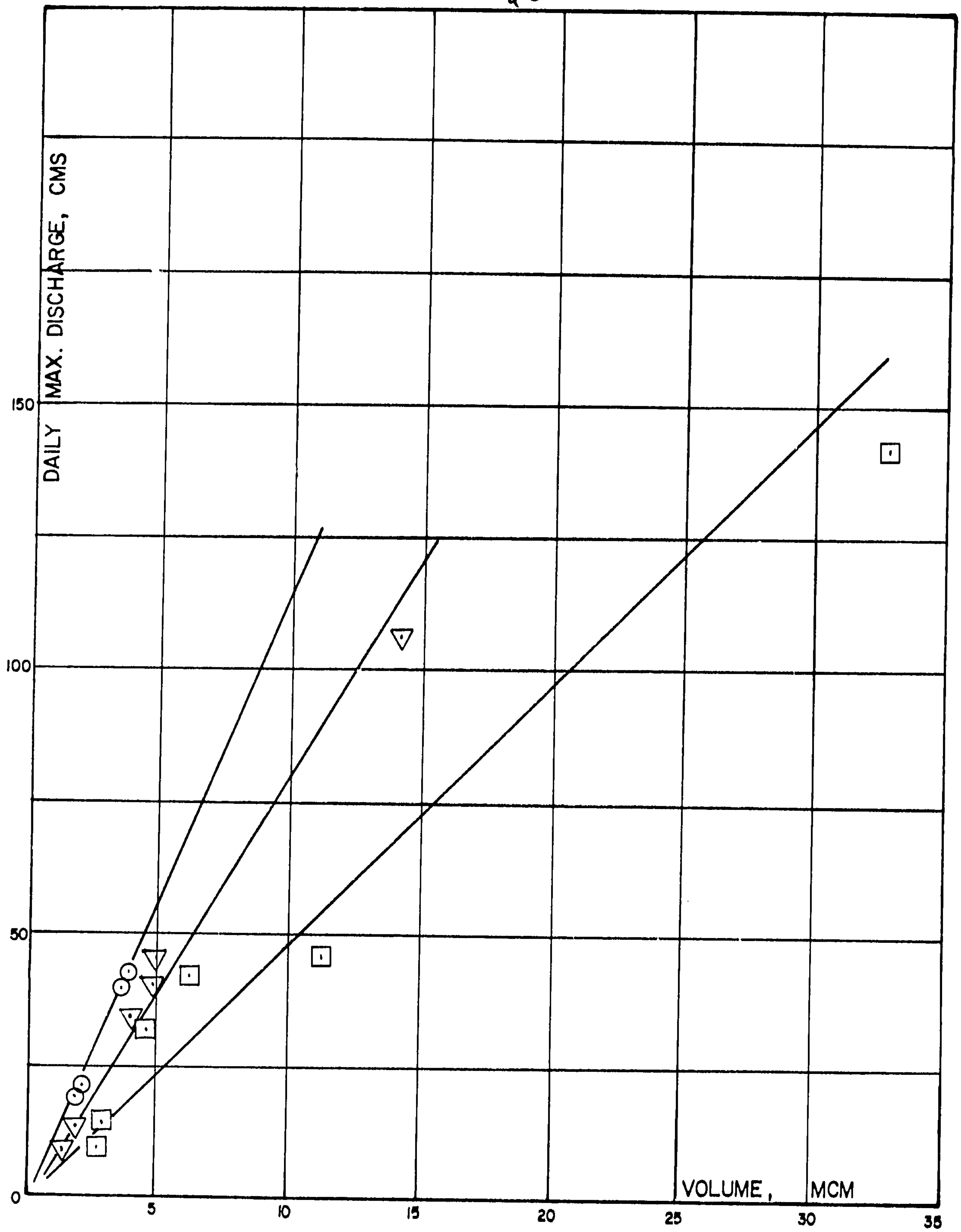


FIG. A-68 Daily Maximum Discharge-Volume Relationship, TALISAY RIVER. Aliang, Ligao, Albay

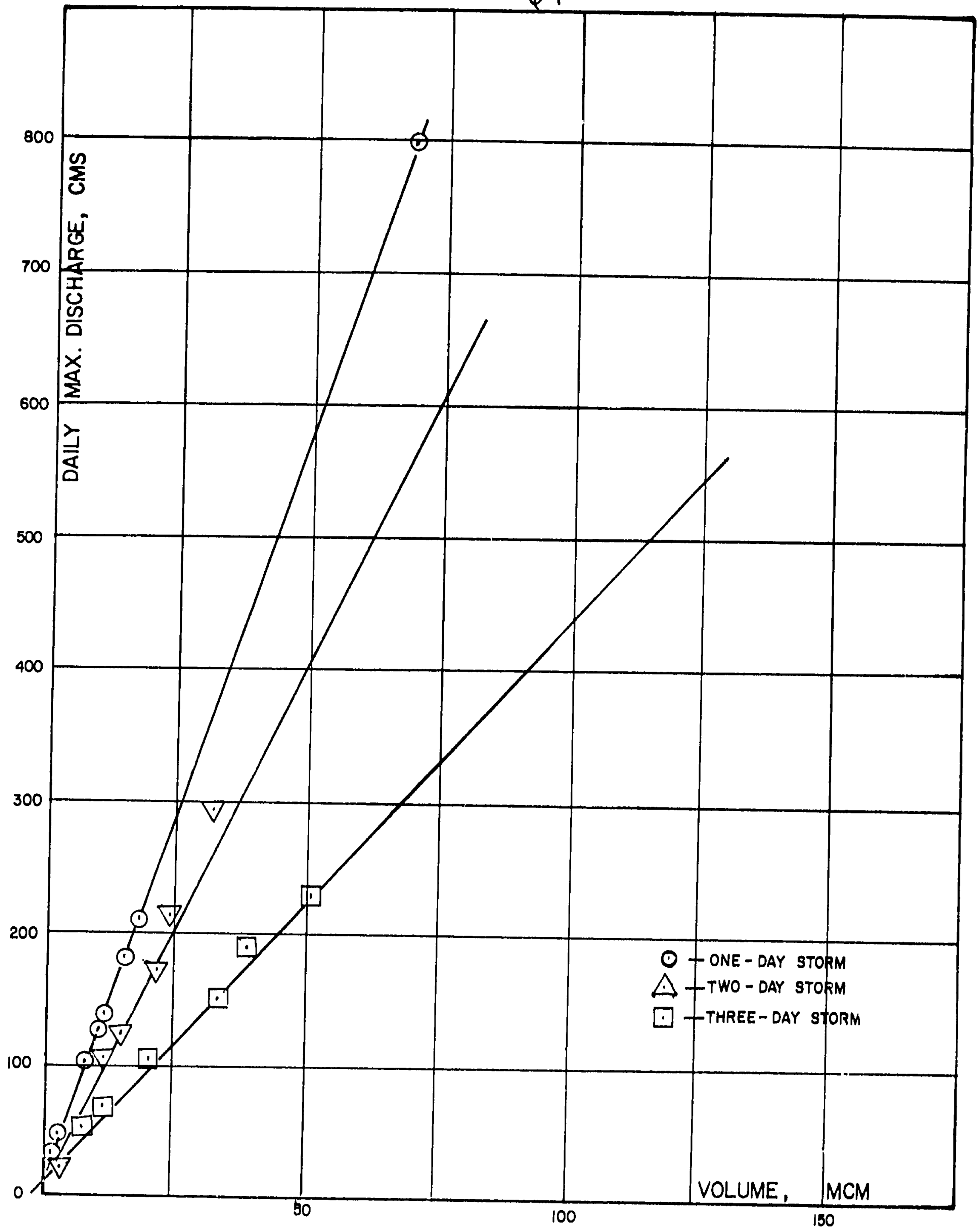


FIG. A-69 Daily Maximum Discharge - Volume Relationship,

PULANTUNA RIVER, Napolidan, Lupi, Cam. Sur

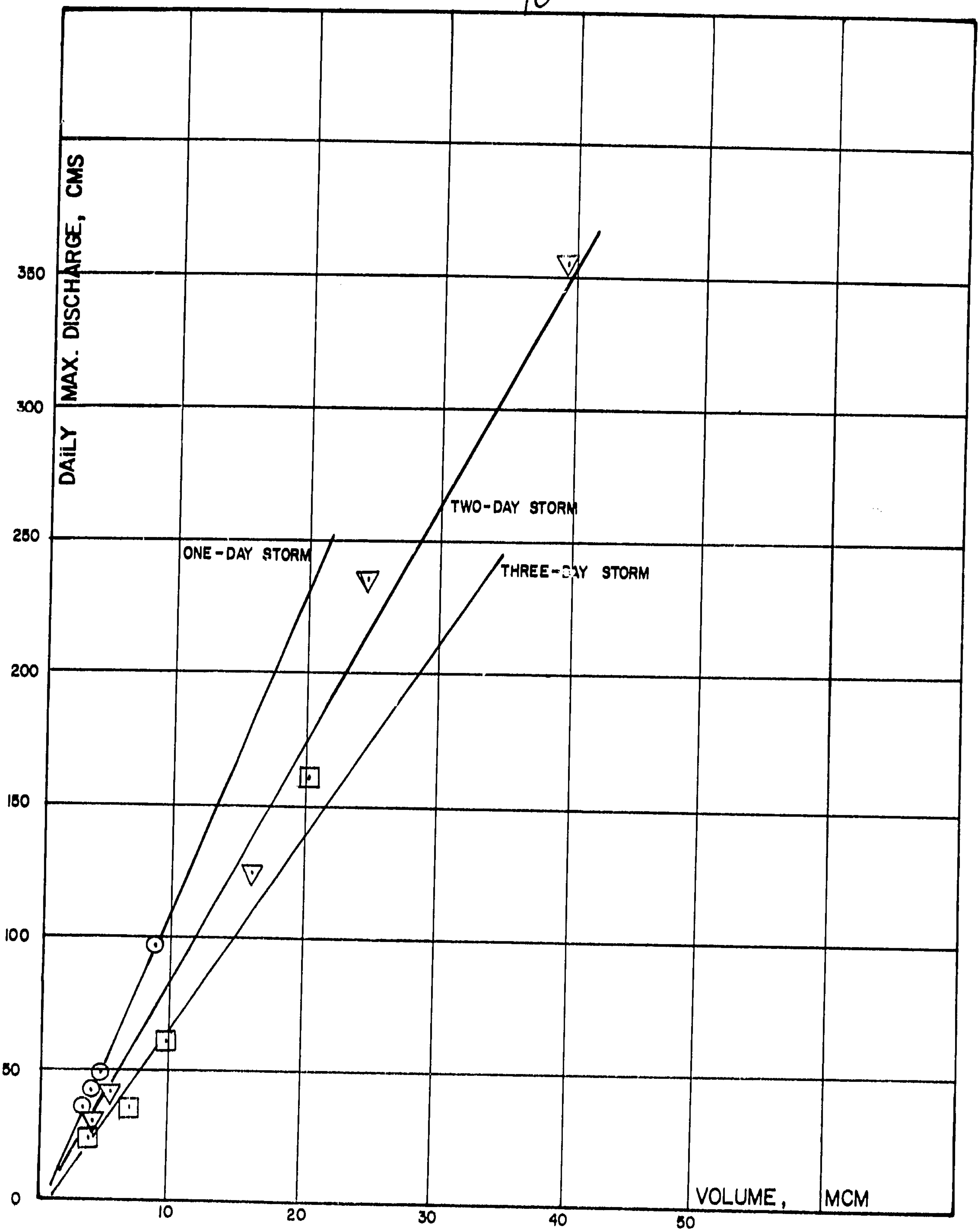


FIG. A-70 Daily Maximum Discharge-Volume Relationship, IRRAYA RIVER, Obaliw, Oas, Albay

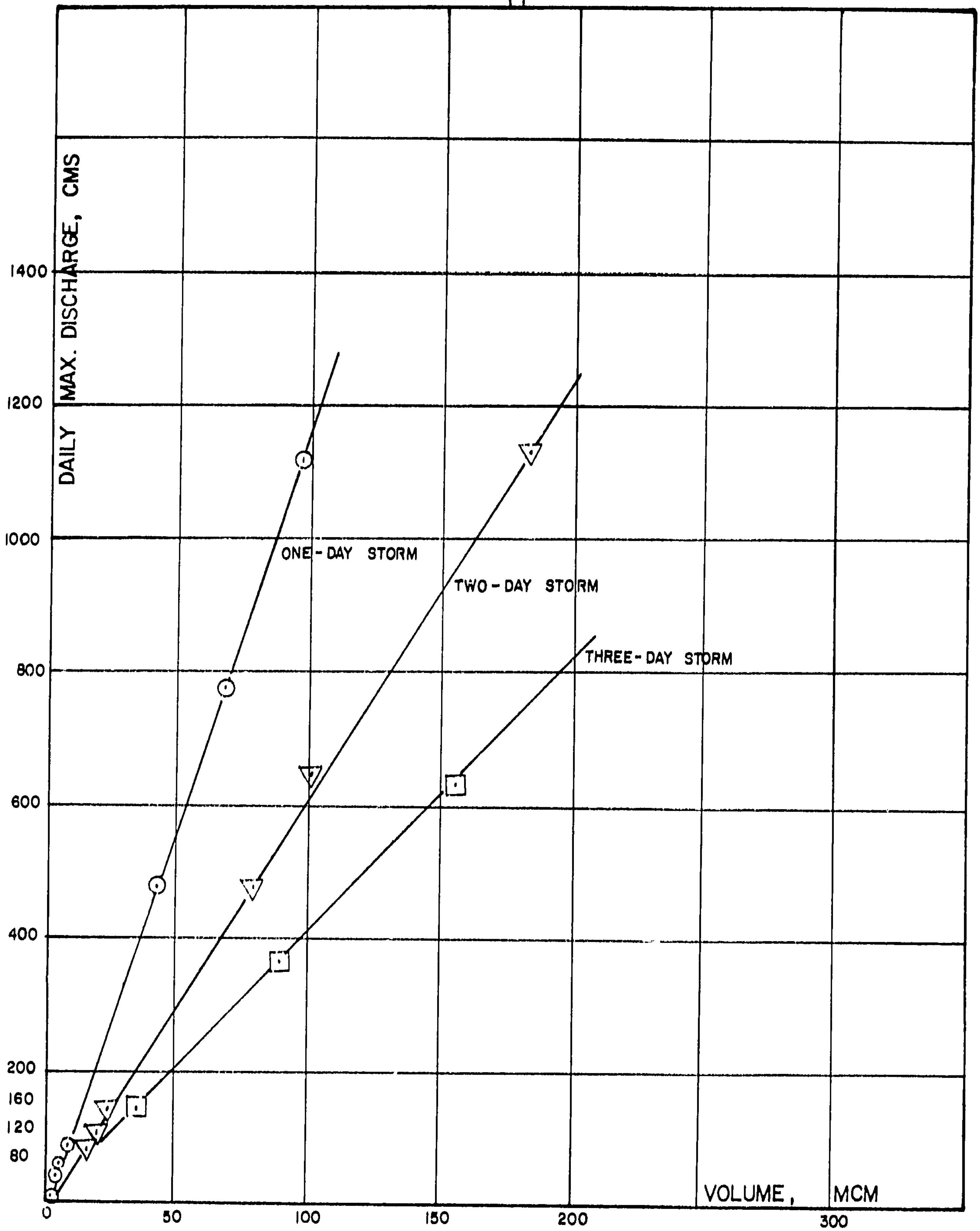


FIG. A-71 Daily Maximum Discharge-Volume Relationship, SIPOCOT RIVER, Sabang, Sipocot

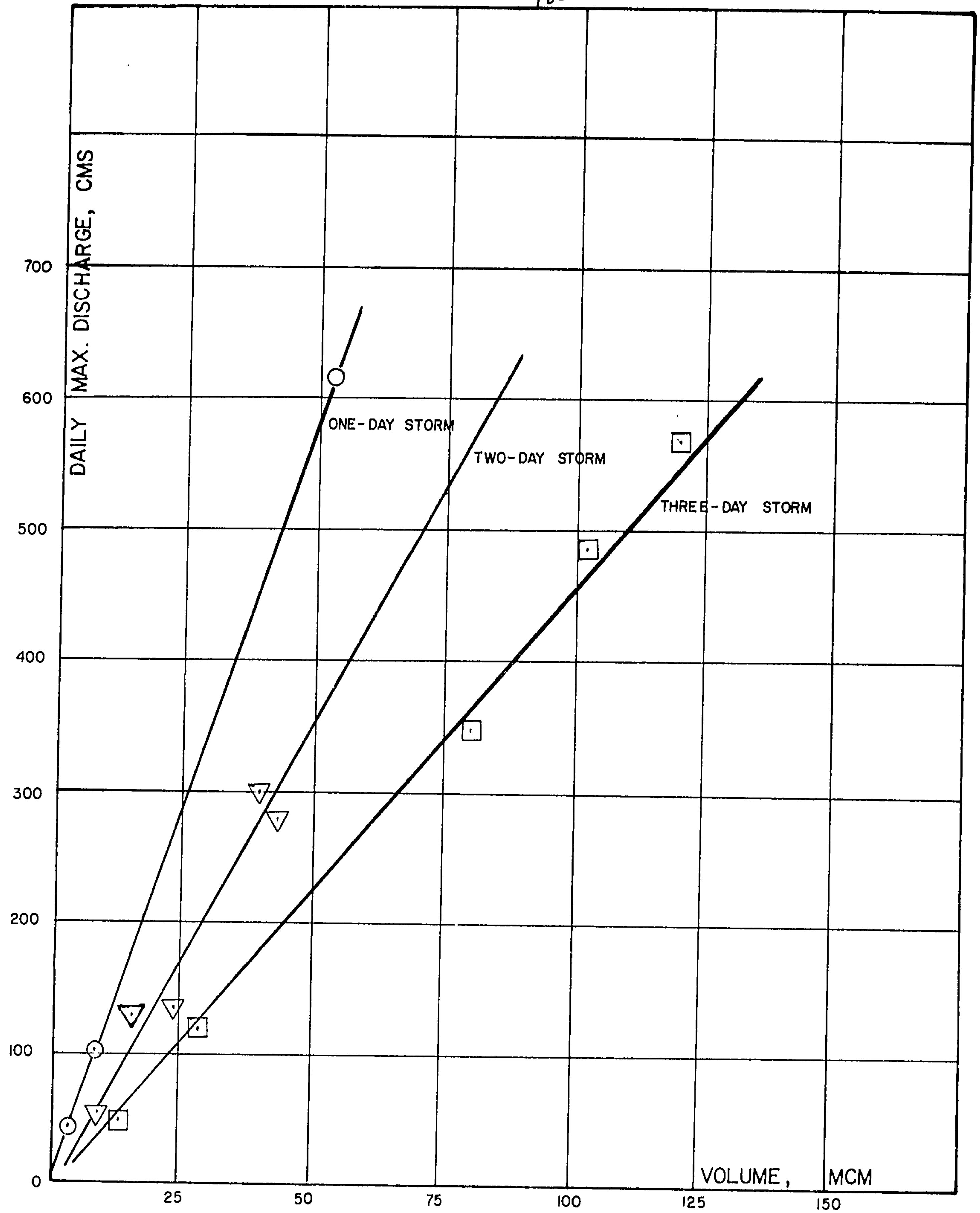


FIG. A-72 Daily Maximum Discharge-Volume Relationship,

PAWILI RIVER, San Roque, Bula, Cam. Sur

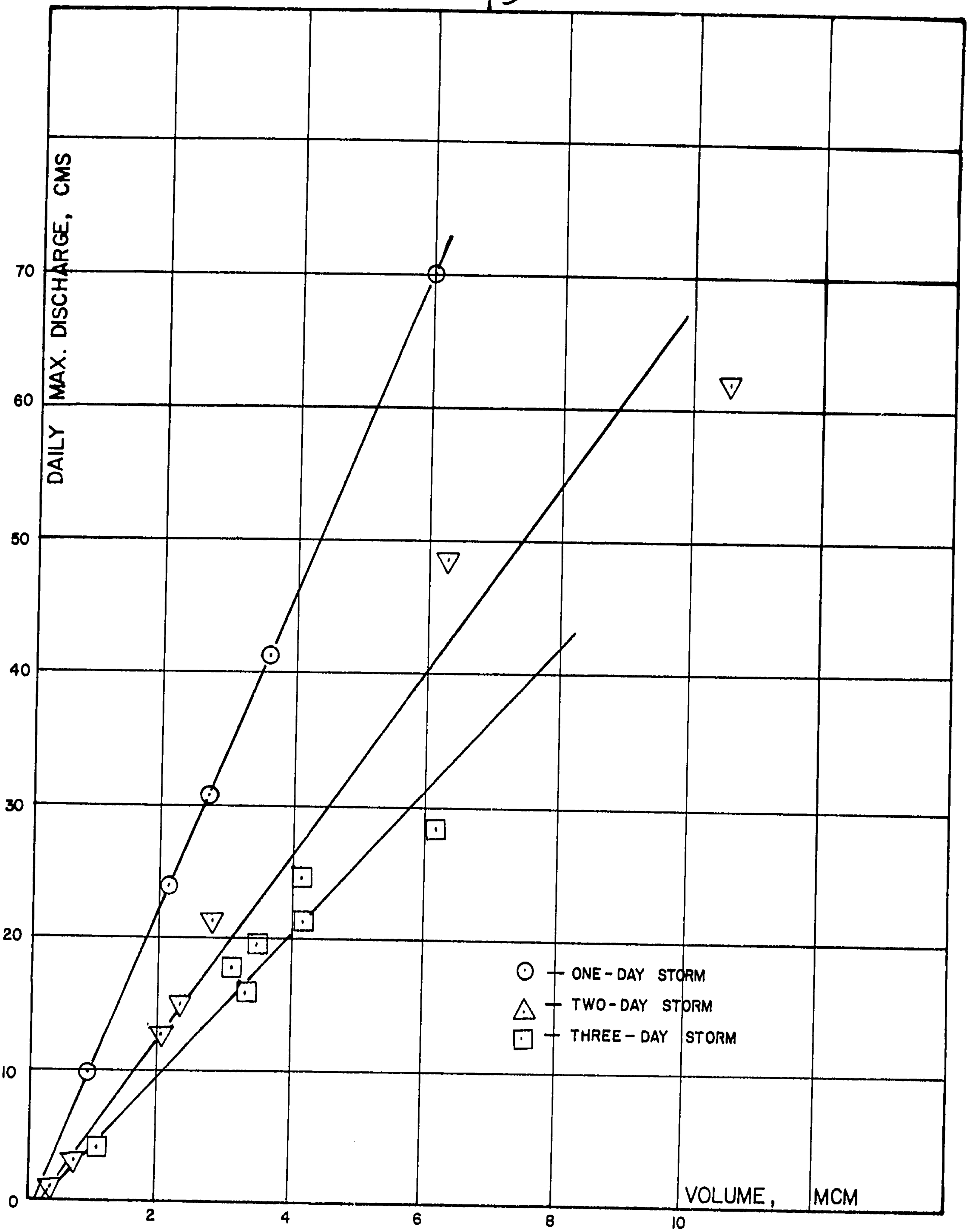


FIG. A-73 Daily Maximum Discharge - Volume Relationship, ASLONG RIVER, San Isidro, Libmanan, Cam. Sur

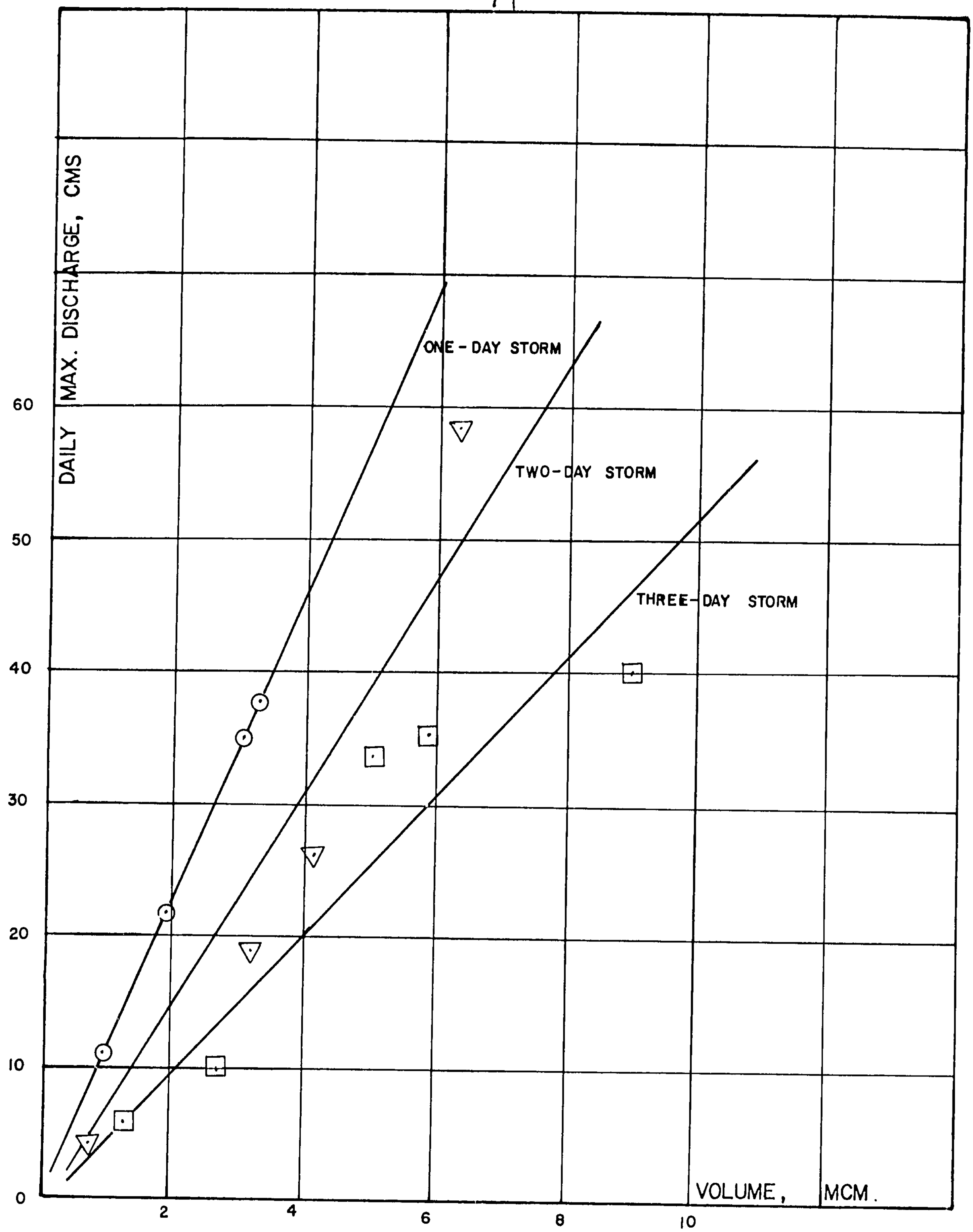


FIG. A-74 Daily Maximum Discharge-Volume Relationship, CULACLING RIVER, Del Rosario, Lupi, Cam. Sur

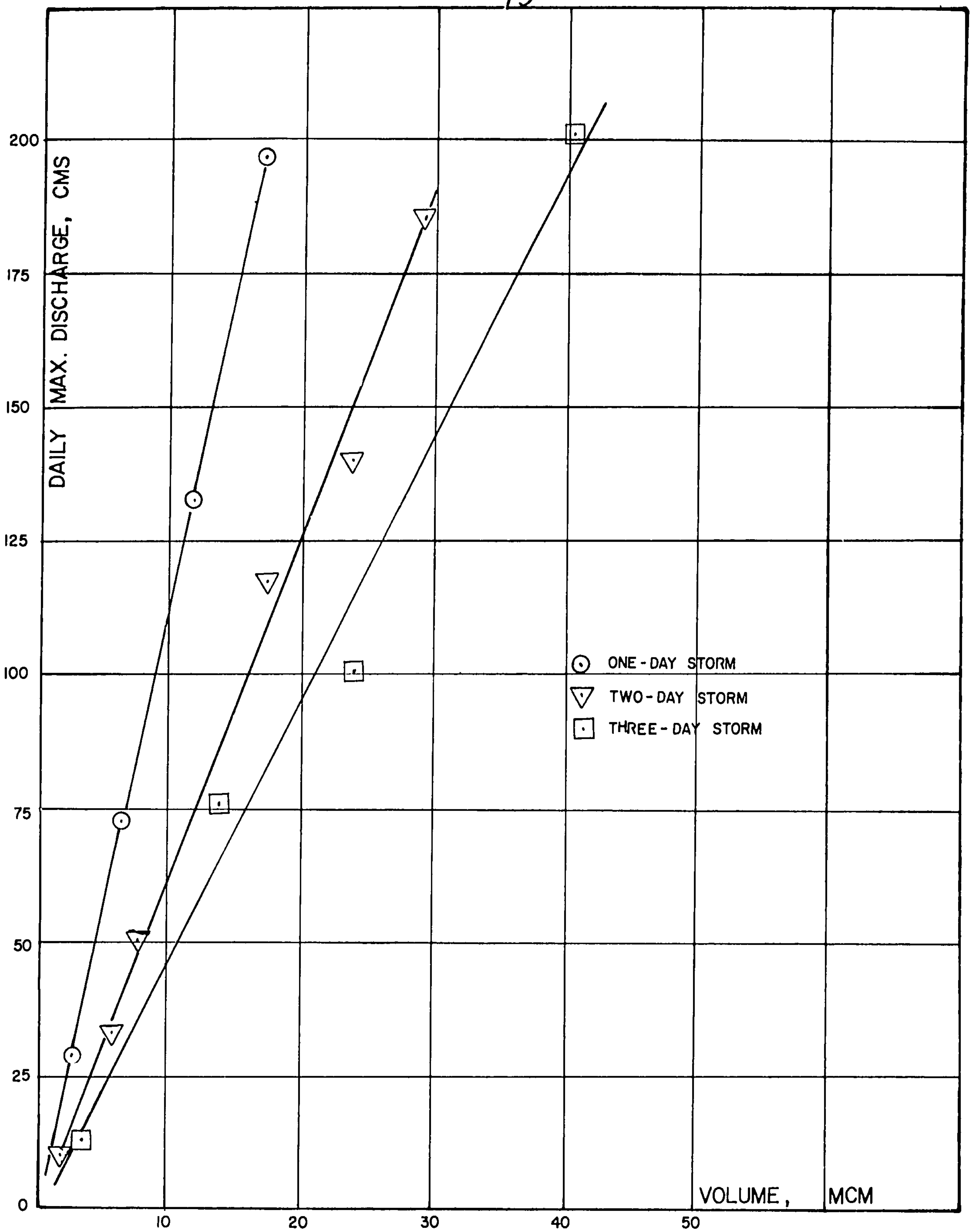


FIG. A-75 Daily Maximum Discharge-Volume Relationship, CABILOGAN RIVER, Bobongsuran, Ligao, Albay

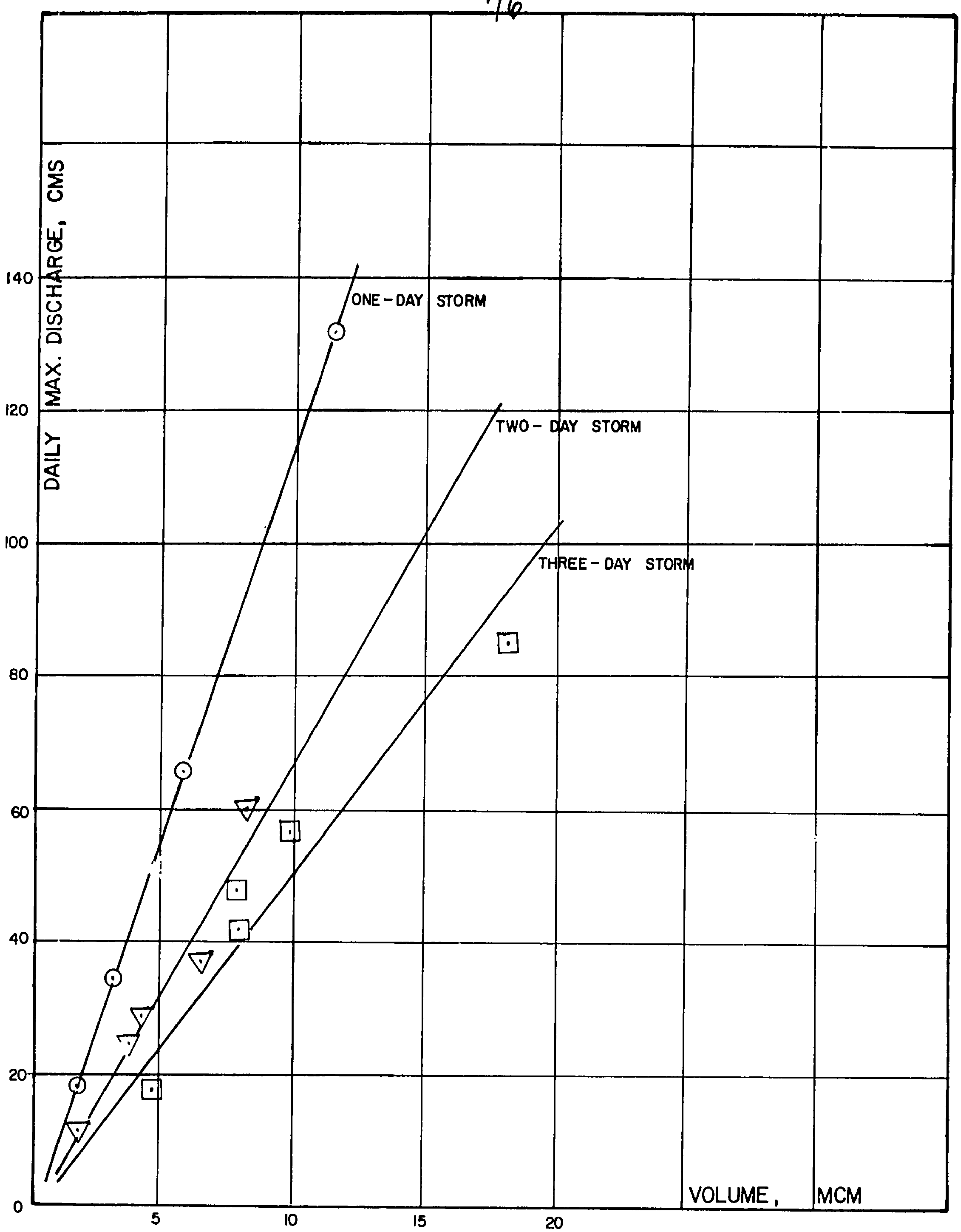


FIG. A-76 Daily Maximum Discharge - Volume Relationship, AGUS RIVER, Agus, Polangui, Albay

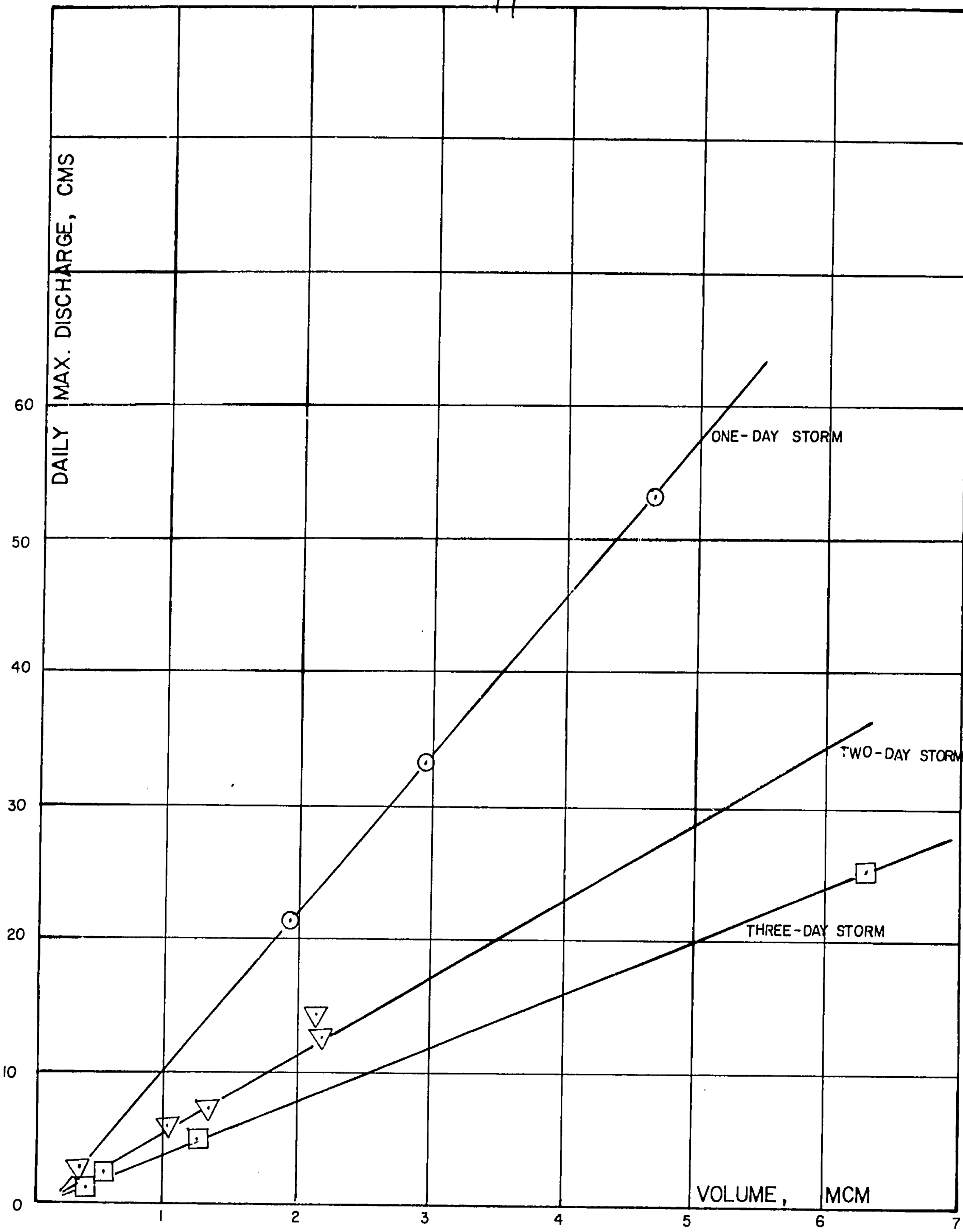


FIG. A-77 Daily Maximum Discharge-Volume Relationship, NASISI RIVER, Nasisi, Ligao, Albay

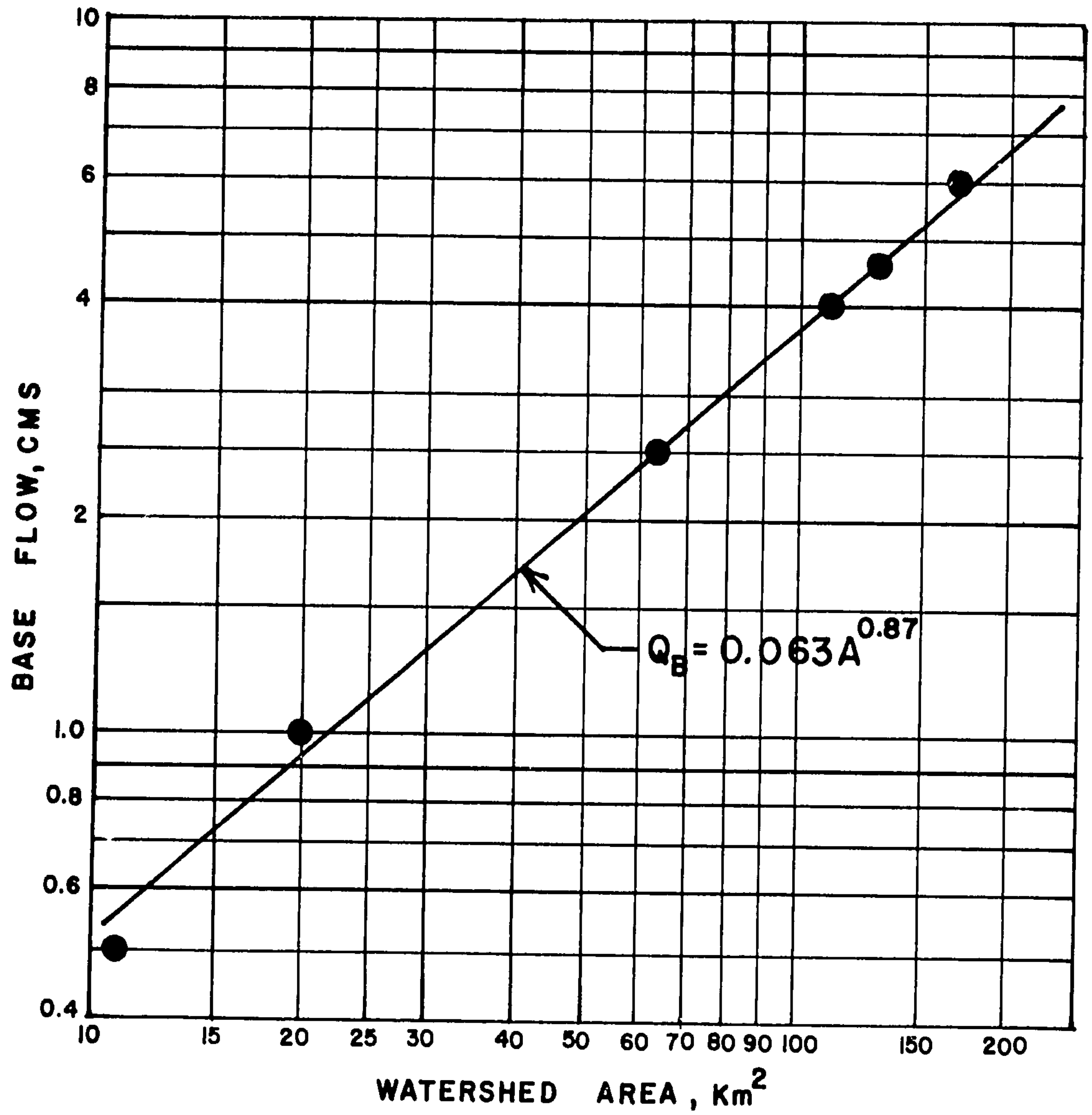


Fig.A-78 Area-Base Flow Relationship of Catchments within the Bicol River Basin (Adopted from AIT Report No. 48)

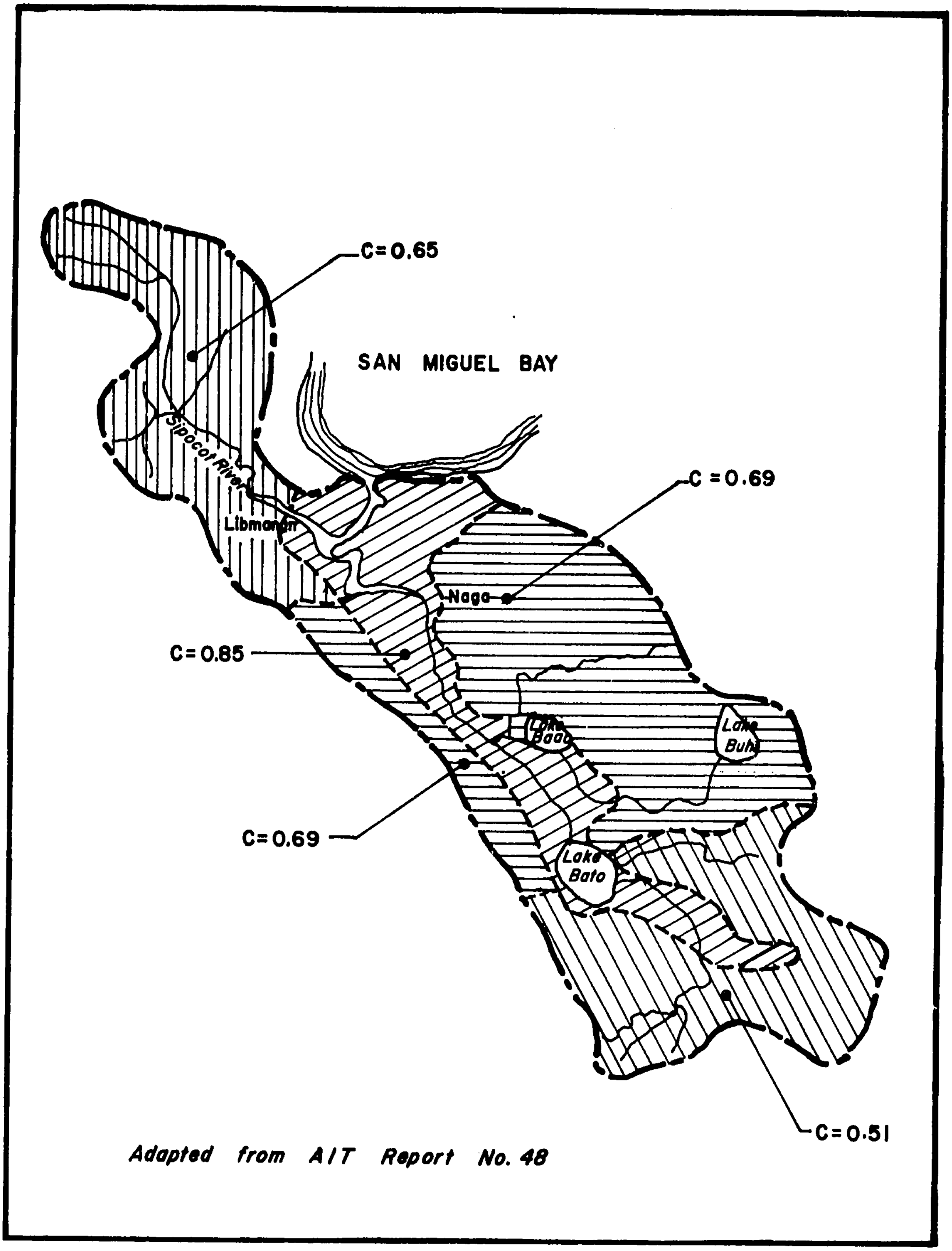
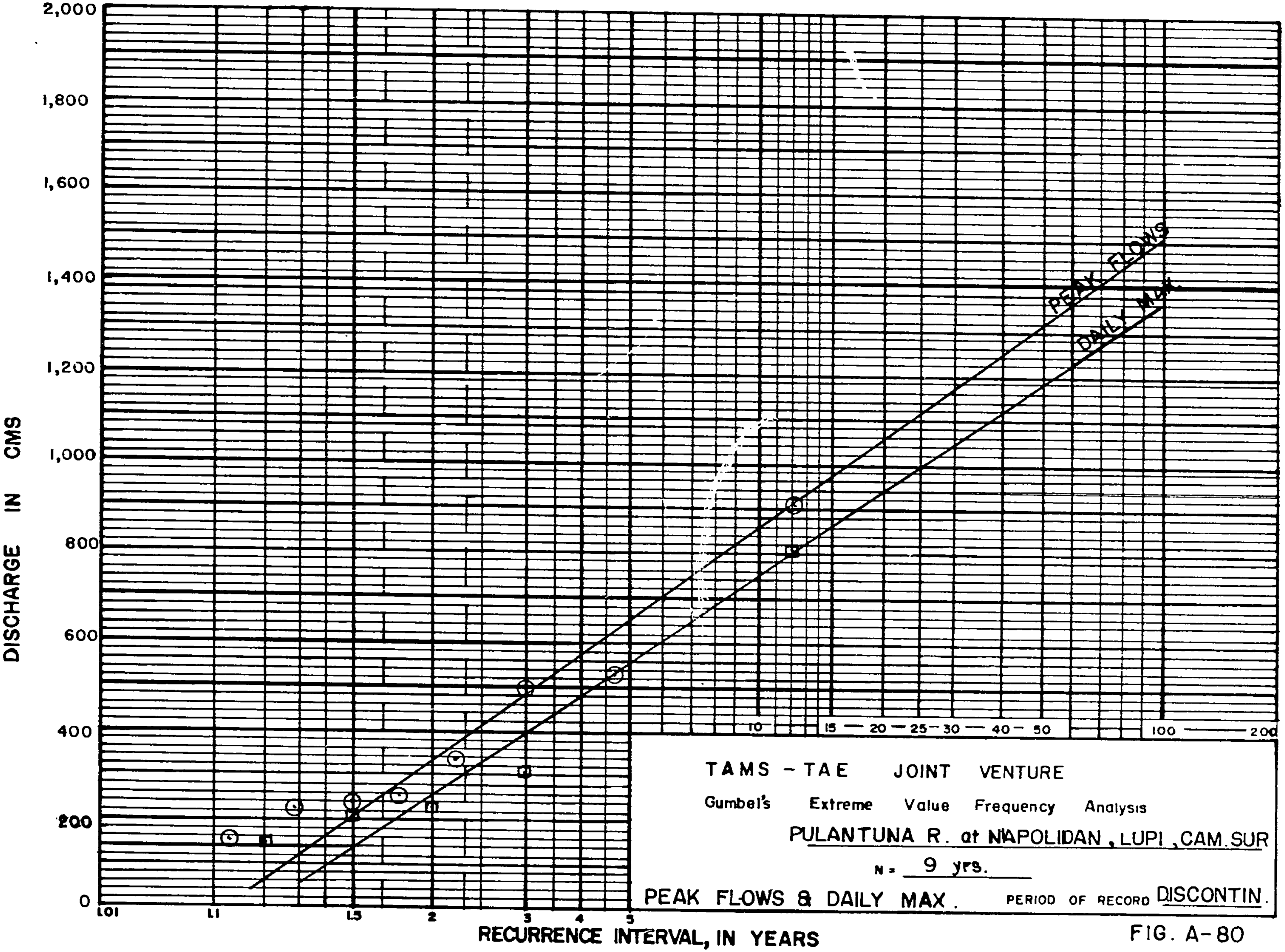


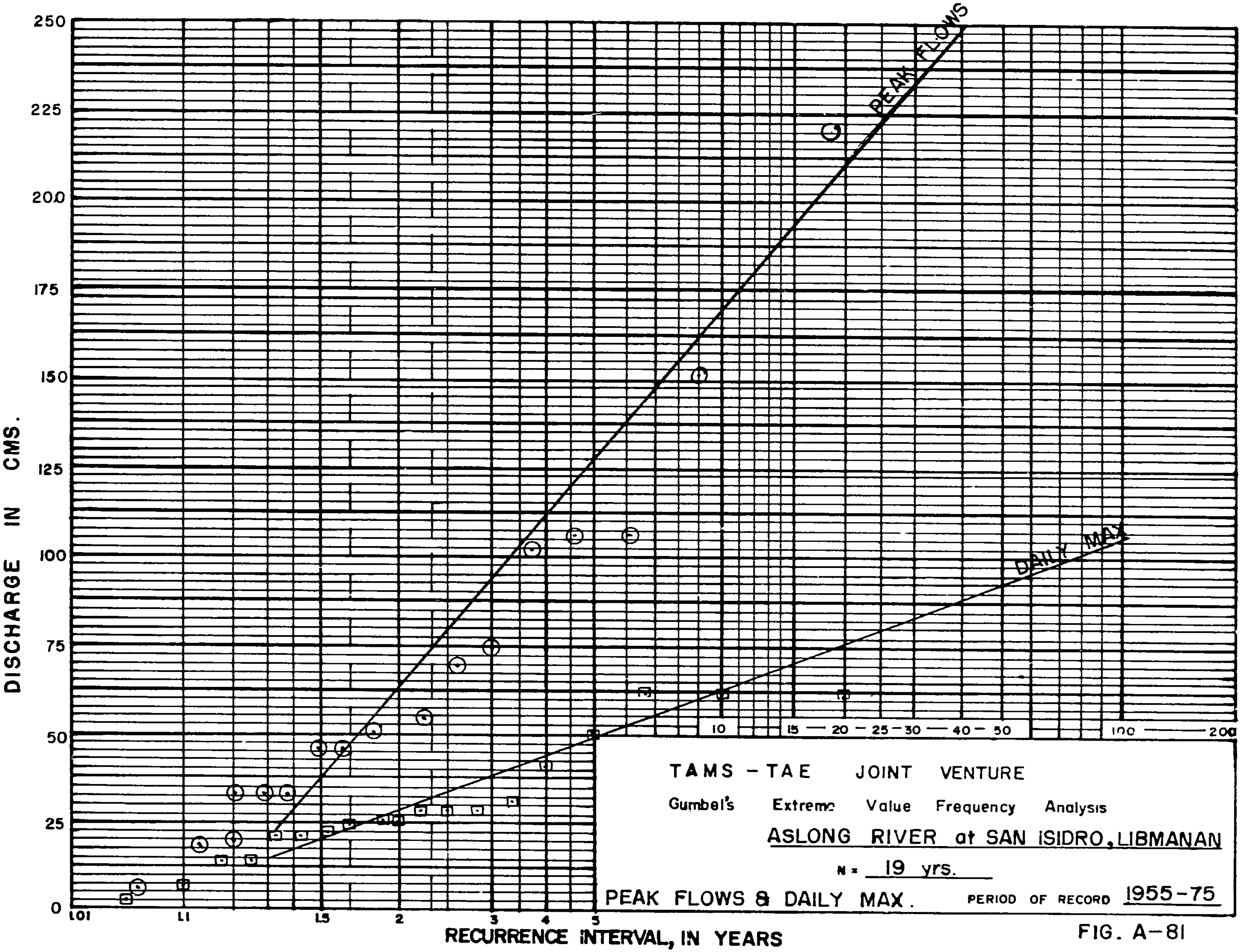
Fig. A-79 Regions of Watersheds with Runoff Coefficients at Flood Conditions, Bicol River Basin

80



2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
DISCHARGE IN CMS
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
RECURRENCE INTERVAL, IN YEARS
PEAK FLOWS
DAILY MAX.
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
PULANTUNA R. at NAPOLIDAN, LUPI, CAM. SUR
N = 9 yrs.
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD DISCONTIN.

FIG. A-80



DISCHARGE IN CMS.
250
225
200
175
150
125
100
75
50
25
0
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
RECURRENCE INTERVAL, IN YEARS
PEAK FLOWS
DAILY MAX
TAMS – TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
ASLONG RIVER at SAN ISIDRO, LIBMANAN
N = 19 yrs.
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD 1955-75

FIG. A-81

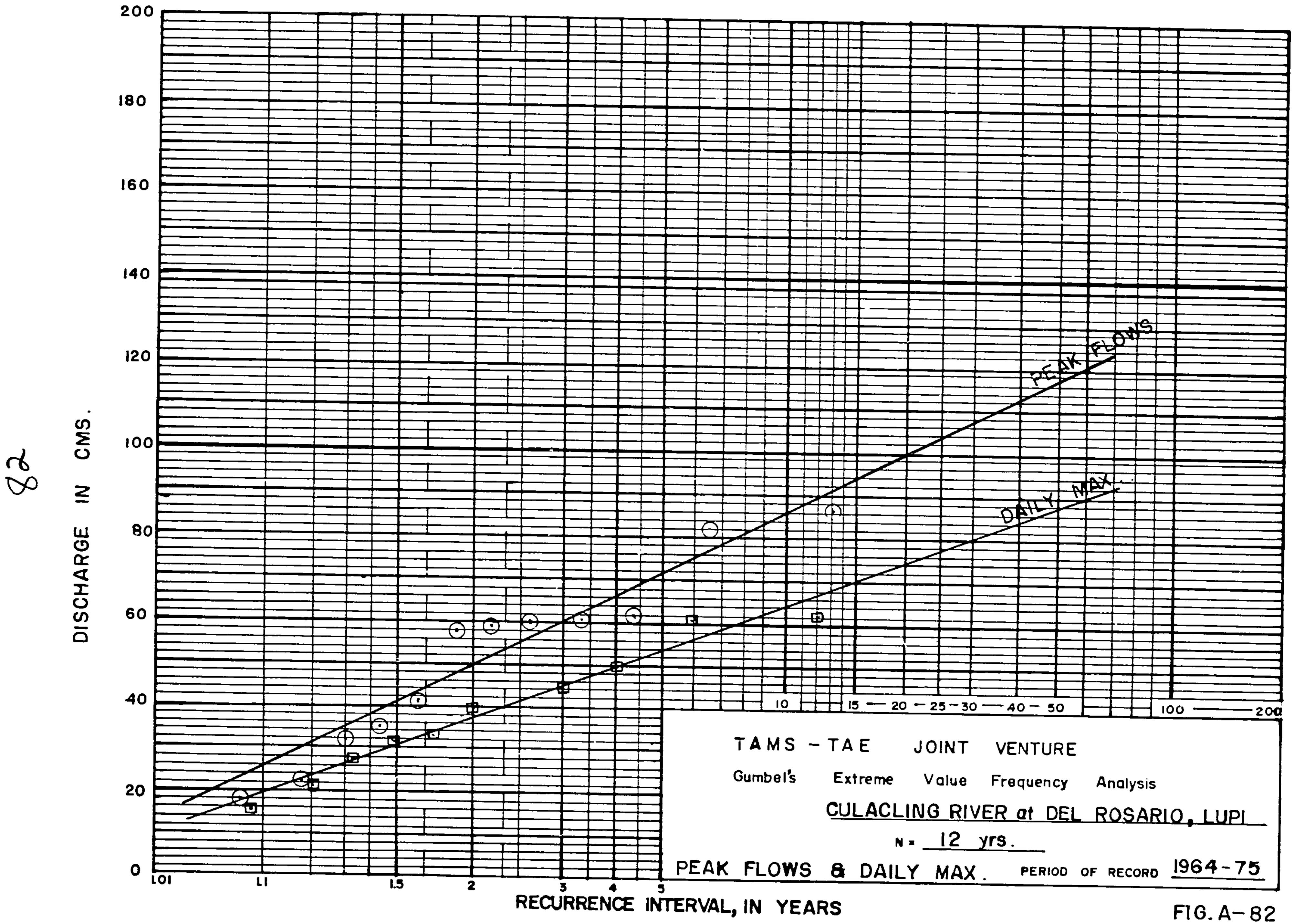
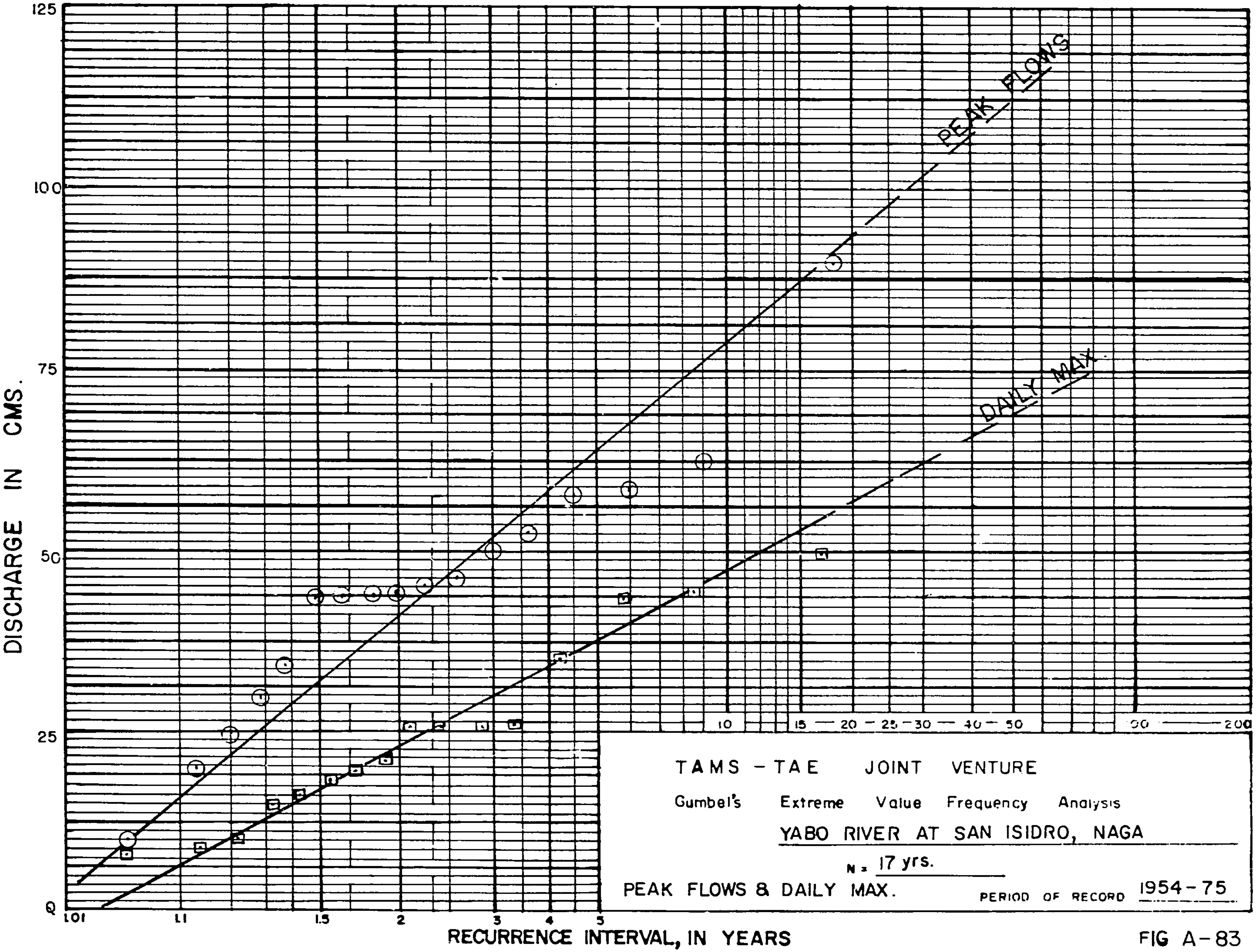

82
DISCHARGE IN CMS.
200
180
160
140
120
100
80
60
40
20
0
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
PEAK FLOWS
DAILY MAX.
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
CULACLING RIVER at DEL ROSARIO, LUPI
N = 12 yrs.
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD 1964-75
RECURRENCE INTERVAL, IN YEARS

FIG. A-82

83



TAMS - TAE JOINT VENTURE

Gumbel's Extreme Value Frequency Analysis

YABO RIVER AT SAN ISIDRO, NAGA

N = 17 yrs.

PEAK FLOWS & DAILY MAX. PERIOD OF RECORD 1954-75

FIG A-83

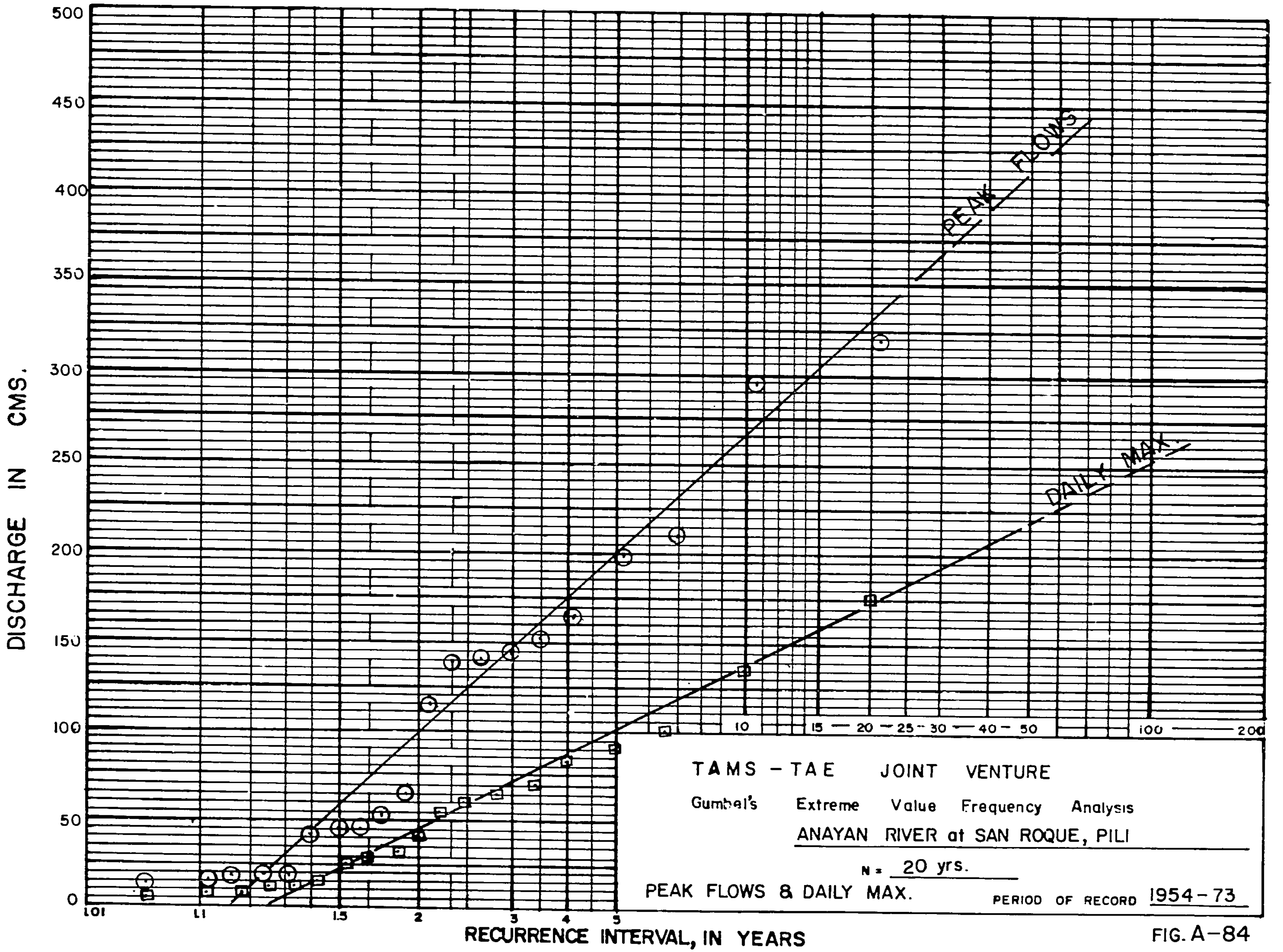
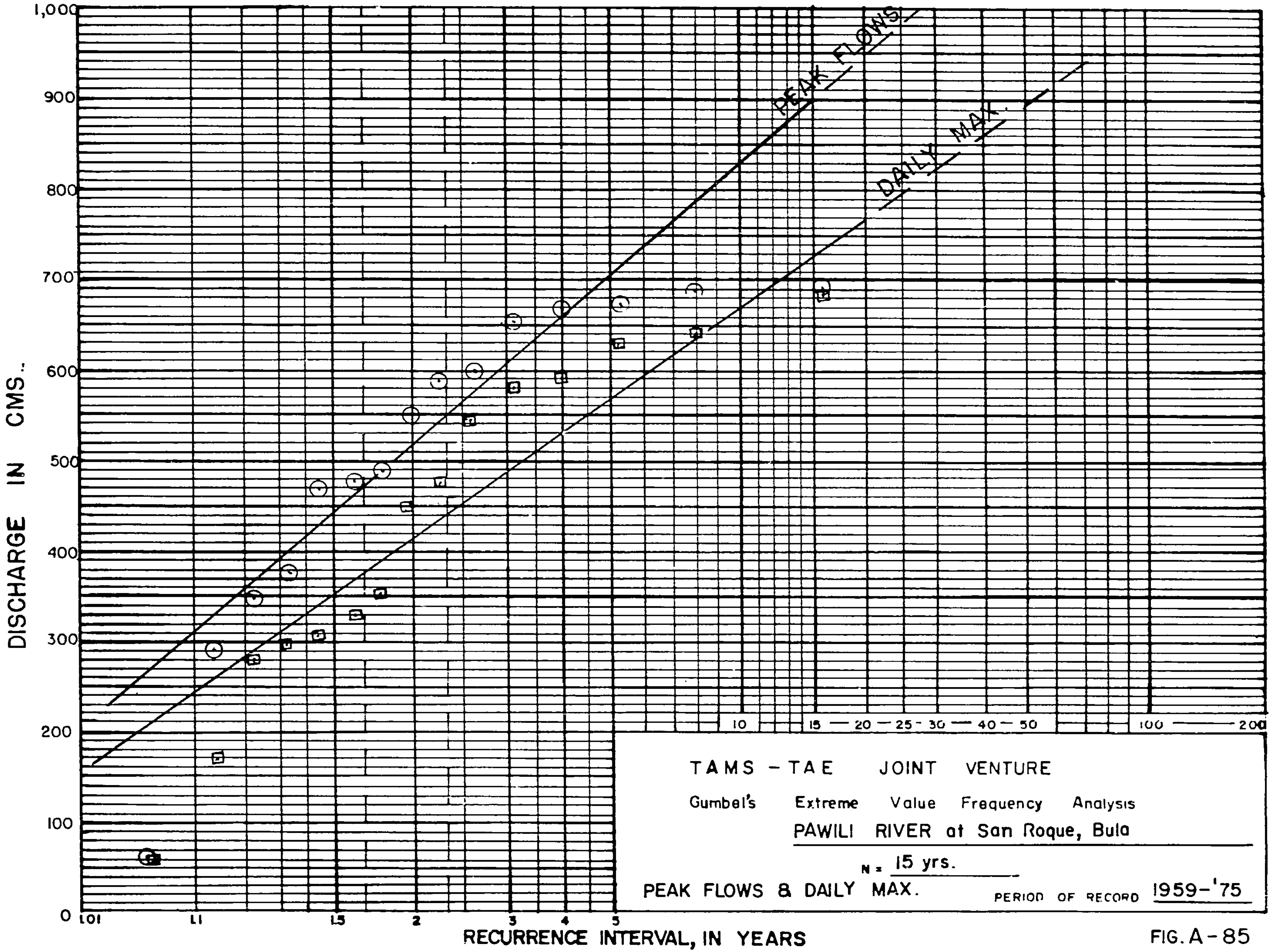
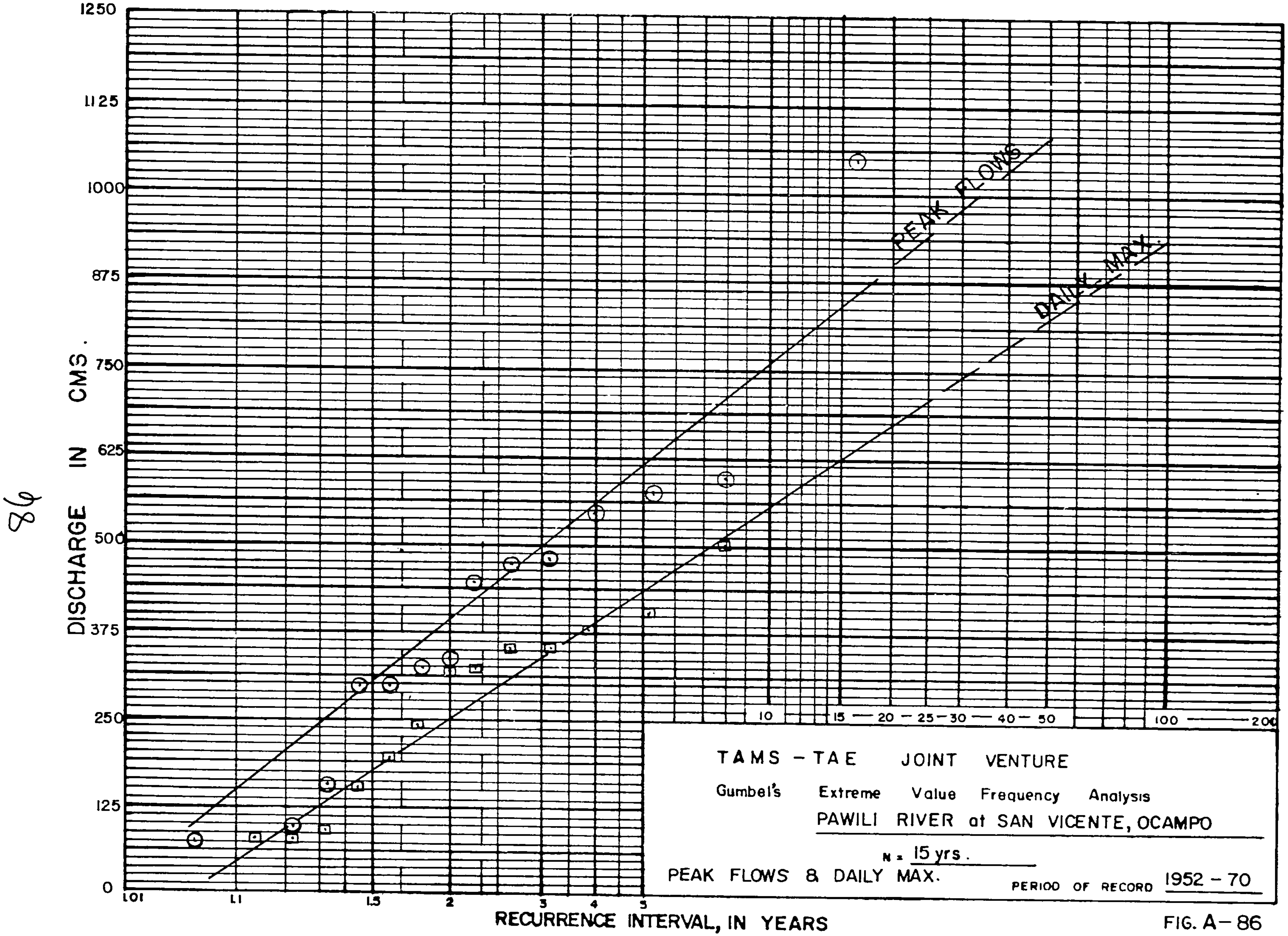

DISCHARGE IN CMS.
0
50
100
150
200
250
300
350
400
450
500
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
RECURRENCE INTERVAL, IN YEARS
PEAK FLOWS
DAILY MAX.
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
ANAYAN RIVER at SAN ROQUE, PILI
N = 20 yrs.
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD 1954-73

FIG. A-84



PEAK FLOWS
DAILY MAX.
DISCHARGE IN CMS.
0
100
200
300
400
500
600
700
800
900
1,000
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 - 30 — 40 — 50
100 — 200
RECURRENCE INTERVAL, IN YEARS
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
PAWILI RIVER at San Roque, Bula
N = 15 yrs.
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD 1959-'75

FIG. A-85



86
1250
1125
1000
875
750
625
500
375
250
125
0
DISCHARGE IN CMS.
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
RECURRENCE INTERVAL, IN YEARS
PEAK FLOWS
DAILY MAX.
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
PAWILI RIVER at SAN VICENTE, OCAMPO
N = 15 yrs.
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD 1952 - 70

FIG. A-86

87

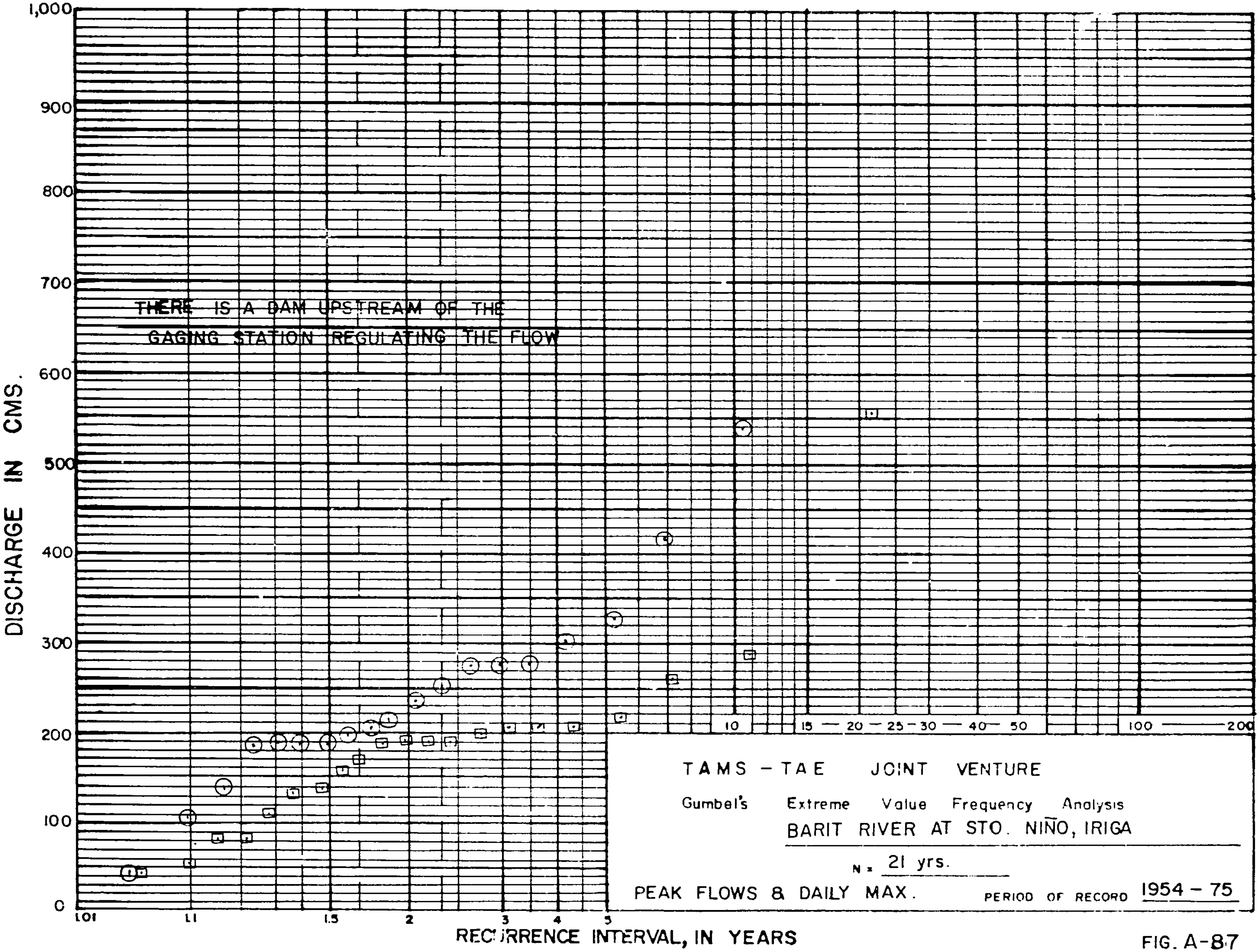
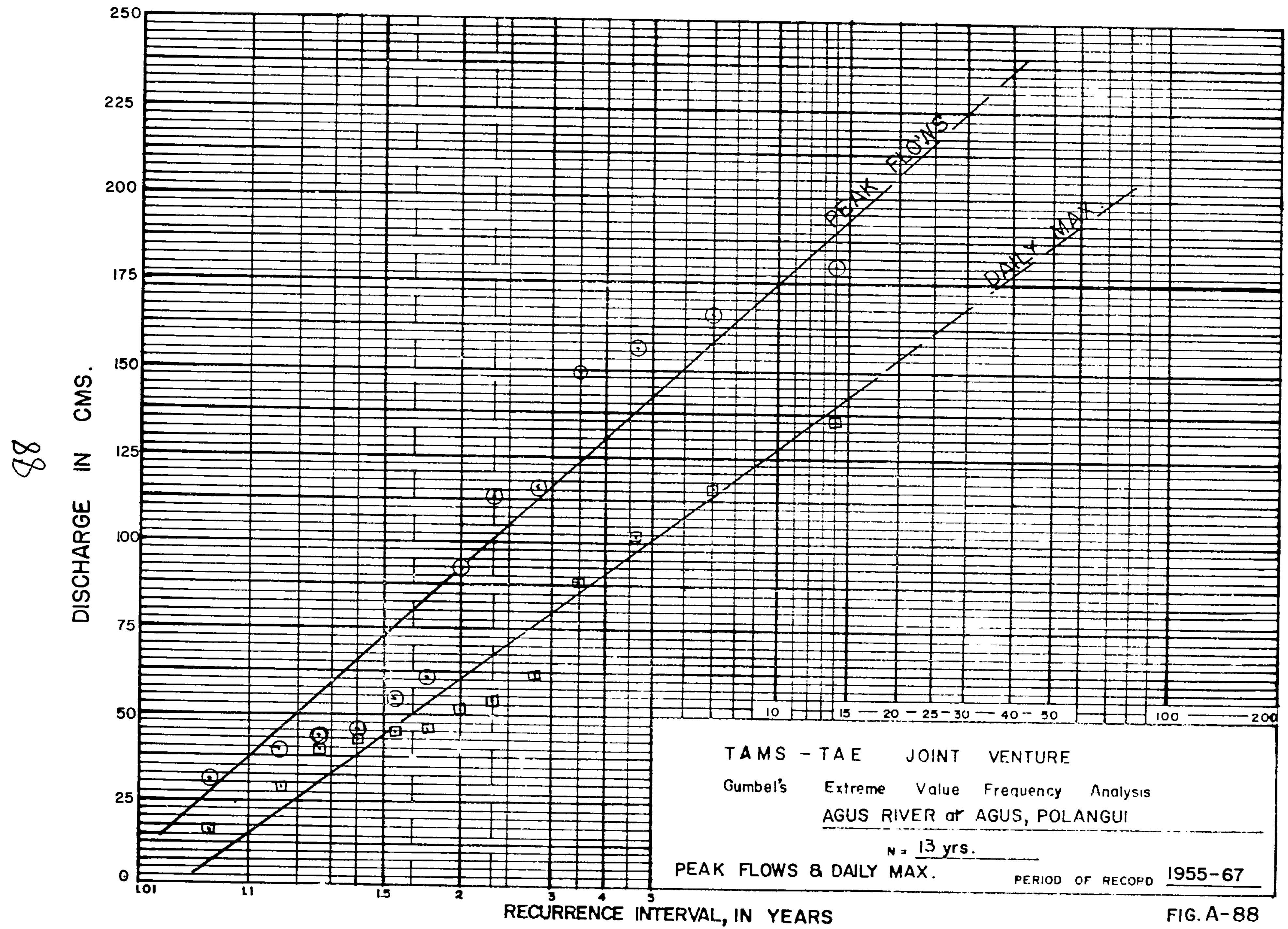

THERE IS A DAM UPSTREAM OF THE GAGING STATION REGULATING THE FLOW
DISCHARGE IN CMS.
1,000
900
800
700
600
500
400
300
200
100
0
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
BARIT RIVER AT STO. NIÑO, IRIGA
N = 21 yrs.
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD 1954 – 75

FIG. A-87



88
DISCHARGE IN CMS.
250
225
200
175
150
125
100
75
50
25
0
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
PEAK FLOWS
DAILY MAX.
RECURRENCE INTERVAL, IN YEARS
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
AGUS RIVER at AGUS, POLANGUI
N = 13 yrs.
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD 1955-67

FIG. A-88

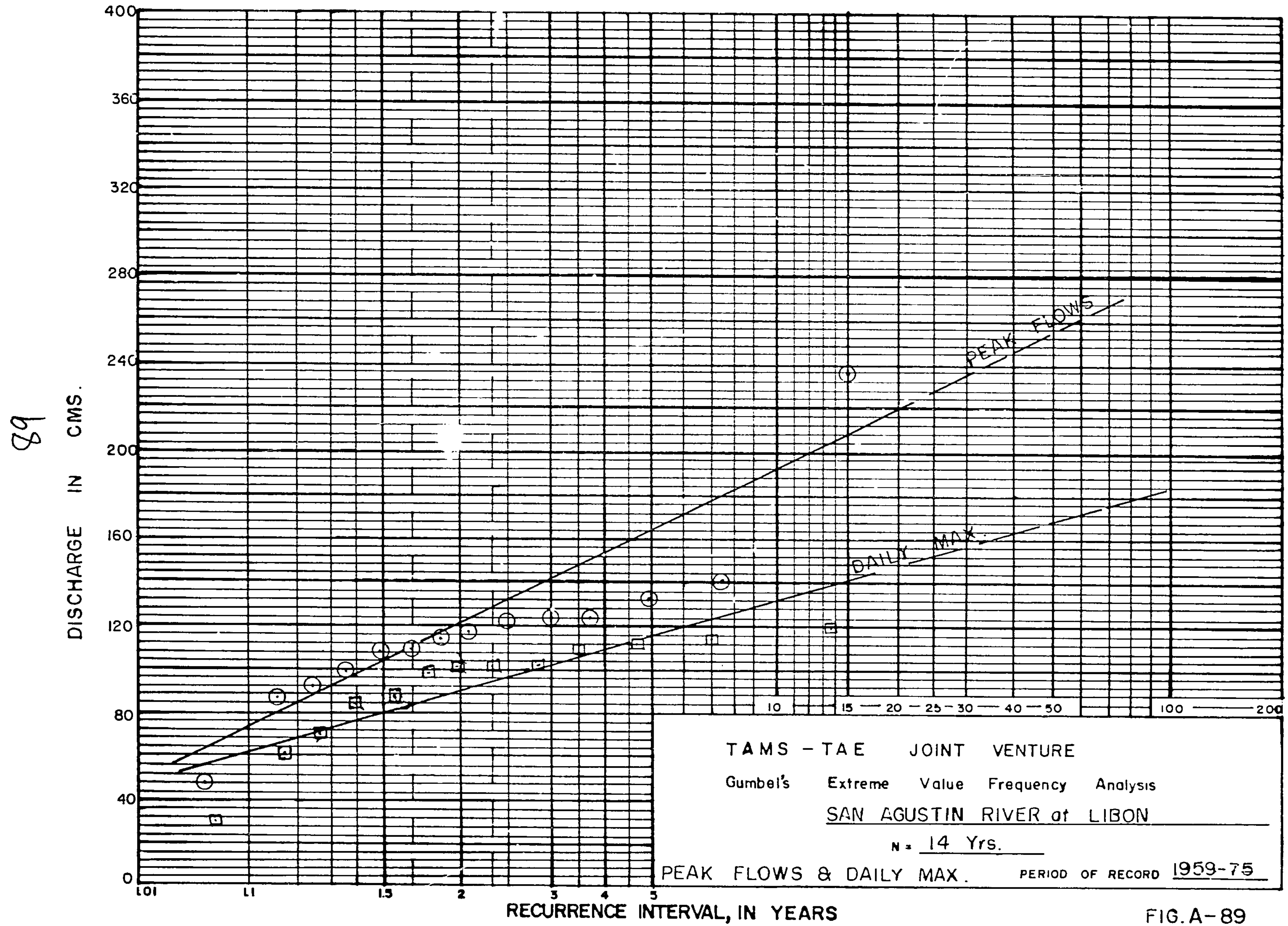

89
DISCHARGE IN CMS.
400
360
320
280
240
200
160
120
80
40
0
PEAK FLOWS
DAILY MAX.
10
15 20 25 30 40 50
100 200
1.01
1.1
1.5
2
3
4
5
RECURRENCE INTERVAL, IN YEARS
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
SAN AGUSTIN RIVER at LIBON
N = 14 Yrs.
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD 1959-75

FIG. A-89

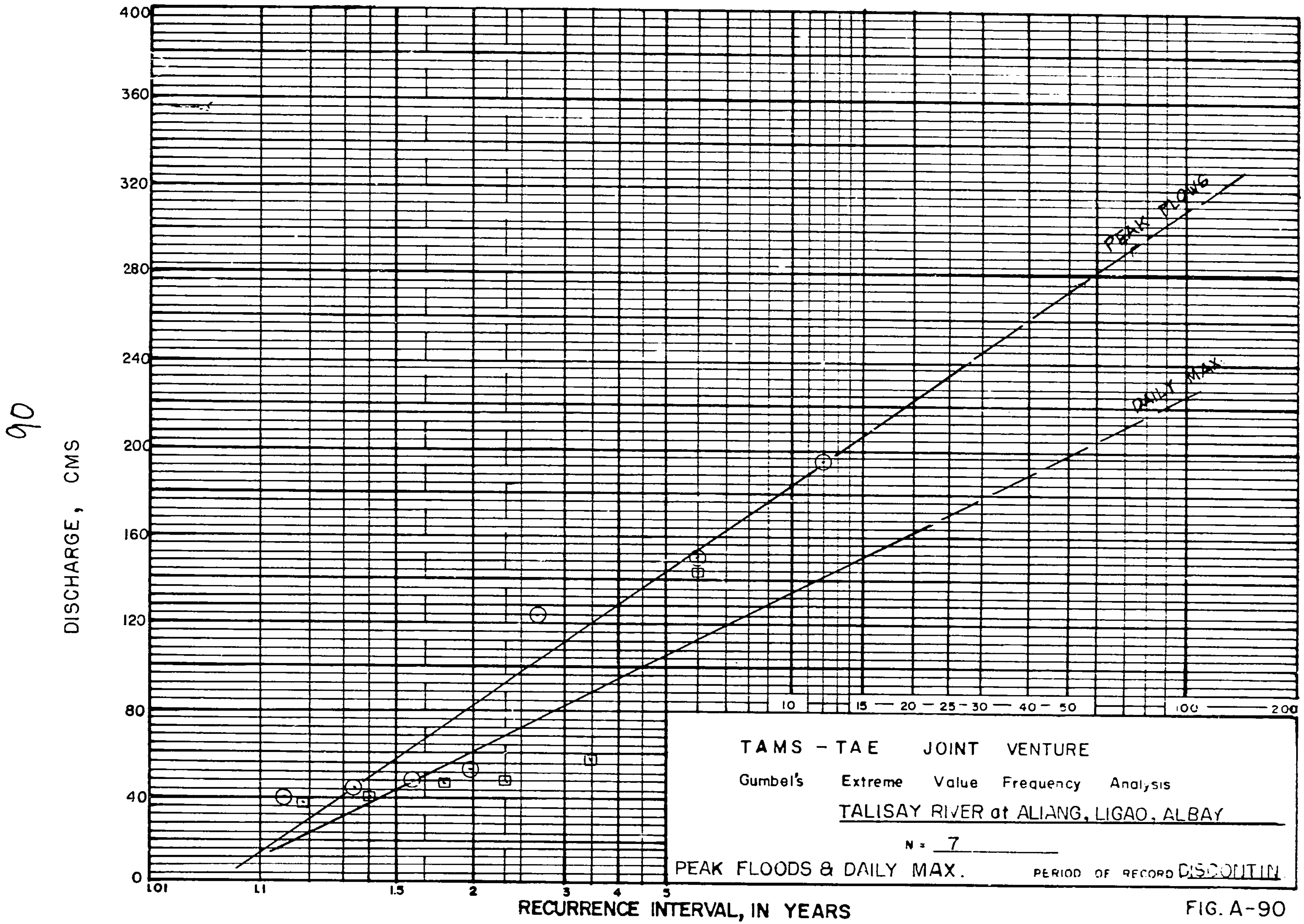
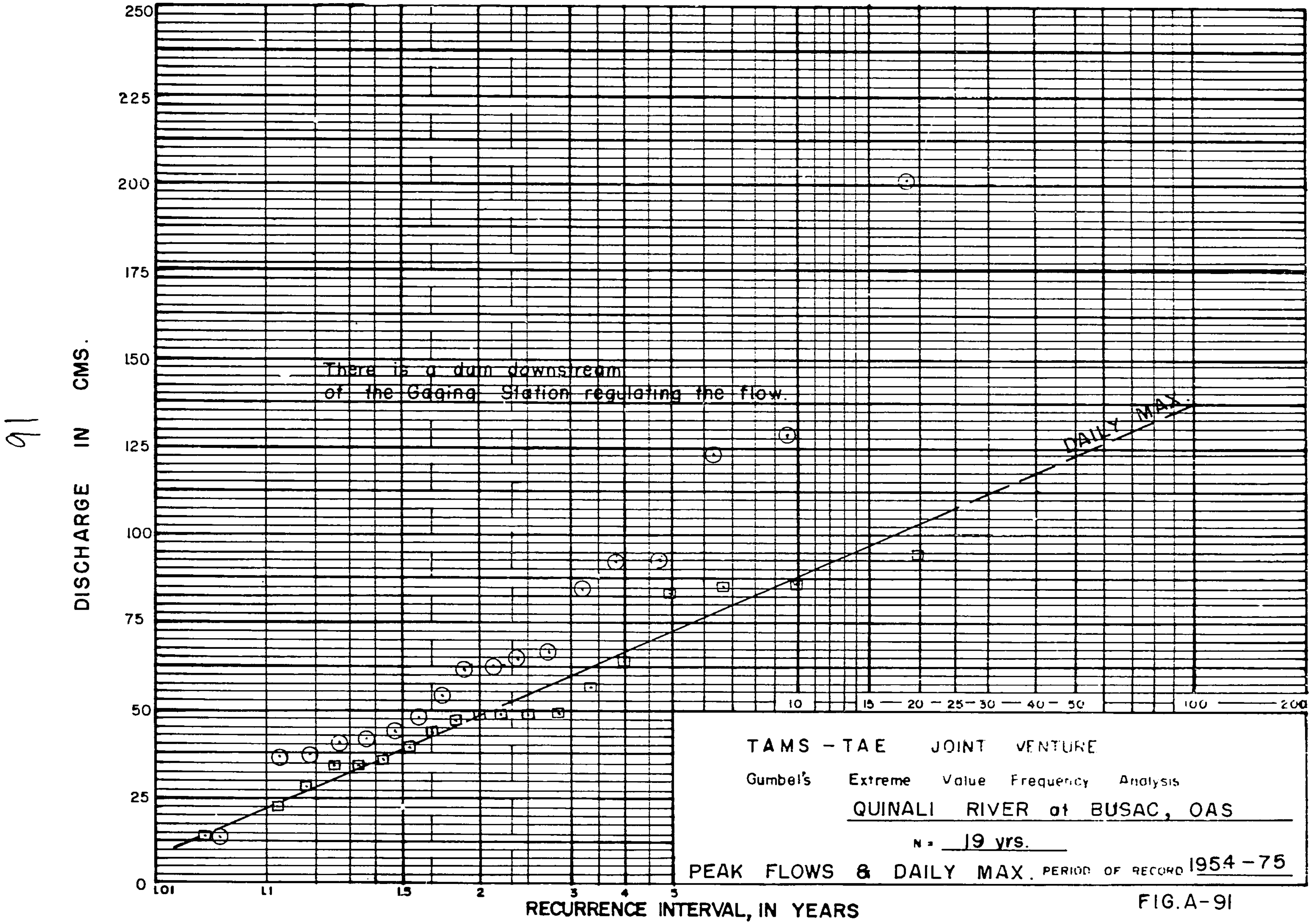
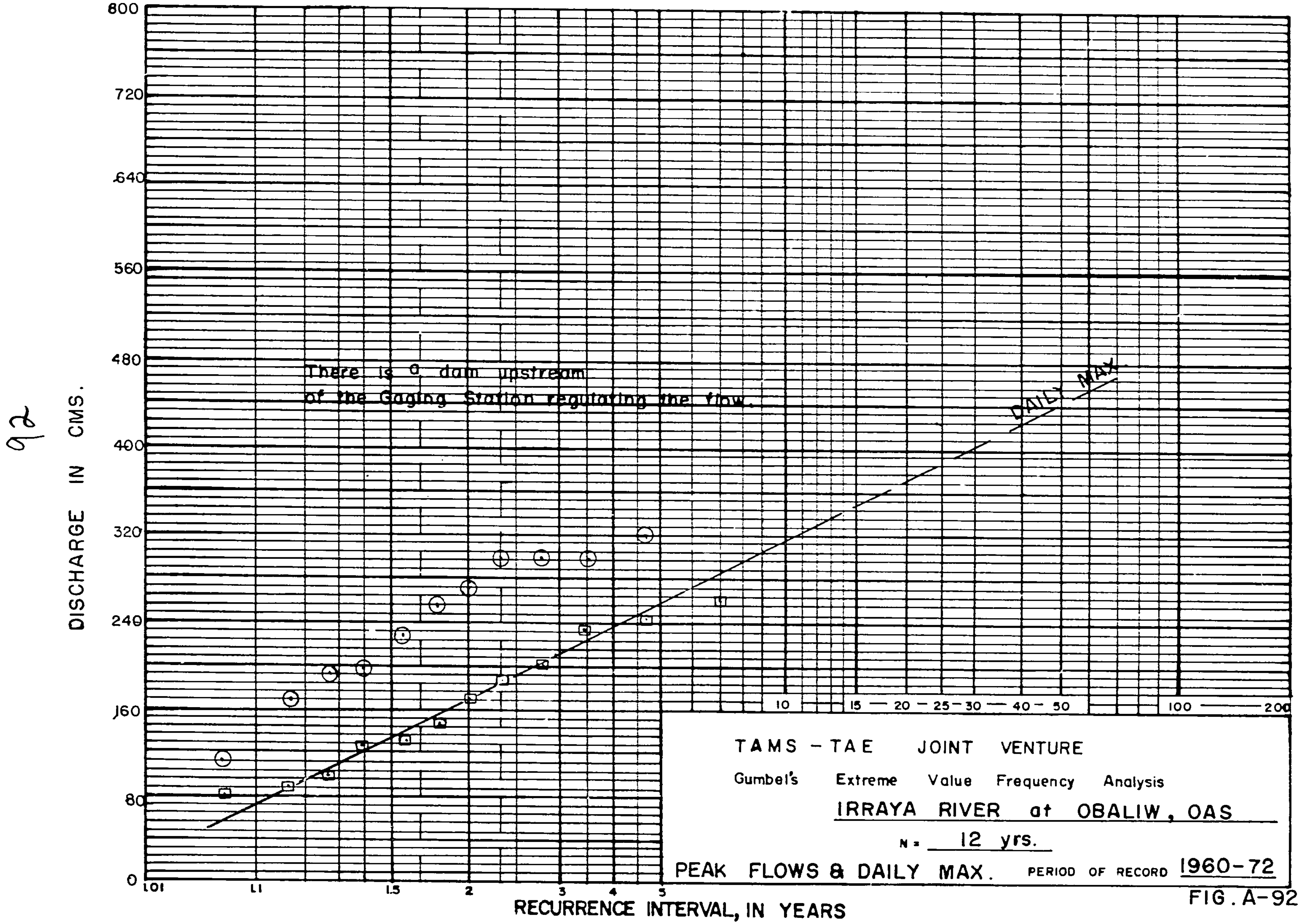

90
DISCHARGE, CMS
400
360
320
280
240
200
160
120
80
40
0
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
RECURRENCE INTERVAL, IN YEARS
PEAK FLOWS
DAILY MAX
TAMS – TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
TALISAY RIVER at ALIANG, LIGAO, ALBAY
N = 7
PEAK FLOODS & DAILY MAX.
PERIOD OF RECORD DISCONTIN.

FIG. A-90



91
DISCHARGE IN CMS.
250
225
200
175
150
125
100
75
50
25
0
There is a dam downstream
of the Gaging Station regulating the flow.
DAILY MAX.
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
RECURRENCE INTERVAL, IN YEARS
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
QUINALI RIVER at BUSAC, OAS
N = 19 yrs.
PEAK FLOWS & DAILY MAX. PERIOD OF RECORD 1954 - 75

FIG. A-91



TAMS – TAE JOINT VENTURE

Gumbel's Extreme Value Frequency Analysis

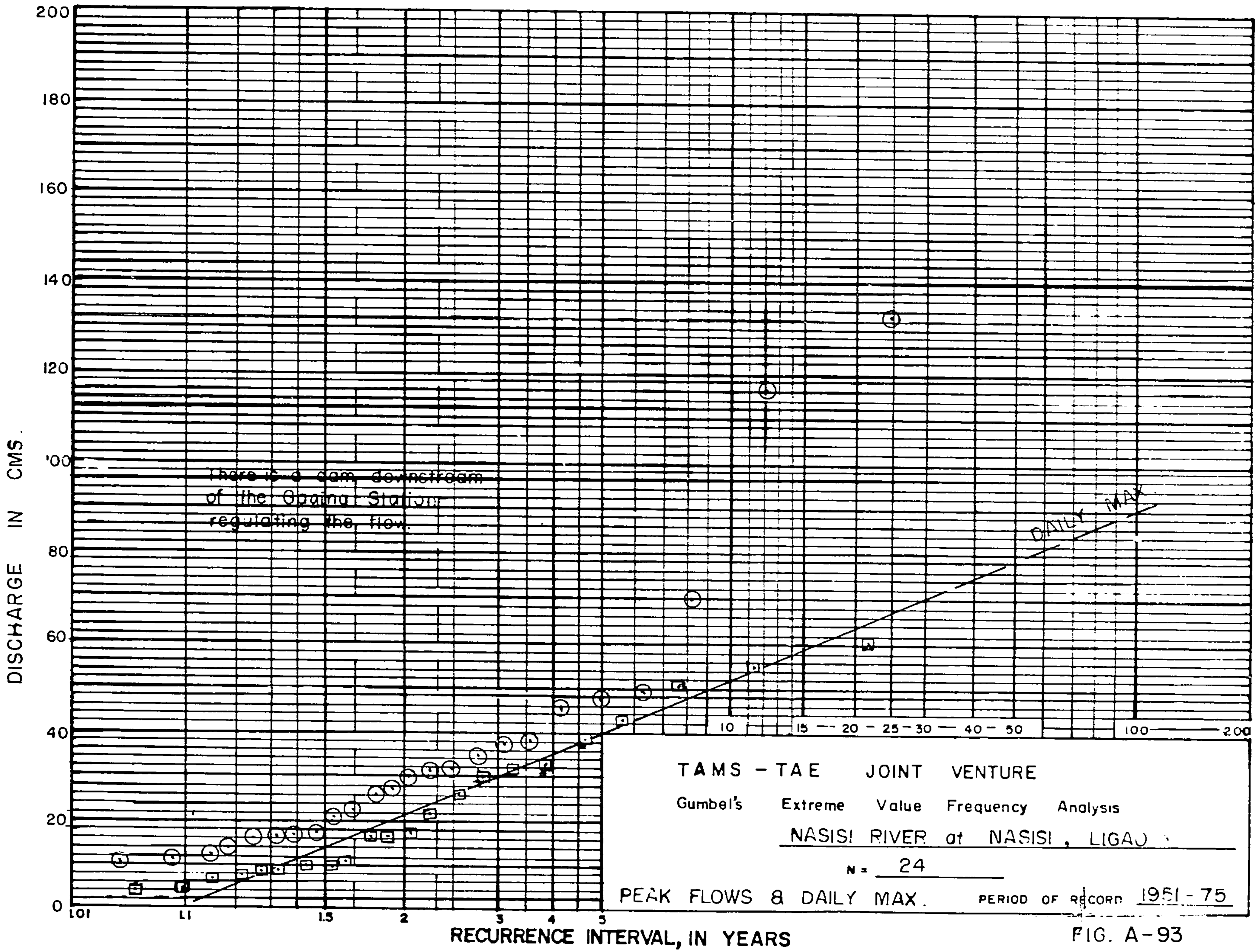
IRRAYA RIVER at OBALIW, OAS

N = 12 yrs.

PEAK FLOWS & DAILY MAX. PERIOD OF RECORD 1960-72

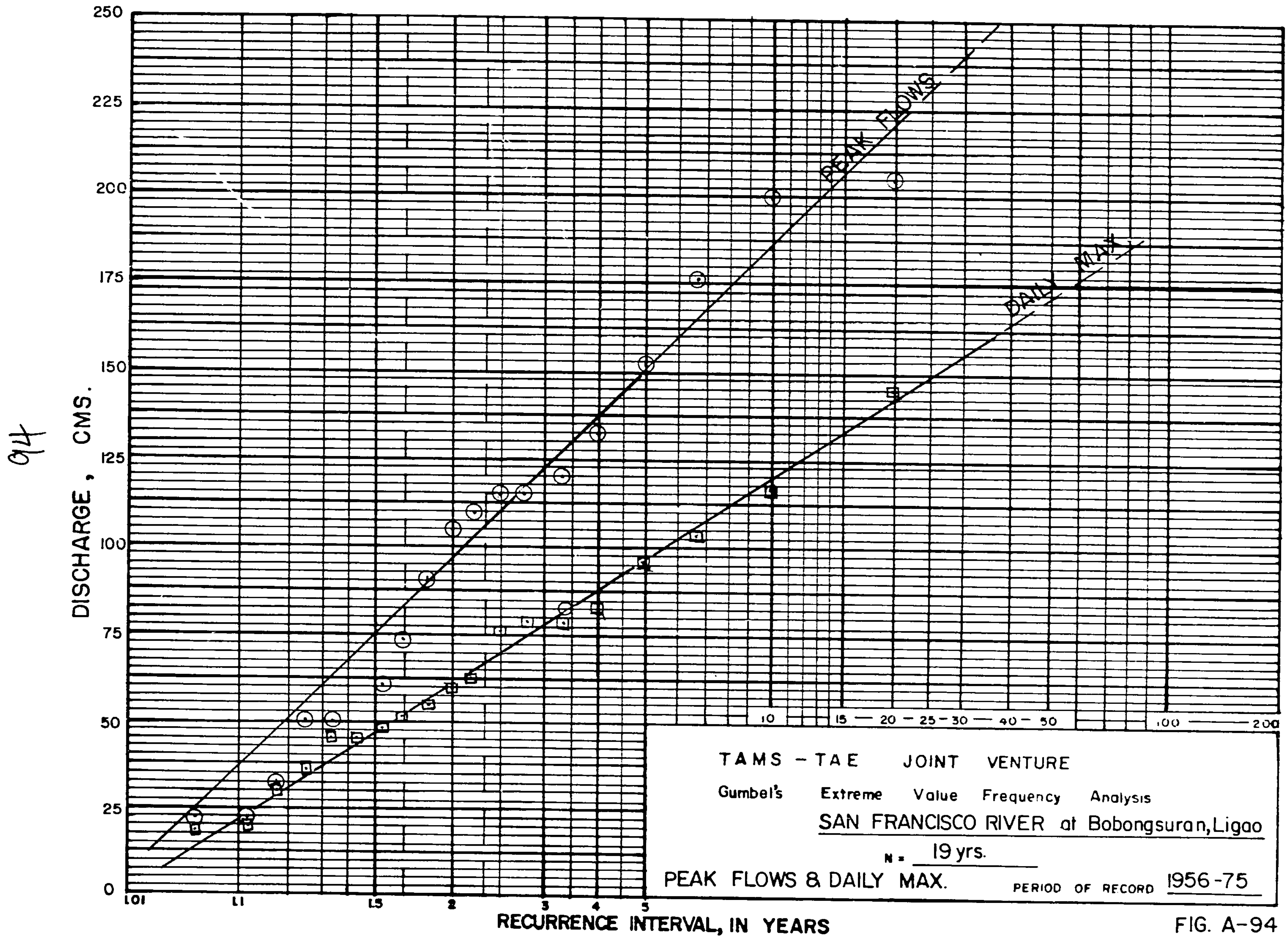
FIG. A-92

93



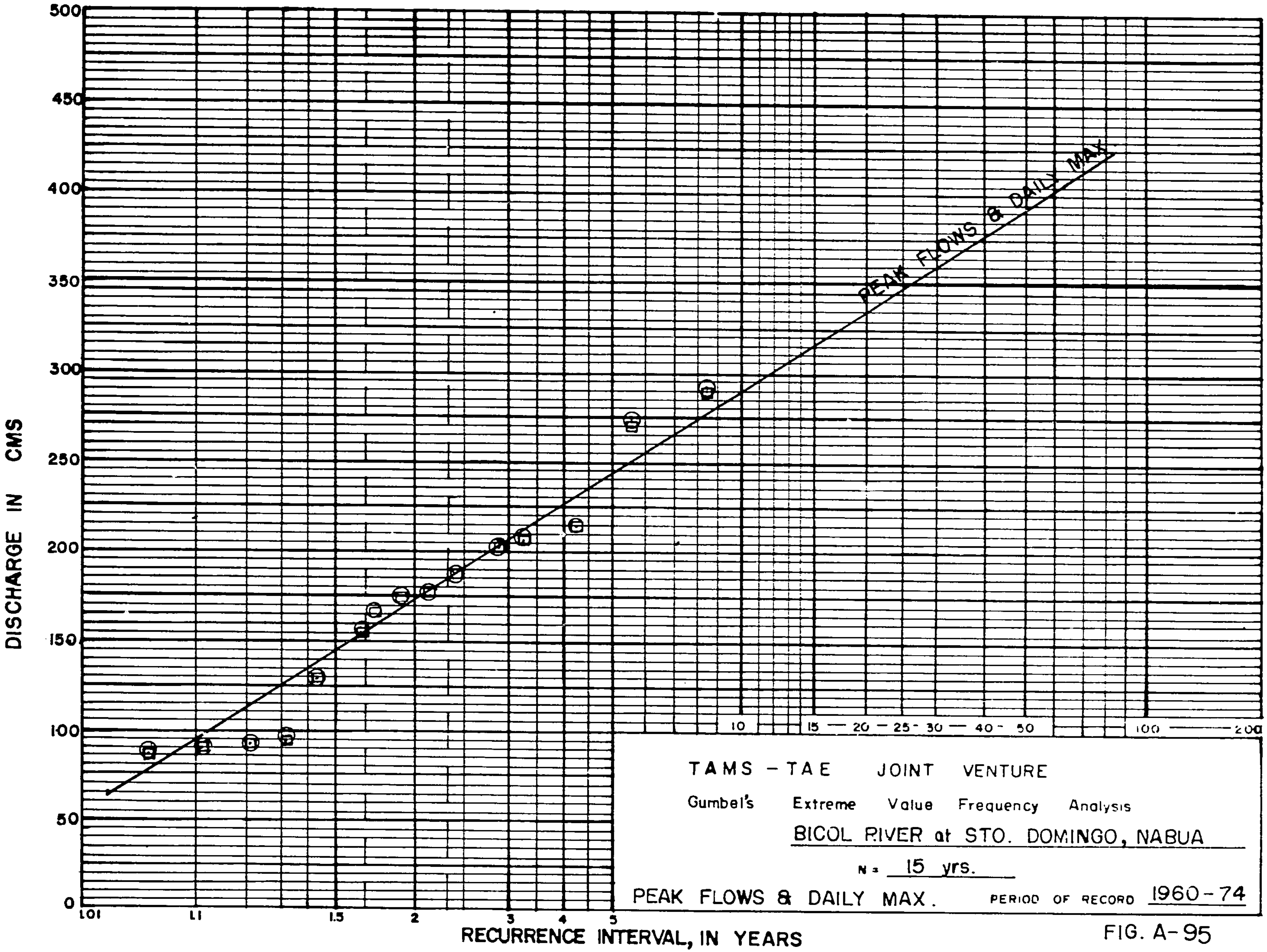
DISCHARGE IN CMS.
200
180
160
140
120
100
80
60
40
20
0
1.01
1.1
1.5
2
3
4
5
10
15 20 25 30 40 50
100 200
RECURRENCE INTERVAL, IN YEARS
There is a dam downstream of the Gaging Station regulating the flow.
DAILY MAX.
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
NASISI RIVER at NASISI , LIGAO
N = 24
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD 1951 - 75

FIG. A-93



94
DISCHARGE , CMS.
250
225
200
175
150
125
100
75
50
25
0
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
PEAK FLOWS
DAILY MAX
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
SAN FRANCISCO RIVER at Bobongsuran, Ligao
N = 19 yrs.
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD 1956-75
RECURRENCE INTERVAL, IN YEARS

FIG. A-94



TAMS - TAE JOINT VENTURE

Gumbel's Extreme Value Frequency Analysis

BICOL RIVER at STO. DOMINGO, NABUA

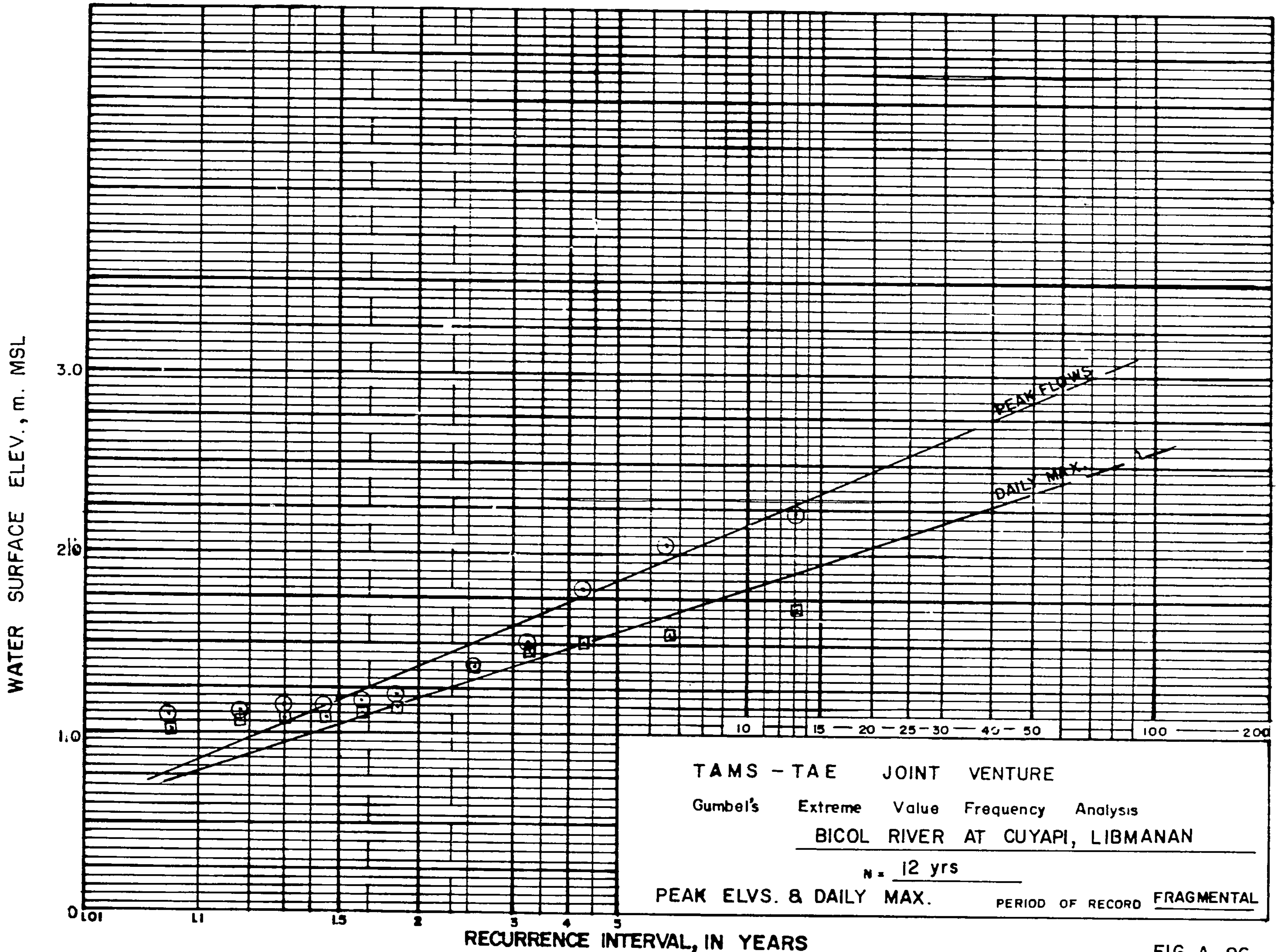
N = 15 yrs.

PEAK FLOWS & DAILY MAX. PERIOD OF RECORD 1960-74

FIG. A-95

95

96



TAMS – TAE JOINT VENTURE

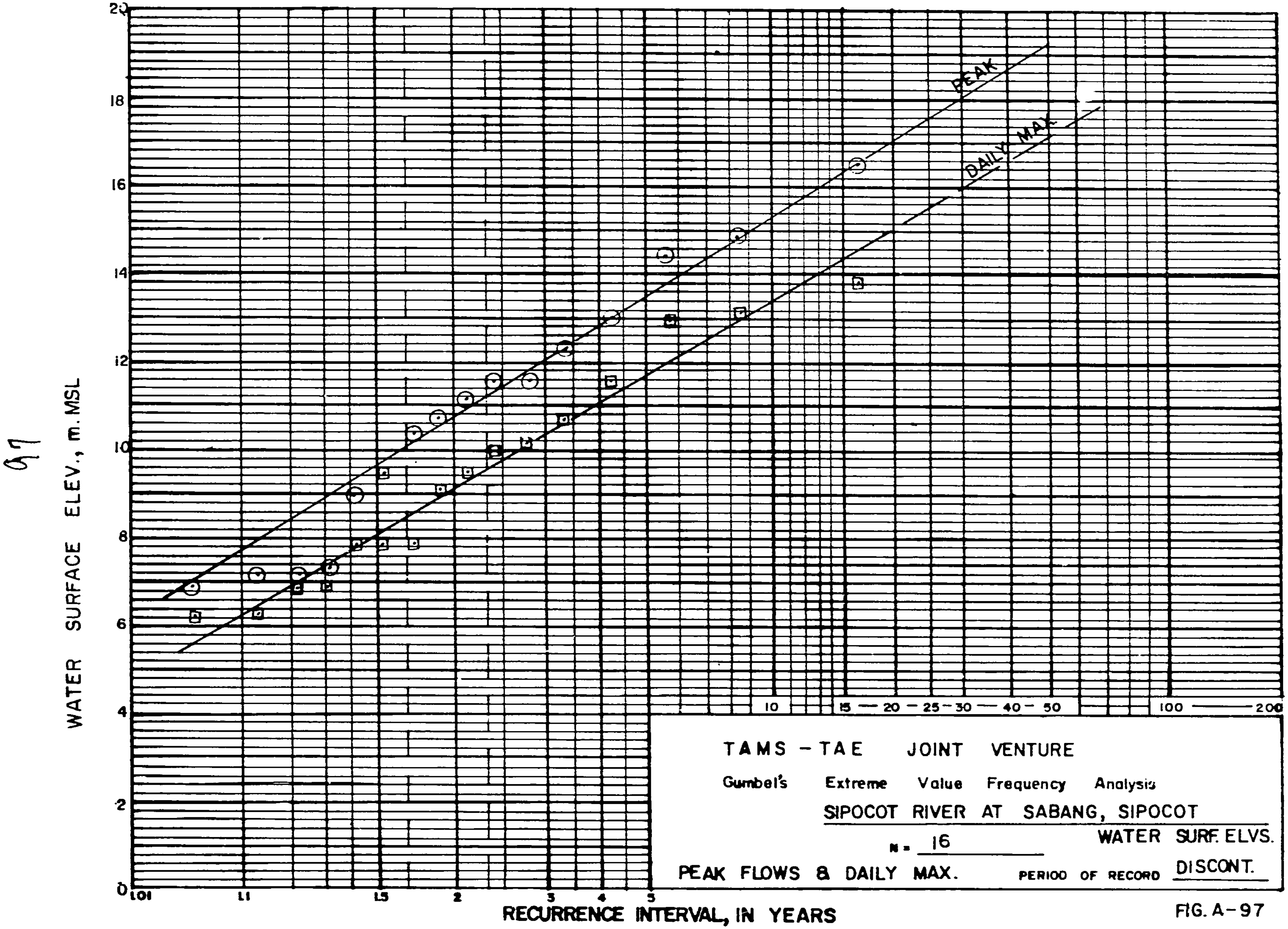
Gumbel's Extreme Value Frequency Analysis

BICOL RIVER AT CUYAPI, LIBMANAN

N = 12 yrs

PEAK ELVS. & DAILY MAX. PERIOD OF RECORD FRAGMENTAL

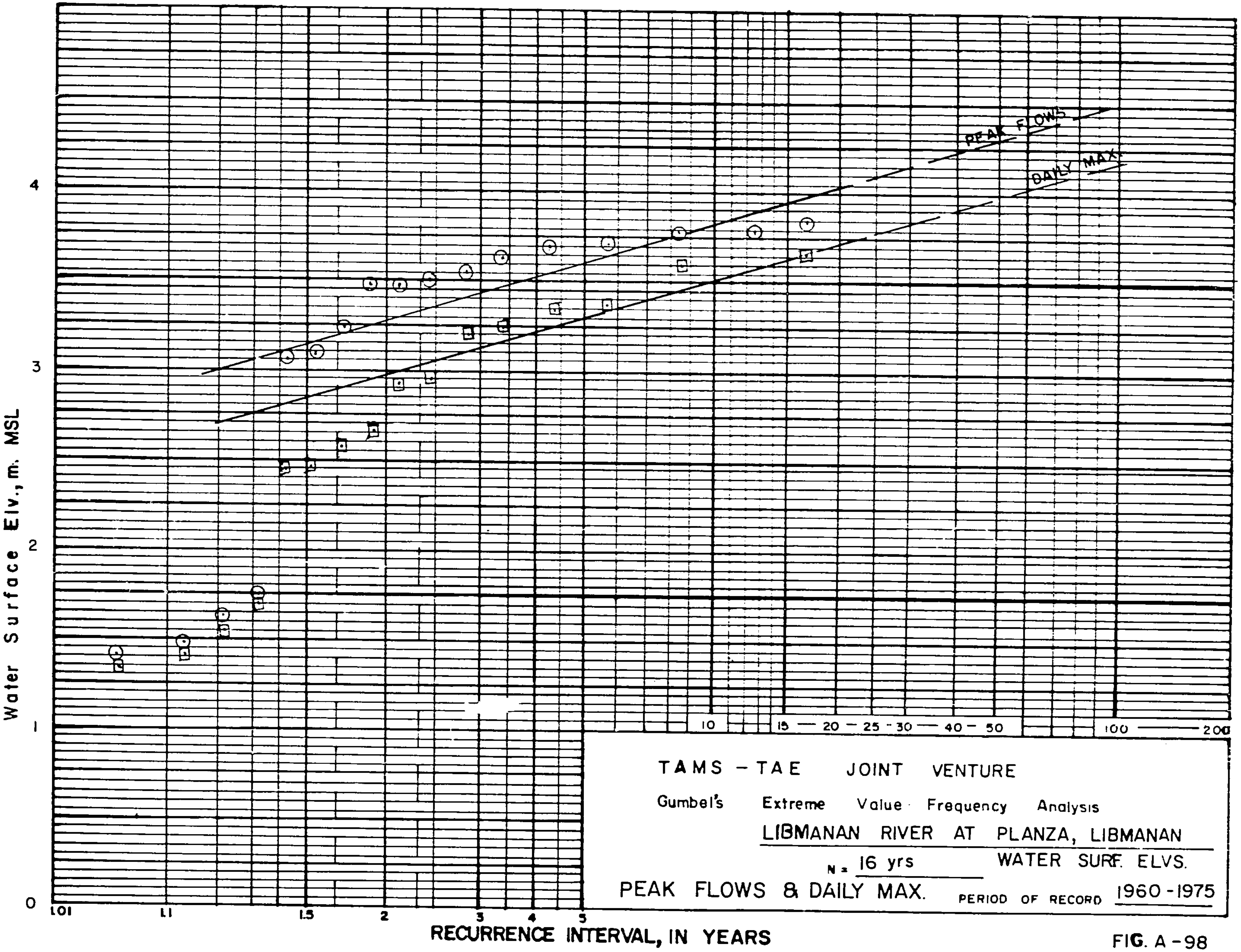
FIG. A-96



97
WATER SURFACE ELEV., m. MSL
PEAK
DAILY MAX
RECURRENCE INTERVAL, IN YEARS
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
SIPOCOT RIVER AT SABANG, SIPOCOT
N = 16
WATER SURF. ELVS.
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD DISCONT.

FIG. A-97

98



TAMS – TAE JOINT VENTURE

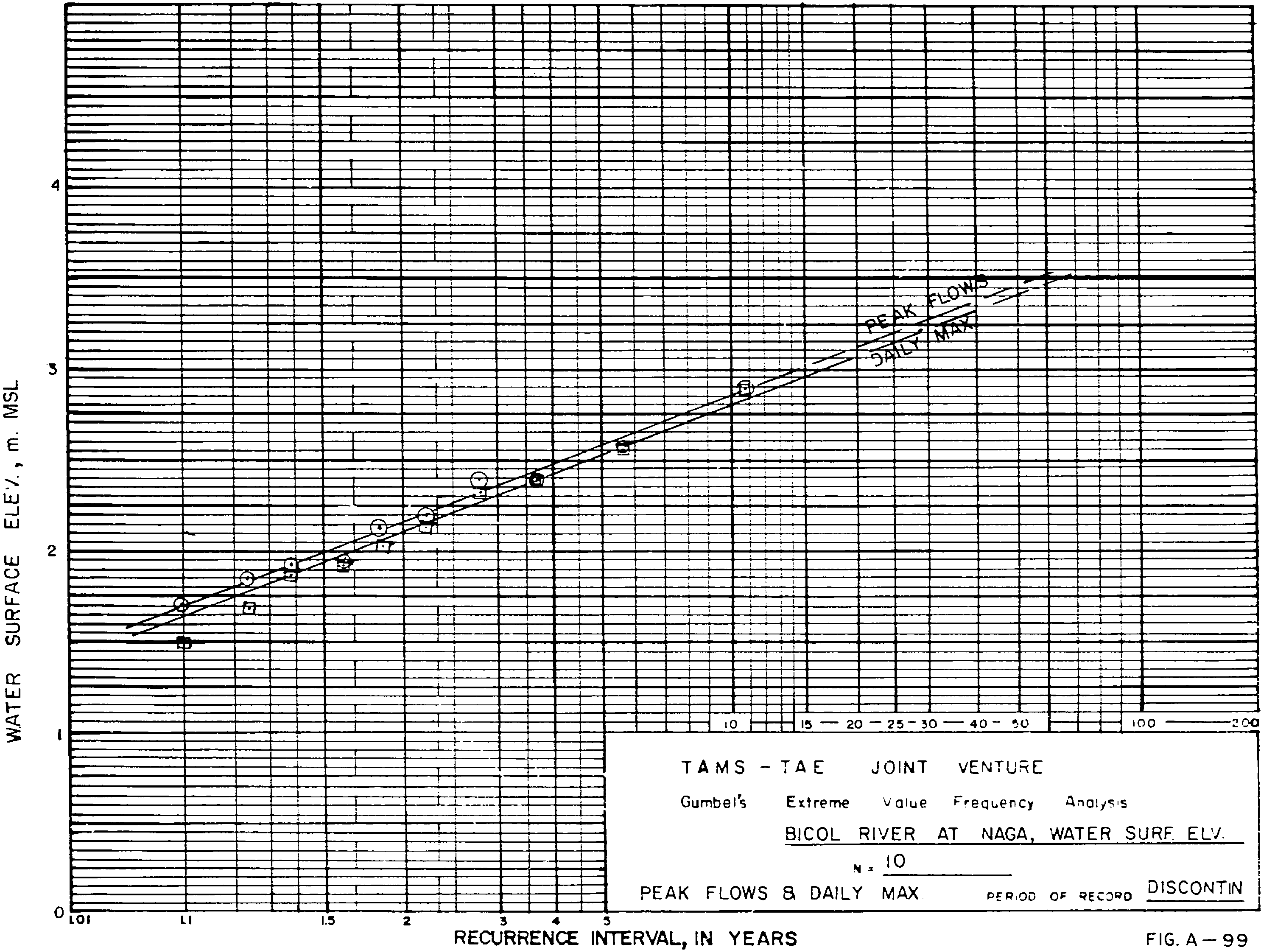
Gumbel's Extreme Value Frequency Analysis

LIBMANAN RIVER AT PLANZA, LIBMANAN

N = 16 yrs WATER SURF. ELVS.

PEAK FLOWS & DAILY MAX. PERIOD OF RECORD 1960-1975

FIG. A-98



WATER SURFACE ELEV., m. MSL
0
1
2
3
4
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
PEAK FLOWS
DAILY MAX.
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
BICOL RIVER AT NAGA, WATER SURF. ELV.
N = 10
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD DISCONTIN

FIG. A—99

99

100

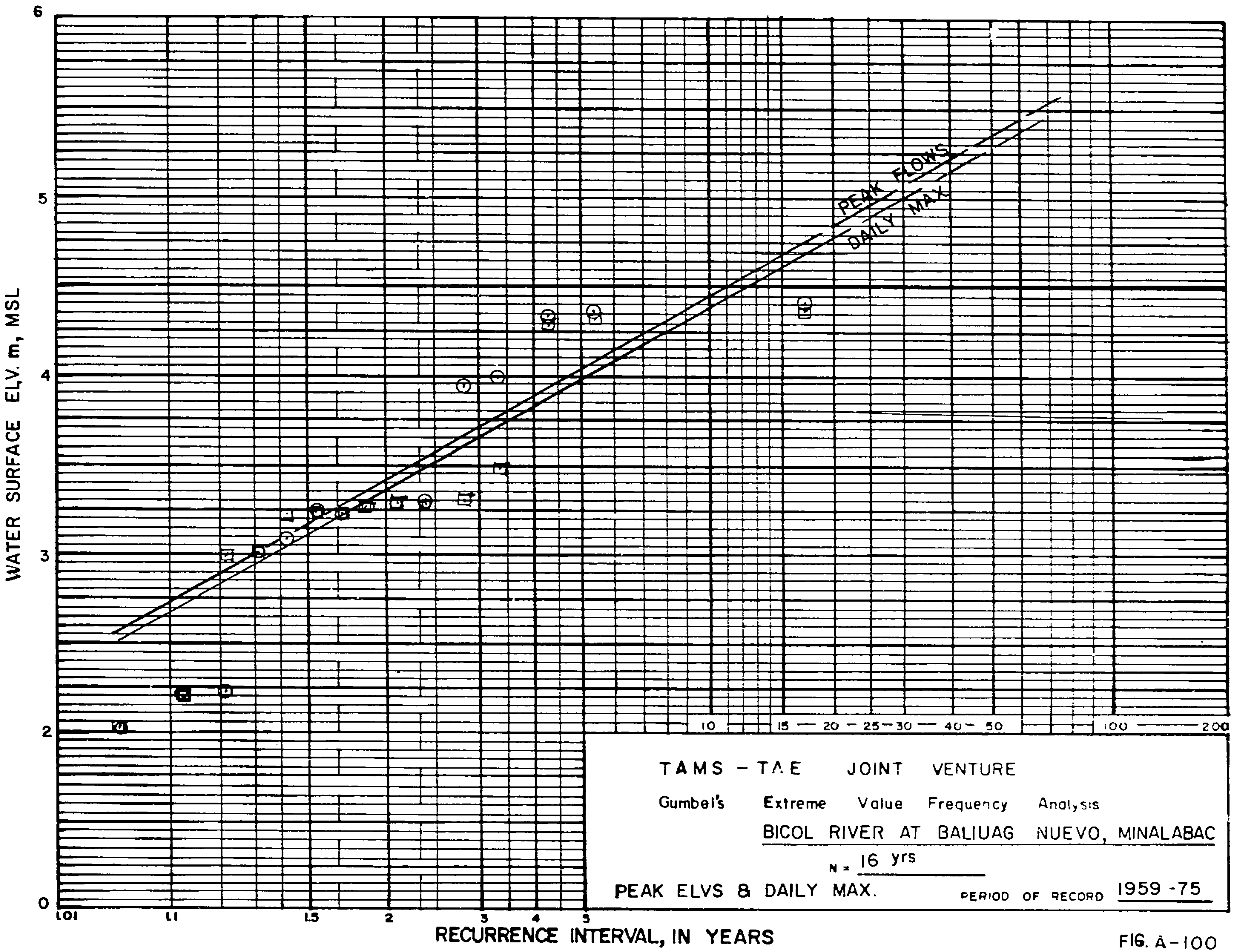
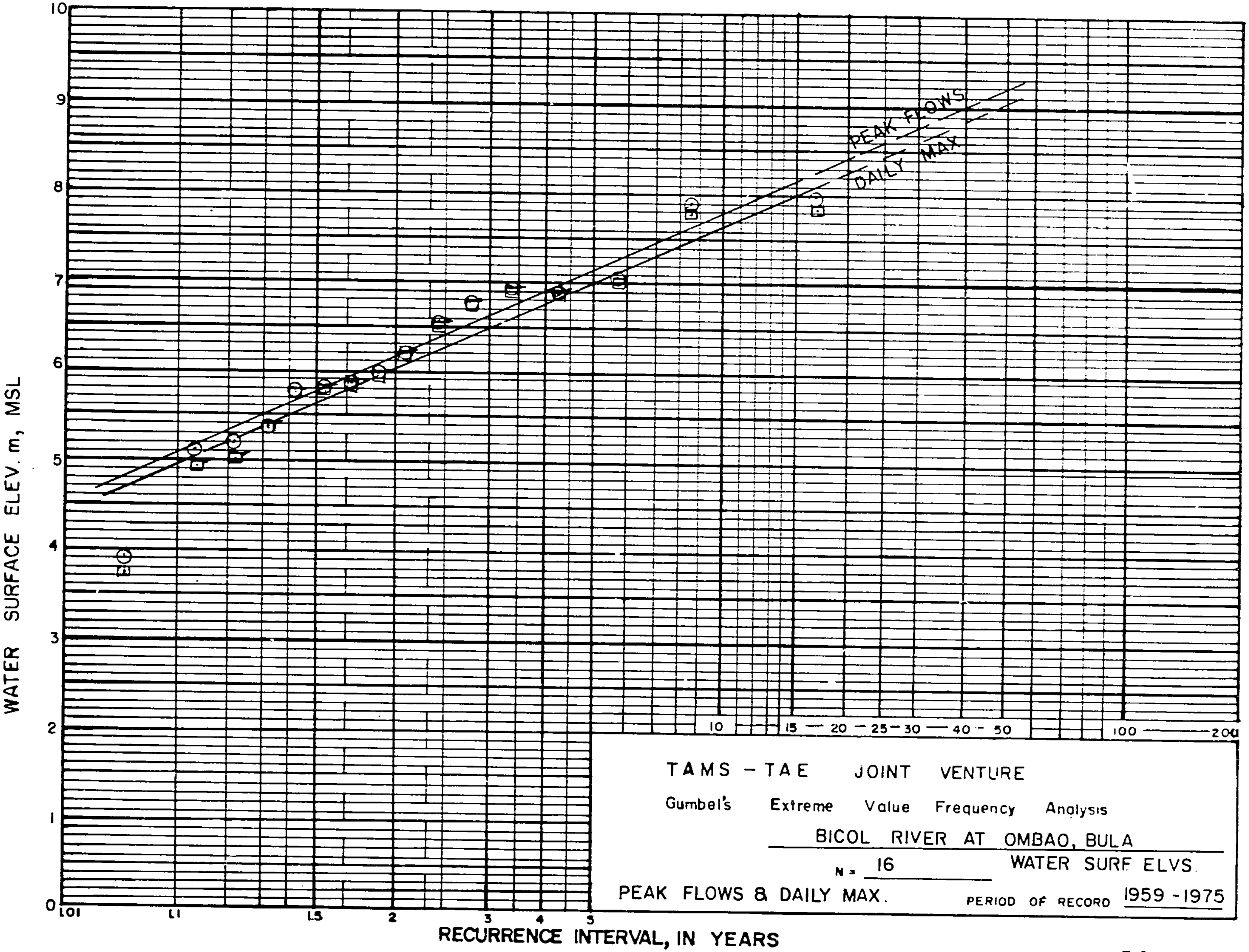

WATER SURFACE ELV. m, MSL
RECURRENCE INTERVAL, IN YEARS
PEAK FLOWS
DAILY MAX
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
BICOL RIVER AT BALIUAG NUEVO, MINALABAC
N = 16 yrs
PEAK ELVS & DAILY MAX.
PERIOD OF RECORD 1959 -75

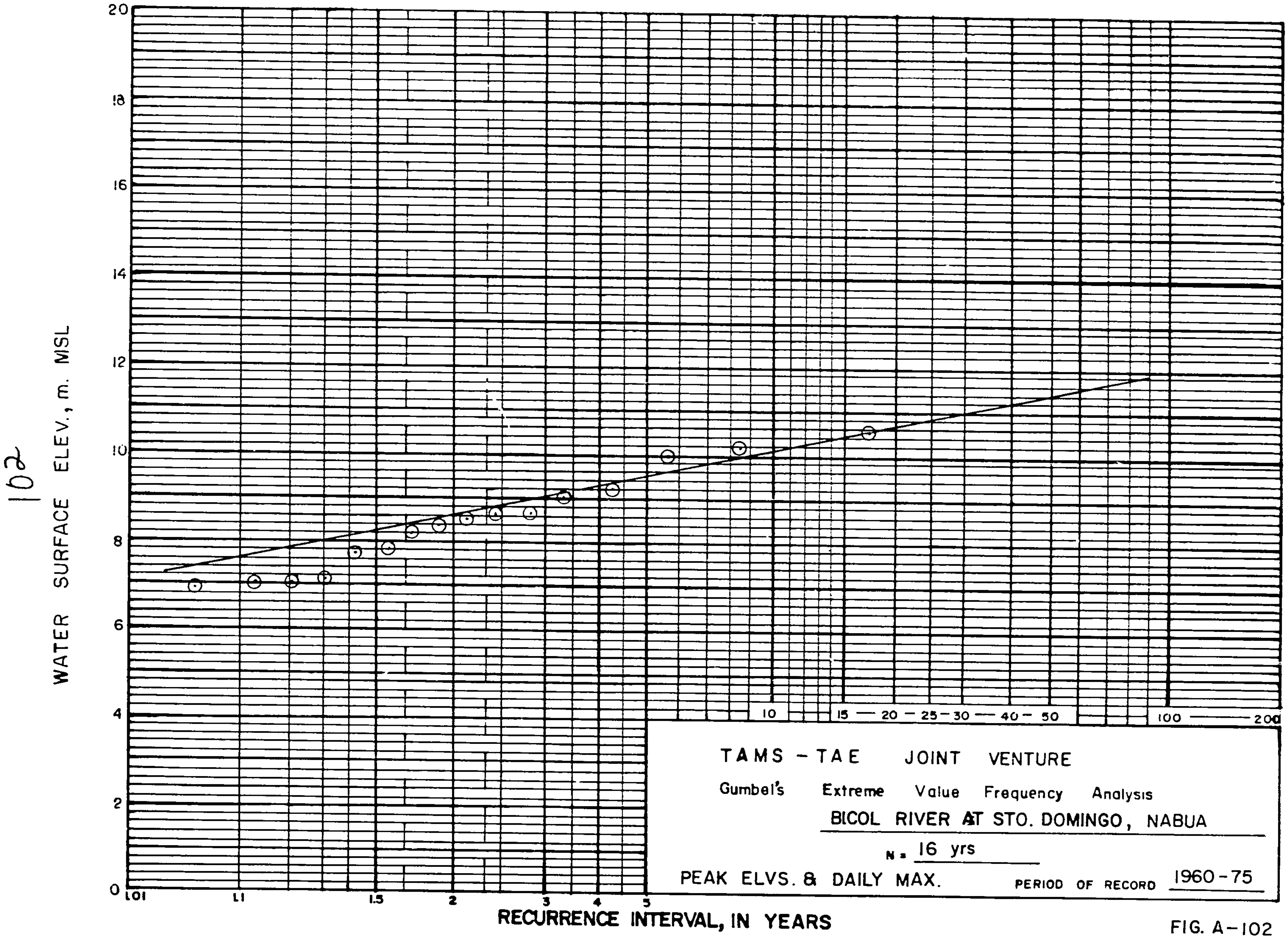
FIG. A-100

101



WATER SURFACE ELEV. m, MSL
RECURRENCE INTERVAL, IN YEARS
PEAK FLOWS
DAILY MAX
0
1
2
3
4
5
6
7
8
9
10
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
TAMS – TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
BICOL RIVER AT OMBAO, BULA
N = 16
WATER SURF ELVS.
PEAK FLOWS & DAILY MAX.
PERIOD OF RECORD 1959 - 1975

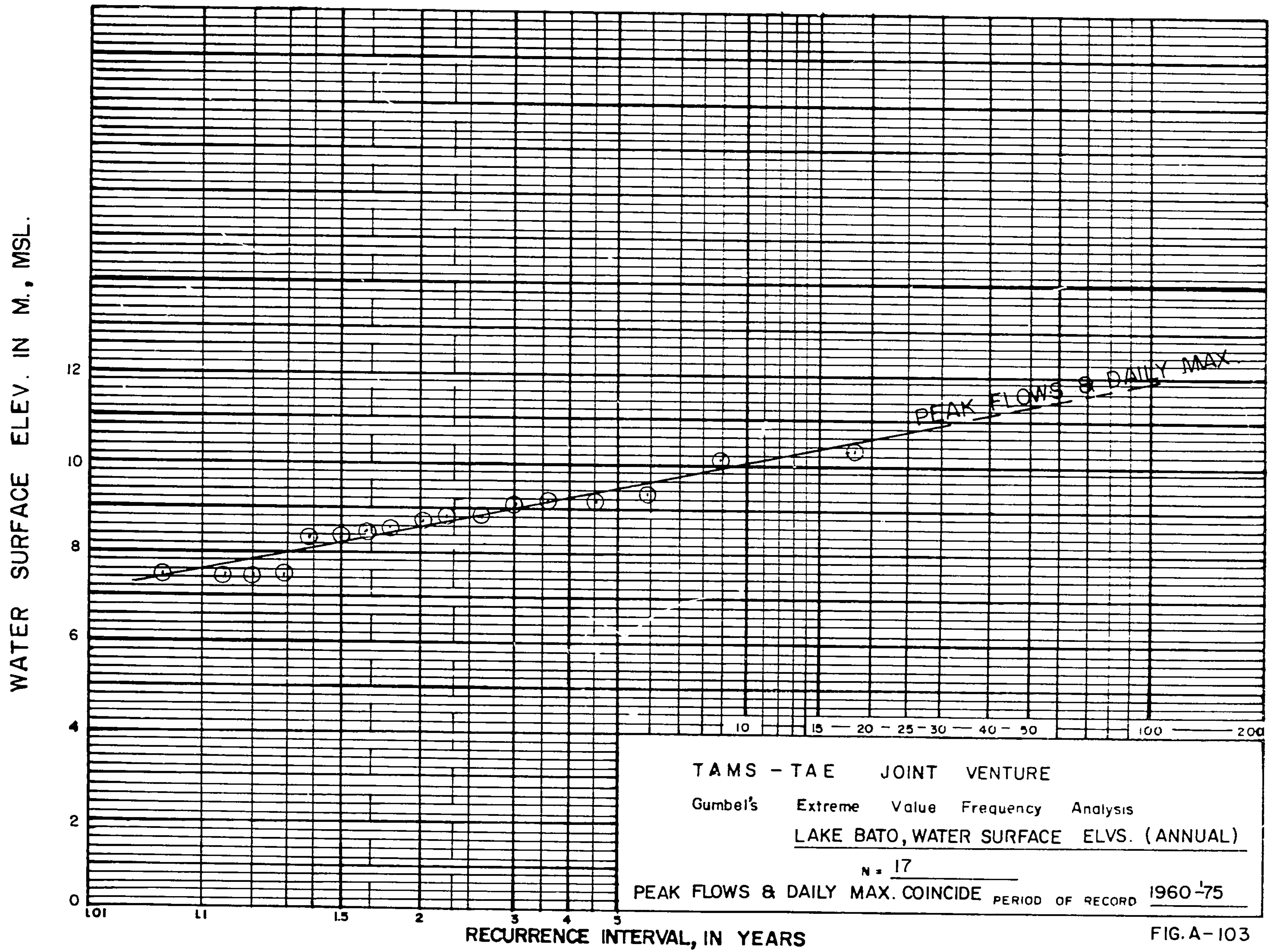
FIG. A—101



102
WATER SURFACE ELEV., m. MSL
20
18
16
14
12
10
8
6
4
2
0
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
BICOL RIVER AT STO. DOMINGO, NABUA
N = 16 yrs
PEAK ELVS. & DAILY MAX.
PERIOD OF RECORD 1960-75

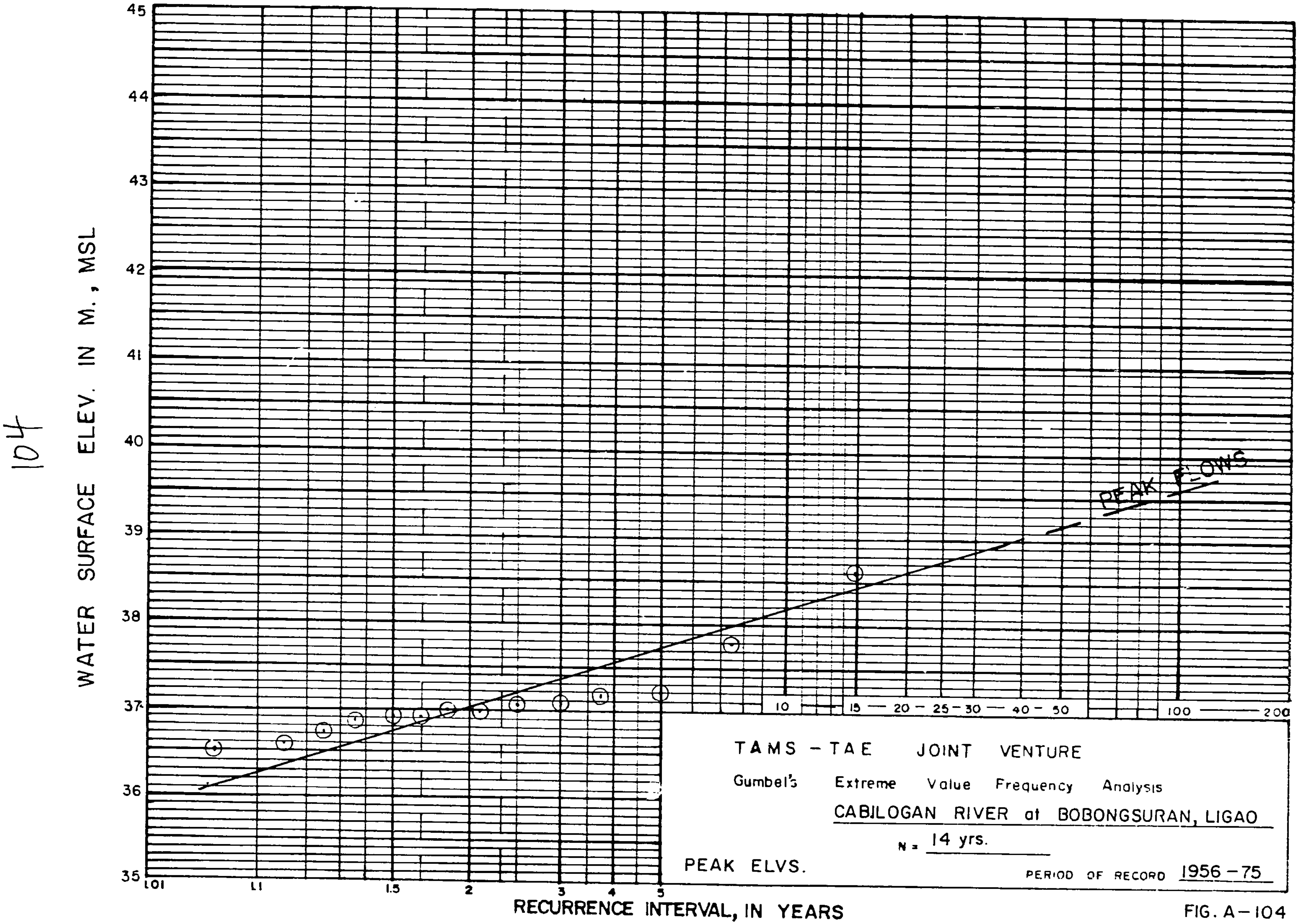
FIG. A-102

103



WATER SURFACE ELEV. IN M., MSL.
0
2
4
6
8
10
12
PEAK FLOWS & DAILY MAX.
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
RECURRENCE INTERVAL, IN YEARS
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
LAKE BATO, WATER SURFACE ELVS. (ANNUAL)
N = 17
PEAK FLOWS & DAILY MAX. COINCIDE PERIOD OF RECORD 1960-75

FIG. A-103


104
WATER SURFACE ELEV. IN M., MSL
45
44
43
42
41
40
39
38
37
36
35
1.01
1.1
1.5
2
3
4
5
10
15 — 20 — 25 — 30 — 40 — 50
100 — 200
RECURRENCE INTERVAL, IN YEARS
PEAK FLOWS
TAMS - TAE JOINT VENTURE
Gumbel's Extreme Value Frequency Analysis
CABILOGAN RIVER at BOBONGSURAN, LIGAO
N = 14 yrs.
PEAK ELVS.
PERIOD OF RECORD 1956 - 75
FIG. A-104

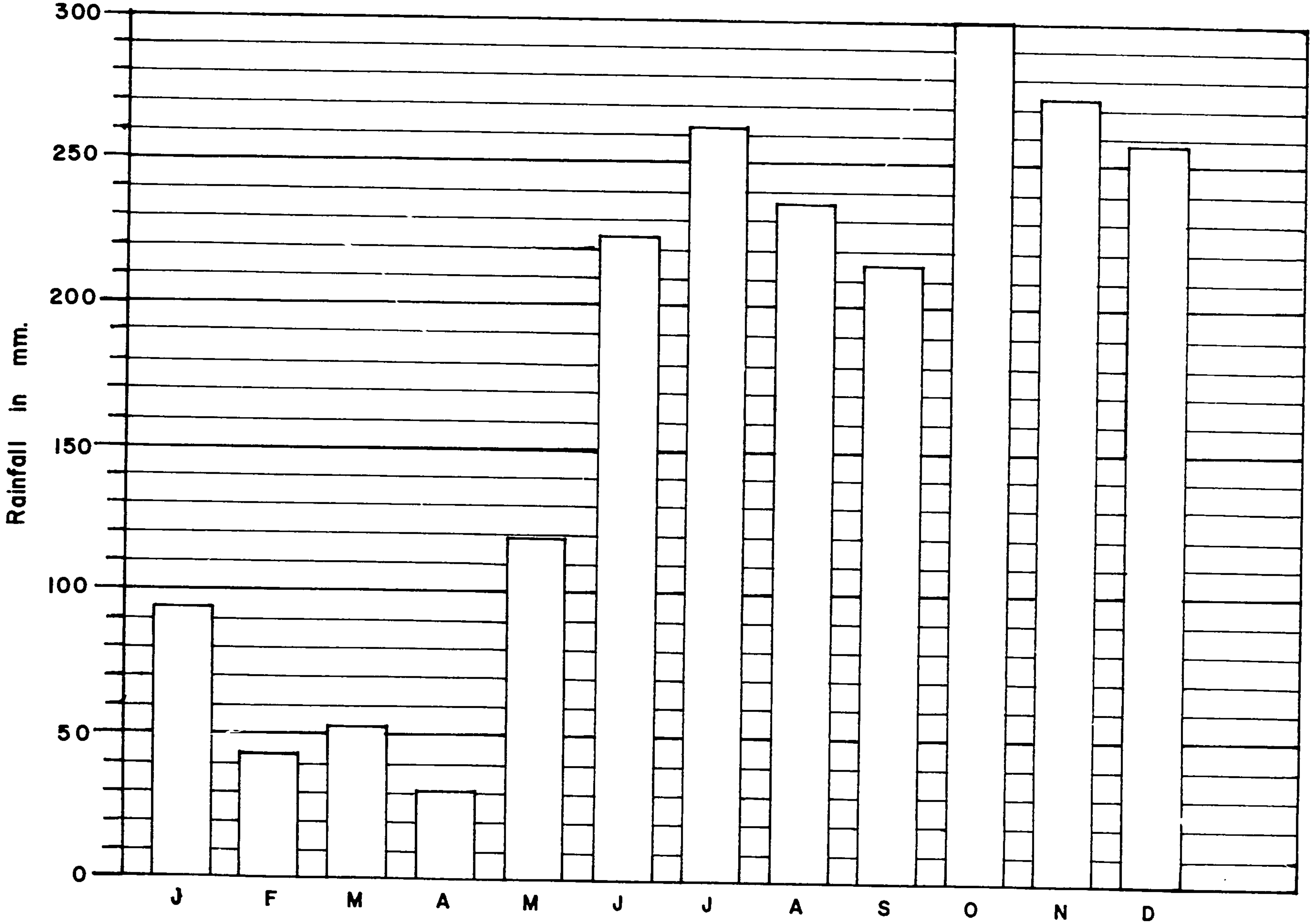


Fig. A - 105 Monthly Distribution of Rainfall at Pili, Camarines Sur

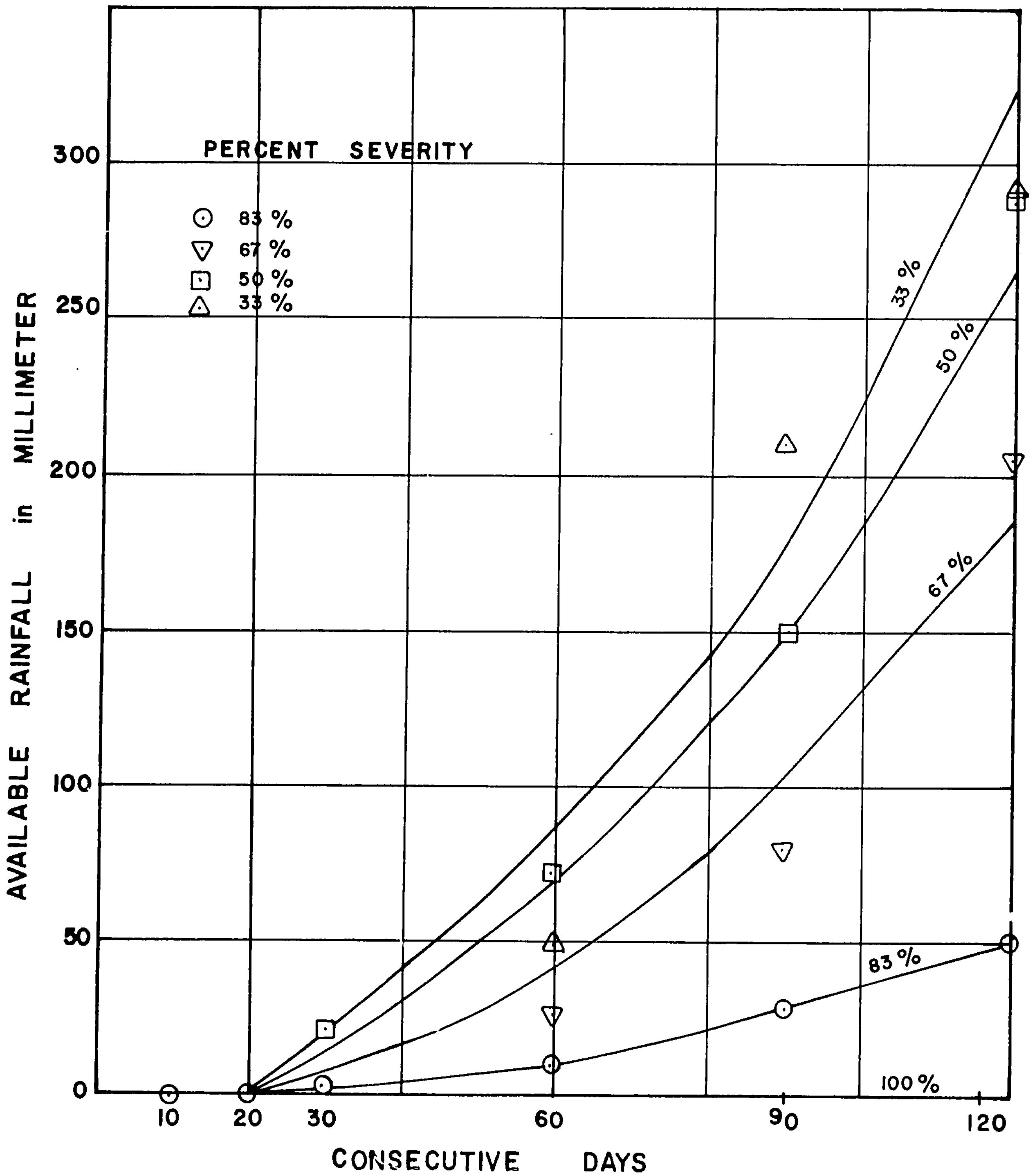


FIG. A-106 LOW RAINFALLS, SIPOCOT - Drought Severity

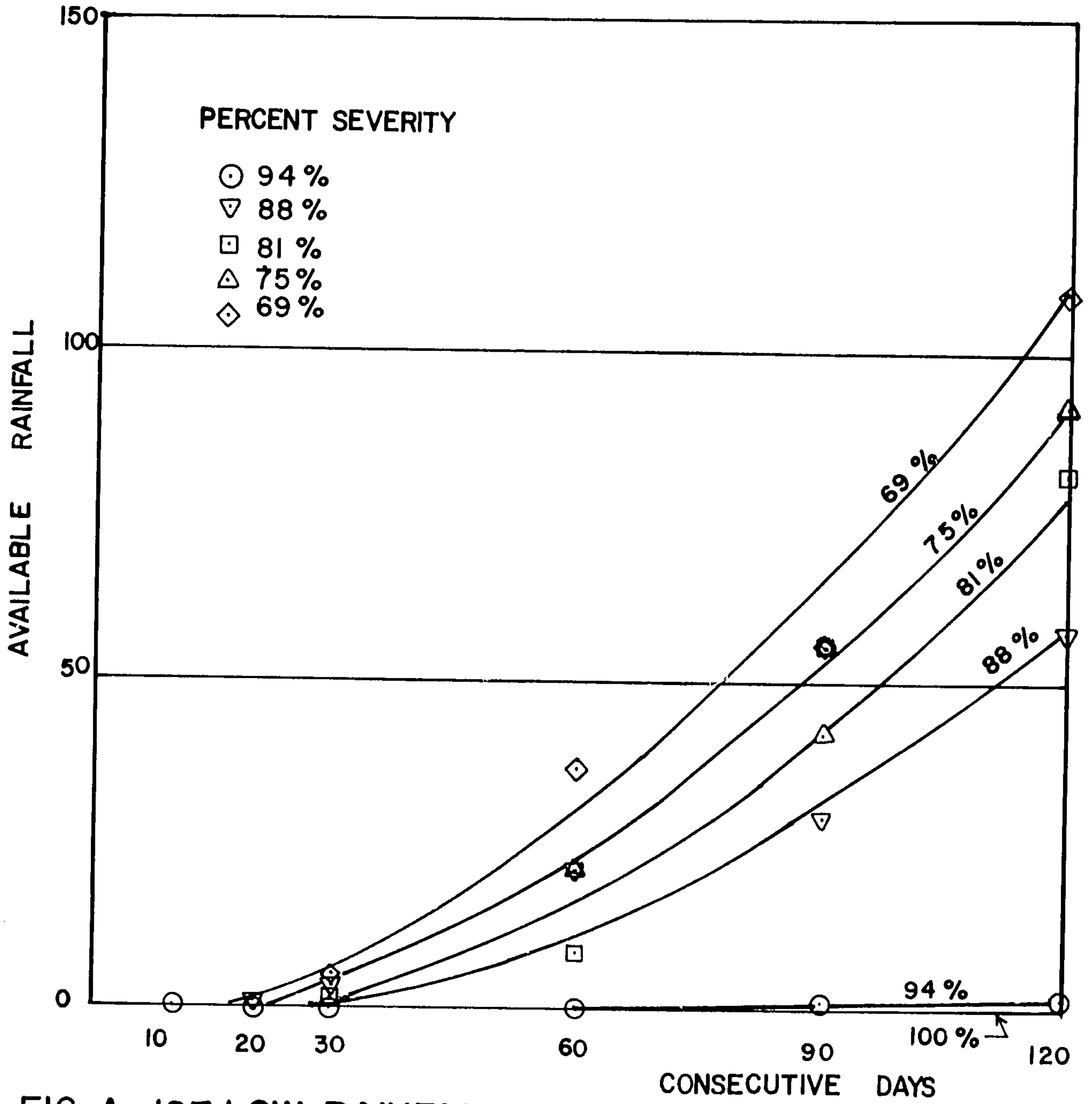


FIG. A-107 LOW RAINFALLS, YABO, PILI & NAGA – Drought Severity

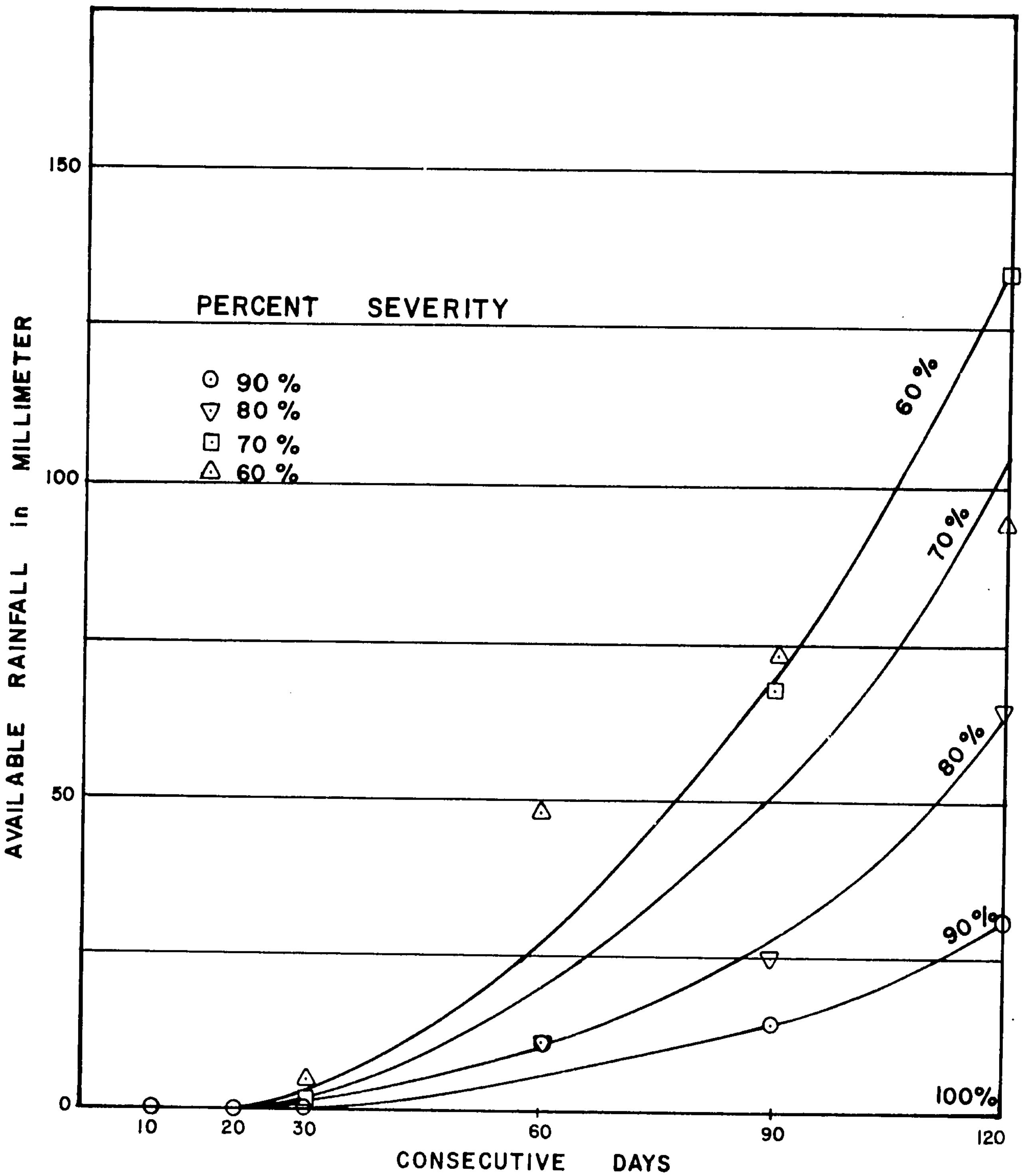


FIG. A-107a LOW RAINFALLS, BRCES, PILI – Drought Severity

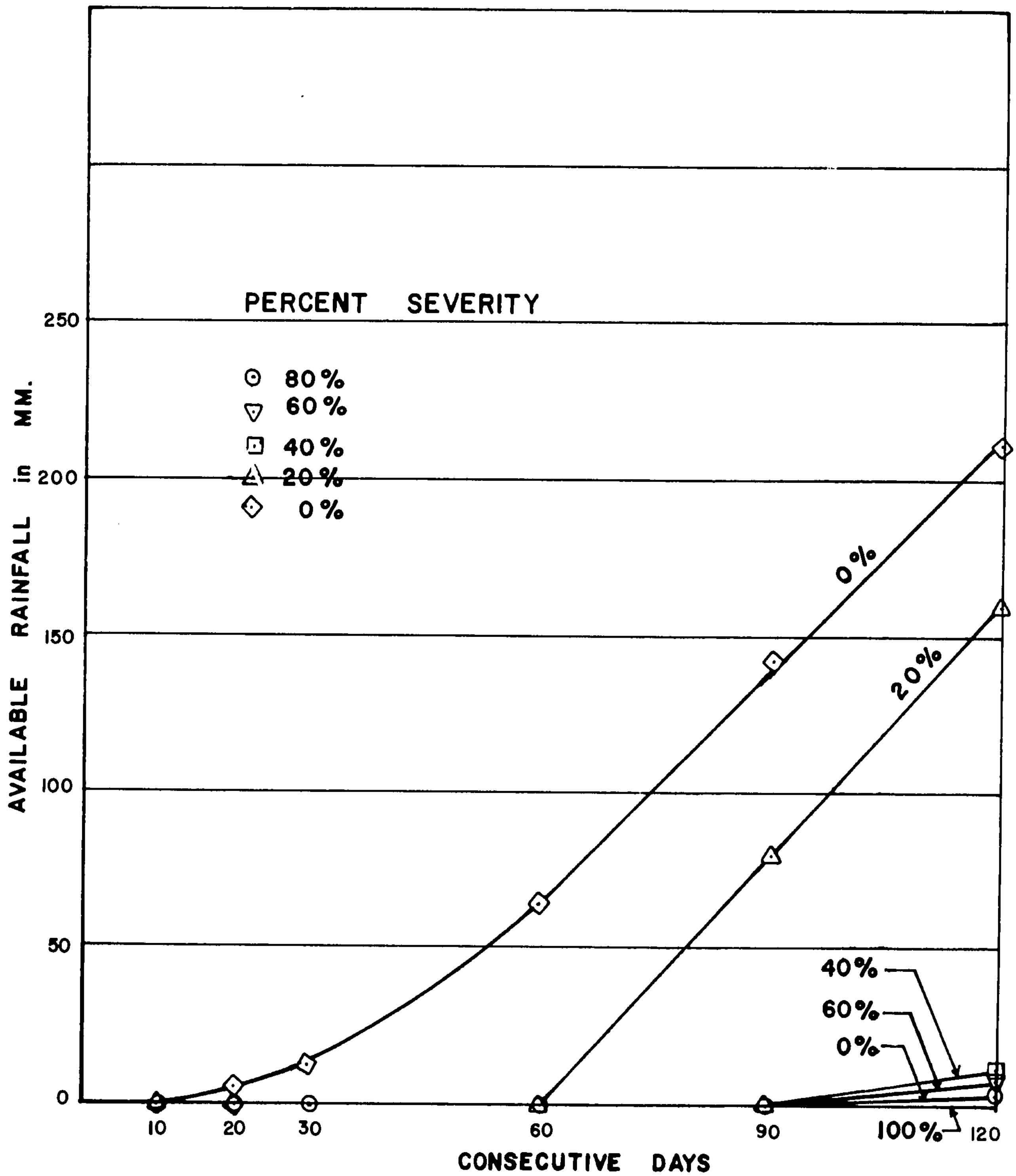


FIG. A-108 LOW RAINFALLS, INARIHAN IRRIG. SYSTEM CALABANGA – Drought Severity

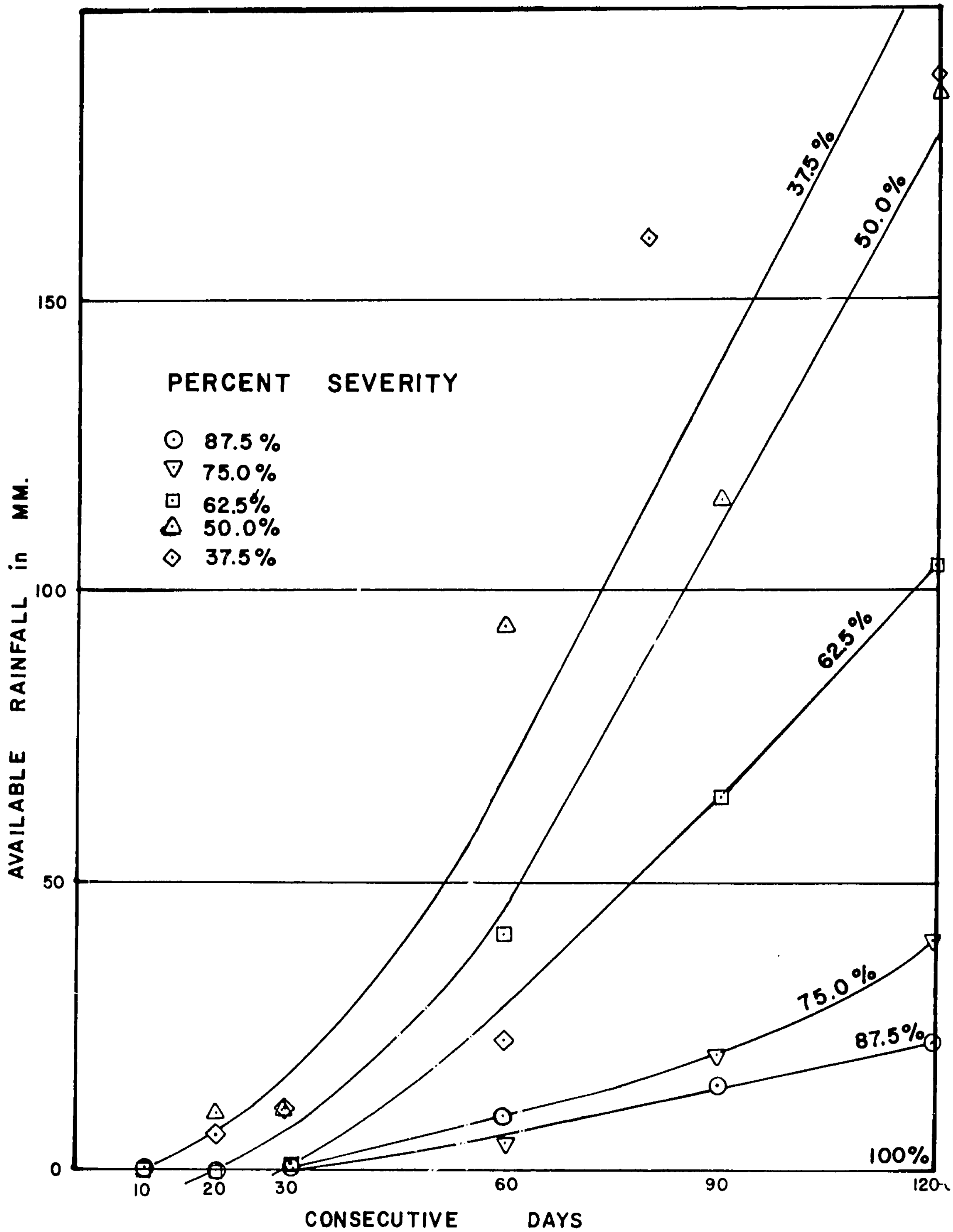


FIG. A-109 LOW RAINFALLS, SAN JOSE , BANASI, BUL A- Drought Severity

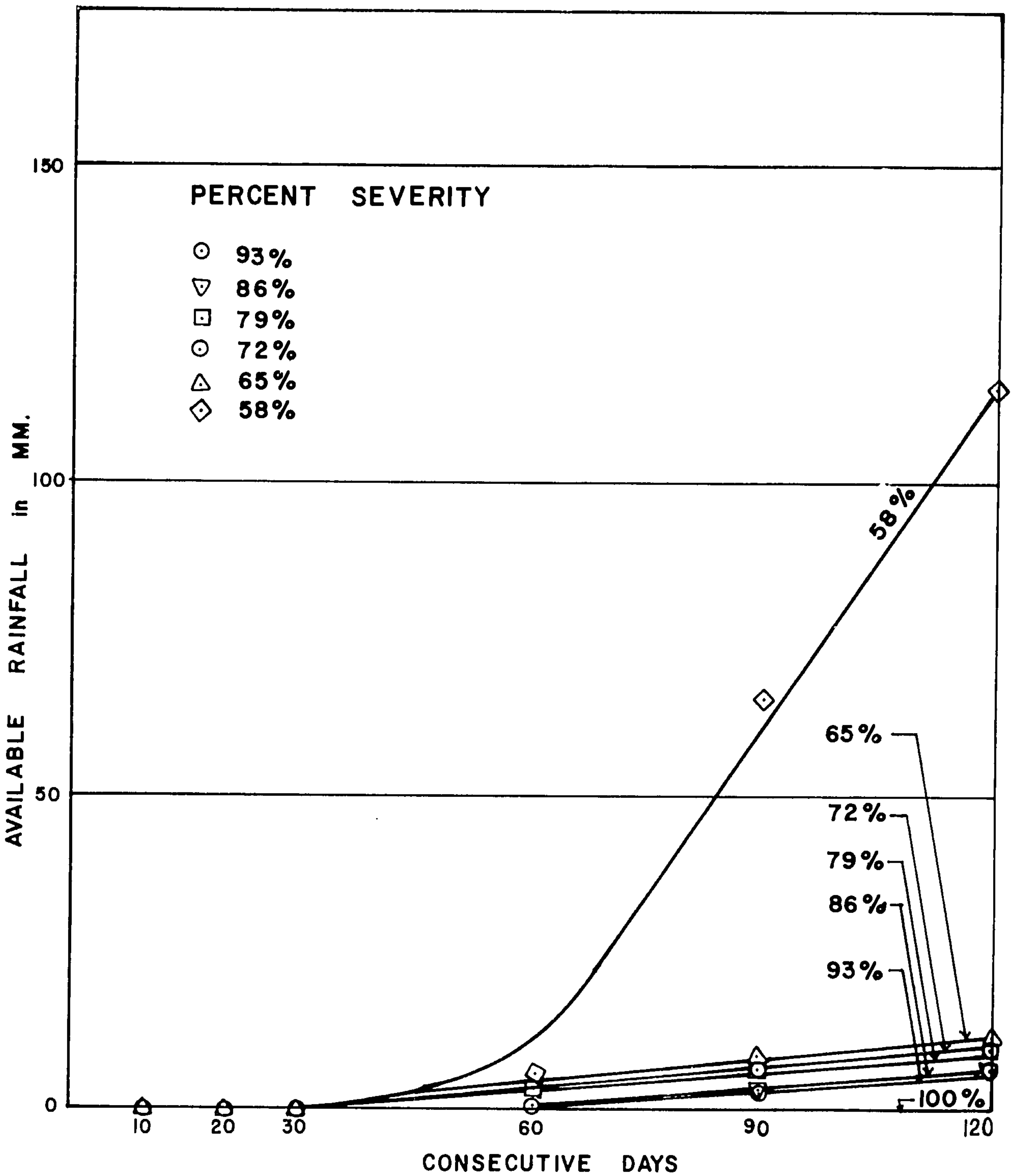


FIG. A-110 LOW RAINFALLS, BUHI — Drought Severity

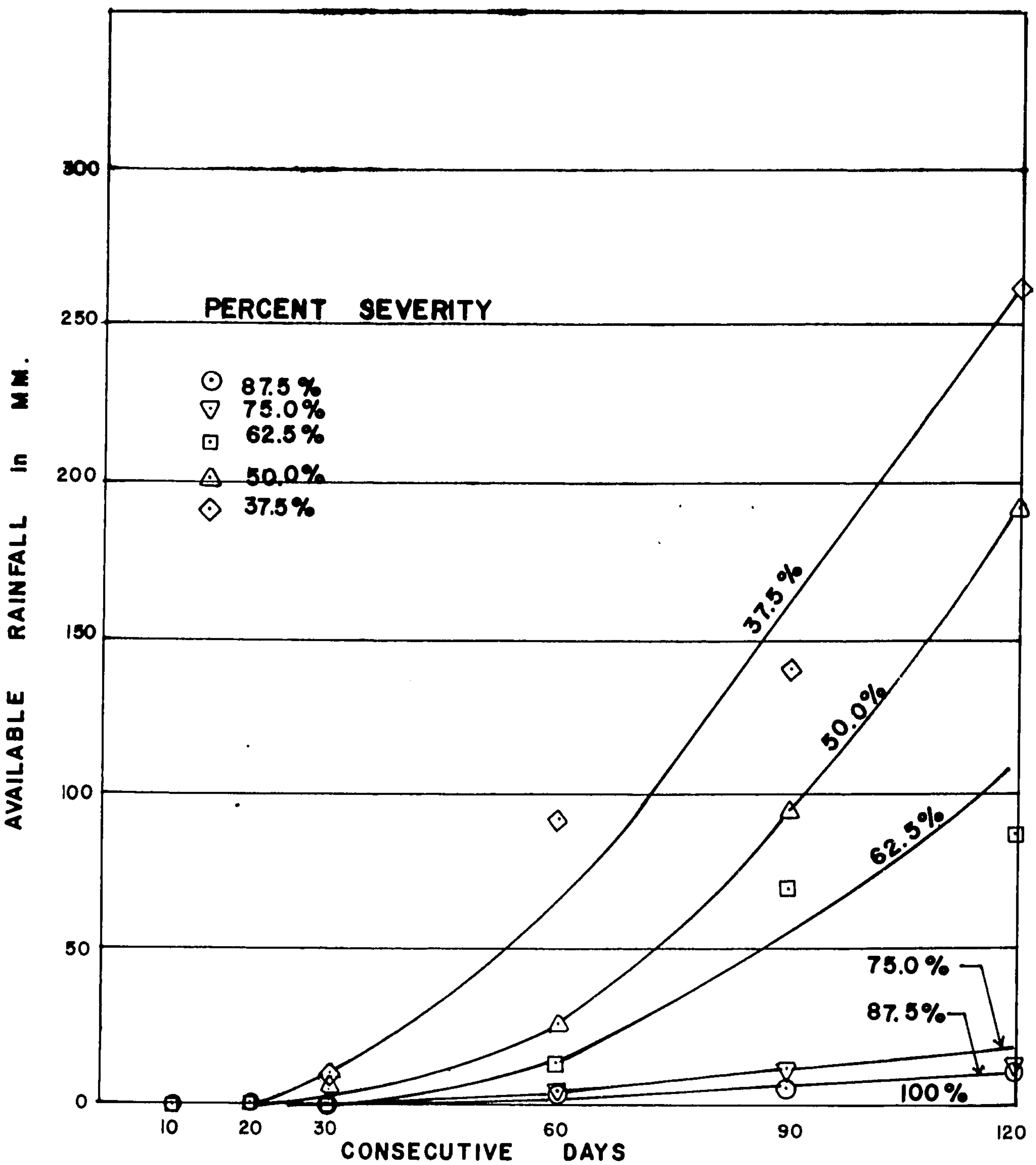
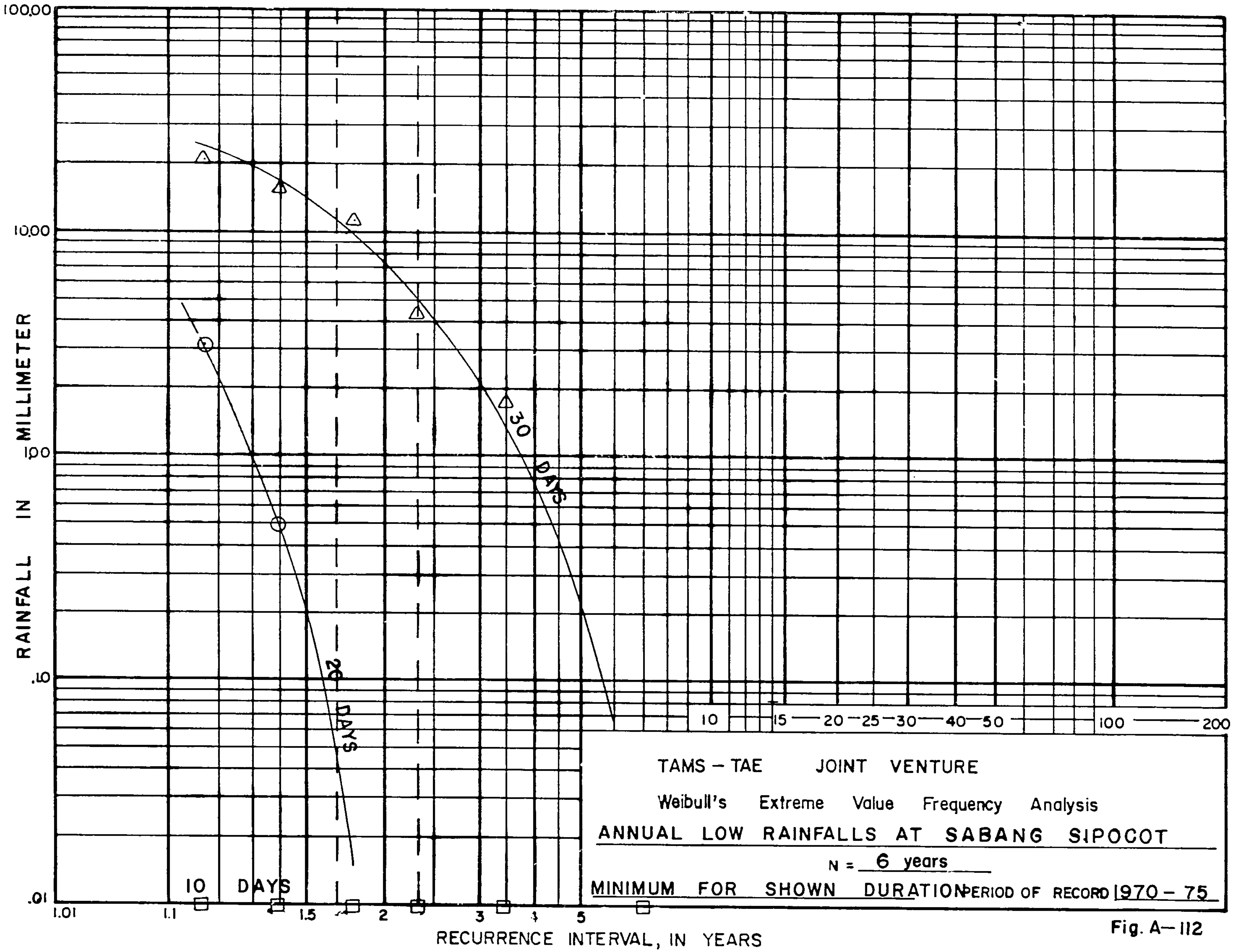


FIG. A-111 LOW RAINFALLS, GUINOBATAN – Drought Severity

112



TAMS – TAE JOINT VENTURE

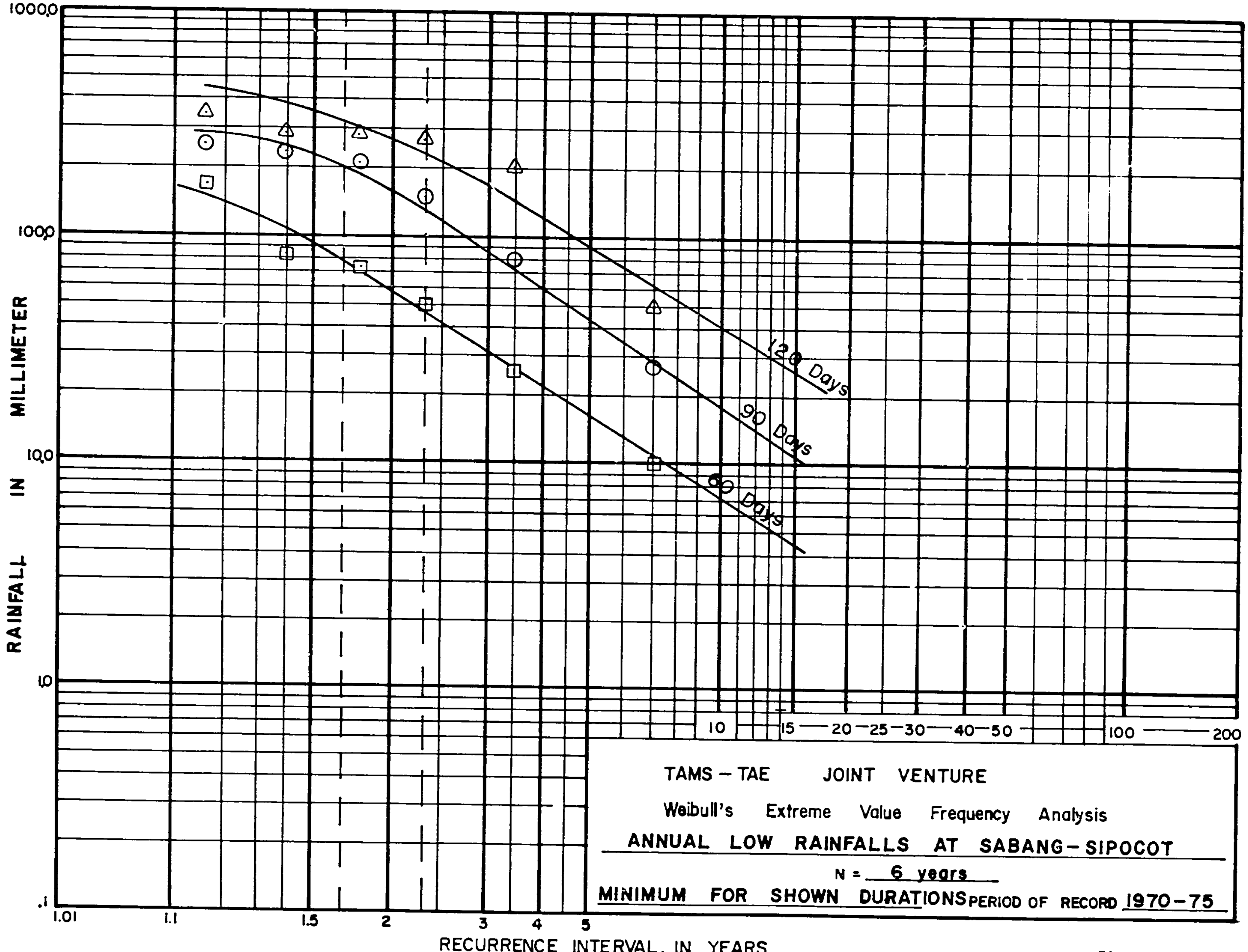
Weibull's Extreme Value Frequency Analysis

ANNUAL LOW RAINFALLS AT SABANG SIPOCOT

N = 6 years

MINIMUM FOR SHOWN DURATION PERIOD OF RECORD 1970 – 75

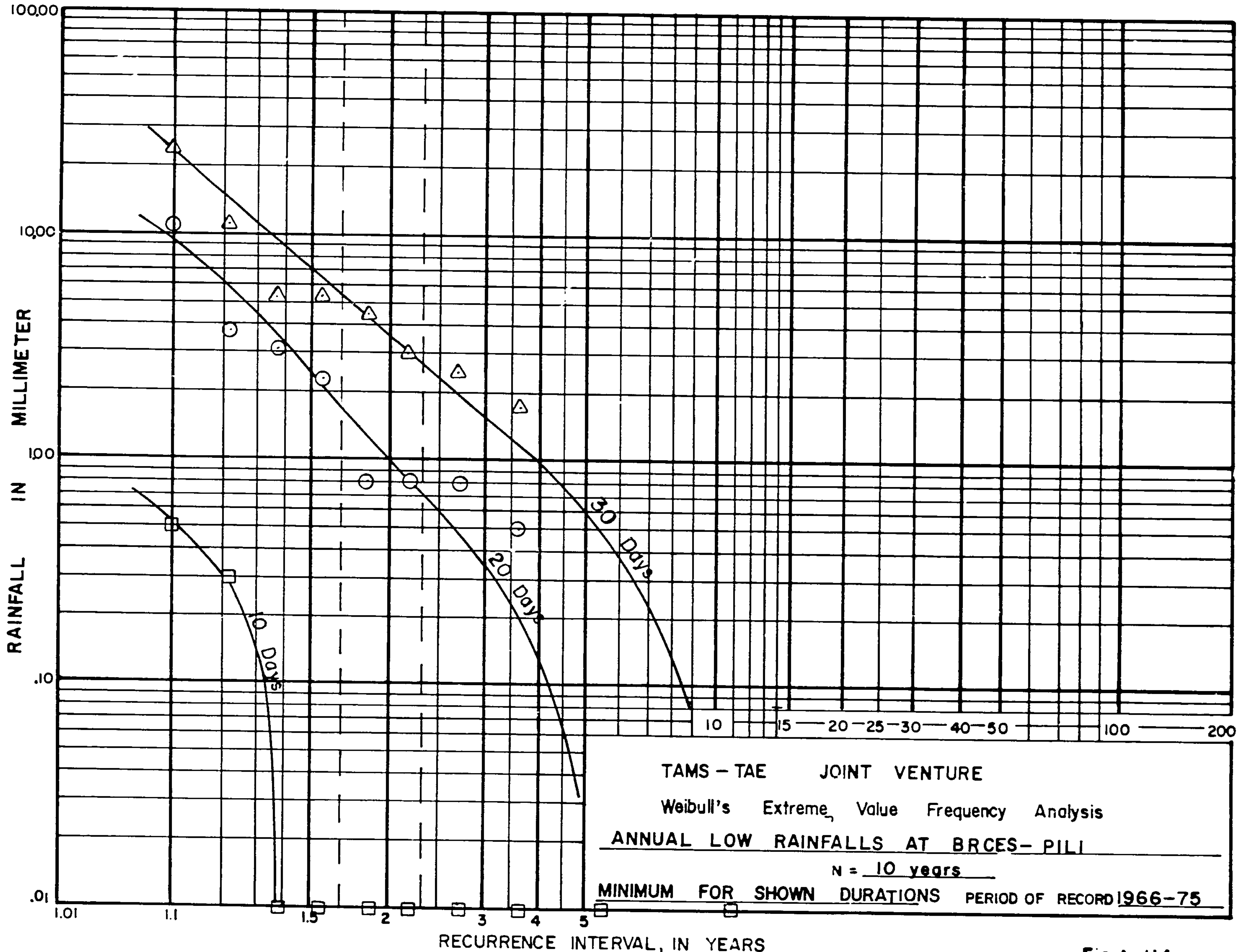
Fig. A–112


1000.0
100.0
10.0
1.0
.1
RAINFALL IN MILLIMETER
120 Days
90 Days
60 Days
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
ANNUAL LOW RAINFALLS AT SABANG – SIPOCOT
N = 6 years
MINIMUM FOR SHOWN DURATIONS PERIOD OF RECORD 1970-75

113

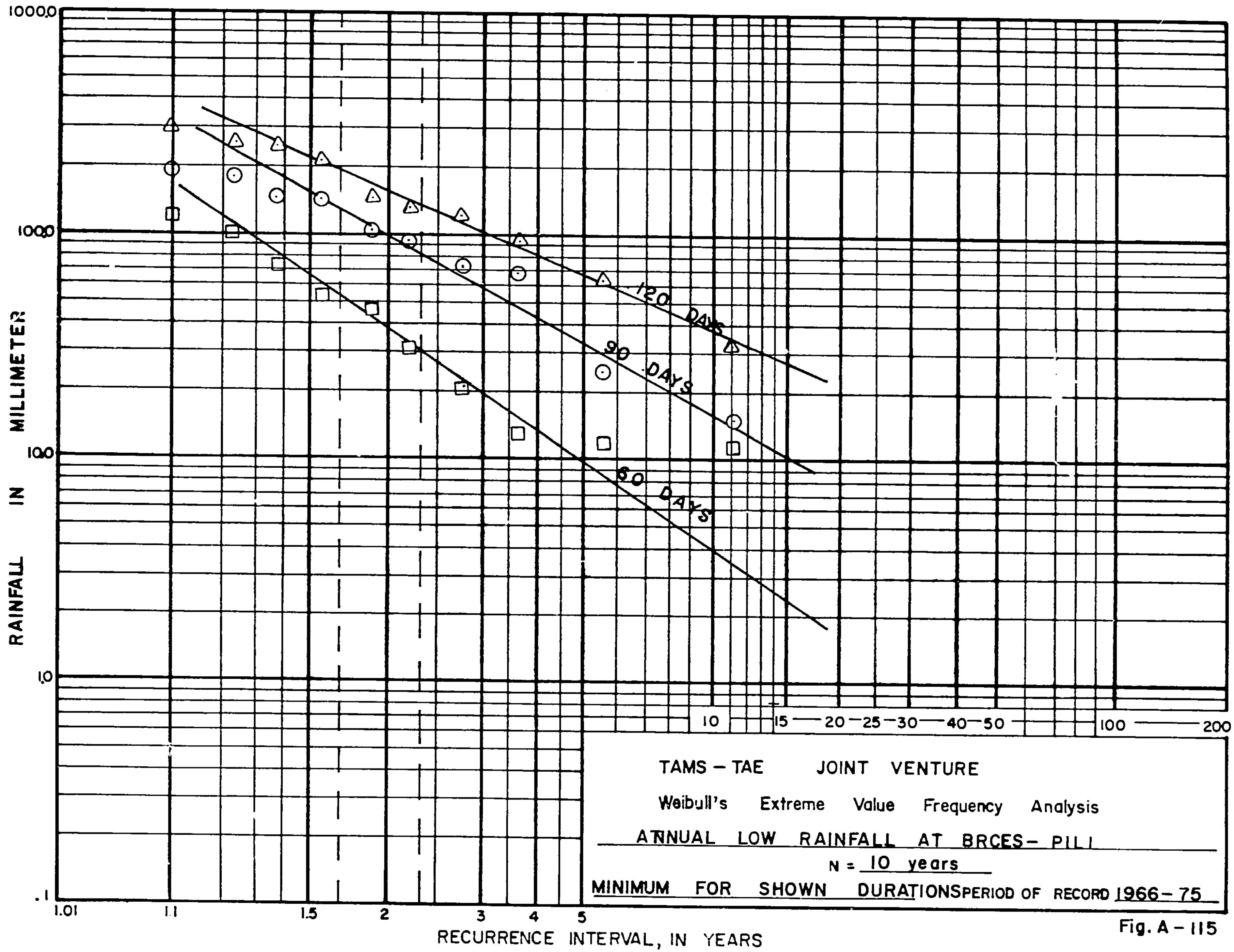
Fig. A–113

114



100.00
10.00
1.00
.10
.01
RAINFALL IN MILLIMETER
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
10 Days
20 Days
30 Days
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
ANNUAL LOW RAINFALLS AT BRCES– PILI
N = 10 years
MINIMUM FOR SHOWN DURATIONS PERIOD OF RECORD 1966-75

Fig. A-114

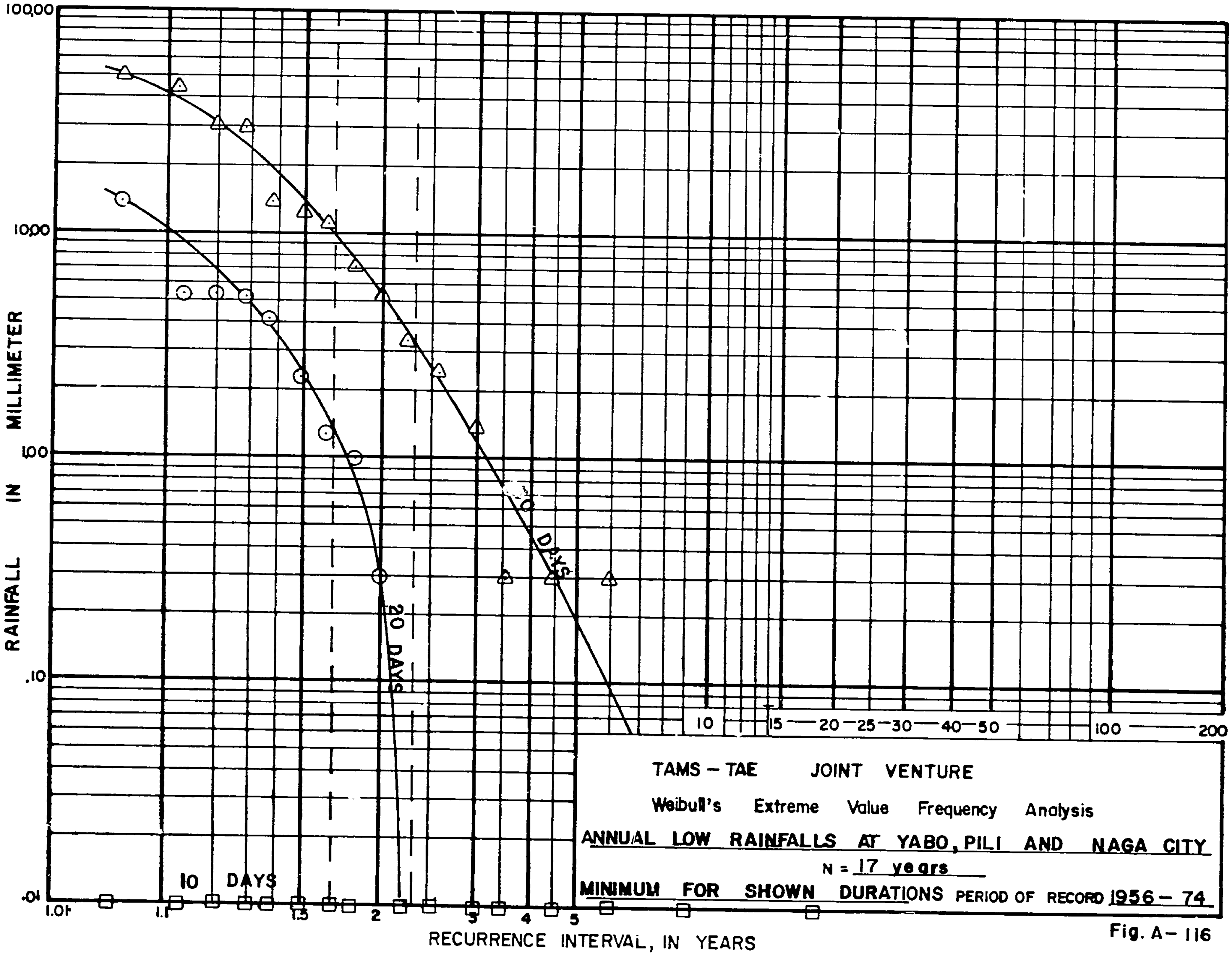


1000.0
100.0
10.0
1.0
.1
RAINFALL IN MILLIMETER
120 DAYS
90 DAYS
60 DAYS
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
ANNUAL LOW RAINFALL AT BRCES – PILI
N = 10 years
MINIMUM FOR SHOWN DURATIONS PERIOD OF RECORD 1966 – 75

Fig. A – 115

115

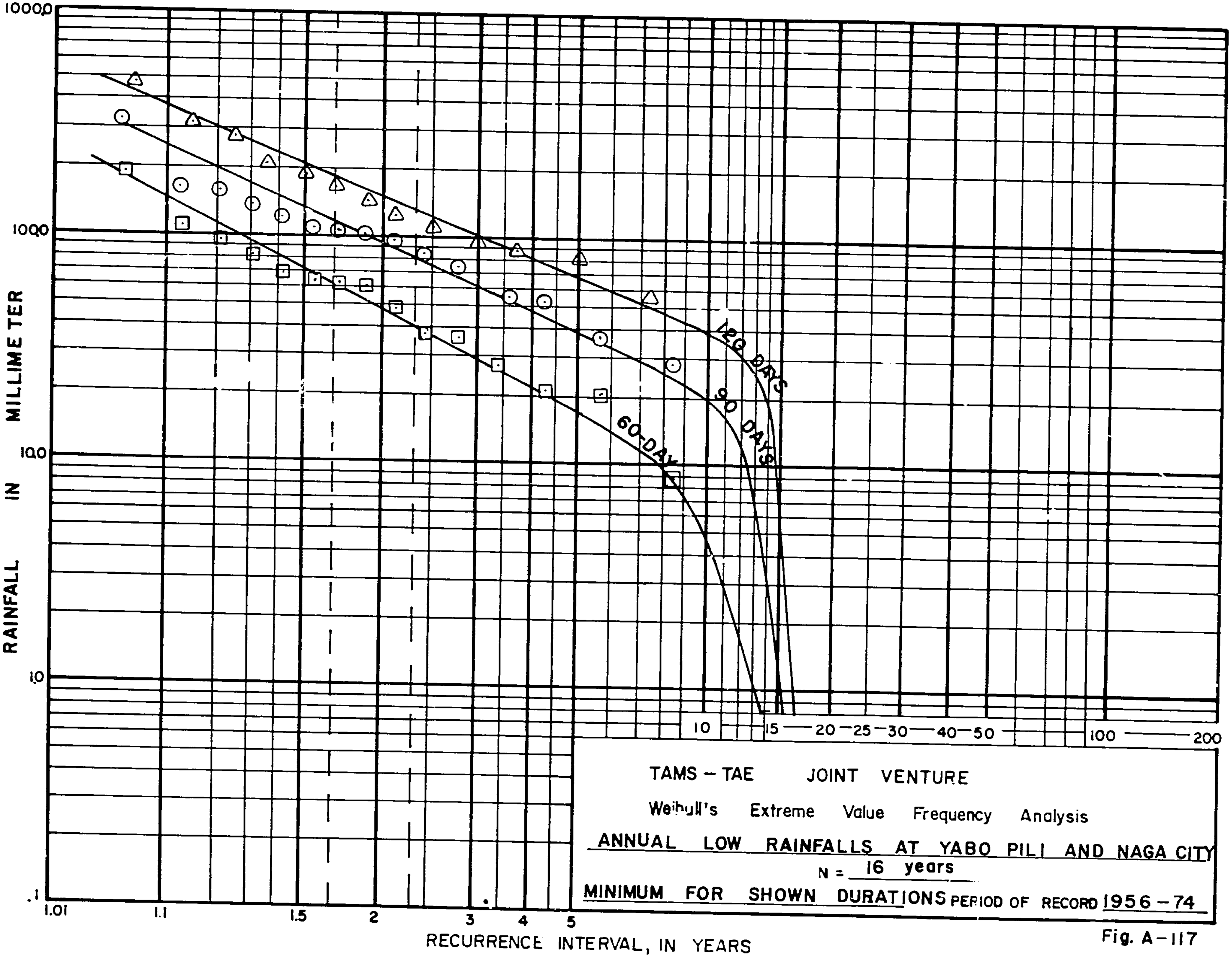
116



100,00
10,00
1,00
.10
.01
RAINFALL IN MILLIMETER
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
10 DAYS
20 DAYS
DAYS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
ANNUAL LOW RAINFALLS AT YABO, PILI AND NAGA CITY
N = 17 years
MINIMUM FOR SHOWN DURATIONS PERIOD OF RECORD 1956 – 74

Fig. A– 116

117



TAMS – TAE JOINT VENTURE

Weibull's Extreme Value Frequency Analysis

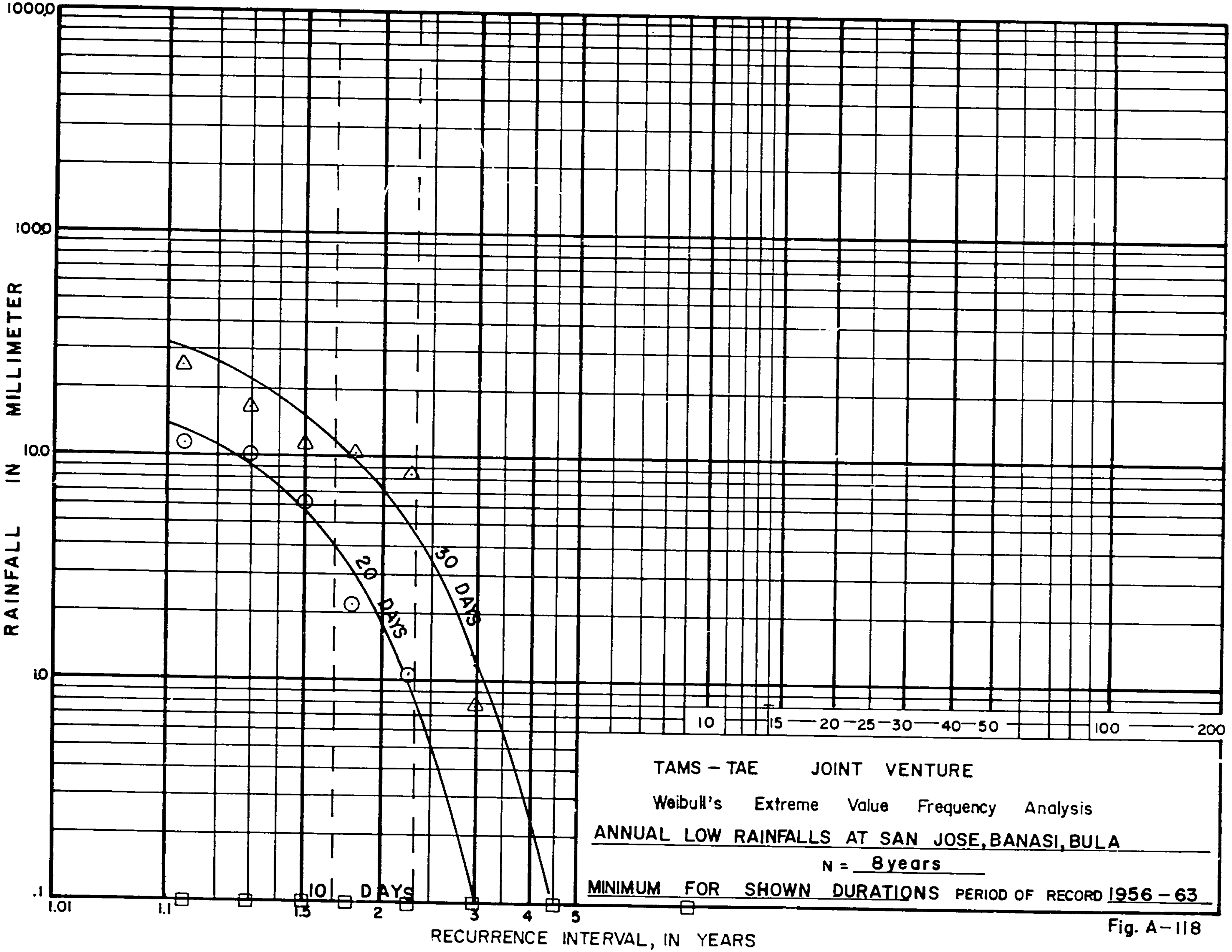
ANNUAL LOW RAINFALLS AT YABO PILI AND NAGA CITY

N = 16 years

MINIMUM FOR SHOWN DURATIONS PERIOD OF RECORD 1956 – 74

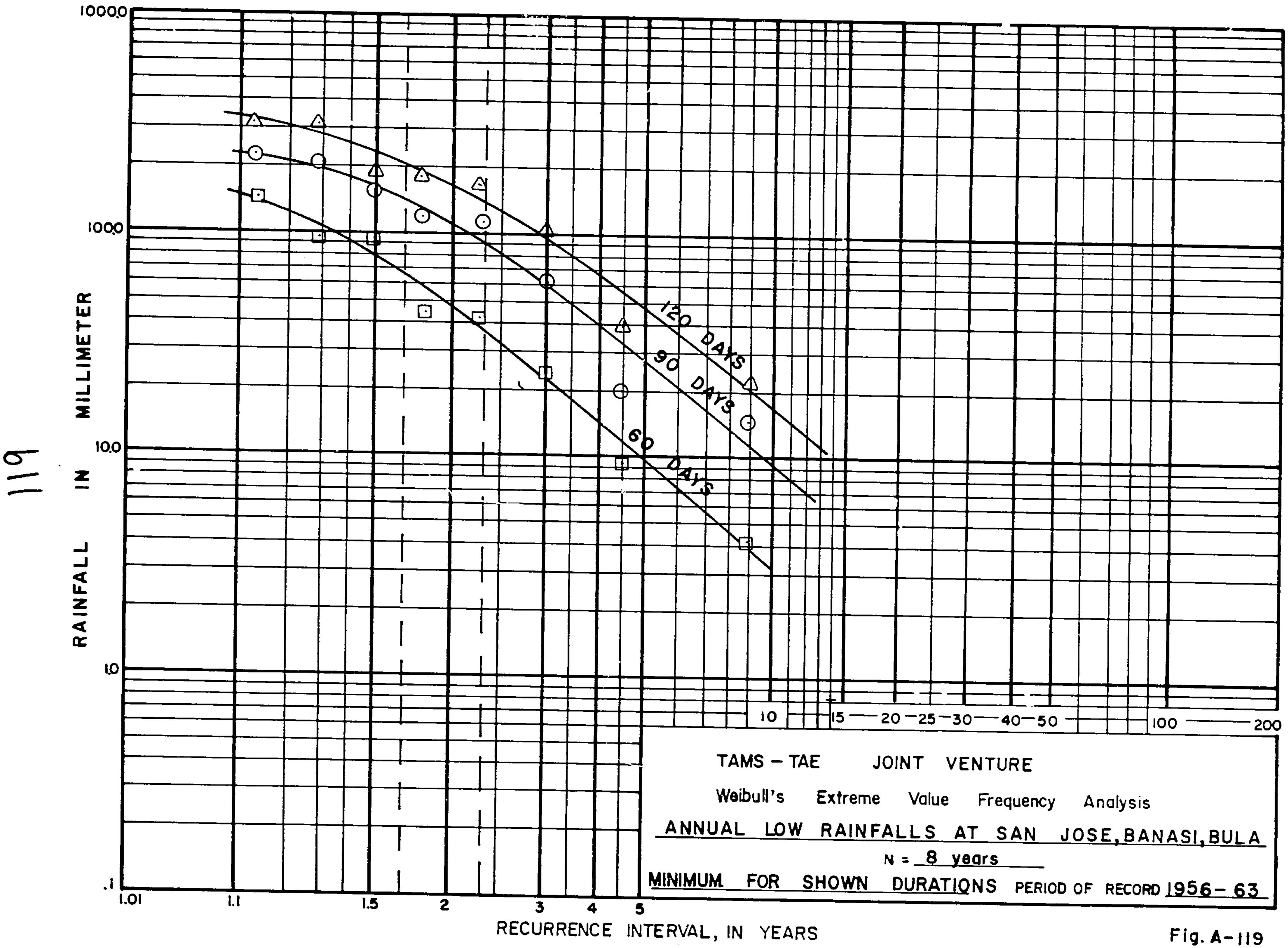
Fig. A-117

118



1000.0
100.0
10.0
1.0
.1
RAINFALL IN MILLIMETER
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
10 DAYS
20 DAYS
30 DAYS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
ANNUAL LOW RAINFALLS AT SAN JOSE, BANASI, BULA
N = 8years
MINIMUM FOR SHOWN DURATIONS PERIOD OF RECORD 1956 – 63

Fig. A–118



TAMS – TAE JOINT VENTURE

Weibull's Extreme Value Frequency Analysis

ANNUAL LOW RAINFALLS AT SAN JOSE, BANASI, BULA

N = 8 years

MINIMUM FOR SHOWN DURATIONS PERIOD OF RECORD 1956 – 63

Fig. A–119

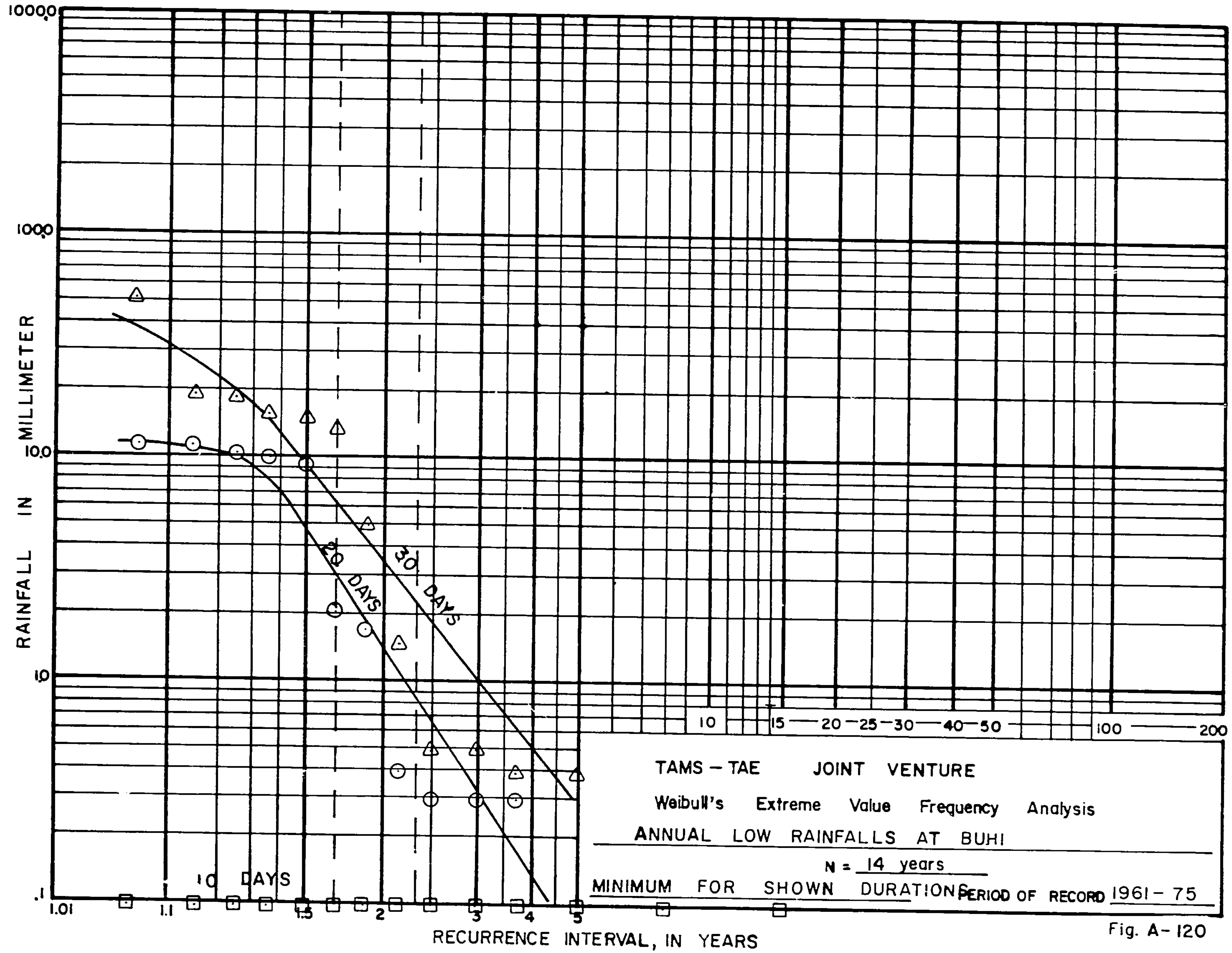
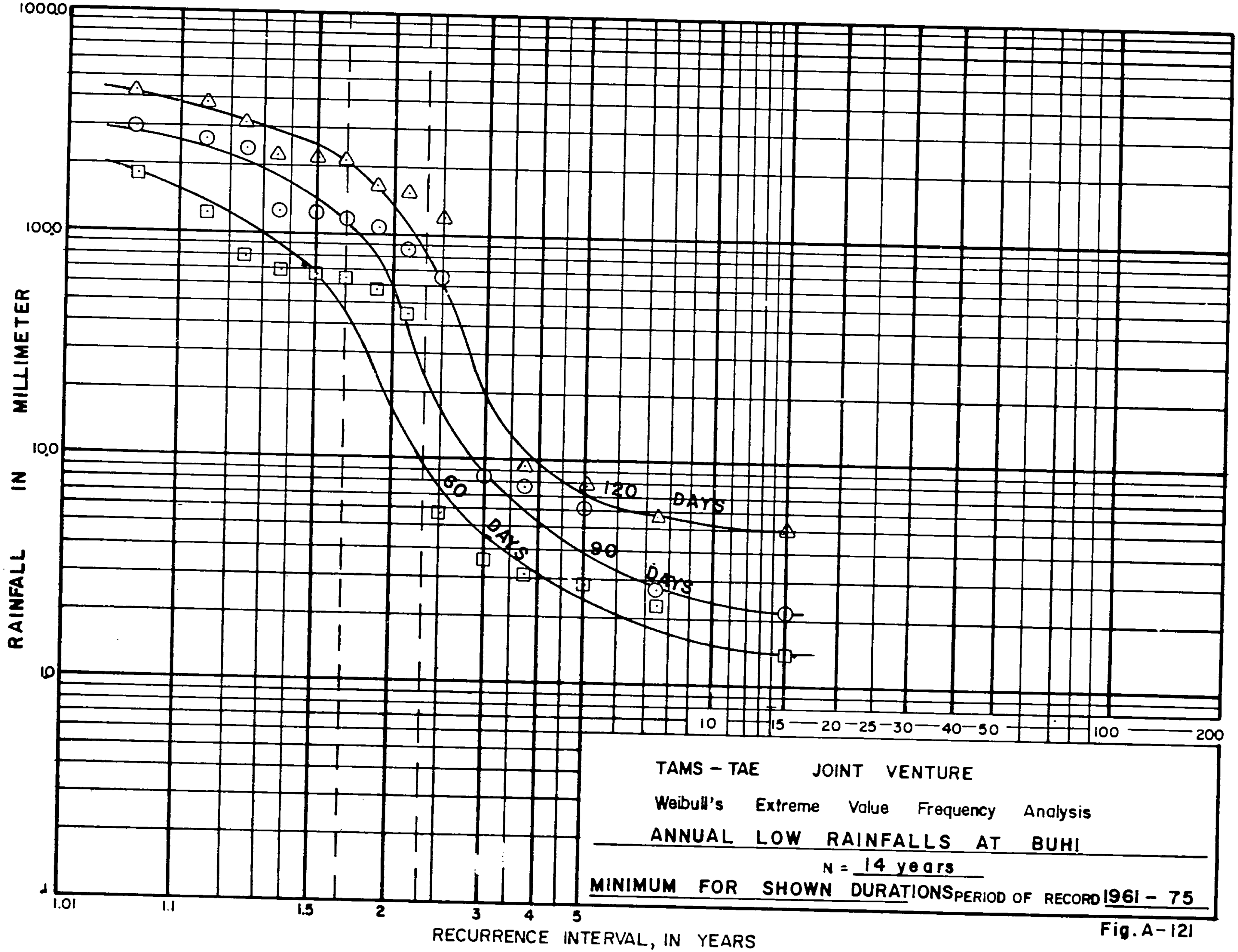

TAMS — TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
ANNUAL LOW RAINFALLS AT BUHI
N = 14 years
MINIMUM FOR SHOWN DURATIONS
PERIOD OF RECORD 1961 – 75
RAINFALL IN MILLIMETER
RECURRENCE INTERVAL, IN YEARS
10 DAYS
20 DAYS
30 DAYS
1000.0
100.0
10.0
1.0
.1
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200

Fig. A- 120

120

121



TAMS – TAE JOINT VENTURE

Weibull's Extreme Value Frequency Analysis

ANNUAL LOW RAINFALLS AT BUHI

N = 14 years

MINIMUM FOR SHOWN DURATIONS PERIOD OF RECORD 1961 – 75

Fig. A-121

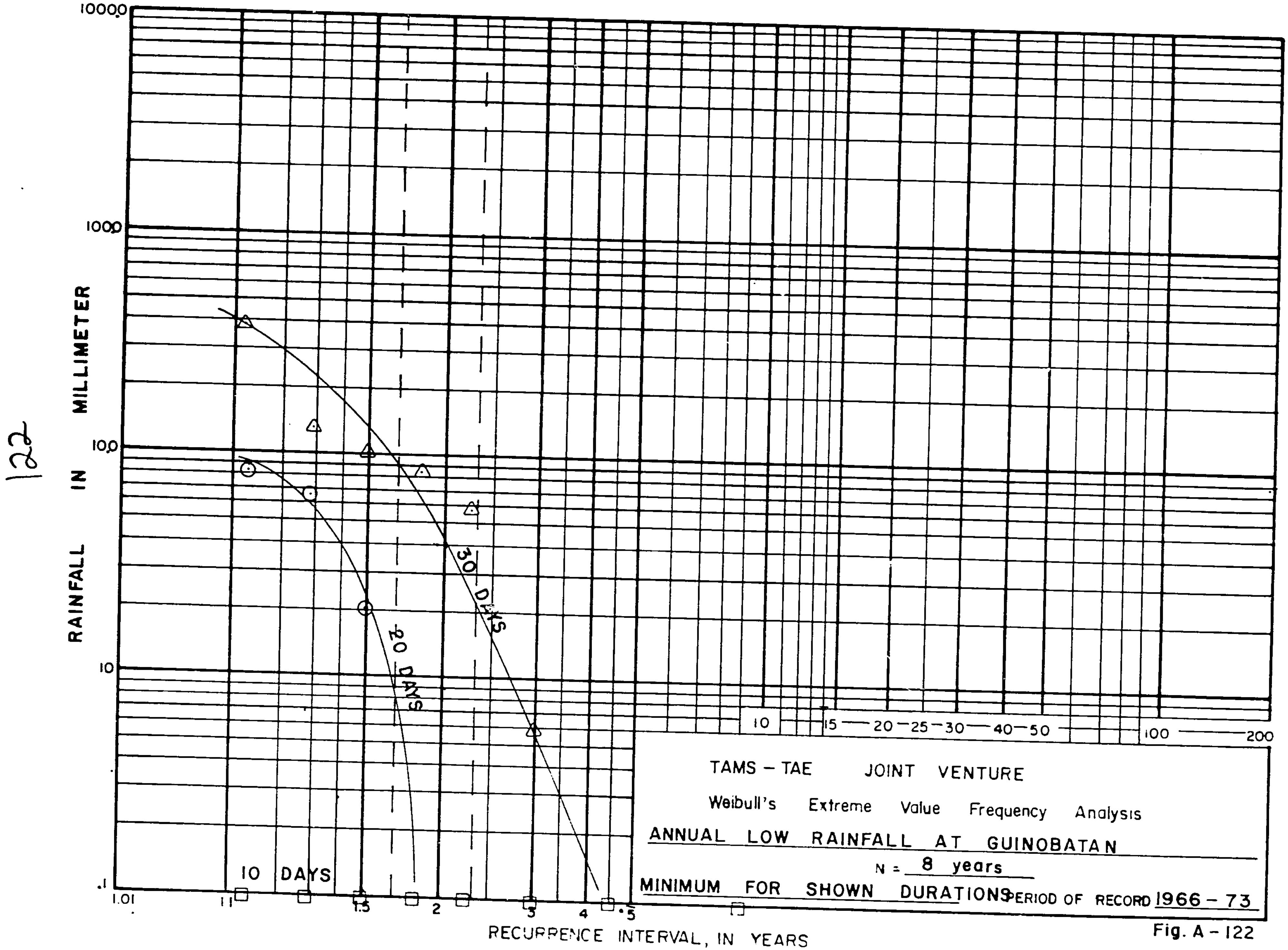
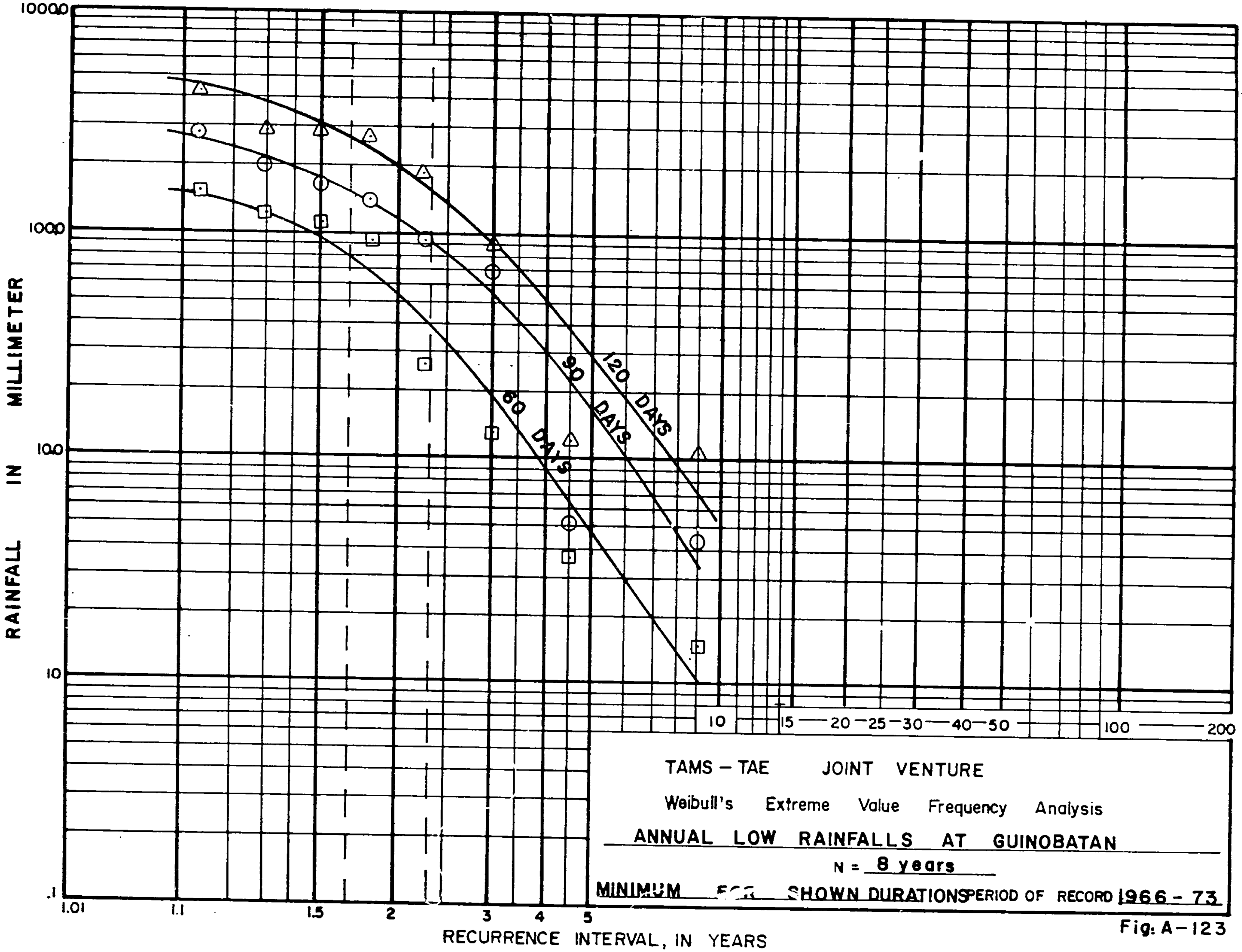

122
RAINFALL IN MILLIMETER
10000
1000
10.0
10
.1
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
10 DAYS
20 DAYS
30 DAYS
RECURRENCE INTERVAL, IN YEARS
TAMS - TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
ANNUAL LOW RAINFALL AT GUINOBATAN
N = 8 years
MINIMUM FOR SHOWN DURATIONS
PERIOD OF RECORD 1966 - 73

Fig. A - 122

123



RAINFALL IN MILLIMETER
10000
1000
100
10
1
.1
120 DAYS
90 DAYS
60 DAYS
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
ANNUAL LOW RAINFALLS AT GUINOBATAN
N = 8 years
MINIMUM FOR SHOWN DURATIONS
PERIOD OF RECORD 1966 - 73

Fig: A-123

124

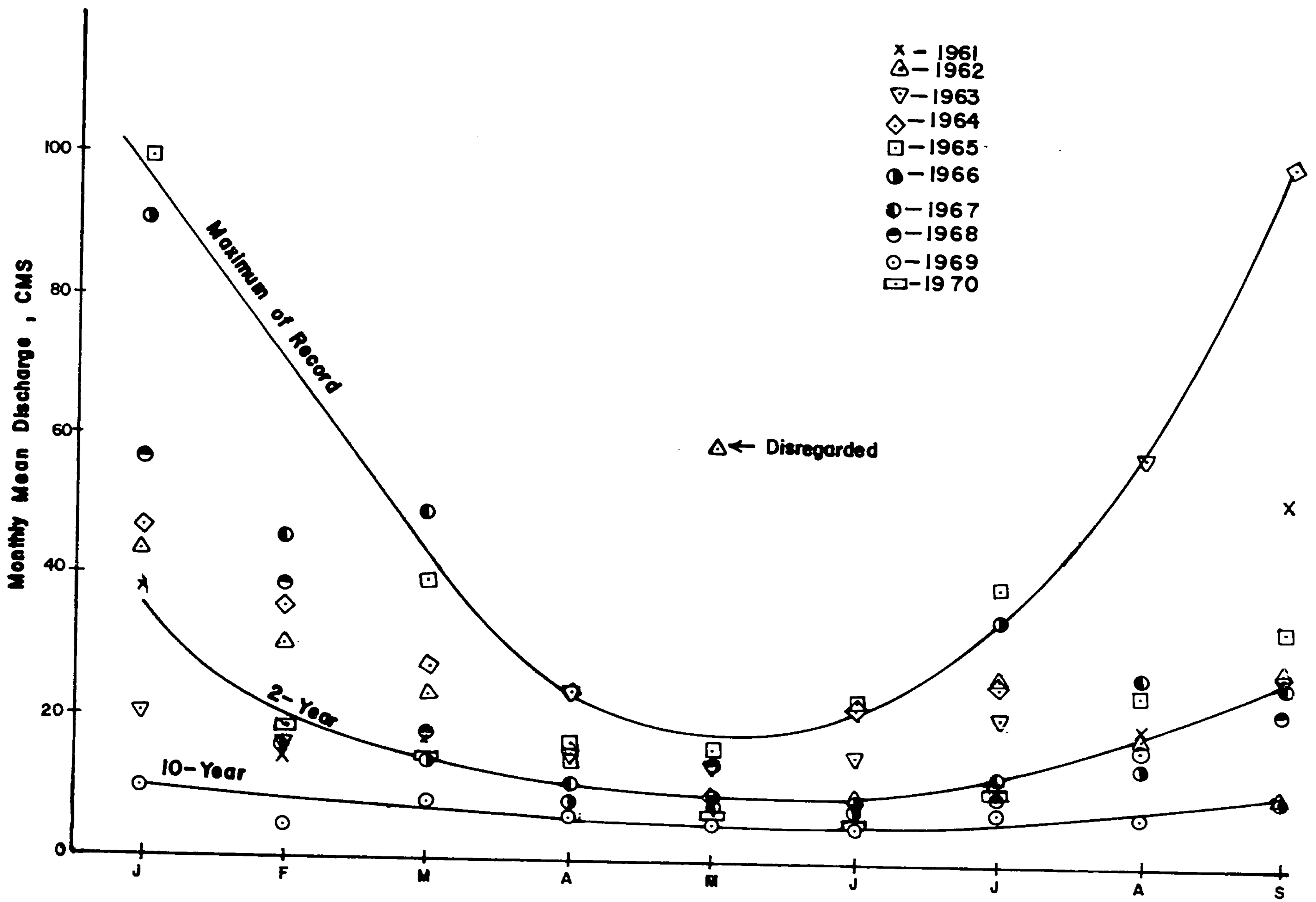


FIG. A-124 SIPOCOT RIVER, Sabang, Sipocot (Adjusted Flow Record)

125

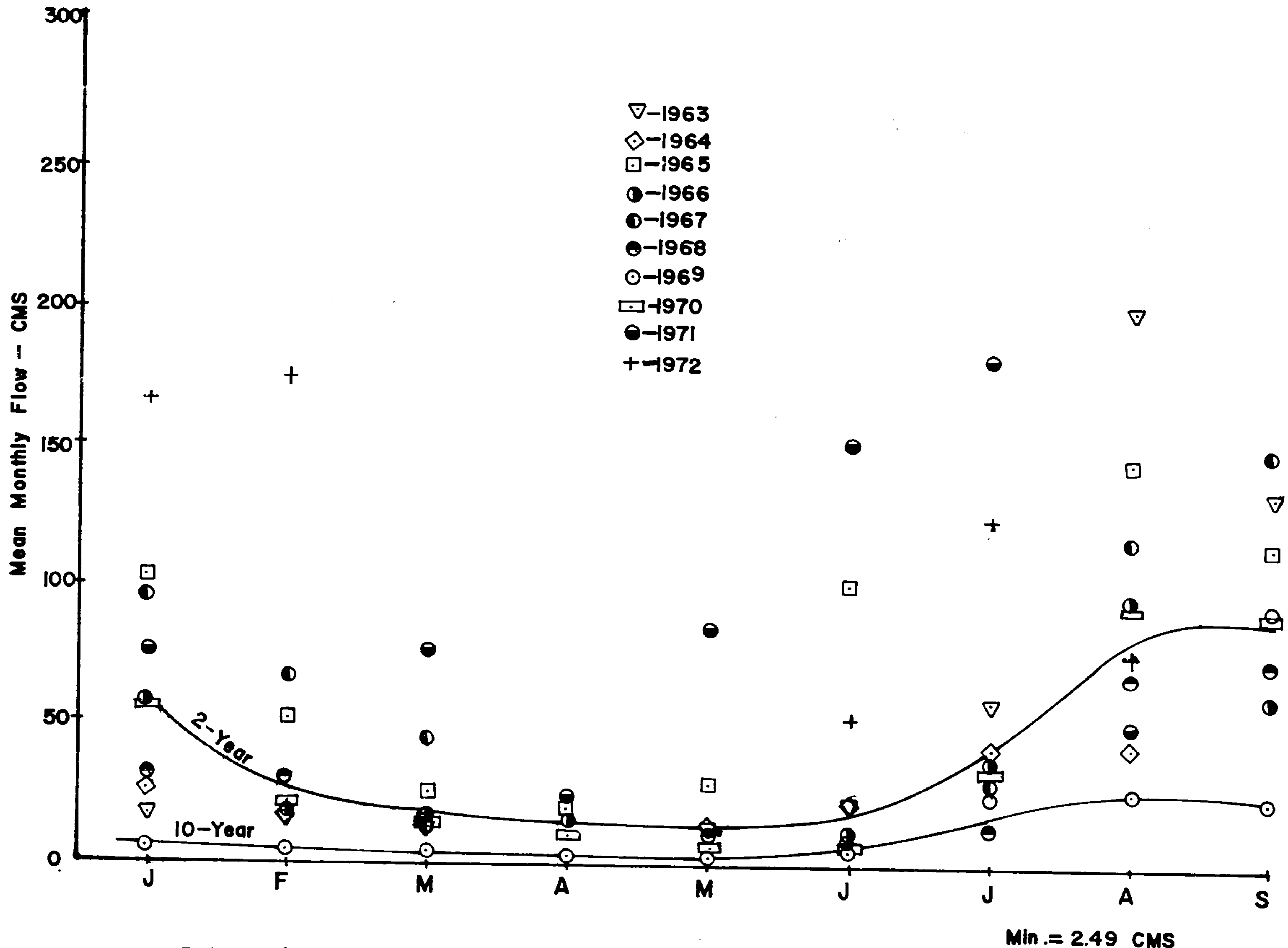
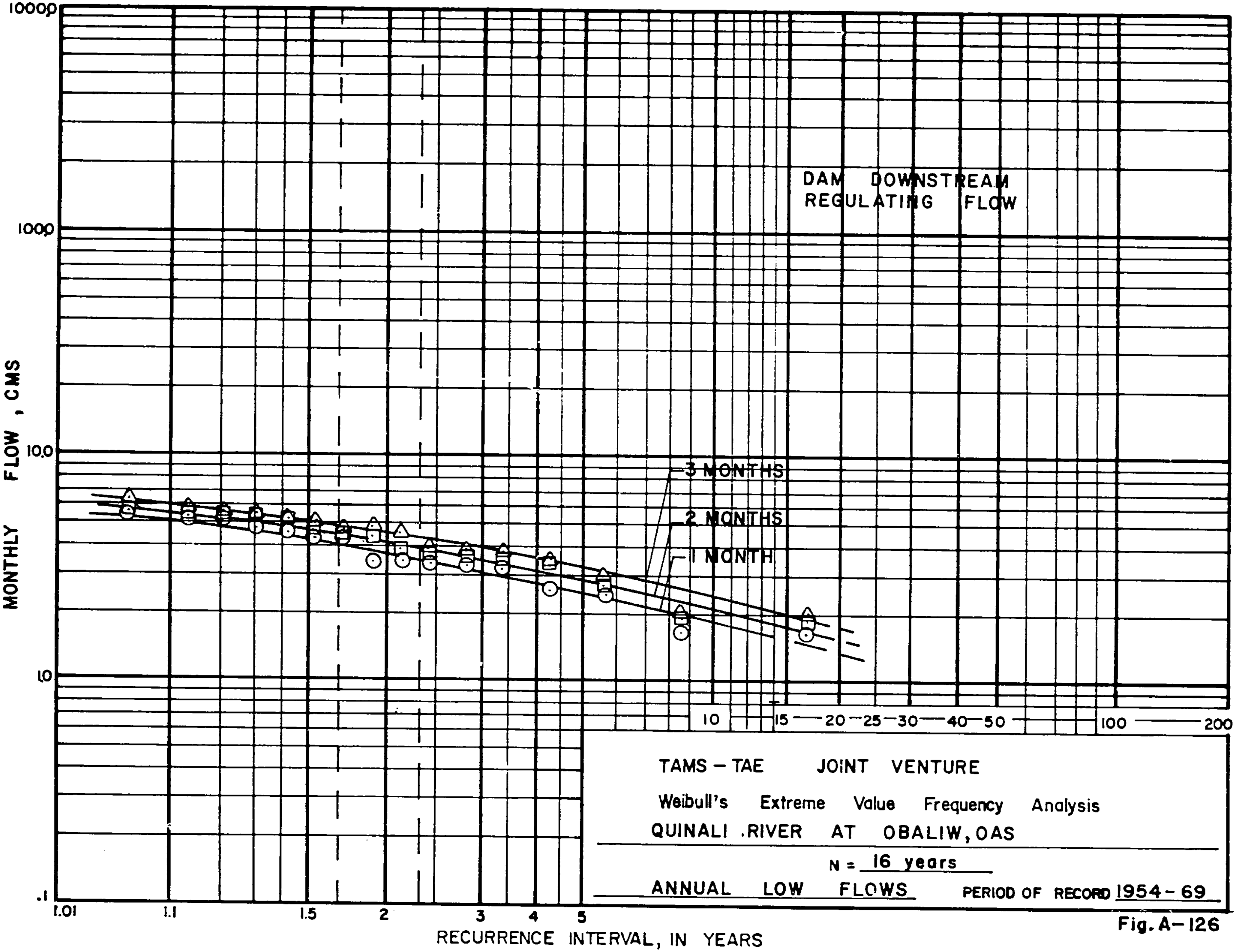


FIG. A-125 BICOL RIVER, Ombao, Bula (Synthetic Flow Record)

126



TAMS – TAE JOINT VENTURE

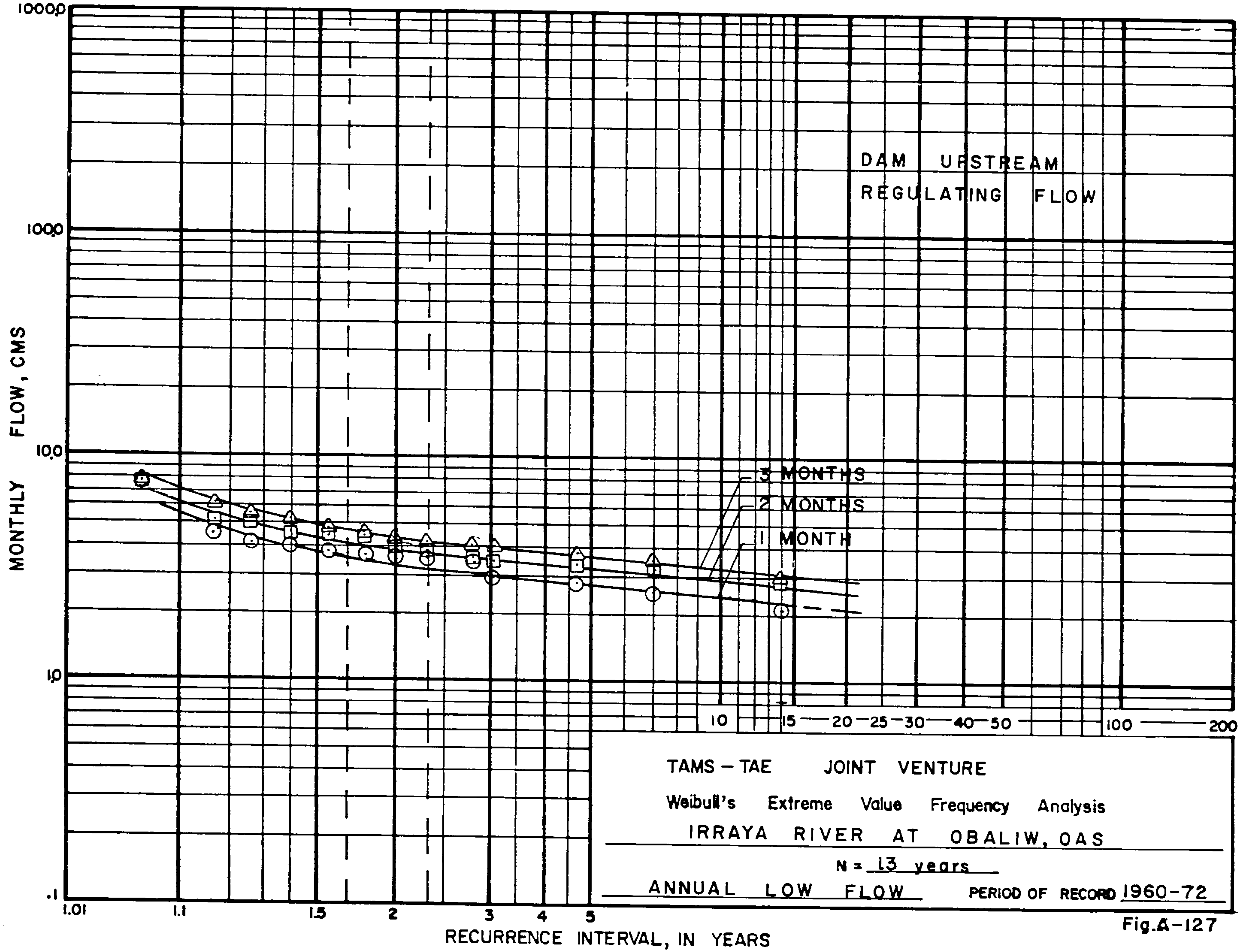
Weibull's Extreme Value Frequency Analysis

QUINALI RIVER AT OBALIW, OAS

N = 16 years

ANNUAL LOW FLOWS PERIOD OF RECORD 1954 - 69

Fig. A-126



TAMS – TAE JOINT VENTURE

Weibull's Extreme Value Frequency Analysis

IRRAYA RIVER AT OBALIW, OAS

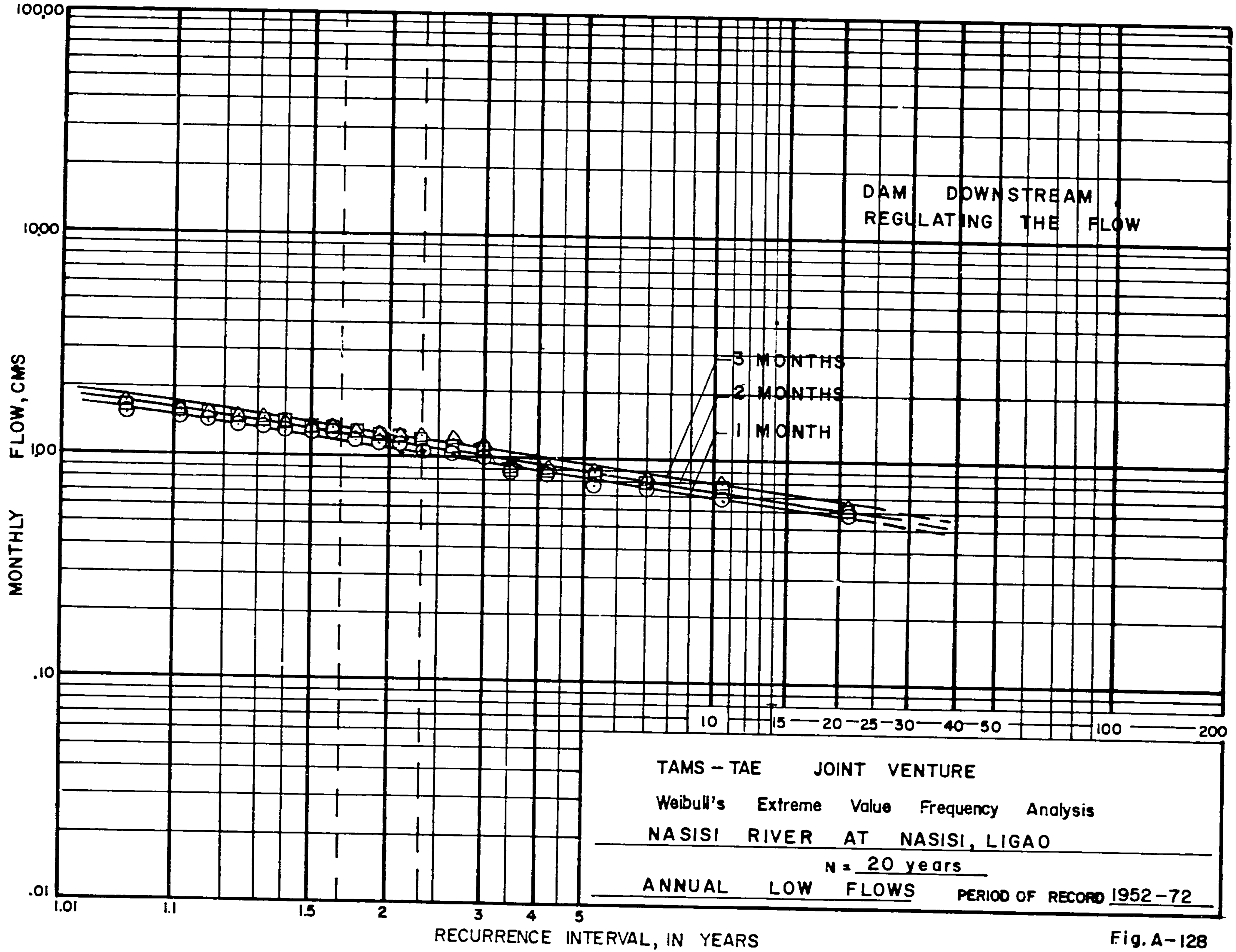
N = 13 years

ANNUAL LOW FLOW PERIOD OF RECORD 1960-72

Fig.A-127

121

128



TAMS – TAE JOINT VENTURE

Weibull's Extreme Value Frequency Analysis

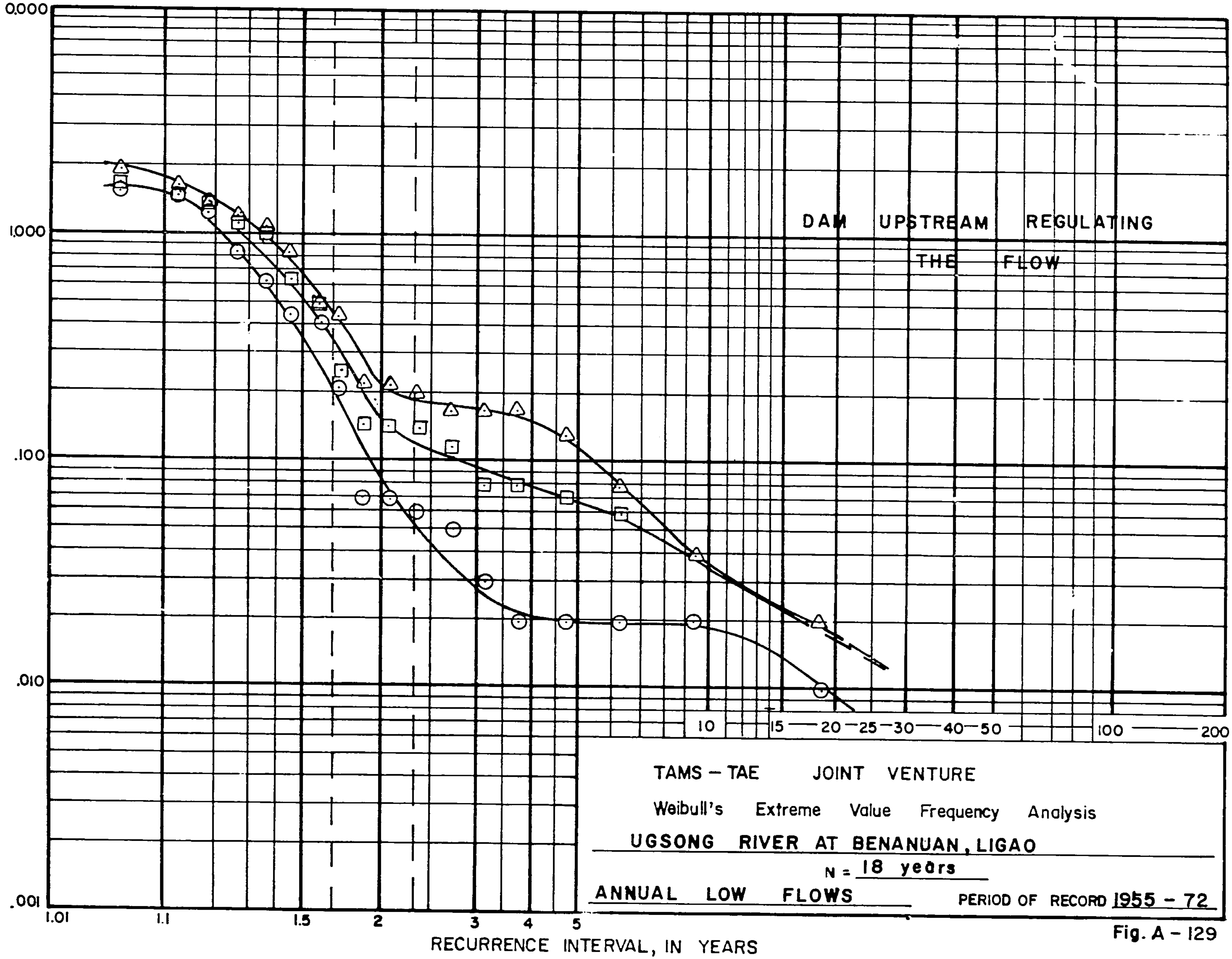
NASISI RIVER AT NASISI, LIGAO

N = 20 years

ANNUAL LOW FLOWS PERIOD OF RECORD 1952–72

Fig. A-128

129



0,000
1,000
.100
.010
.001
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
DAM UPSTREAM REGULATING THE FLOW
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
UGSONG RIVER AT BENANUAN, LIGAO
N = 18 years
ANNUAL LOW FLOWS
PERIOD OF RECORD 1955 – 72

Fig. A – 129

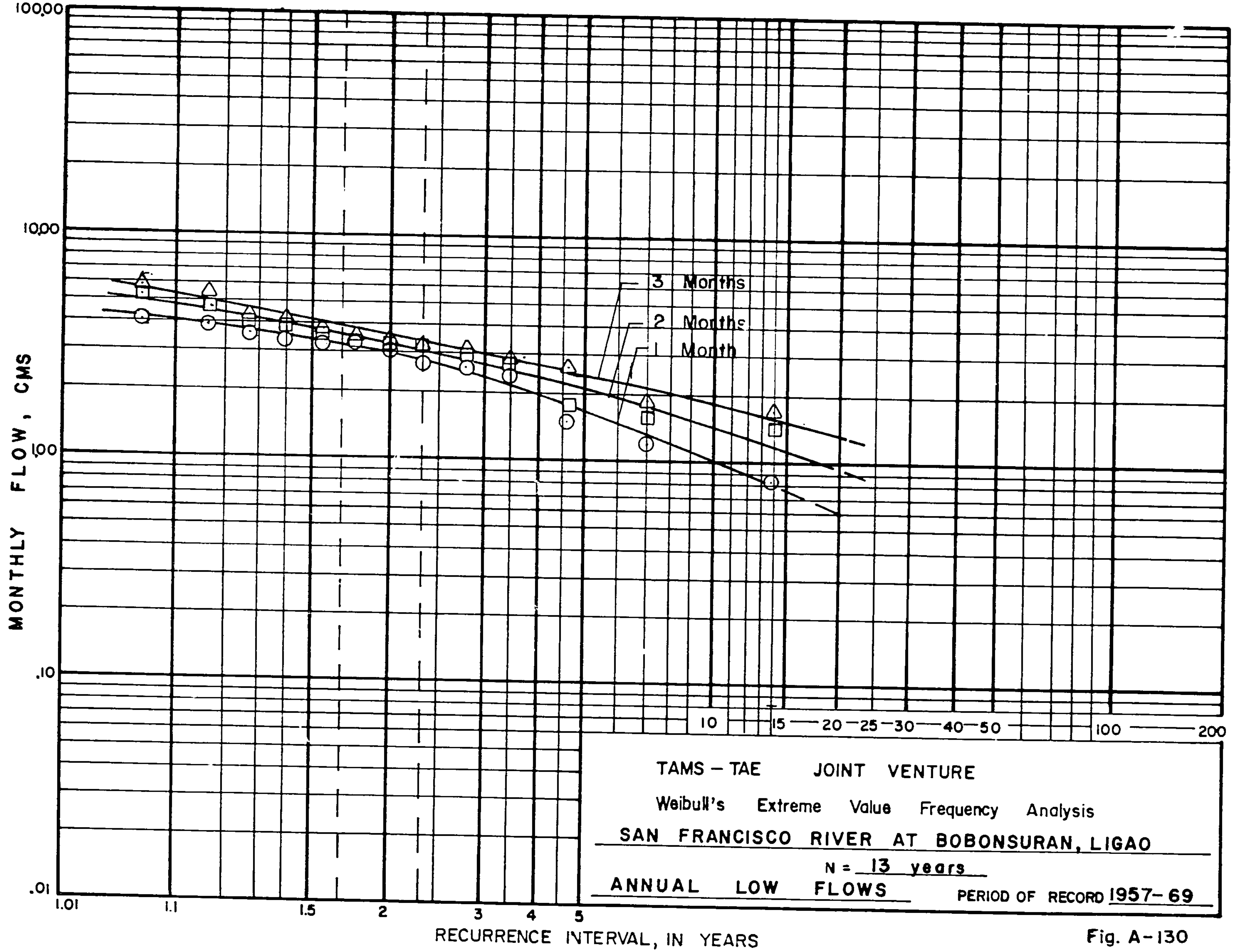
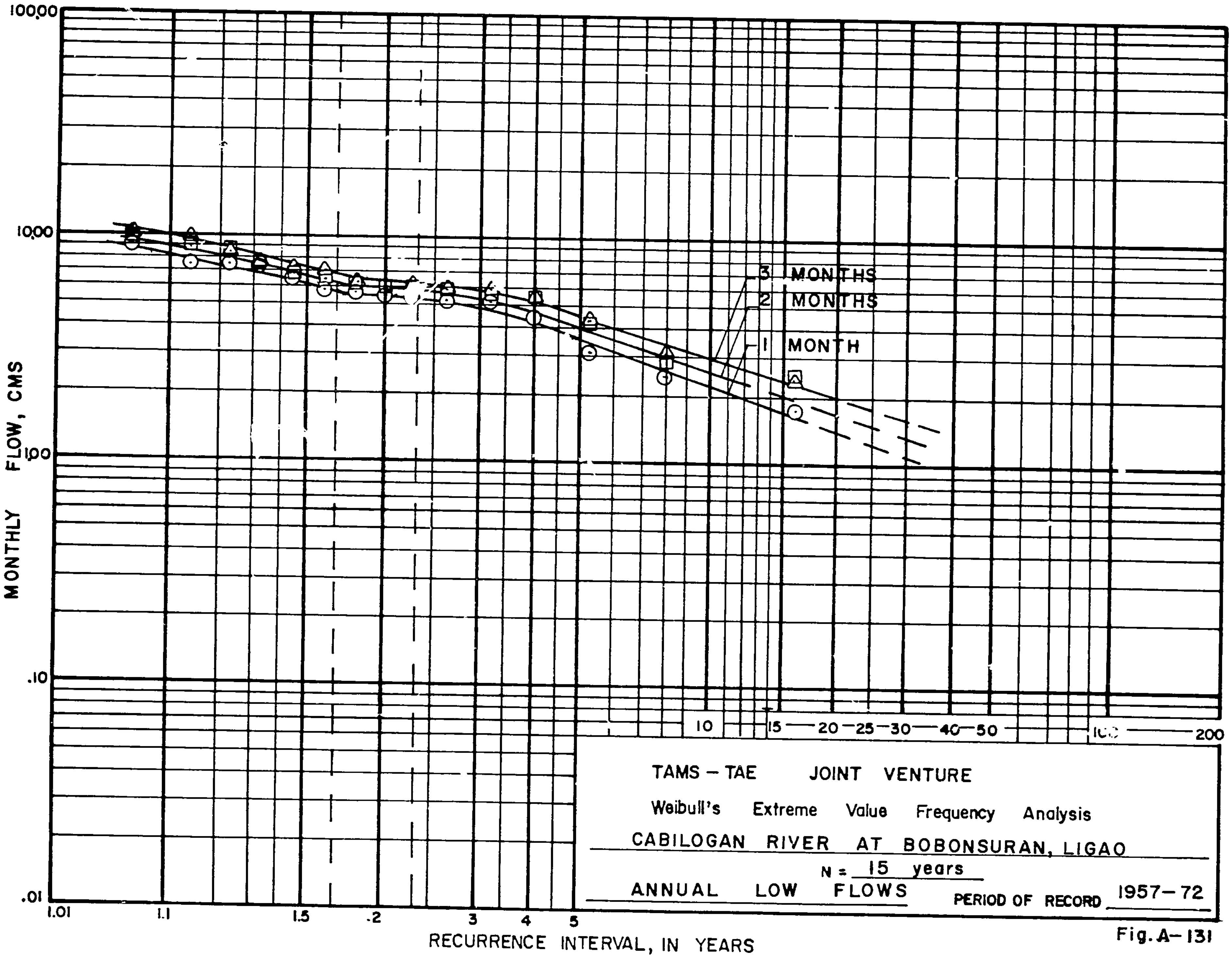

100.00
10.00
1.00
.10
.01
MONTHLY FLOW, CMS
3 Months
2 Months
1 Month
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
SAN FRANCISCO RIVER AT BOBONSURAN, LIGAO
N = 13 years
ANNUAL LOW FLOWS
PERIOD OF RECORD 1957-69

Fig. A-130

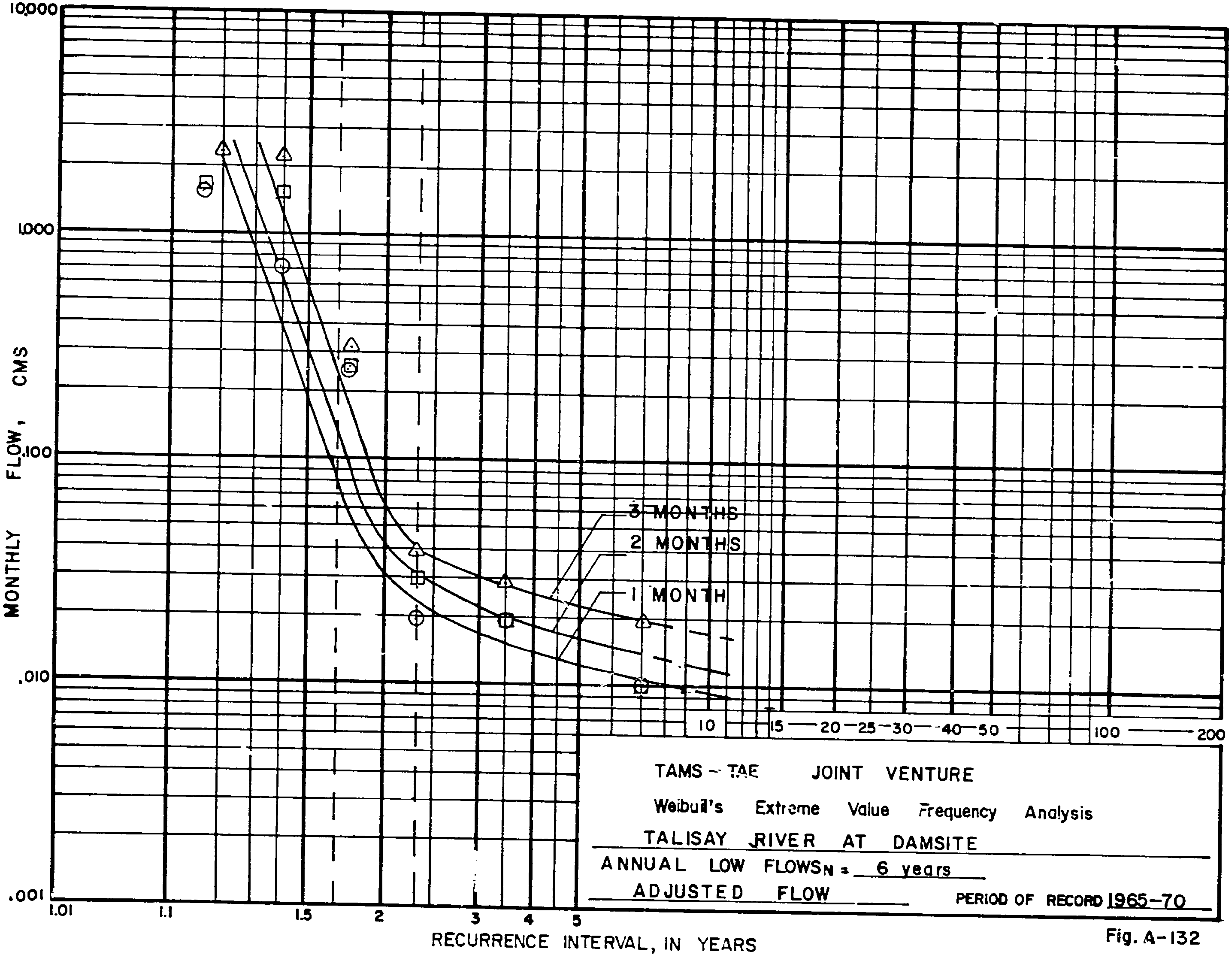


10.00
1.00
.10
.01
100.00
MONTHLY FLOW, CMS
3 MONTHS
2 MONTHS
1 MONTH
1.01
1.1
1.5
.2
3
4
5
10
15
20
25
30
40
50
200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
CABILOGAN RIVER AT BOBONSURAN, LIGAO
N = 15 years
ANNUAL LOW FLOWS
PERIOD OF RECORD 1957–72

Fig. A-131

131

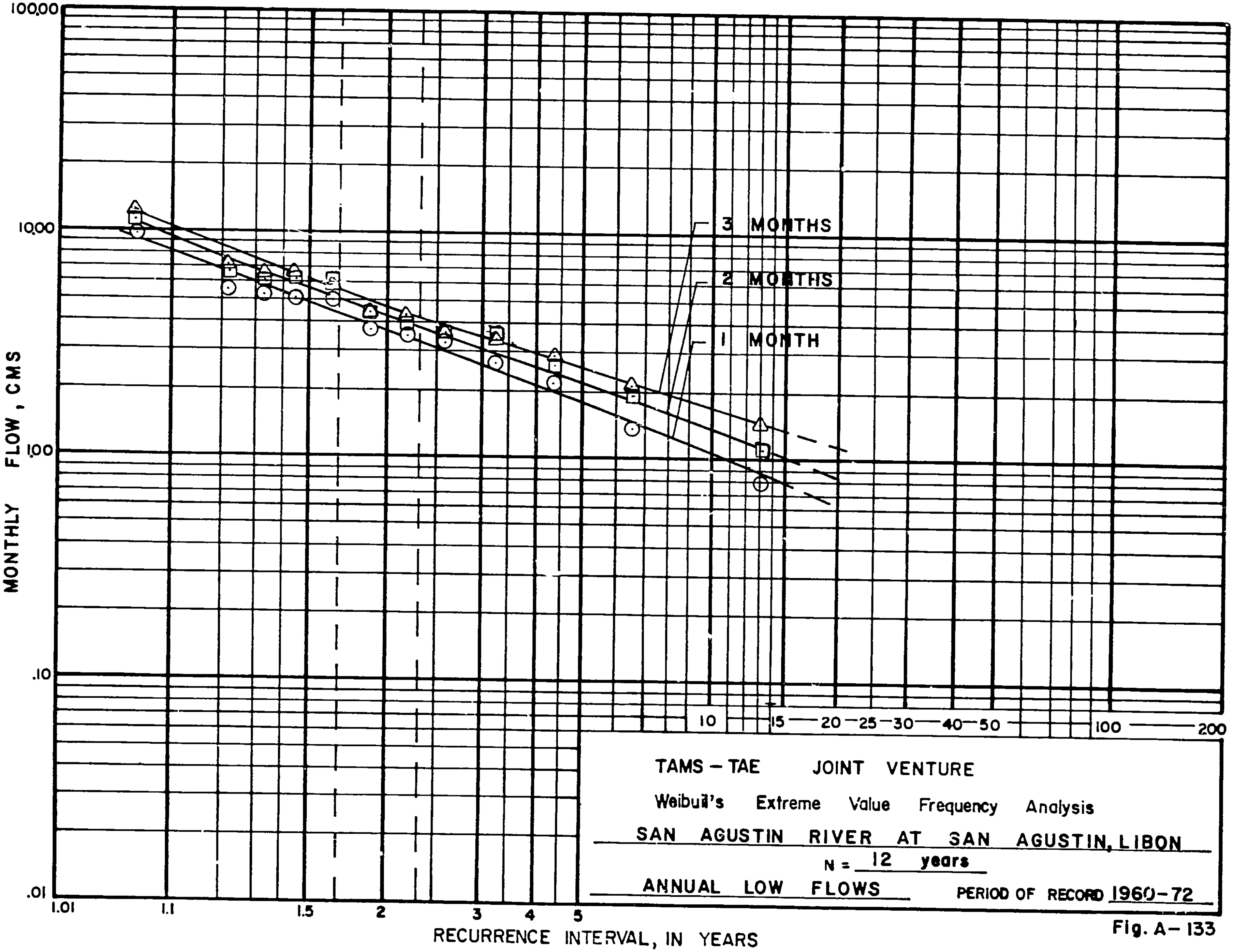
132



10,000
1,000
.100
.010
.001
MONTHLY FLOW, CMS
3 MONTHS
2 MONTHS
1 MONTH
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
TAMS - TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
TALISAY RIVER AT DAMSITE
ANNUAL LOW FLOWS N = 6 years
ADJUSTED FLOW
PERIOD OF RECORD 1965-70

Fig. A-132

133



TAMS – TAE JOINT VENTURE

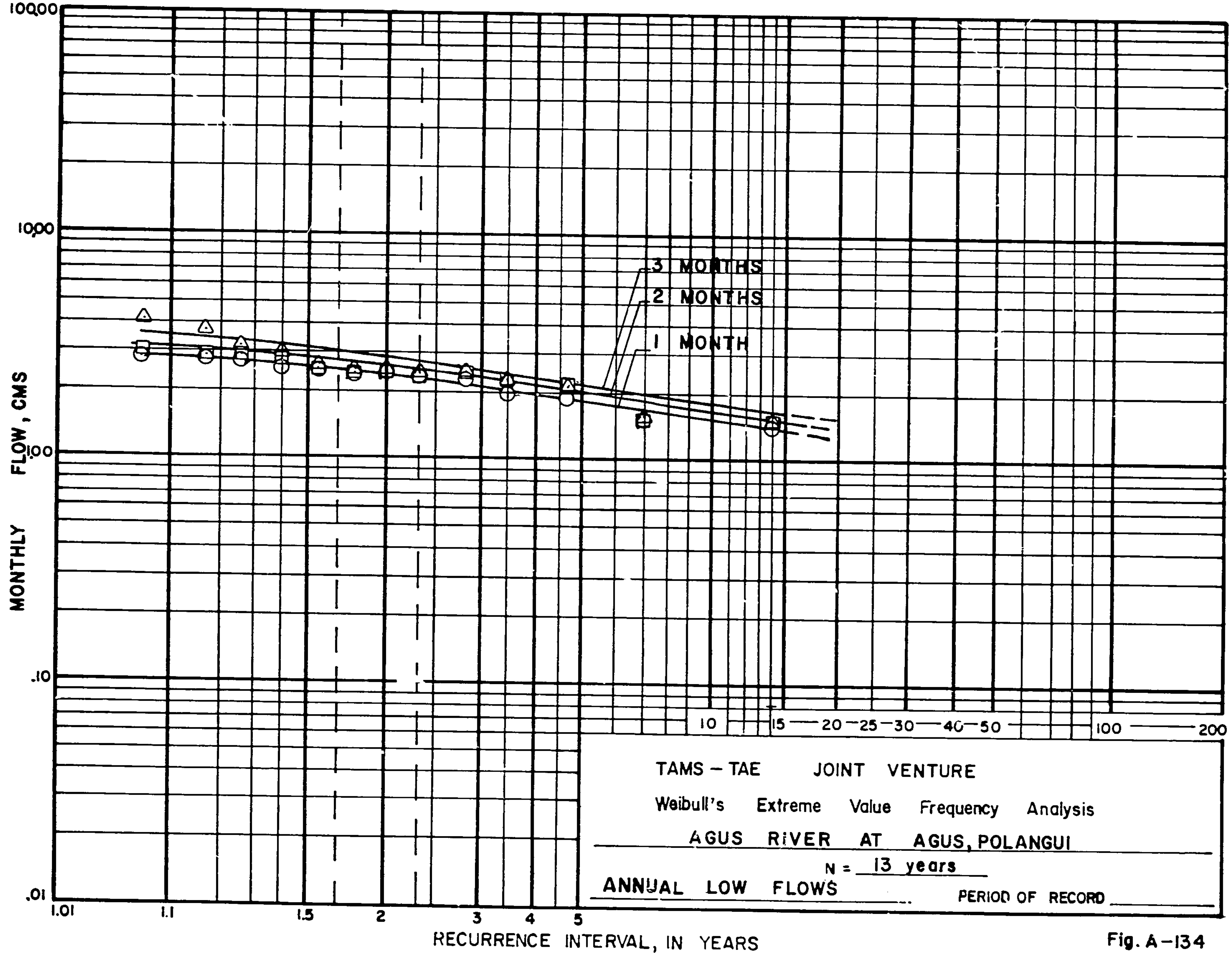
Weibull's Extreme Value Frequency Analysis

SAN AGUSTIN RIVER AT SAN AGUSTIN, LIBON

N = 12 years

ANNUAL LOW FLOWS PERIOD OF RECORD 1960-72

Fig. A-133



TAMS – TAE JOINT VENTURE

Weibull's Extreme Value Frequency Analysis

AGUS RIVER AT AGUS, POLANGUI

N = 13 years

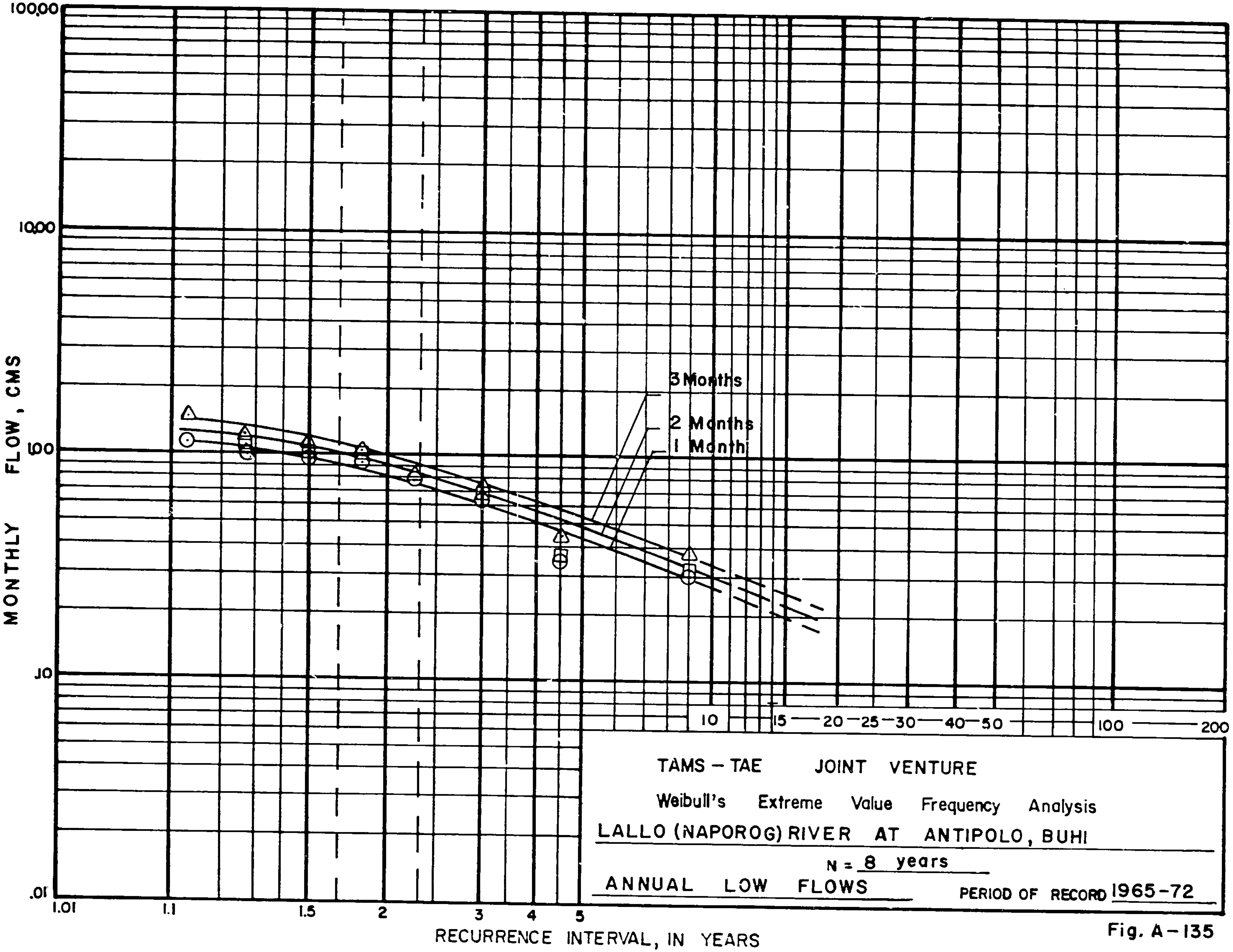
ANNUAL LOW FLOWS

PERIOD OF RECORD

Fig. A–134

134

135



TAMS – TAE JOINT VENTURE

Weibull's Extreme Value Frequency Analysis

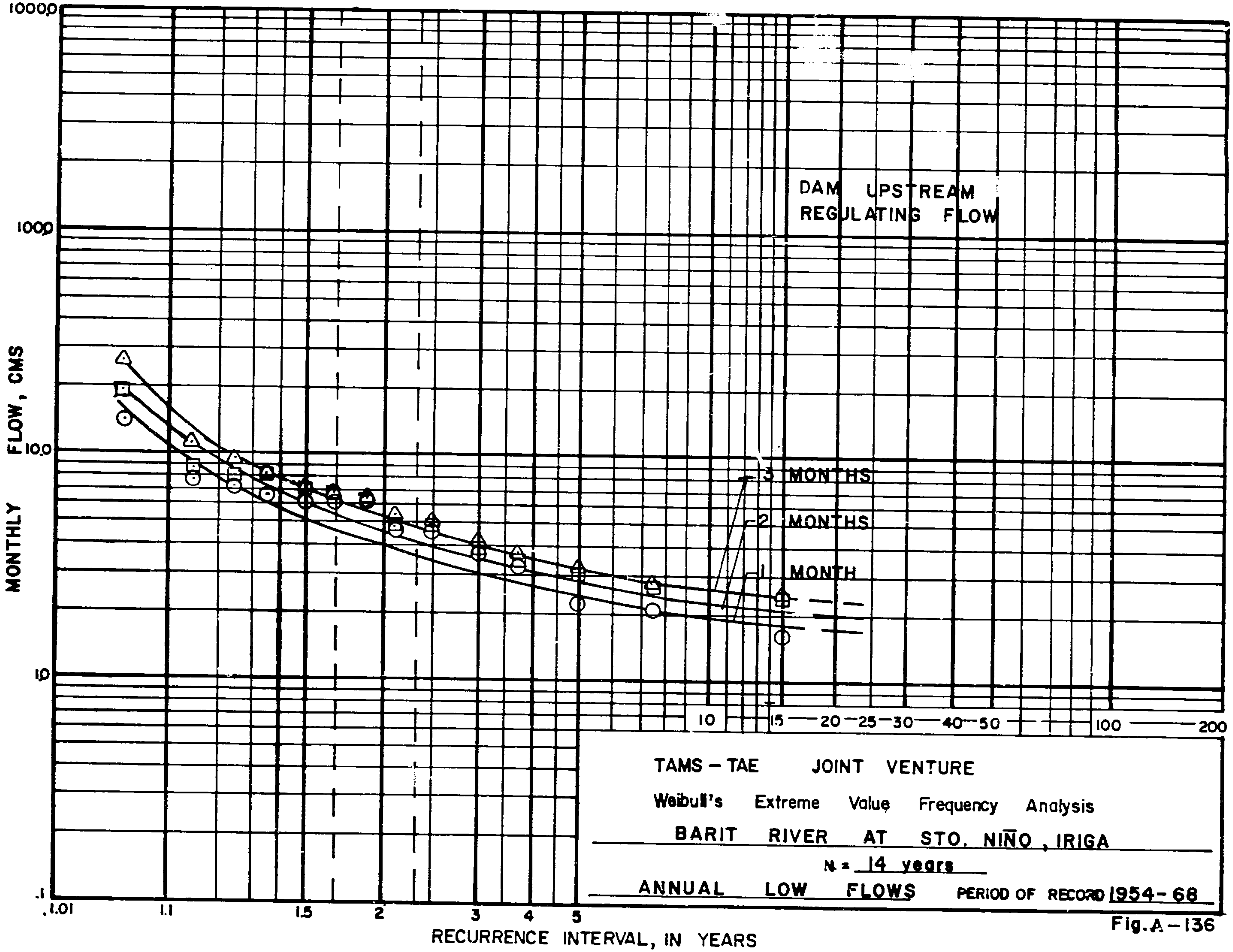
LALLO (NAPOROG) RIVER AT ANTIPOLO, BUHI

N = 8 years

ANNUAL LOW FLOWS

PERIOD OF RECORD 1965-72

Fig. A-135


DAM UPSTREAM
REGULATING FLOW
3 MONTHS
2 MONTHS
1 MONTH
MONTHLY FLOW, CMS
1000.0
100.0
10.0
1.0
.1
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
BARIT RIVER AT STO. NIÑO, IRIGA
N = 14 years
ANNUAL LOW FLOWS
PERIOD OF RECORD 1954-68
Fig. A–136

136

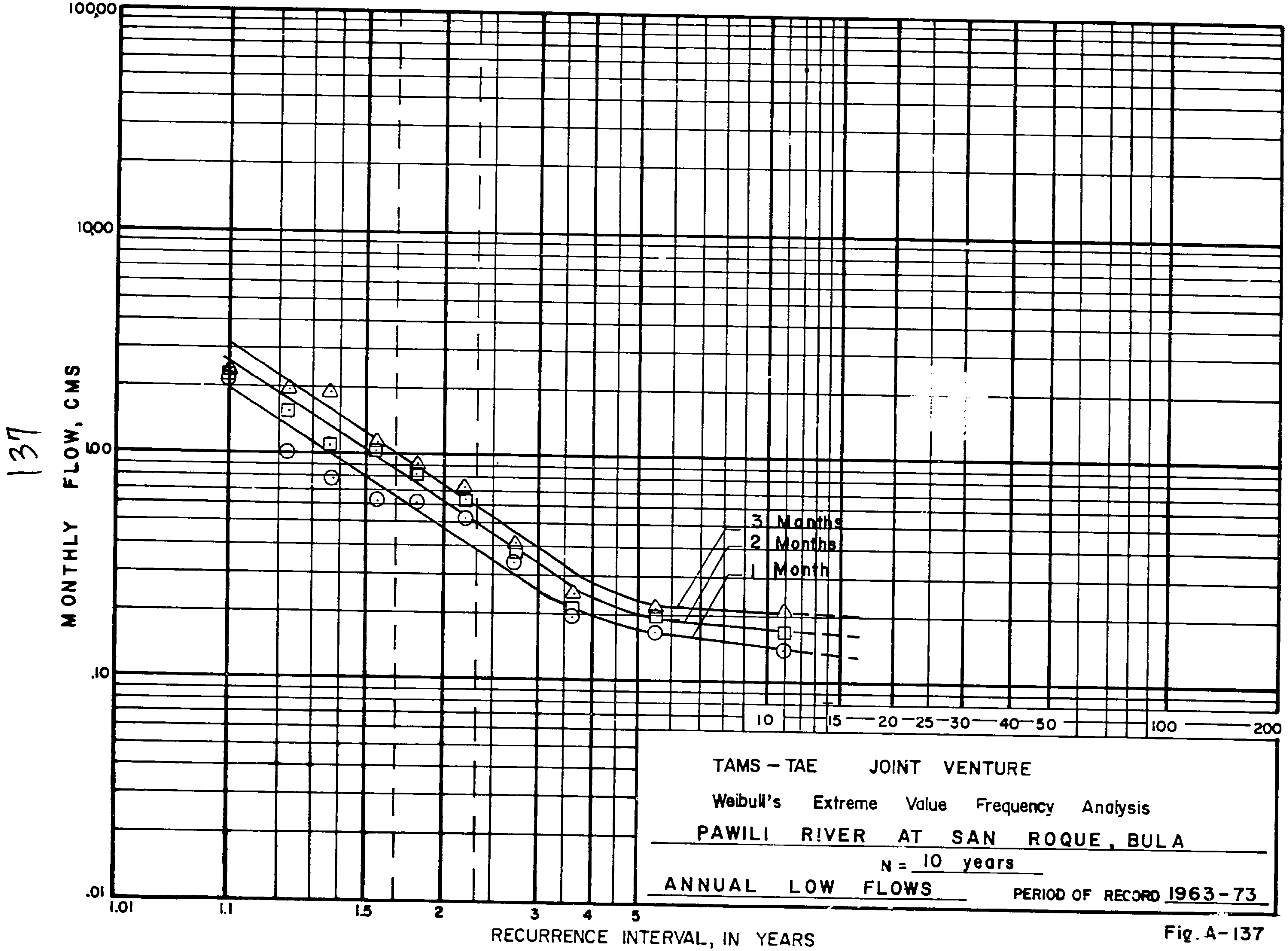
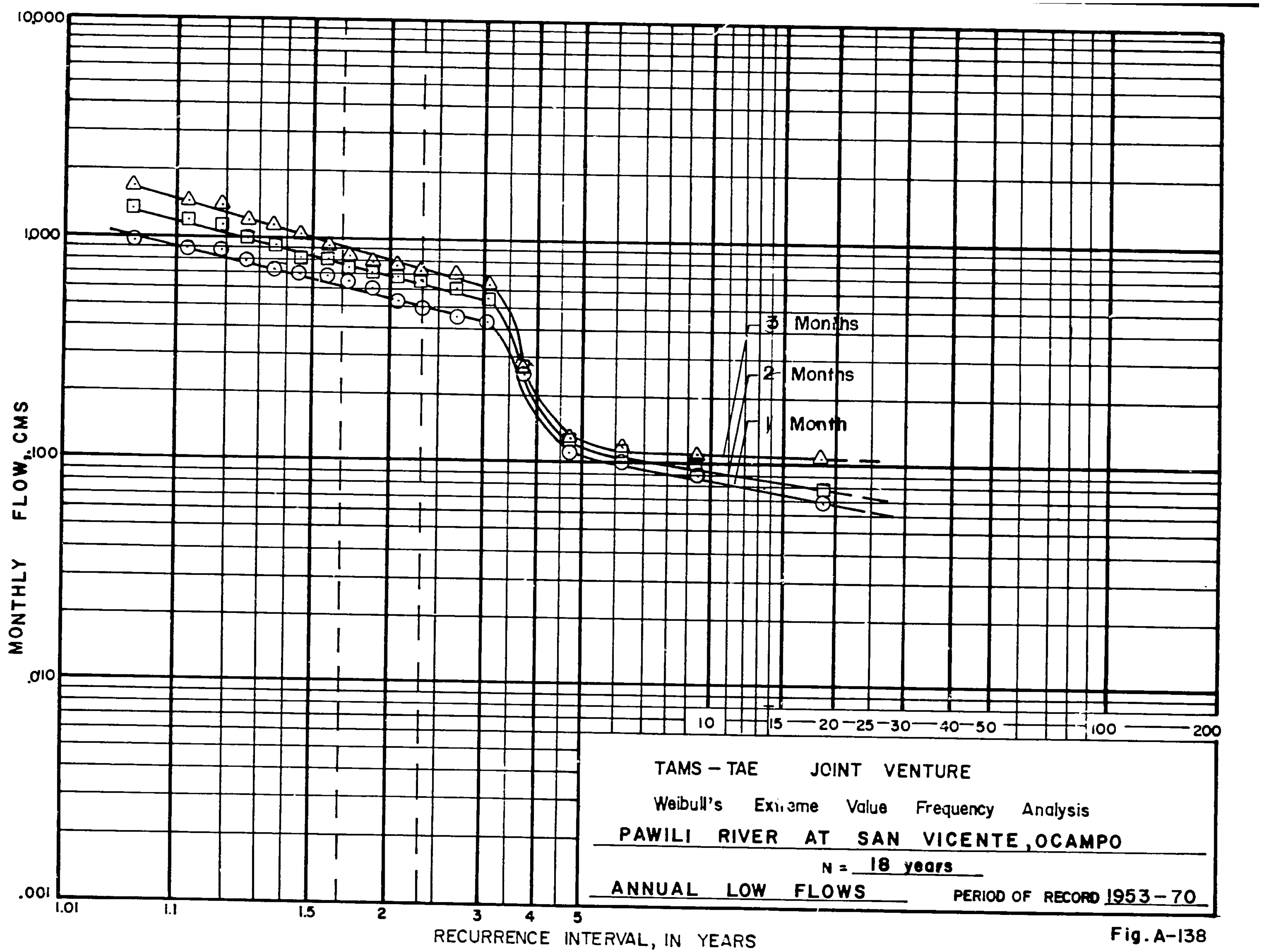
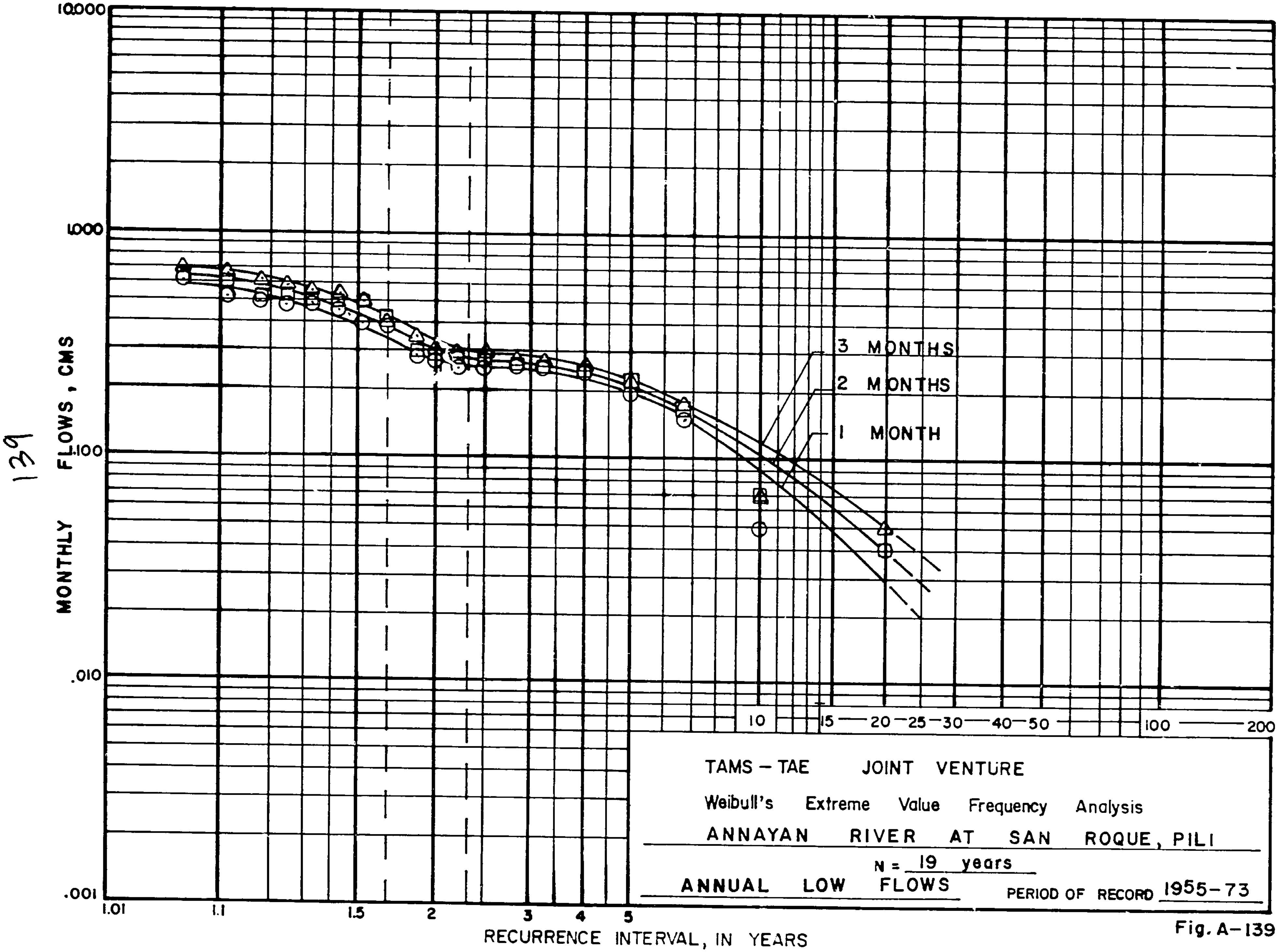

137
MONTHLY FLOW, CMS
100.00
10.00
1.00
.10
.01
3 Months
2 Months
1 Month
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
PAWILI RIVER AT SAN ROQUE, BULA
N = 10 years
ANNUAL LOW FLOWS
PERIOD OF RECORD 1963-73

Fig. A-137



10,000
1,000
.100
.010
.001
MONTHLY FLOW, CMS
3 Months
2 Months
1 Month
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
PAWILI RIVER AT SAN VICENTE, OCAMPO
N = 18 years
ANNUAL LOW FLOWS
PERIOD OF RECORD 1953–70

Fig. A-138



10,000
1,000
.100
.010
.001
MONTHLY FLOWS , CMS
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
3 MONTHS
2 MONTHS
1 MONTH
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
ANNAYAN RIVER AT SAN ROQUE, PILI
N = 19 years
ANNUAL LOW FLOWS
PERIOD OF RECORD 1955-73

Fig. A-139

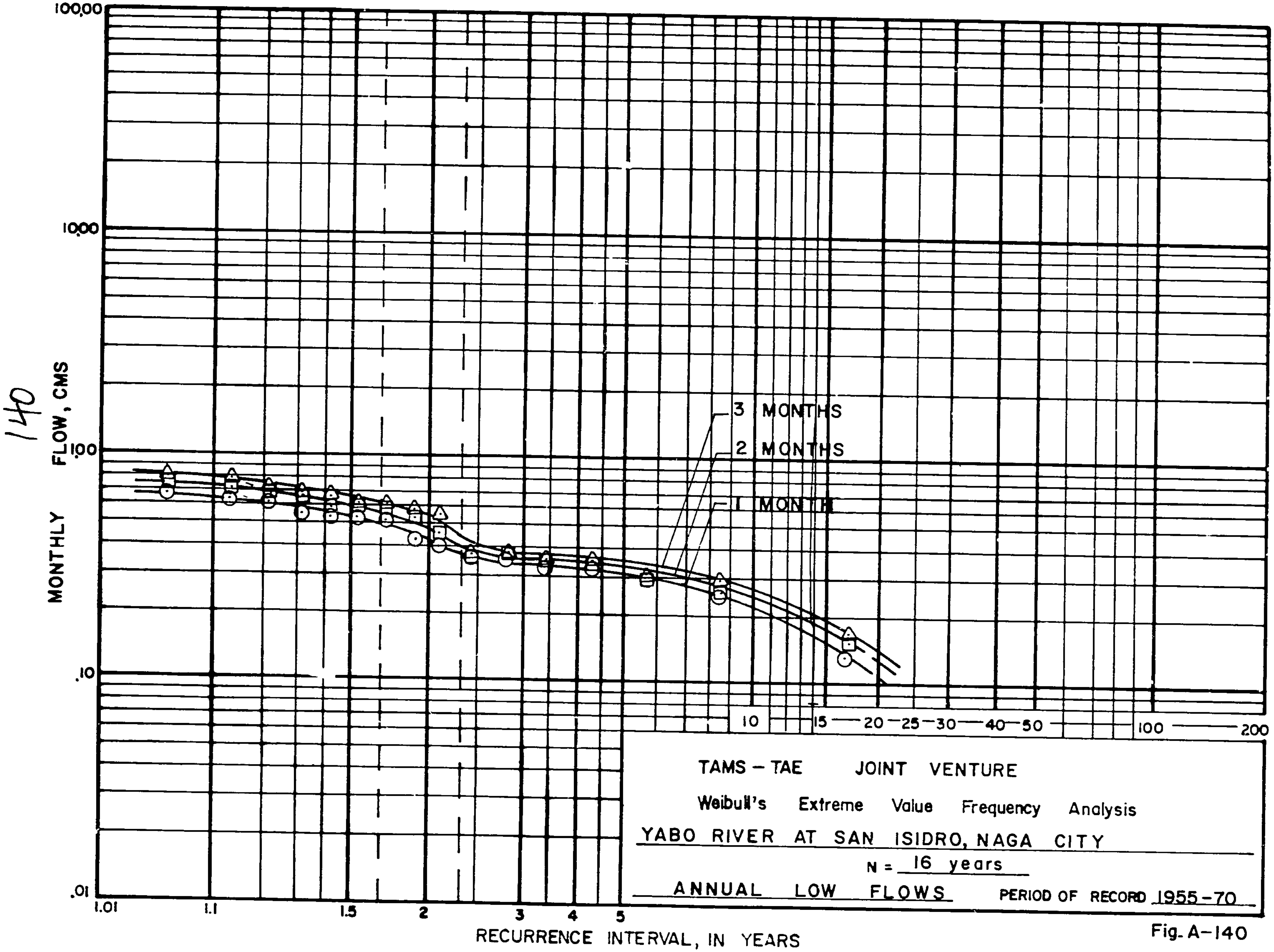

140
MONTHLY FLOW, CMS
100.00
10.00
1.00
.10
.01
3 MONTHS
2 MONTHS
1 MONTH
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
YABO RIVER AT SAN ISIDRO, NAGA CITY
N = 16 years
ANNUAL LOW FLOWS
PERIOD OF RECORD 1955-70

Fig. A-140

141

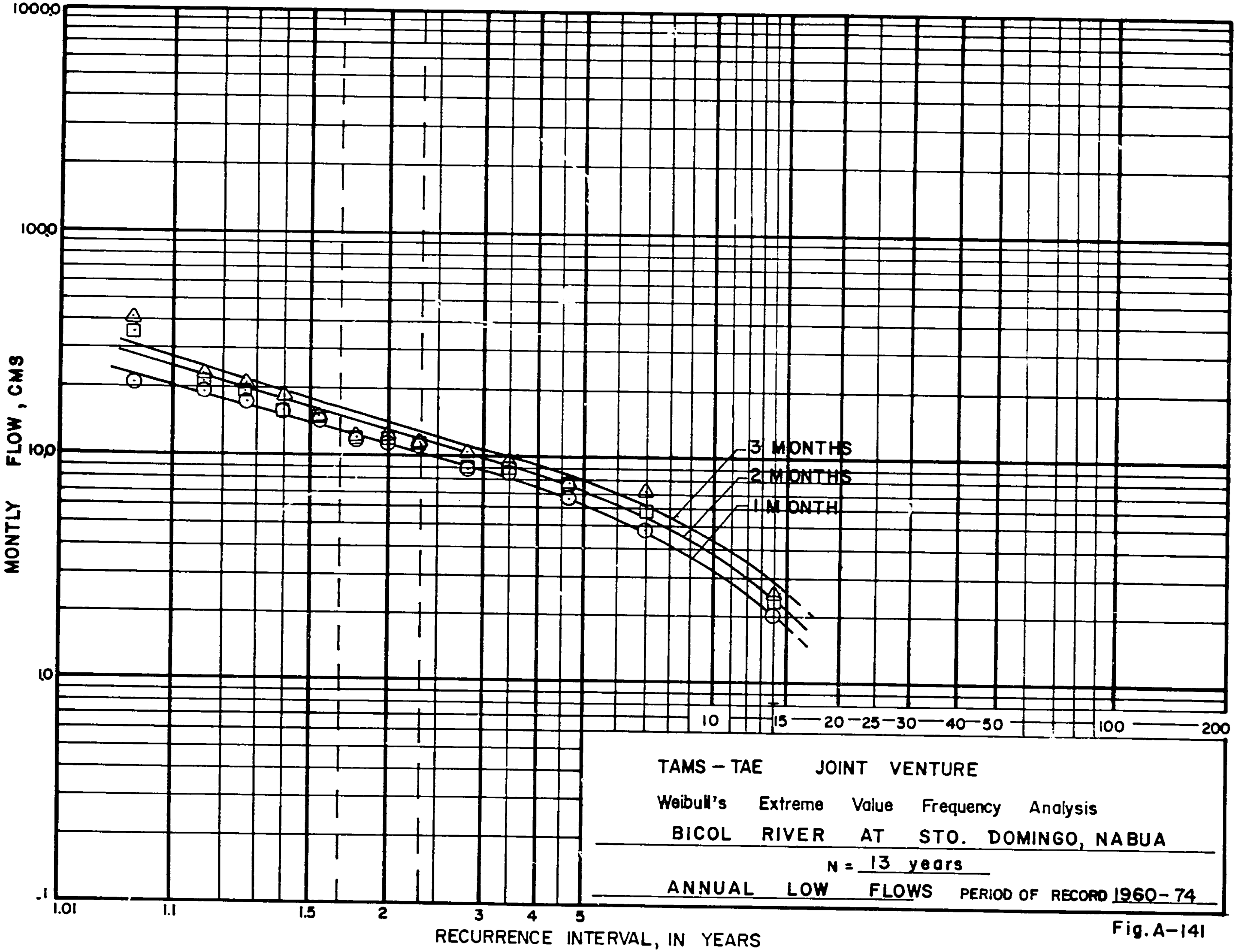
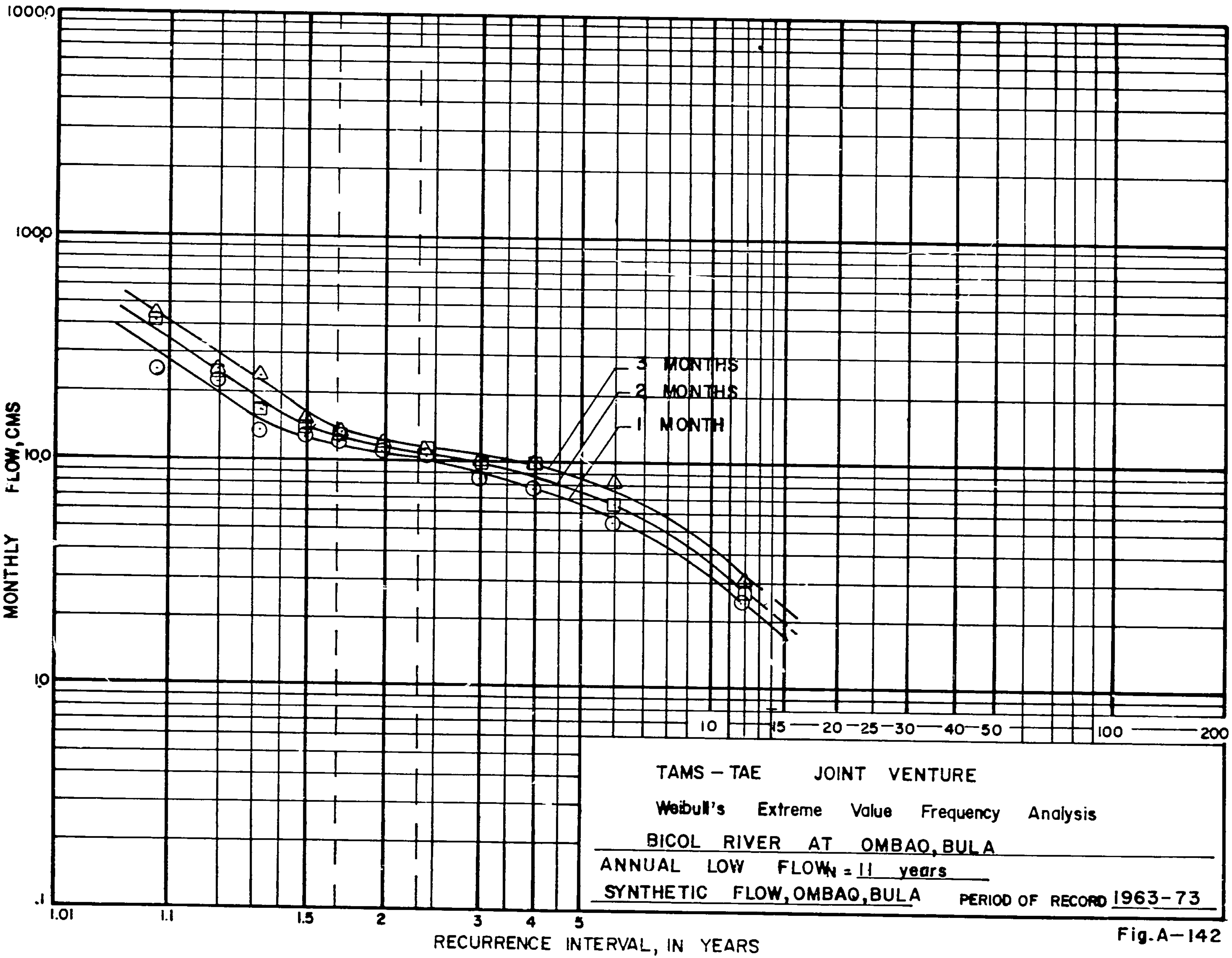

1000.0
100.0
10.0
1.0
.1
MONTLY FLOW, CMS
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
3 MONTHS
2 MONTHS
1 MONTH
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
BICOL RIVER AT STO. DOMINGO, NABUA
N = 13 years
ANNUAL LOW FLOWS PERIOD OF RECORD 1960-74

Fig. A-141

142



TAMS – TAE JOINT VENTURE

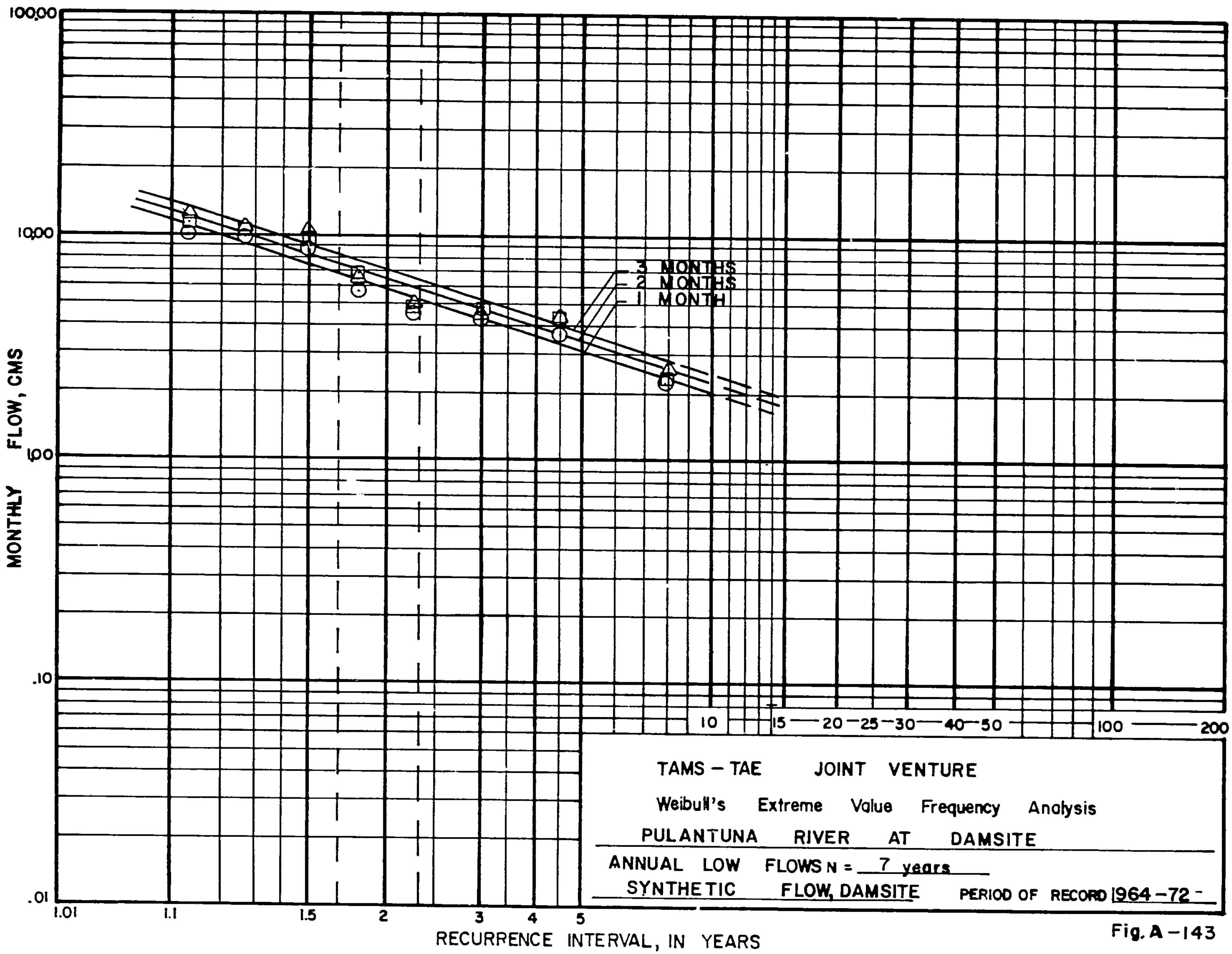
Weibull's Extreme Value Frequency Analysis

BICOL RIVER AT OMBAO, BULA

ANNUAL LOW FLOW $_{N}$ = 11 years

SYNTHETIC FLOW, OMBAO, BULA PERIOD OF RECORD 1963-73

Fig. A–142



TAMS – TAE JOINT VENTURE

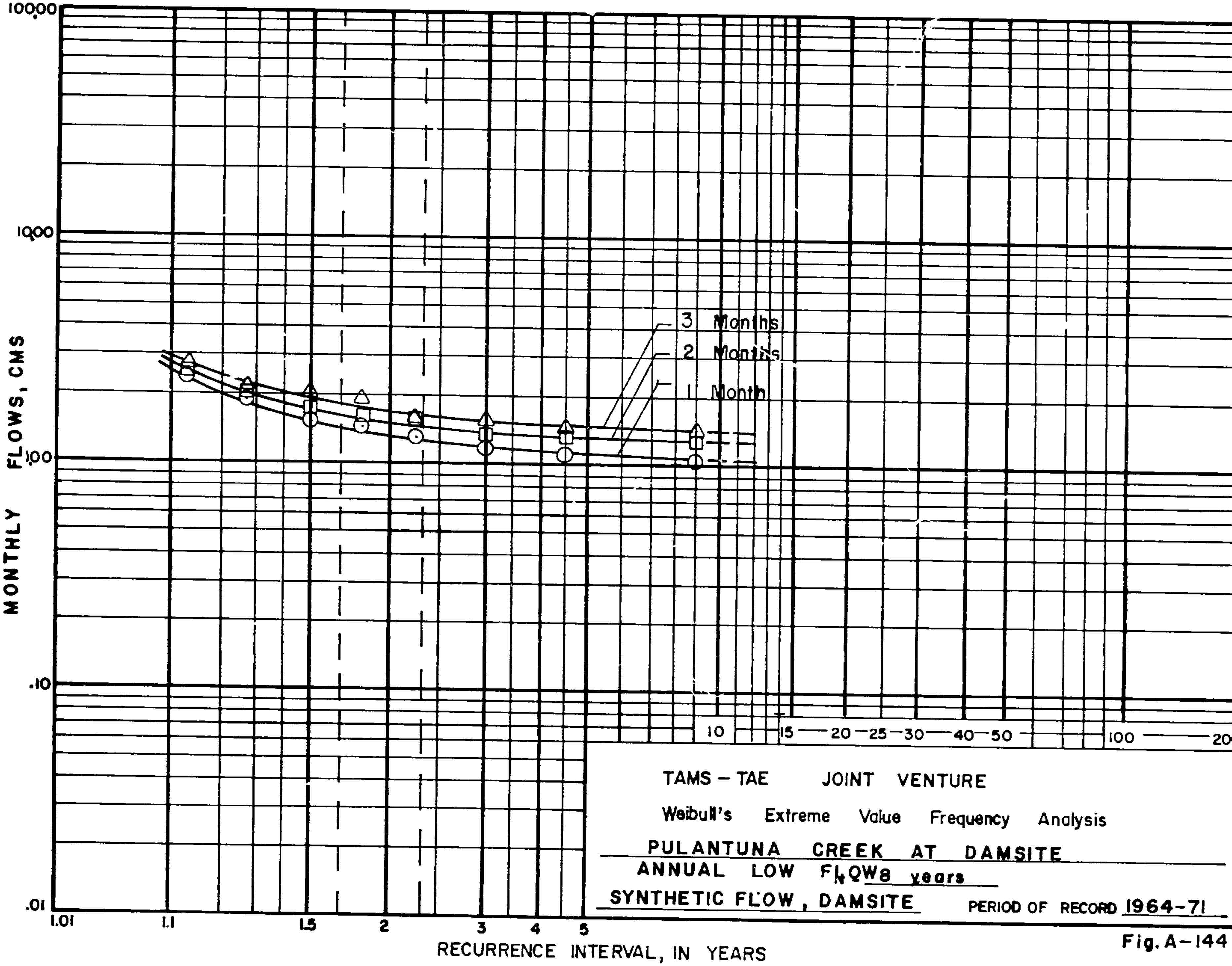
Weibull's Extreme Value Frequency Analysis

PULANTUNA RIVER AT DAMSITE

ANNUAL LOW FLOWS N = 7 years

SYNTHETIC FLOW, DAMSITE PERIOD OF RECORD 1964-72

Fig. A-143



TAMS – TAE JOINT VENTURE

Weibull's Extreme Value Frequency Analysis

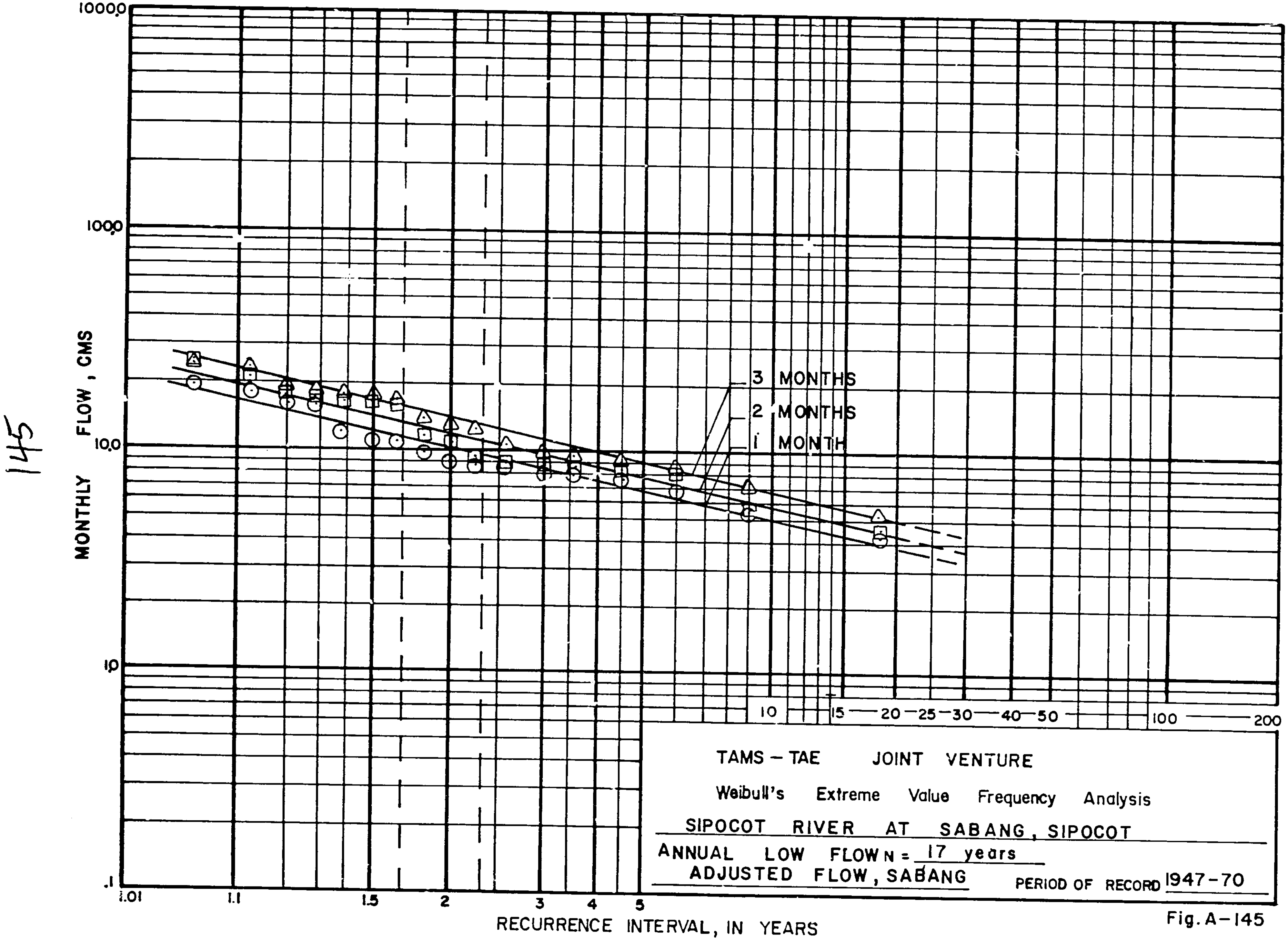
PULANTUNA CREEK AT DAMSITE

ANNUAL LOW FLOW 8 years

SYNTHETIC FLOW, DAMSITE PERIOD OF RECORD 1964-71

Fig. A-144

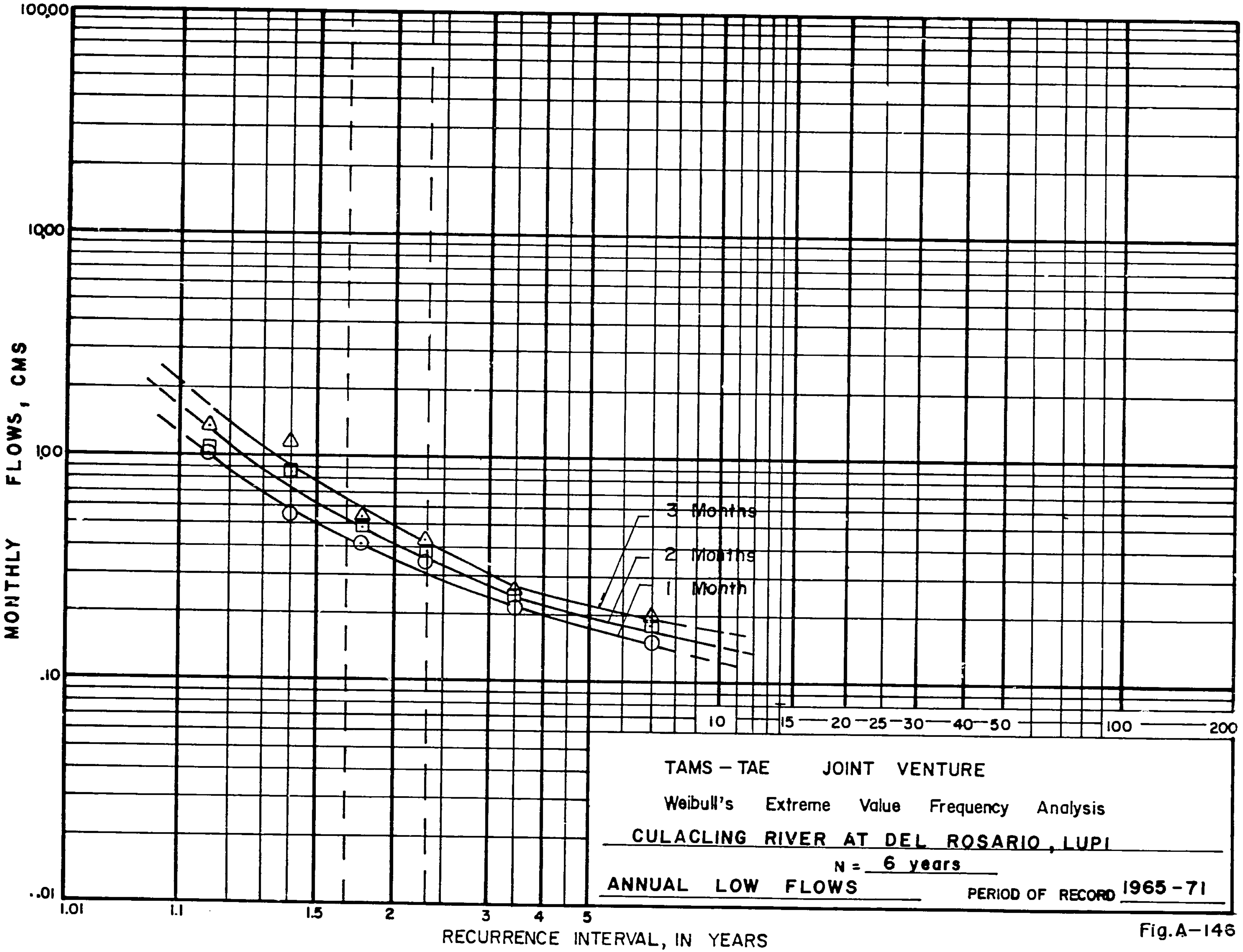
144



145
MONTHLY FLOW, CMS
1000.0
100.0
10.0
1.0
.1
3 MONTHS
2 MONTHS
1 MONTH
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
SIPOCOT RIVER AT SABANG, SIPOCOT
ANNUAL LOW FLOW N = 17 years
ADJUSTED FLOW, SABANG
PERIOD OF RECORD 1947-70

Fig. A-145

146



100.00
10.00
1.00
.10
.01
MONTHLY FLOWS, CMS
3 Months
2 Months
1 Month
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
CULACLING RIVER AT DEL ROSARIO, LUPI
N = 6 years
ANNUAL LOW FLOWS
PERIOD OF RECORD 1965-71

Fig. A-146

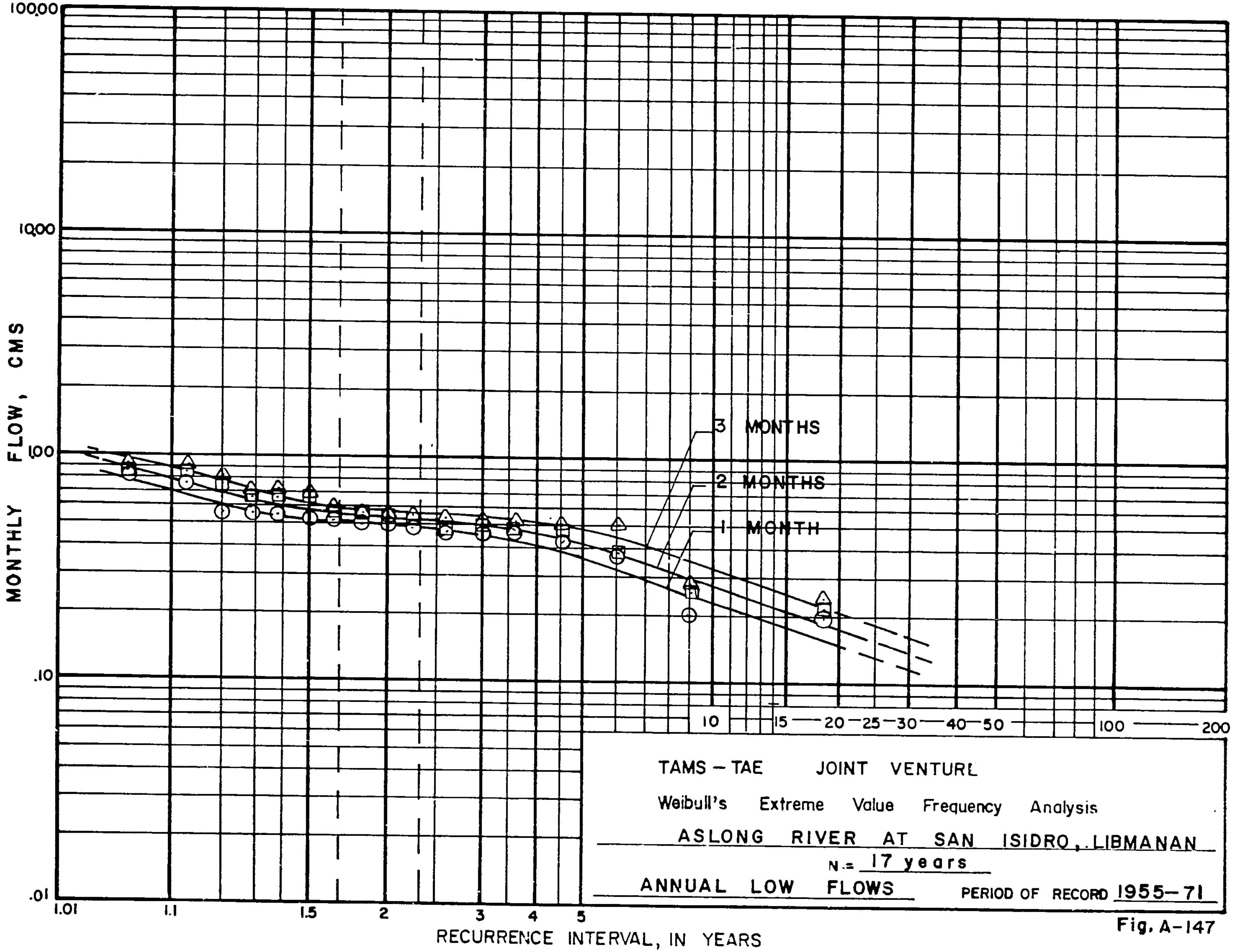

100.00
10.00
1.00
.10
.01
MONTHLY FLOW, CMS
3 MONTHS
2 MONTHS
1 MONTH
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
ASLONG RIVER AT SAN ISIDRO, LIBMANAN
N = 17 years
ANNUAL LOW FLOWS
PERIOD OF RECORD 1955–71

Fig. A-147

147

148

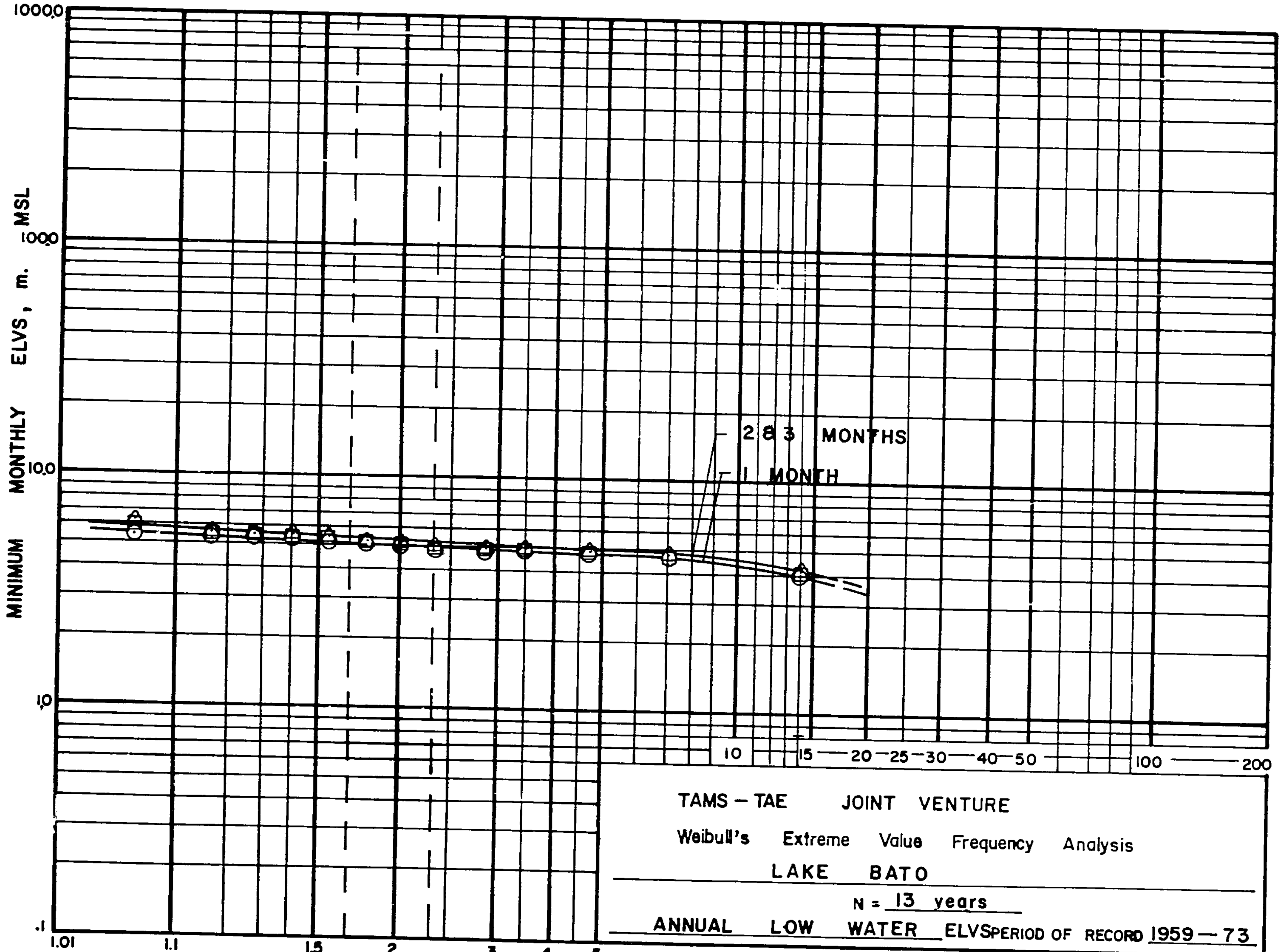

MINIMUM MONTHLY ELVS, m. MSL
1000.0
100.0
10.0
1.0
.1
2 & 3 MONTHS
1 MONTH
1.01
1.1
1.5
2
3
4
5
10
15
20
25
30
40
50
100
200
RECURRENCE INTERVAL, IN YEARS
TAMS – TAE JOINT VENTURE
Weibull's Extreme Value Frequency Analysis
LAKE BATO
N = 13 years
ANNUAL LOW WATER ELVS PERIOD OF RECORD 1959 – 73

Fig. A–148

PROBABILITY THAT WATER-YEAR ANNUAL FLOODS WILL BE EXCEEDE

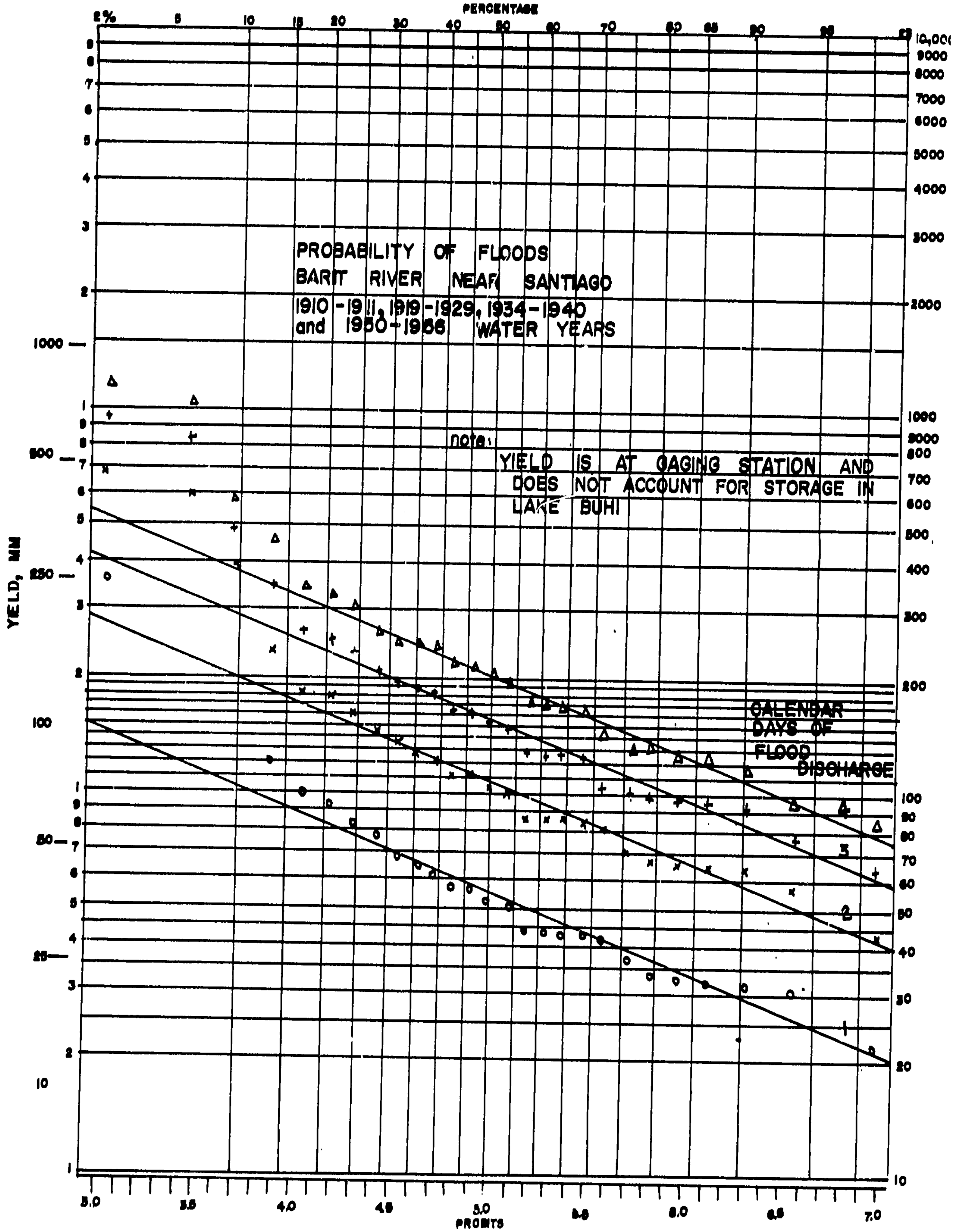


FIG. A-149

TABLE A-7

BARIT RIVER Near Santiago, Iriga, Camarines Sur

Monthly and Annual Discharge

(CMS)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	YIELD, MM
1910	--	--	--	--	(7.71)	7.13	10.02	8.58	8.46	12.33	21.74	40.0	--	--
1911	28.74	19.17	17.16	13.12	9.69	7.54	19.73	10.30	6.66	4.86	3.84	4.85	12.15	3041
1912	4.18	6.51	5.87	--	--	--	--	--	--	--	--	--	--	--
1919	--	(3.64)	3.75	3.59	3.08	4.58	7.59	9.50	8.80	7.51	13.29	14.71	--	--
1920	13.69	8.60	6.40	4.61	4.81	4.52	5.14	2.30	4.38	8.76	8.77	10.19	6.82	1711
1921	8.45	16.84	25.75	10.05	5.22	7.82	12.49	5.57	9.85	10.29	37.37	26.86	14.68	3675
1922	20.35	10.00	7.07	6.27	5.45	4.50	6.07	10.48	9.53	8.87	15.98	36.88	11.84	2864
1923	52.94	27.72	15.34	8.96	8.46	30.63	22.44	15.81	16.49	17.38	29.22	15.16	17.61	4408
1924	12.69	10.06	8.87	7.07	5.08	12.39	14.75	12.01	12.27	13.28	15.19	44.01	14.02	3518
1925	15.57	23.45	22.28	11.39	7.70	8.70	21.18	12.99	16.16	18.24	19.50	23.62	16.72	4185
1926	24.05	16.52	10.50	7.37	6.02	8.99	27.54	16.90	14.22	18.68	36.50	34.83	18.68	4677
1927	19.16	12.34	11.61	15.82	9.67	14.16	12.73	11.24	11.10	14.83	23.74	14.94	13.92	3483
1928	20.89	24.40	20.11	13.15	9.40	9.92	12.72	11.59	17.99	23.13	27.48	30.34	18.41	4620
1929	52.55	29.73	20.52	15.81	12.40	14.78	20.06	20.10	40.33	25.08	25.88	28.40	26.11	6535
1934	--	--	--	--	(11.91)	9.44	11.93	16.78	21.67	32.06	32.80	29.59	--	--
1935	17.15	21.64	16.82	17.09	12.10	12.11	12.43	10.16	12.24	22.21	29.41	16.81	16.13	4038
1936	22.92	17.16	10.51	14.14	12.30	10.31	12.10	16.04	15.48	14.91	17.57	25.13	15.72	3946
1937	16.96	10.91	11.94	9.27	9.41	8.18	12.25	10.99	15.44	15.22	20.11	21.31	13.52	3385
1938	15.82	13.33	19.93	18.13	12.59	10.68	12.87	7.42	12.01	15.93	18.74	29.22	15.77	3948
1939	26.84	20.94	13.30	10.56	16.04	10.65	10.81	10.52	12.62	12.19	14.52	16.89	14.63	3662
1940	23.00	14.22	11.65	8.60	7.72	7.70	10.67	17.47	22.08	13.52	13.24	30.66	15.07	3783
1950	--	--	--	7.02	4.36	4.63	4.83	3.71	12.52	9.46	13.87	9.80	--	--
1951	14.62	9.65	6.78	5.20	9.95	5.97	6.08	9.81	8.59	8.92	15.27	22.40	10.29	2577
1952	16.90	13.04	9.39	6.16	4.56	4.40	5.69	13.23	16.85	39.08	27.59	39.44	16.41	4117
1953	25.68	11.02	10.70	6.76	6.16	9.56	7.48	9.28	8.92	8.25	14.94	26.49	12.10	3029
1954	13.40	5.85	9.20	5.26	13.30	3.94	5.81	6.65	8.47	8.24	28.39	24.07	10.23	2561
1955	47.58	15.41	10.13	4.71	5.39	6.68	6.60	7.53	5.55	6.60	34.89	49.71	16.79	4201
1956	9.46	10.64	11.39	15.04	8.15	5.16	19.06	6.71	7.85	11.98	12.25	100.27	18.29	4580
MEAN	21.82	14.88	12.60	9.81	8.47	9.07	12.27	10.87	13.51	14.80	20.97	28.39	15.04	3768
MAX.	52.94	29.73	25..5	18.13	16.04	30.53	27.54	20.10	40.33	39.08	37.37	100.27	26.11	6535
MIN.	4.18	3.64	3.75	3.59	3.08	3.92	4.83	2.30	4.38	4.86	3.84	4.85	6.82	1711

TABLE A-7a

YEAR	MONTH	Discharge near Santiago cms.-months	Discharge at Lake BUHI outlet, cms.-mos.	Σ RUNOFF LAKE BUHI cms.-mo.
				0
1949	D	e 18.93	15.78	15.78
1950	J	e 14.55	12.12	27.90
	F	e 9.92	8.27	36.17
	M	e 8.45	7.04	43.21
	A	7.02	5.85	49.06
	M	4.36	3.63	52.69
	J	4.63	3.86	56.55
	J	4.83	4.02	60.57
	A	3.71	3.09	63.66
	S	12.52	10.43	74.09
	O	9.46	7.88	81.97
	N	13.87	11.56	93.53
	D	19.80	8.17	101.70
1951	J	14.62	12.18	113.88
	F	9.65	8.04	121.92
	M	6.78	5.65	127.57
	A	5.20	4.33	131.90
	M	9.95	8.29	140.19
	J	5.97	4.98	145.17
	J	6.08	5.07	150.24
	A	9.81	8.18	158.42
	S	8.59	7.16	165.58
	O	8.92	7.43	173.01
	N	15.67	12.72	185.73
	D	22.40	18.67	204.40
1952	J	16.90	14.08	218.48
	F	13.04	10.87	229.35
	M	9.39	7.82	237.17
	A	6.16	5.13	242.30
	M	4.56	3.80	246.10
	J	4.40	3.67	249.77
	J	5.69	4.74	254.51
	A	13.23	11.02	265.53
	S	16.85	14.04	279.59
	O	39.08	32.57	312.14
	N	27.59	22.99	335.13
	D	39.44	32.87	368.0
1953	J		21.40	389.40
	F		9.18	398.58
	M		8.92	407.50

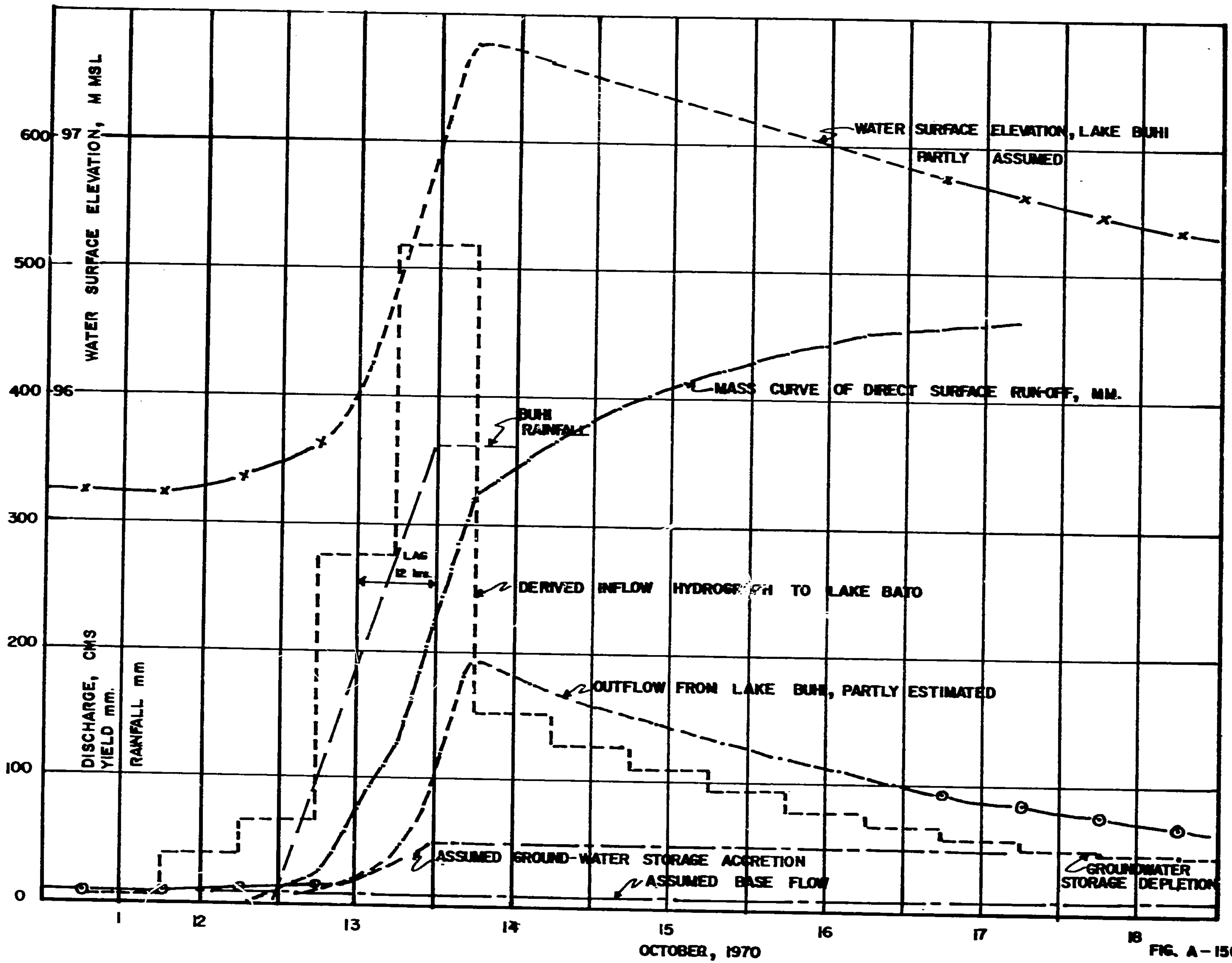


FIG. A-150

RAINFALL AT BUHI AND DISCHARGE INTO AND OUT OF LAKE BUHI — TYPHOON SENING, OCTOBER 1970

150

TABLE A-8 150a

ANALYSIS OF RUNOFF OF Lake BUHI Drainage Basin -- TYPHOON SENING OCTOBER 1970

zero = 93.79

OCT. 1970	Hr.	Lake BUHI Water Level, m			Lake BUHI Discharge, cms		Δ Lake Level	Q Equiv. of Storage	INFLOW to Lake	Assumed G.W. Accretion, cms	BASE FLOW ESTIMATE	Direct Surface Runoff		Σ YIELD
		G.H.		MSL	e Elev.	Av.	m	cms	cms			cms	$10^6 m^3$	mm
11	6	1.83		95.62	9.9	9.9.	0	0	10.	0	10	0		
-	18	1.83		95.62	9.9	9.8	-.01	-4.2	6	0	6	0	0	0
12	6	1.82		95.61	9.8	10.5	+.07	+29.2	40	0	8	3	0.13	0
-	18	1.89		95.68	11.2	13.0	13	+54.2	67	0	↑	59	2.55	1
13	6	2.02		95.81	14.8	29.4	+.59	+245.0	275	12		255	11.02	26
-	18		e	96.40	44.	117.5	+.96	+400.0	518	42		468	20.22	130
14	6		e	97.36	191.	100.5	-.07	-29.2	151	↑		101	4.36	323
-	18		e	97.29	170.	161.	-.08	-33.3	128			78	3.37	365
15	6		e	97.21	152.	143.	-.08	-33.3	110			60	2.50	397
-	18		e	97.13	134.	127.	-.08	-33.3	94			44	1.90	421
16	6		e	97.05	120.	112.5	-.08	-33.3	79			29	1.25	439
-	18		e	96.97	105.	99.0	-.08	-33.3	66			16	0.69	451
17	6	3.10		96.89	93.	88.5	-.07	-29.2	59	↓		9	0.39	458
-	18	3.03		96.82	84.	79.5	-.07	-29.2	50	42		0	0	462
18	6	2.96		96.75	75.	71.5	-.06	-25.0	46					
-	18	2.90		96.69	68.	66.0	-.05	-20.8	45				48.47	
19	6	2.85		96.64	64.	62.0	-.04	-16.7	45					
-	18	2.81		96.60	60.	59.0	-.02	-8.3	57					
20	6	2.79		96.58	58.	56.0	-.04	-16.7	39					
-	18	2.75		96.54	54.	53.0	-.02	-8.3	45					
21	6	2.73		96.52	52.	50.5	-.04	-16.7	34					
-	18	2.69		96.48	49.	48.2	-.04	-16.7	32					
22	6	2.65		96.44	46.5	46.2	-.03	-16.7	32					
-	18	2.62		96.41	44.	43.0	-.03	-12.5	30					
23	6	2.59		96.38	42.0	41.0	-.03	-12.5	29					
-	18	2.56		96.35	40.	39.0	-.03	-12.5	27					
24	6	2.53		96.32	38.	37.0	-.03	-12.5	25					
-	18	2.50		96.29	36.	35.2	-.03	-12.5	23					
25	6	2.47		96.26	34.3	33.4	-.03	-12.5	21					
-	18	2.44		96.23	32.6	31.8	-.03	-12.5	19					
26	6	2.41		96.20	31.0	30.5	-.02	-8.3	22.					
-	18	2.39		96.18	30.0	29.2	-.03	-12.5	17					
27	6	2.36		96.15	28.4	27.6	-.03	-12.5	15					
-	18	2.33		96.12	26.8	26.1	-.03	-12.5	11					
28	6	2.30		96.09	25.4	24.7	-.03	-12.5	12.					
-	18	2.27		96.06	24.0	23.6	-.02	-8.3	15					
29	6	2.25		96.04	23.2	22.8	-.02	-8.3	14					
-	18	2.23		96.02	22.4	22.4	0	- - -	22.					
30	6	2.23		96.02	22.4	22.2	-.01	-4.2	18					
-	18	2.22		96.01	22.0	21.6	-.02	-8.3	13					
31	6	2.20		95.99	21.3	21.6	+.02	+8.3	30		↓ 8			
-	18	2.22		96.01	22.0									

151

RAINFALL AT BUHI AND DISCHARGE INTO AND OUT OF LAKE BUHI, TYPHOON PATSY, NOVEMBER 1955

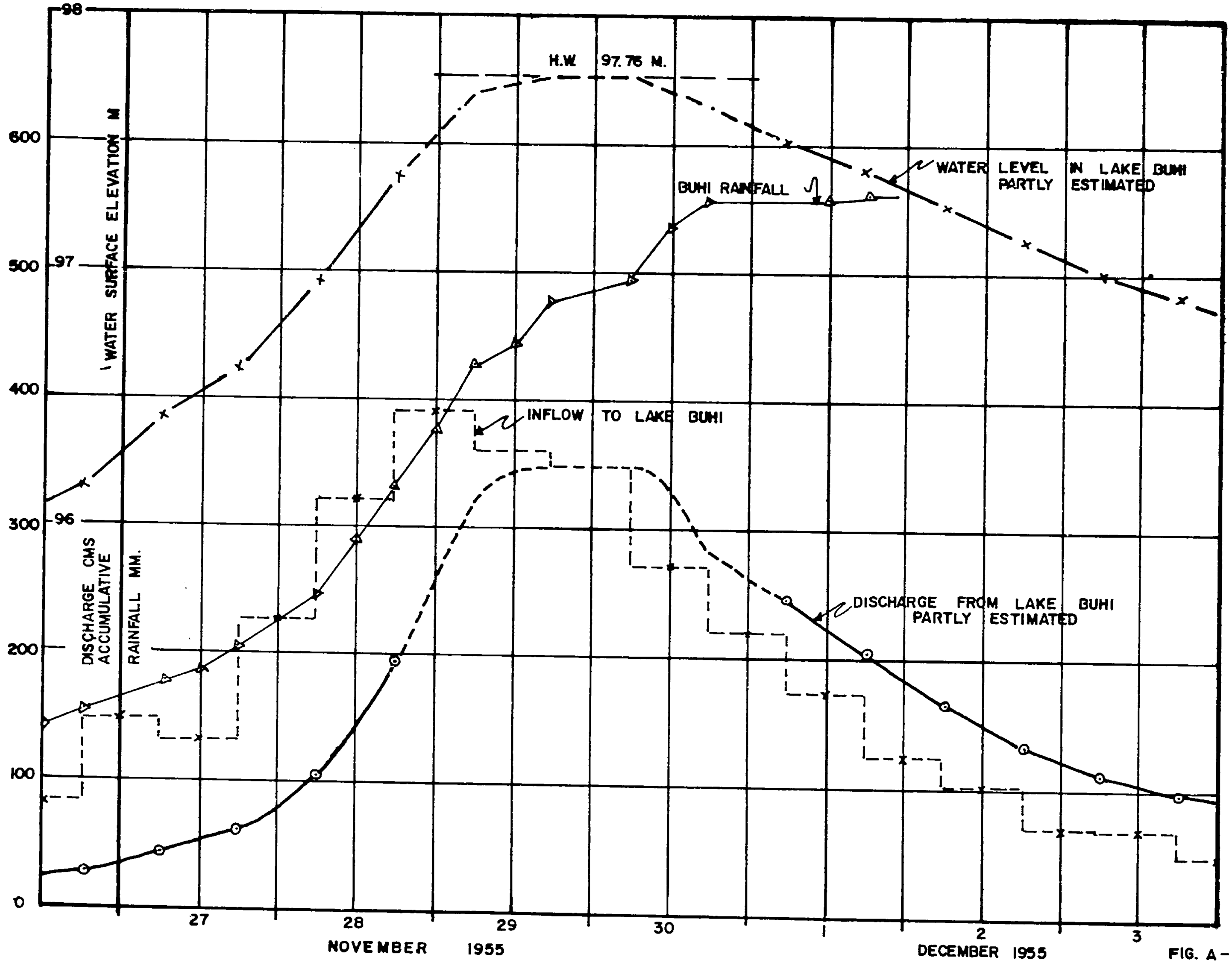


FIG. A - 151

TABLE A-9

ANALYSIS OF RUNOFF OF Lake BUHI Drainage Basin
TYPHOON Patsy, November 1955

Zero = 94.23

1955	Hr.	Lake BUHI Water Level		OUTLET Discharge	Mean Q	Δ Lake Level	Q Equiv. of Storage	Inflow to Lake Buhi	Estimated Direct Surface Runoff, cms	BUHI Rainfall		
NOV.		C.H.	MSL	Cms	Cms.	M	Cms	CMS		In.	Mm.	Σ
23	6	1.30	95.53	8.2	8.2	0	0	8	0			
	18	1.30	95.53	8.2	8.4	+.03	+ 12.5	21	12			
24	6	1.33	95.56	8.7	8.8	+.01	+ 4.2	13	3	1.11	28.2	28.2
	18	1.34	95.57	9.0	9.6	+.06	+ 25.0	35	24	0 .05	0 1.3	28.2 29.5
25	6	1.40	95.63	10.1	12.6	+.19	+ 79.2	92	80	N.O. .47	11.9	41.4
	18	1.59	95.82	15.0	18.5	+.19	+ 79.2	98	80	1.26 .77	32.0 19.6	73.4 93.0
26	6	1.78	96.01	22.0	25.2	+.14	+ 58.3	84	60	N.O. 1.15	– 29.2	– 122.2
	18	1.92	96.15	28.5	36.8	+.27	+ 112.5	149	119	.86 .50	21.8 12.7	144.0 156.7
27	6	2.19	96.42	45.0	53.0	+.19	+ 79.2	132	196	N.O. .90	– 22.9	– 179.6
	18	2.38	96.61	61.0	82.5	+.35	+ 145.8	228	106	.27 .66	6.9 16.8	186.5 203.3
28	6	2.73	96.96	104.0	149.5	+.41	+ 170.8	320	271	N.O. 1.71	– 43.4	– 246.7
	18	3.14	97.37	195.0	252.0	+.33	+ 137.5	390	335	1.72 1.62	43.7 41.1	290.4 331.5
29	6	FLOOD	97.70e	319.0	334.5	+.06	+ 25.0	360	299	1.75 2.00	44.4 50.8	375.9 426.7
	18	H.W. =	97.76e	350.0	350.0	0	0.	350	282	.60 1.45	15.2 36.8	441.9 478.7
30	6	97.96 e	97.76e	350.0	321.0	–.12	– 50.	271	197	N.O. .67	– 17.0	– 495.7
DEC.	18		97.64e	292.0	269.0	–.12	– 50.	219	208	1.72 .80	43.7 20.3	539.4 559.7
1	6	3.29	97.52	246.0	224.5	–.12	– 50.	174	87			
	18	3.17	97.40	203.	104.0	–.14	– 58.3	126	32	.03	0.8	560.6
2	6	3.03	97.66	165.	150.0	–.12	– 50.	100	0			
	18	2.91	97.14	135.	123.5	–.13	– 54.2	69	2371			
3	6	2.78	97.01	112.	104.5	–.09	– 37.5	67	or 102.4 million m³			
	18	2.69	96.92	97.	90.5	–.10	–41.7	49	or			
4	6	2.59	96.82	84.	79.0	–.12	–50.	29	975 mm			
	18	2.51	96.74	74.	69.0	–.10	–41.7	27	Yield			
5	6	2.41	96.64	64.	60.0	–.08	– 33.3	27				
	18	2.33	96.56	56.	53.0	–.08	– 33.3	20				
6	6	2.25	96.48	50.	47.5	–.07	– 29.2	18				
	18	2.18	96.41	45.	42.5	–.06	– 25.0	17				
7	6	2.12	96.35	40.	38.0	–.06	–25.0	13				
	18	2.06	96.29	36.	34.5	–.05	– 20.3	14				
8	6	2.01	96.24	33.	32.0	–.04	–16.7	15				
	18	1.97	96.20	31.	30.5	–.03	– 12.5	18				
9	6	1.94	96.17	30.	30.0	0	0	30				
	18	1.94	96.17	30.	29.5	–.01	– 4.2	25		.06		
10	6	1.93	96.16	29.	29.0	0	0	29		.06		
	18	1.93	96.16	29.	28.7	–.01	– 4.2	24				
11	6	1.92	96.15	28.5	28.0	–.02	– 8.3	30		.15		
	18	1.90	96.13	27.5	26.6	–.03	–12.5	14		.33 .37		
12	6	1.87	96.10	25.6	25.4	–.01	– 4.2	21		.63		
	18	1.86	96.09	25.1	26.0	+.03	+12.5	38		.05		
13	6	1.89	96.12	26.9	26.5	–.01	– 4.2	22		.10		
	18	1.88	96.11	26.2						10 .03		

RAINFALL AT BUHI AND DISCHARGE INTO AND OUT OF LAKE BUHI – TYPHOON TRIX, OCTOBER, 1952

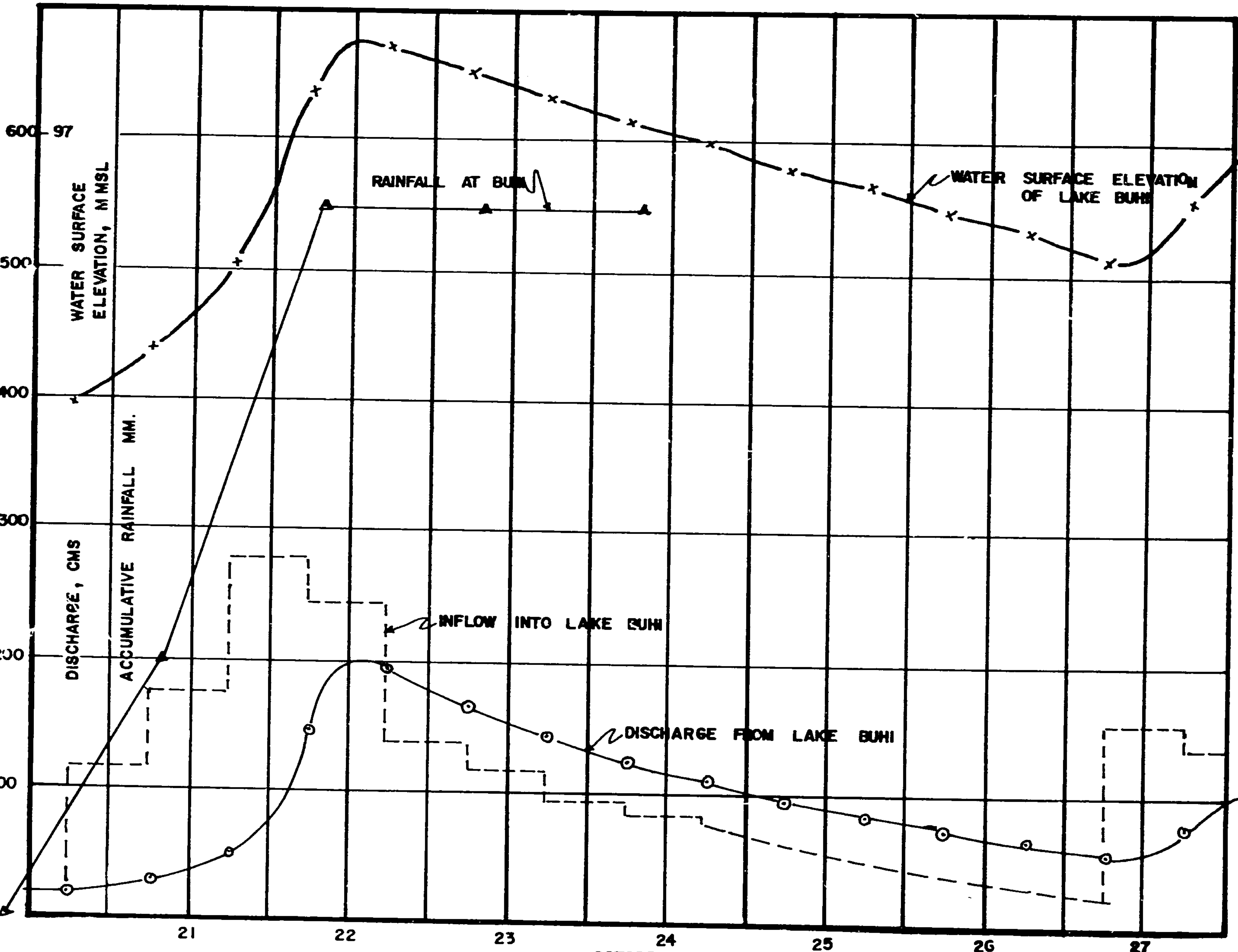


FIG. A – 152

152

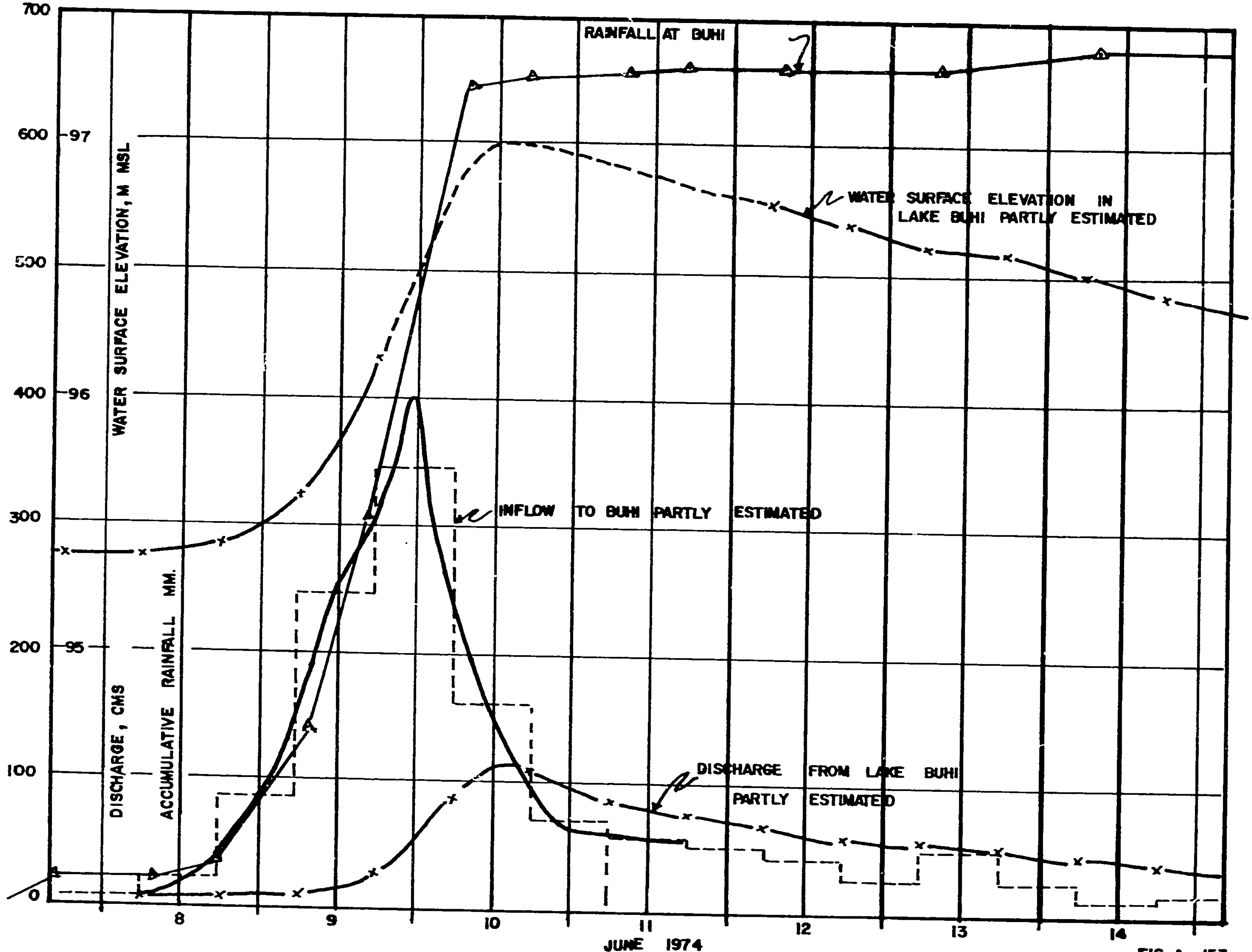
152a

TABLE A-10
ANALYSIS OF RUNOFF OF Lake BUHI Drainage Basin
TYPHOON TRIX, October 1952

Zero = 94.43

OCT. 1952	Hr.	Lake BUHI Water Level, m * G.H.	Lake BUHI Water Level, m MSL	Lake BUHI OUTLET Discharge	Mean Q cms.	Δ Q Lake Level	Equiv. of Storage, cms.	Inflow to Lake BUHI cms.		Rainfall at BUHI, OBSERVATIONS Hr.	In.	Mm.	Σ
19	6	1.57	96.00	21.5	21.1	-.02	-8.3	13		8	0		
	18	1.55	95.98	20.7	20.5	-.01	-4.2	16					
20	6	1.54	95.97	20.3	20.3	0	0	20		8	.03	0.8	0.8
	18	1.54	95.97	20.3	25.4	+.22	+91.7	117					
21	6	1.76	96.19	30.5	41.2	+.32	+133.3	174		8	7.79	197.9	198.7
	18	2.08	96.31	52.	98.5	+.67	+279.2	278					
22	6	2.75	97.18	145.	169.	+.18	+75.0	244		8	13.78	350.0	548.7
	18	2.93	97.36	193.	179.	+.10	-41.7	137					
23	6	2.83	97.26	165.	154.	-.09	-37.5	117		8	0		
	18	2.74	97.17	143.	134.	-.09	-37.5	96					
24	6	2.65	97.08	125.	118	-.08	-33.3	85		8	0		
	18	2.57	97.00	111.	103.	-.10	-41.7	61					
25	6	2.47	96.90	95.	90.	-.06	-25.0	65					
	18	2.41	96.84	85.	79.5	-.10	-41.7	38					
26	6	2.31	96.74	74.	71.	+.06	-25.0	46					
	18	2.25	96.68	68.	63.	-.10	-41.7	21					
27	6	2.15	96.58	58.	68.5	+.21	+87.5	56					
	18	2.36	96.79	79.	87.5	+.12	+50.0	38					
28	6	2.48	96.91	96.	90.5	-.08	-33.3	57					
	18	2.40	96.83	85.	80.	-.08	-33.3	47					
29	6	2.32	96.75	75.	71.5	-.07	-29.2	42					
	18	2.25	96.68	68.	64.	-.08	-33.3	31					
30	6	2.17	96.60	60	57.	-.06	-25.0	32					
	18	2.11	96.54	54.	52.	-.05	-20.8	31					
31	6	2.06	96.49	50.	48.5	-.04	-16.7	32					
NOV.	18	2.02	96.45	47.	47.	0	0	47					
1	6	2.02	96.45	47.	42.5	-.14	-58.3	26					
	18	1.88	96.31	38.	40.	+.06	+25.0	23					
2	6	1.94	96.37	42.	37.5	-.14	-58.3	21					
	18	1.80	96.23	33.	34.5	+.06	+25.0	18					
3	6	1.86	96.29	36.	35.	-.04	-167.	18					
	18	1.82	96.25	34.	33.	-.04	-16 7.	16					
4	6	1.78	96.21	32.	31.	-.04	-167.	14					
	18	1.74	96.17	30.	29.	-.03	-12.5	16					
5	6	1.71	96.14	28	27.	-.02	-8.9	14					
	18	1.69	96.12	27.	26	-.03	-12.5	13					
6	6	1.66	96.09	25.	24.5	-.02	-8.3	16					
	18	1.64	96.07	24.	23.5	-.03	-12.5	9					
7	6	1.61	96.04	23.	22.5	-.02	-8.3	14					
	18	1.59	96.02	22.	21.5	-.03	+12.5	9					
8	6	1.56	95.99	21.	20.5	-.02	-8.3	12					
	18	1.54	95.97	20.									

* Gage observations do not seem to have been taken at stated hours of 6 and 18



RAINFALL AT BUHI AND DISCHARGE INTO AND OUT OF LAKE BUHI, TYPHOON DINAH, JUNE 1974

153

FIG. A-153

TABLE A-II
ANALYSIS OF RUNOFF OF Lake BUHI Drainage Basin
TYPHOON DINAH, June 1974

JUNE 1974	Hour	Lake BUHI Level: G.H., m.	Lake BUHI Level: Elev. m, msl	Discharge from lake: cms.	Discharge from lake: Av. Cms.	Δ Lake Level	Discharge Equiv. of Storage	INFLOW to Lake, cms.	Rainfall at BUHI, mm.: Hr.	Rainfall at BUHI, mm.: Obs.	Rainfall at BUHI, mm.: Σ
7	6	1.58	95.37						8	0	
	18	1.60	95.39						17	26.7	26.7
8	6	1.60	95.39	6.6	6.1	0	0	6.1	8	0	26.7
	18	1.64	95.43	6.6	6.35	+.04	16.7	23	17	10.4	37.1
9	6	1.33	95.62	10.	8.3	+.19	79.2	87	8	104.1	141.2
	18	2.37	96.16	29.	19.5	+.54	225	245	17	165.2	306.4
10	6	GAGE WAS SUBMERGED	e 96.85	87.	58	+.69	287.5	345	8	340.6	647.0
	18		e 97.00	110.	98.5	+.15	62.5	461	17	6.8	653.0
11	6		e 96.92	97.	103.5	-.08	-33.3	70	8	3.1	656.9
	18		e 96.84	86.	91.5	-.08	-33.3	38	17	3.5	660.4
12	6	2.98	96.77	77	81.5	-.07	-29.2	52	8	0	660.4
	18	2.91	96.70	69	73	-.07	-29.2	44	17		
13	6	2.82	96.61	61	65	-.09	-37.5	28	8		660.4
	18	2.80	96.59	59	60	-.02	-8.3	52			
14	6	2.73	96.52	53	56	-.07	-29.2	27	8	18.8	679.2
	18	2.65	96.44	46	49.5	-.08	-33.3	16			
15	6	2.59	96.38	42	44.2	-.06	-25.0	19			
	18	2.53	96.32	38	40.2	-.06	-25.0	15			
16	6	2.47	96.26	34.5	36.2	-.06	-25.0	11	8		679.2
	18	STAFF GAGE WAS BROKEN WHEN (THE REMNANT) APPEARED THE WATER LEVEL WAS LESS (THAN ON JUNE 16).	e 94.25								
17	6		e 96.20						8	10.4	689.6
	18		e 96.15								
18	6		e 96.10								
	18		e 96.06								
19	6		e 96.02								
	18		e 95.99								
20	6		e 95.96								
	18		e 95.93								
21	6		e 95.91								
	18		e 95.89								
22	6	2.08	95.87						8		689.6
	18	2.07									
23	6	2.05							8	10.9	700.5
	18	2.03									
24	6	2.00									
	18	1.98									
25	6	1.96									
	18	1.94									
26	6	1.92									
	18	1.91									
27	6	1.89									
	18	1.87									

RAINFALL at BUHI AND DISCHARGE INTO AND OUT OF LAKE BUHI, TYPHOON ALIANG, JANUARY 1972

154

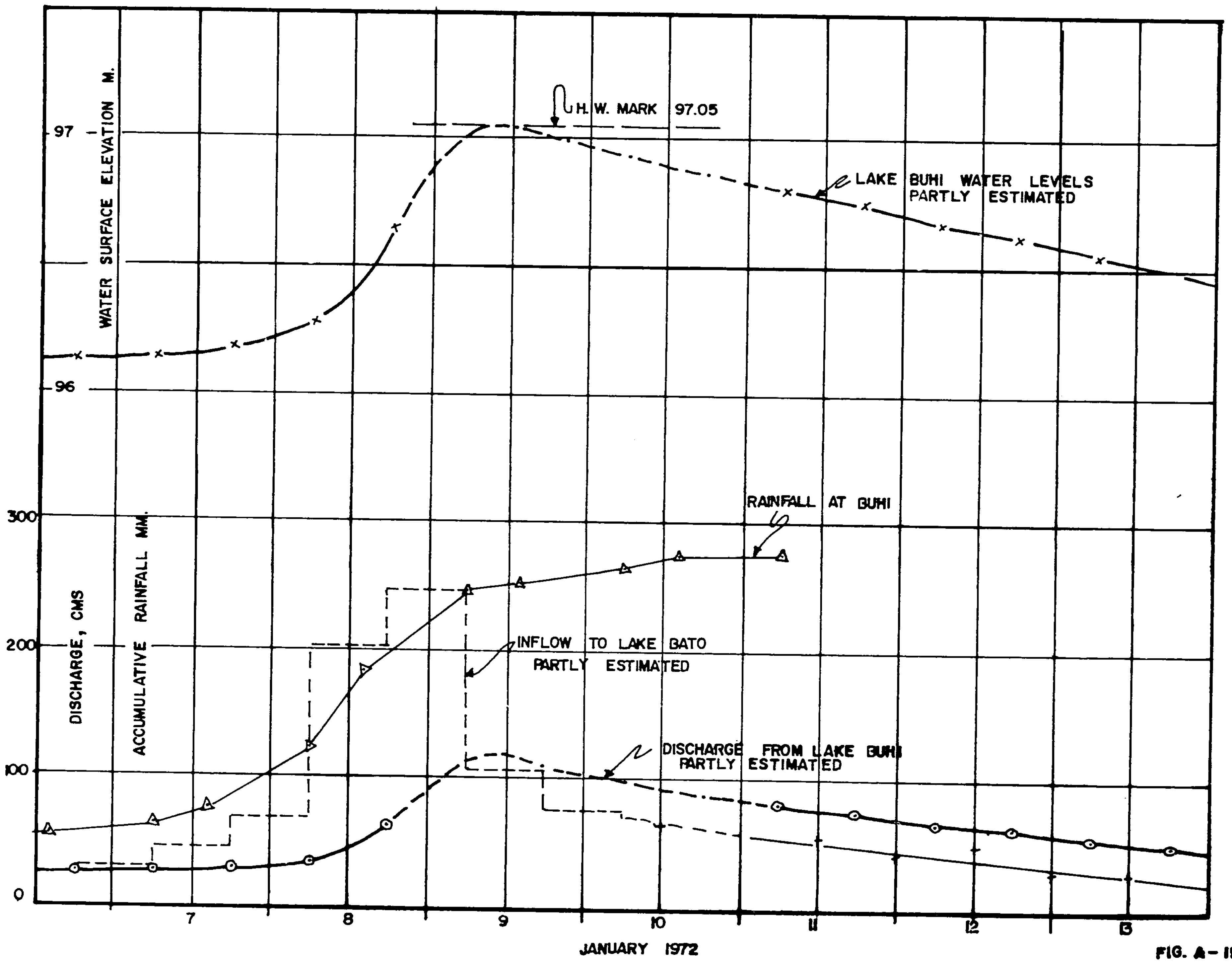


FIG. A-154

154a

TABLE A-12

ANALYSIS OF RUNOFF OF Lake BUHI Drainage Basin
TYPHOON ALIANG JANUARY 1972

JAN. 1972	Hr.	Lake BUHI Water Level, m: * G.H.	Lake BUHI Water Level, m: MSL	Lake BUHI Outlet Discharge: CMS	Lake BUHI Outlet Discharge: Av	Δ Lake Level, m	Q Equiv. of Storage cms	Inflow to Lake, cms
6	6	2.35	96.14	28.0				
	18	2.35	96.14	28.0	28.0	0	0	28
7	6	2.36	96.15	28.4	28.2	+.01	+ 4.2	32
	18	2.40	96.19	30.2	29.3	+.04	+ 16.7	46
8	6	2.49	96.28	35.6	32.9	+.09	+ 37.5	70
	18	2.86	96.65	65	50.3	+.37	+154.2	204
9	6	GAGE SUPERSEDED	e 97.03	115	90.	+.38	+158.3	248
	1C		e 97.01	113	114	-.02	- 8.3	106
10	6		e 96.94	100	106.5	-.07	- 29.2	77
	18		e 96.87	90	95.	-.07	-29.2	66
11	6	3.02	96.81	81	85.5	-.06	-25.0	60
	18	2.97	96.76	76	78.5	-.05	-20.8	58
12	6	2.90	96.69	69	72.5	-.07	- 29.2	43
	18	2.85	96.64	64	66.5	-.05	-20.8	46
13	6	2.78	96.57	58	61.	-.07	-29.2	32
	18	2.72	96.51	53	55.5	-.06	-25.0	30
14	6	2.65	96.44	46	49.5	-.07	-25.2	20
	18	2.62	96.41	44	45.	-.03	-12.5	32
15	6	2.58	96.37	42	43	-.04	-16.7	26
	18	2.57	96.36	41	41.5	-.01	- 4.2	37
16	6	2.55	96.34	39	40.	-.02	- 8.3	32
	18	2.53	96.32	38	38.5	-.02	-8.3	
17	6	2.51	96.30	37	37.5	-.02	- 8.3	
	18	2.49	96.29	36	36.5	-.02	-8.3	
18	6	2.46	96.25	34	35.	-.03	- 12.5	
	18	2.44	96.23	33	33.5	-.02	- 8.3	
19	6	2.41	96.20	31	32.	-.03	- 12.5	
	18	2.39	96.18	30	30.5	-.02	- 8.3	
20	6	2.37	96.16	29	29.5	-.02	-8.3	
	18	2.35	96.14	27.5	28.2	-.02	- 8.3	
21	6	2.32	96.11	26.5	27.	-.03	-12.5	
	18	2.31	96.10	26.	26.2	-.01	-4.2	
22	6	2.29	96.08	25	25.5	-.02	- 8.3	
	18	2.28	96.07	24.5	24.8	-.01	-4.2	
23	6	2.26	96.05	23.5	24.0	-.02	-8.3	
	18	2.25	96.04	23.	23.2	-.01	- 4.2	
24	6	2.23	96.02	22.5	22.8	-.02	- 8.3	
	18	2.22	96.01	22	22.2	-.01	-4.2	
	6	2.20	95.99	21	21.5	-.02	-8.3	
	18	2.19	95.98	20.7	20.8	-.01	- 4.2	
	6	2.18	95.97	20.4	20.5	-.01	-4.2	
	18	2.17	95.96	20.	20.2	-.01	- 4.2	

BUHI Rainfall, mm.

DATE	Hr.	Obs.	Σ
3	6	17.3	17.3
	14	3.1	20.4
4	6	5.8	26.2
	14	2.3	28.5
6	6	1.8	30.3
	14	3.1	33.4
6	6	21.1	54.5
	14	2.5	57.0
7	6	7.1	64.1
	14	10.9	75.0
8	6	49.3	124.3
	14	55.7	184.0
9	6	63.0	247.0
	14	6.9	253.4
10	6	12.4	266.3
	14	11.2	277.5
11	6	0.	277.5
	14		

* THE RECORD SUGGESTS THAT THE GAGE WAS OBSERVED AT OTHER HOURS THAN THOSE STATED

Appendix B
Mathematical Model of the Bicol System
August 1976

COMPREHENSIVE WATER RESOURCES DEVELOPMENT STUDY

BICOL RIVER BASIN
LUZON ISLAND, PHILIPPINES

APPENDIX B

MATHEMATICAL MODEL OF THE BICOL SYSTEM

August 1976

TAMS-TAE JOINT VENTURE

New York Manila

BICOL RIVER BASIN DEVELOPMENT PROGRAM
Baras, Canaman, Camarines Sur

APPENDIX B

TABLE OF CONTENTS

APPENDIX B

LIST OF TABLES

LIST OF FIGURES

APPENDIX B

MATHEMATICAL MODEL OF THE BICOL SYSTEM

INTRODUCTION

The contract between the BRBC and the TAMS/TAE Joint Venture required an evaluation of several flood control schemes which had been proposed in previous studies and analyzed by the Asian Institute of Technology using a mathematical model formulated to represent the basin and the flood control measures in a schematic way. In view of the need for a more detailed computation of discharges and elevations in the river system and its flood plains, and to simulate the behavior of some flood protection measures not represented in the AIT model, it was decided to construct another model with the use of Program LATIS developed by TAMS and used in a number of similar cases. This was considered more convenient than to try to modify the AIT model to increase its degree of detail, within the time and budgetary constraints imposed by the BRBC-TAMS/TAE contract.

In addition, the LATIS model was prepared also to represent low flow conditions for analysis of salinity intrusion in the lower Bicol system after field data was collected.

THE EQUATIONS OF MOTION IN CHANNEL NETWORKS AND THEIR SOLUTIONS IN FINITE DIFFERENCES

The one-dimensional dynamic equation of flow in an open channel is written:

$$\frac{\partial H}{\partial x} = -\frac{1}{g}\frac{\partial V}{\partial t} - \frac{|Q|\,Q}{K^2} - \frac{V}{g}\frac{\partial V}{\partial x} \qquad (1)$$

where H is the water surface elevation; x, the length of the channel; t, the time; g, the acceleration due to gravity; V, the velocity; Q, the discharge; and K, the conveyance.

The continuity equation may be written for node i of a channel network:

$$\sum_{j=1}^{N} Qj_i = A_i \frac{\partial H_i}{\partial t} \quad H_i \qquad (2)$$

where the subscript j indicates any of the N nodes connected to Node i and A_i is the surface area associated with the node, (a function of H_i) which will serve as a reservoir.

Equations 1 and 2 are not linear but do not contain terms with products of the derivatives. To solve them they will be expressed in finite differences and linearized. The quadratic term in the discharge in Equation 1 is substituted by the product of the unknown discharge at time t and the discharge computed one (or two) time intervals before for the same channel reach, which reduces the term to a linear one. The other non-linear terms are similarly linearized by using previously computed values of the variables in a recursive form.

When the space derivatives are defined in terms of the unknown values of the variables, the resulting system of linear equations is implicit, that is, each equation contains more than one unknown. If the space derivatives are defined in terms of previously computed values of the unknowns, each equation contains only one unknown, provided by the temporal derivative, or by the friction term, and the system is explicit.

There are advantages and disadvantages to each system. Implicit systems are in general unconditionally stable, independently of the time interval. Consequently, relatively long time intervals may be used, which reduces the number of operations and allows for the representation of long periods of real time with reasonable computer times. Explicit systems are subject to the Courant condition, which imposes a limit to the integration time interval, depending on the depth and length of the channel reach and, in general, they are more suitable for relatively short real time representations. Implicit systems are somewhat difficult to modify once the network is defined and unless the matrices are tri-diagonal, each solution may consume a considerable amount of computer time, which tends to compensate for the savings obtained by increasing the time interval and therefore, decreasing the number of solutions for a given integration.

In addition to the Courant condition, which applies to the explicit solution, there is a limitation on the time increment which applies also to implicit solution. When parts of the network are gradually flooded, long time intervals may be conducive to solution "blowups" if the volumes of water which flow through a link during the time interval are large in comparison with the capacity available at the node being flooded.

Instabilities may also appear when models present abrupt changes in hydraulic or topographic characteristics, such as reach length, conveyance, cross-sectional area, depth, flood plain width and area, etc.

SOLUTION STRATEGY FOR THE BICOL SYSTEM

In view of the complicated geometry of the problem at hand, including two rivers and their estuary and a substantial flood plain, it was decided to use an explicit finite difference system which would allow progressive flooding of links located outside of the permanent channels of the system. There are in the natural river system, a number of multiple connections and its complexity increases when the proposed flood protection measures are represented.

The use of an implicit solution system would have resulted in a less flexible procedure, and the introduction of modifications would have been more time consuming.

PROGRAM LATIS

The Bicol Mathematical Model was formulated using Program LATIS which had been used in a number of previous network analyses, and has been continuously revised to extend its range of application. LATIS is explicit, so it is subject to the Courant condition which, for the LATIS procedure may be written:

$$\Delta t < \frac{L_{ij}}{2\,(V_{ij} + \sqrt{g y_{ij}})} \qquad (3)$$

In which: Δt is the time interval; L_{ij}, the length of reach (or link) ij; V_{ij}, the maximum absolute value of the velocity in the link; g, the acceleration due to gravity; y_{ij}, the depth.

The equations are written in terms of the variables for three consecutive times: t, t-1, and t-2 each separated by a constant Δt. The variables for time t are unknown; the previous ones are already computed. To obtain the variables for the interval (t) - (t-2 Δt) a weighed value is computed. Referring to water surface elevation:

$$H^{(t-1)+a} = (1+a)\,H^{(t-1)} - aH^{(t-2)} \qquad (4)$$

in which a is a constant less than one in absolute value.

The dynamic equation may then be written for link ij of the network as follows:

$$
\begin{aligned}
&((1+a)\, H_j^{(t-1)} - a\, H_j^{(t-2)}) - ((1+a)H_i^{(t-1)} - a\, H_i^{(t-1)}) = \\
&- \frac{L_{ij}\, (Q_{ij}^{(t)} - Q_{ij}^{(t-2)})}{2g \;\Delta t((1+a)\, A_{ij}^{(t-1)} - a\, A_{ij}^{(t-2)})} - \frac{L_{ij} \left| Q_{ij}^{(t-2)} \right| Q_{ij}^{(t)}}{(\mathrm{CALIB}\; ((1+a)\, K_{ij}^{(t-1)} - aK_{ij}^{(t-2)}))^2} \\
&+ \frac{((1+a)\, Q_{ij}^{(t-1)} - a\, Q_{ij}^{(t-2)})}{g((1+a)A_{ij}^{(t-1)} - a\, A_{ij}^{(t-2)})} \Bigg[((1+a)\, \left(\frac{B_{ij}}{A_{ij}}\right)^{(t-1)} - a\, \left(\frac{B_{ij}}{A_{ij}}\right)^{(t-2)})\, L_{ij} \\
&\cdot \frac{1}{2} \left(\frac{\sum_{l=1}^{N} ((1+a)\, Q_{il}^{(t-1)} - a\, Q_{il}^{(t-2)})}{((1+a)\, A_i^{(t-1)} - a\, A_i^{(t-2)})} + \frac{\sum_{k=1}^{M} ((1+a)\, Q_{jk}^{(t-1)} - a\, Q_{jk}^{(t-2)})}{((1+a)\, A_j^{(t-1)} - a\, A_j^{(t-2)})} \right. \\
&+ \left(\frac{((1+a)\, Q_{ij}^{(t-1)} - a\, Q_{ij}^{(t-2)})}{((1+a)\, A_{ij}^{(t-1)} - a\, A_{ij}^{(t-2)})^2} \cdot ((1+a)\, (A_{ij}^{(t-1)}\; (H_j) - A_{ij}^{(t-1)}\; H_i)) \right. \\
&\left.\left. - \; a(A_{ij}^{(t-2)}\; (H_j) \; - \; A_{ij}^{(t-2)}\; (H_i)))) \right) \Bigg] \qquad (5)
\end{aligned}
$$

In which A_{ij} is the cross-sectional area for the link at midpoint, which is a function of the average water surface elevation at nodes i and j; CALIB is a calibration constant, which modifies the conveyance and is equal to the ratio of the Manning's n used to determine K and a revised value, when the dimensions of the channel are kept constant; K_{ij} is the conveyance of link ij corresponding to the average water surface elevation at nodes i and j; B_{ij} is the channel top width; L and K are respectively the nodes connected to i and j; A_i and A_j are the surface areas of nodes i and j; $A_{ij}(H)_j$ and $A_{ij}(H)_i$ are cross-sectional areas of the link at nodes j and i, which are functions of water surface elevations H_j and H_i.

The third term in the right hand member is a finite difference expression of the convective inertia term $(V/g)\ \partial V/\partial x$, in which the spacial velocity derivative has been obtained using first the continuity equation applied to link ij, and second the continuity equation applied to nodes i and j to obtain an average value of the temporal derivative of H, which is required in the first one.

In many models this term is considerably smaller than the other two in the right hand side of Equation 5, respectively the local inertia and the friction. In addition, some solution instabilities may start in its computation and Program LATIS has an option to ignore it. This is justified when the solution is gradually changing, as in the flood problems of the Bicol Basin, but would be required in a fast moving wave problem such as a dam collapse wave.

Program LATIS admits links with constrictions. A check is first made to find the submergence conditions, for which the depths between the downstream node and the bottom elevation at the constriction and between the upstream node and the same bottom elevation are computed. If the ratio of the former and latter is less than 2/3, a critical flow is assumed and the discharge is computed using the corresponding formula for critical flow in a constriction, so Equation 5 is bypassed (1) (2). If the ratio is larger than 2/3 a constriction head loss term is added in Equation 5 to the friction loss term, using standard relations for bridge pier constrictions [1] [2], but the convective term is ignored.

If the link is a boundary link, (or pseudo link), a hydrograph is input as a table of discharges and times, again Equation 4 is bypassed, and the discharge is interpolated. These discharges may correspond to a hydrological inflow or to a diversion subject to a time rule.

If a weir is present at the end of a link, the discharge is interpolated from a table of discharges versus elevations at the upstream node. If a tidal gate is present at a link, the discharge is computed only when the water surface elevation at the upstream node is higher than the downstream one. Otherwise it is set to zero.

There may be river and overflow links. In the first case, if one of the nodes is wet, the other will become wet when the water surface elevation in the wet node is higher than the bottom elevation in the dry node. Overflow links are defined by the bank elevations at both nodes. In this case, if one of the nodes is wet, and the other dry, the latter will become wet when the water surface elevation of the neighbor node reaches a level higher than both bank elevations. When both nodes are wet the program will compute the discharge. Otherwise the link will not be acknowledged.

Overtopping of roads may be represented assuming a fictitious constriction with bottom elevation at the road crest.

The continuity equation referred to a node i connected to N nodes j may be written in finite differences as:

$$2 \Delta t \sum_{j=1}^{N} \left((1+a)\, Q_{ij}^{(t-1)} - aQ_{ij}^{(t-2)}\right) = \left((1+a)A_i^{(t-1)} - aA_i^{(t-2)}\right) \left(H_i^{(t)} - H_i^{(t-2)}\right) \quad (6)$$

Equation 6 is bypassed in the case of pseudo-nodes, where a table of elevations versus time may be input, or a sinusoidal tide may be computed. In the first case, interpolation may be linear or sinusoidal. If sinusoidal interpolation is used, the input table must contain the successive maxima and minima of the elevation hydrograph.

Figure B-1 shows a schematic flow chart of the program, which in its present version requires approximately 230 K bytes of memory, and is able to analyze a network of 250 nodes and 250 links with up to 35 constrictions.

Printouts are obtained at prescribed intervals (one hour for the Bicol model) and consist of tables of elevations and discharges for all nodes and links.

The program may also be applied to two-dimensional problems, using a rectangular network with automatic computation of hydraulic characteristics. In this case, a shear term is added to Equation 5 to take care of lateral transfer of momentum.

LATIS may be coupled with Program SALTI, for salinity propagation in a channel network, which was developed by TAMS following a strategy similar to that of G. T. Orlob and others.[3]

The topographical information for each node is obtained from maps where their limits are established. These limits may be topographic features or arbitrary lines not unlike Thiessen polygon sides (see Fig. B-2). The areas of each contour are planimetered within each polygon, including surface areas of channels, and input in LATIS as tables of areas-versus-elevations assigned to each node.

The channel hydraulic characteristics are computed with an auxiliary program: PRELATIS, which processes up to five cross-sections per link. These cross-sections are input as tables of coordinates of up to 30 points with up to 29 different values of Manning's n. The program then computes cross-sectional areas and conveyances for each cross-section and obtains representative areas and conveyances for the link by averaging the values obtained for each cross-section at discrete elevations. These average values are printed and punched in LATIS format. PRELATIS also computes the steady state uniform flow corresponding to each link using the bottom slope. This feature is useful to establish a plausible value of water surface elevation for initial condition estimates. Finally, PRELATIS may compute the volumes of the link at each elevation. This is desirable when salinity studies are coupled with a hydraulic study. In that case, LATIS may use volumes instead of areas in the continuity equation of each link. The volumes are then computed as the sum of one-half of each of the volumes computed for each link connected to the node at each elevation.

MATHEMATICAL MODEL OF THE BICOL SYSTEM

The model was constructed with 140 nodes generally of no more than 10 square km and 165 links with lengths ranging between 1500 and 5000 m. Figs. B-2 and B-3 show respectively a map and a schematic representation of the model. The links form a network which represents the physical channel network. Some of the links follow the rivers and others represent possible overflow on the flood plain. In this case, the links were assumed following logical flow patterns according to topographic features, such as natural relief, roads, railroads, etc. This required a good qualitative knowledge of the real system.

Two existing man-made cutoffs (Numbers 1 and 2) are also represented in the model. The model has five pseudo nodes in San Miguel Bay where the tide and surge conditions are input as identical time histories; or as a sinusoidal function to represent low water conditions. The other boundary conditions are hydrographs of discharges versus time input in the pseudo-links. There are 49 such hydrographs, some of them representing direct rainfall in the flood plain and others tributary flows. The program admits transferring a hydrograph to more than one link, whether multiplied or not by a constant factor. This feature is useful to avoid needless repetition of input work, especially for ungaged tributary flows, when they are estimated from similar unit-hydrographs, or in the case of direct rainfall contribution.

After several trials, it was concluded that the longest feasible time interval for this system, is around 90 seconds. This Δt was adopted for final calibration and production runs.

Typhoon Sening of 1970 and its attendant flood and surge were used for calibration. The hydrological information was obtained from published records and from an Asian Institute of Technology Report.

A model run of 100 hours of real time takes approximately 3.3 minutes of CPU time, in an IBM 370/168 computer system.

CALIBRATION

Calibration was obtained by numerical experimentation, changing CALIB, the configuration of some links, the area of some nodes, etc., until a satisfactory agreement is obtained between computed and observed rules.

Figs. B-4, 5, 6, 7 and 8 are graphs of water surface elevations and times for several stations of the system. It may be seen that the agreement between recorded and computed elevations was satisfactory.

Fig. B-4(A) shows the input tide at the mouth (Node 1, boundary condition) as established in the above mentioned report by the Asian Institute of Technology, which shows the important surge produced by the Typhoon. Fig. B-4(B) shows the derived tide at Balongay, Node 3, where the effects of the high fresh water flows are already noticeable. It may be observed that the mean tide level is raised for a longer time than at Node 1 and the tidal amplitude is substantially decreased. In addition, the tidal curves show the usual lack of symmetry in tidal streams, where the ebb branch is longer than the flood branch in each tidal cycle. No detailed records of these tides were obtained.

The model reproduced stage-discharge rating curves computed for the gaging stations not subject to tidal fluctuations: especially Sto. Domingo and Ombao, on the Bicol, and Sabang on the Sipocot.

The model showed that the important discharges of the Pawili River were able to reverse temporarily the flow of the Bicol upstream at the junction, a phenomenon that has been qualitatively observed during floods.

The final calibration Manning's coefficients for the river channels in the model are given in Table B-1.

TABLE B-1

FINAL CALIBRATION MANNING'S COEFFICIENTS

River	Reach	Manning's Coefficient
Bicol	Estuary	0.028
Bicol	Estuary - Node 23	0.028
Bicol	Node 23 - Node 26	0.028 - 0.037
Bicol	Node 26 - Node 29	0.037
Bicol	Link 29 - 30	0.028
Bicol	Node 30 - Lake Bato	0.037
Sipocot	Estuary - Node 74	0.028
Sipocot	Node 74 - Node 80	0.028 - 0.037

In addition to the flood simulation runs, calibration was also made using low fresh water inflow and a sinusoidal tide at Node 1. The observed lag for high water at Naga is 2 hours with respect to Balongay. This lag was adequately reproduced by the model.

PRODUCTION RUNS

In addition to the calibration runs, the model was used to study the effects of several proposed flood control measures and to compare the relative merits of them.

These runs were made using the hydrological and tide inputs for Typhoon Sening, to obtain comparisons between the various cases and the calibration run in the presence of a major flooding event. Therefore, the comparisons are more reliable than if the model had been extrapolated to conditions other than those used for calibration.

The maximum water surface elevations should be rounded to the nearest tenth of a meter, as neither data nor computation accuracy warrant further precision. Table B-2 provides figures to the nearest centimeter only for comparison purposes.

The following schemes were simulated:

PR 1. Lake Bato Diversion. It was assumed that all the outflow of Lake Bato was diverted to the Ragay Gulf. Reductions of maximum water surface elevation with respect to the calibration run were obtained in the upper reaches of the Bicol River, up to 2 meters at Santo Domingo. There was no appreciable reduction at Naga City or in the Sipocot River.

PR 2. Lake Bato and Pulantuna Diversions. The outflow from Lake Bato was assumed diverted and, in addition, all the Pulantuna Reservoir outflow was diverted to the San Miguel Bay. For the Bicol River, the reductions were practically equal to those obtained in the previous case. In addition, there were substantial reductions in maximum water surface elevations at Sabang and Sipocot in the Sipocot River.

PR 3. Tidal Barrier. A tidal barrier was simulated between Nodes 2 and 3, assuming that it would be closed when the San Miguel Bay water surface elevation was higher than at Node 3. A reduction of 1.6 meters was obtained in the estuary, but it decreased to about 0.1 m at Naga City, with a similar reduction at Libmanan. Fig. B-9 shows the negligible effects of the barrier upstream of Naga City.

PR 4. Diversion of 200 cms from Node 28 to Ragay Gulf. This diversion was simulated with a new pseudo-link 28-51 where a discharge of -200 cms was input. Node 51 was not previously used in the network. The maximum water surface elevations at Naga City and Ombao were reduced by 0.2 m and 0.3 m respectively. Fig. B-10 shows the effects of this diversion on flood elevation hydrographs at Nodes 18, 25, 29 and 33.

PR 5. Sipocot Diversion Channel. This channel was simulated transposing Node 51 of PR 4 to form a new link of 79-51 which was provided with a rating curve. For this, uniform flow was assumed for a bottom width of 60 meters, intake bottom elevation at 8 m MSL and a slope of 0.00077. A weir was assumed in the river with crest elevation at 8 m MSL and a width of 100 m.

The Sipocot River elevations were reduced by 3 meters at Sipocot and 0.3 m at Sabang. There was no appreciable reduction in the Bicol.

PR 6. Ragay Diversion with a 100-m wide side spillway. Node 51 was again transposed to form Link 28-51, which was provided with the rating curve of a 100-m wide spillway with crest elevation at 0.6 m.

The maximum elevation at Naga (Node 18) was reduced by 0.3 m, and at Ombao by about 0.5 m.

PR 7. Cutoff No. 3 with bottom width of 20 m. This channel was simulated connecting Nodes 22 through 14 (See Figs. B-2 and B-3). No levees were assumed in the system. The maximum water surface elevation at Naga (Node 18) was reduced by about 0.1 m. The maximum reduction in water surface elevation (0.4m) was calculated for Node 22, at the inception of the channel.

PR 8. Cutoff No 3 with bottom width of 10 m. The channel was again simulated connecting Nodes 22 through 14 (See Figs. B-2 and B-3). Levees were simulated along the left bank of the Bicol by removing links 21-41; 20-41; 19-112; 18-112; 17-111 and 16-111, which were introduced in the model to simulate the overbank flows. The maximum water surface elevation at Naga (Node 18) was increased by 0.1 m as a result of the presence of the levees. The maximum decrease in water surface elevation (0.2) occurred at Node 22.

PR 9. Cutoff No. 3 with bottom width of 10 m, Levees on Left Bank, Lake Bato Diversion and Control Structure, Downstream of the Pawili. Since the Pawili is responsible for substantial flooding, it was considered convenient to simulate a control structure that would reduce the peak discharges downstream and would increase the storage effect of Lake Baao, enhancing bank flows through Link 30-31. The structure, simulated in Link 30-29, would consist of an ogee weir with crest elevation at 5.0 m MSL, width of $\dot{B}$ = 25 and a metric discharge coefficient $C = Q/(B\ H^{3/2}) = 2.0$. Lake Bato was assumed diverted with no outflow as in PR 1. As was expected, this device compensated for the effect of the levees located on the left bank, which were simulated as in PR 8. The maximum water surface elevation at Naga was practically equal to that obtained in the calibration run (only 0.05 m higher), but the duration of water surface elevation above 2.5 meters was considerably reduced.

PR 10. Cutoff No. 3 with bottom width of 10 m, Levees on Left Bank, Uncontrolled Lake Bato, and Control Structure Downstream of the Pawili. This scheme was equal to that of PR 9, except that Lake Bato was assumed uncontrolled with no diversion simulation. The control structure in Link 30-29 was responsible for compensating the effects of the levees, and the maximum water surface elevation at Naga was practically unchanged with respect to calibration conditions. However, the duration of levels above 2.5 meters was considerably reduced. Reductions of 0.2-0.4 m were computed for other nodes downstream of the control structure such at 25 and 29.

On the other hand, elevations upstream of the control structure were increased although the levels of Lake Bato were not substantially altered with respect to calibration conditions. Fig. B-11 shows the effects of configuration for PR 10 through comparison of water surface elevation hydrographs for Nodes 18, 25, 29 and 33.

Summary of Results. Table B-2 shows a summary of maximum water surface elevations for the whole system. It may be observed that the benefits would be localized in the vicinity of the flood control schemes.

None of the flood control schemes produced important changes in maximum water surface elevation at Naga City.

B-12

TABLE B-2

COMPARISON OF MAXIMUM ELEVATIONS
(Typhoon Sening Flood and Surge)

Location	Node No.	PR 1 Lake Bato Diversion	PR 2 Lake Bato & Pulantuna Diversions	PR 3 Tidal Barrier	PR 4 Diversion (200 cms) Ragay	PR 5 Sipocot Diversion	PR 6 Ragay Diversion	Calibration 1*
Balongay	3	3.44	3.43	1.84	3.44	3.44	3.45	3.44
Cutoff No. 1	11	2.55	2.52	1.99	2.52	2.54	2.51	2.55
Naga	18	2.94	2.93	2.86	2.78	2.96	2.63	2.96
Ombao	29	7.03	7.03	7.73	7.40	7.74	7.26	7.74
Sto. Domingo	33	7.67	7.67	9.83	9.80	9.83	9.78	9.83
Libmanan	69	3.35	3.25	3.23	3.35	3.31	3.35	3.35
Sipocot	77	12.41	3.54	12.41	12.41	9.51	12.41	12.42
Sabang	79	13.31	3.66	13.31	13.31	13.02	13.31	13.31
Lake Bato	35	7.67	7.67	10.36	10.34	10.36	10.33	10.36

* Production runs 1 through 6 were made using calibration 1.

TABLE B-2 (Cont.)

COMPARISON OF MAXIMUM ELEVATIONS
(Typhoon Sening Flood and Surge)

Location	Node No.	PR 7 Cutoff No. 3 20M wide	PR 8 Cutoff No. 3 10M wide	PR 9 Control Structure Link 30-29	PR 10 Control Structure Link 30-29	Calibration 2**	Calibration Final
Balongay	3	3.44	3.44	3.44	3.44	3.44	3.44
Cutoff No. 1	11	2.62	2.67	2.65	2.65	2.67	2.56
Naga	18	2.87	3.05	3.00	3.02	2.95	2.96
Ombao	29	7.65	7.62	6.68	7.44	7.62	7.74
Sto. Domingo	33	9.88	9.88	8.36	10.21	9.88	9.83
Libmanan	69	3.34	3.33	3.33	3.33	3.32	3.35
Sipocot	77	12.41	12.42	12.41	12.41	12.41	12.78
Sabang	79	13.31	13.31	13.31	13.31	13.30	13.93
Lake Bato	35	10.35	10.35	8.36	10.44	10.35	10.36

** Production runs 7 through 10 were made using calibration 2.

B-13

The model printouts provide time histories of discharges at one-hour or two-hour intervals. Table B-3 shows a comparison of the maximum computed discharges for several links of the model located in the vicinity of the nodes reported in Table B-2 and for the same schemes, including calibration. All discharges are given to the nearest cubic meter per second only for comparison purpose.

It may be seen that the maximum discharges at the mouth of the river are one order of magnitude larger than the discharges in Naga City.

The effects of the proposed diversions are also clearly evident from the comparison of the schemes.

CONCLUSIONS

The mathematical model simulates hydraulic transient phenomena produced by the propagation of floods and tides in the complex Bicol System both under natural conditions extant in 1970, when Typhoon Sening struck the Bicol Peninsula.

Since all the proposed alternatives for flood control have been tested under the same hydrologic conditions, the model provides an impartial tool to ascertain their physical results. It may be seen that the flood control benefits of diversions are in general modest, as they are localized to the vicinity of the proposed projects.

The diversion canals would have effects on water surface elevations in either river but only within reaches of, say 20 km downstream of the canal inceptions, and would not have important effects on the water surface elevations at Naga City. This is to a large extent due to the contribution to flooding from the storm surge effects and the large conveyance available in the estuary.

The control structure in Link 30-29 would have a beneficial effect in the levels downstream of it, and would result in reductions in the duration of very high levels in Naga.

It may also be seen that measures for flood alleviation in the Sipocot River would have negligible effects on flood levels in the Bicol and vice-versa.

The tidal barrier would have a pronounced effect on the flood elevations in the estuary and a much more modest one at sections located upstream of the confluence of the Bicol and the Sipocot.

TABLE B-3

COMPARISON OF MAXIMUM DISCHARGES (CMS)
(Typhoon Sening Flood and Surge)

Location	Link	PR 1 Lake Bato Diversion	PR 2 Lake Bato & Pulantuna Diversions	PR 3 Tidal Barrier	PR 4 Ragay Diversion (200 cms)	PR 5 Sipocot Diversion	PR 6 Ragay Diversion	Calibration 1*
Balongay	3- 2	-7295***	-7367	2588	-7295	-7329	-7346	-7295
Cutoff No. 1	11- 5	-1203	-1179	372	-1201	-1191	-1191	-1203
Bicol River	9- 8	-1195	-1143	373	-1196	-1168	-1198	-1195
Cutoff No. 2	14-12	- 277	- 259	181	- 277	- 232	- 271	- 277
Bicol River	14-13	420	420	450	420	468	339	454
Naga	18-17	522	525	533	440	555	353	553
Ombao	29-28	363	363	505	521	505	526	505
Sto. Domingo	33-32	30	30	511	512	511	512	511
Ragay Diversion	51-28	-	-	-	- 200	-	- 368	-
Libmanan	70-69	1594	230	1595	1595	1018	1591	1558
Sipocot	78-77	1840	75	1839	1840	1048	1840	1781
Sabang	80-79	1886	9	1885	1886	2039	1886	1838
San Miguel Div.	79-51	-	-	-	-	969	-	-

---

* Production runs 1 through 6 were made using calibration 1 (New York).

*** - sign means discharge from lower-numbered to higher-numbered node.

TABLE B-3 (Cont.)

COMPARISON OF MAXIMUM DISCHARGES (CMS)
(Typhoon Sening Flood and Surge

Location	Link	PR 7 Cutoff No. 3 20M	PR 8 Cutoff No. 3 10M	PR 9 Control Structure Link 30-29	PR 10 Control Structure Link 30-29	Calibration 2**	Calibration Final
Balongay	3- 2	-7429***	-7399	-7404	-7404	-7399	-7296
Cutoff No. 1	11- 5	-1171	-1176	-1173	-	-1176	-1203
Bicol River	9- 8	-1182	-1166	-1167	528	-1166	-1194
Cutoff No. 2	14-12	- 240	- 177	- 170	232	- 177	- 277
Bicol River	14-13	490	470	447	323	470	454
Naga	18-17	486	567	526	561	567	553
Ombao	29-28	496	489	308	462	489	505
Sto. Domingo	33-32	503	503	27	497	503	511
Ragay Diversion	51-28	-	-	-	-	-	-
Libmanan	70-69	1588	1591	1586	1587	1591	1594
Sipocot	78-77	1804	1803	1801	1801	1803	1840
Sabang	80-79	1850	1852	1850	1850	1852	1886
San Miguel Diversion	79-51	-	-	-	-	-	-

** Production runs 7 through 10 were made using calibration 2 (Manila).

*** -sign means discharge from lower-numbered to higher-numbered node.

ACKNOWLEDGEMENTS

The construction of the model was made in the New York Office of TAMS. Program PRELATIS was written by Armando F. Balloffet (Systems Analyst) during studies made by URS (Denver) Corporation. He also wrote Program LATIS with the collaboration of Armando Balloffet (TAMS Associate) during previous studies made by TAMS, and made important suggestions and contributions to this model. The model was constructed and operated with the important collaboration of Virgilio A. Sahagun (BRBDP/CWRS-MO Assistant Project Manager), who was responsible for the runs made in Manila. Michael L. Scheffler (TAMS Mathematician) was responsible for substantial contributions to LATIS and the model. The collaboration of Vanop Ott Chatuproncharoen (TAMS Civil Engineer), Thomas F. Sergi and William Travis (TAMS Systems Analysts) is also acknowledged. Ricardo R. San Juan (BRBDP Systems Analyst) collaborated in the work performed to institute the model in three computer centers in Manila, where it is operational.

The hydrological information was obtained from published records and from the above mentioned AIT report, after review by Robert Kreiss (TAMS Hydrologist) and Cengiz Ertuna (TAE Hydrologist). The channel cross-sections were obtained from surveys made by BRBDP and the geographical characteristics of the basin from maps at scale of 1:50,000 and 1:25,000 by the Board of Technical Surveys and Maps of the Philippine Government.

APPENDIX B

REFERENCES

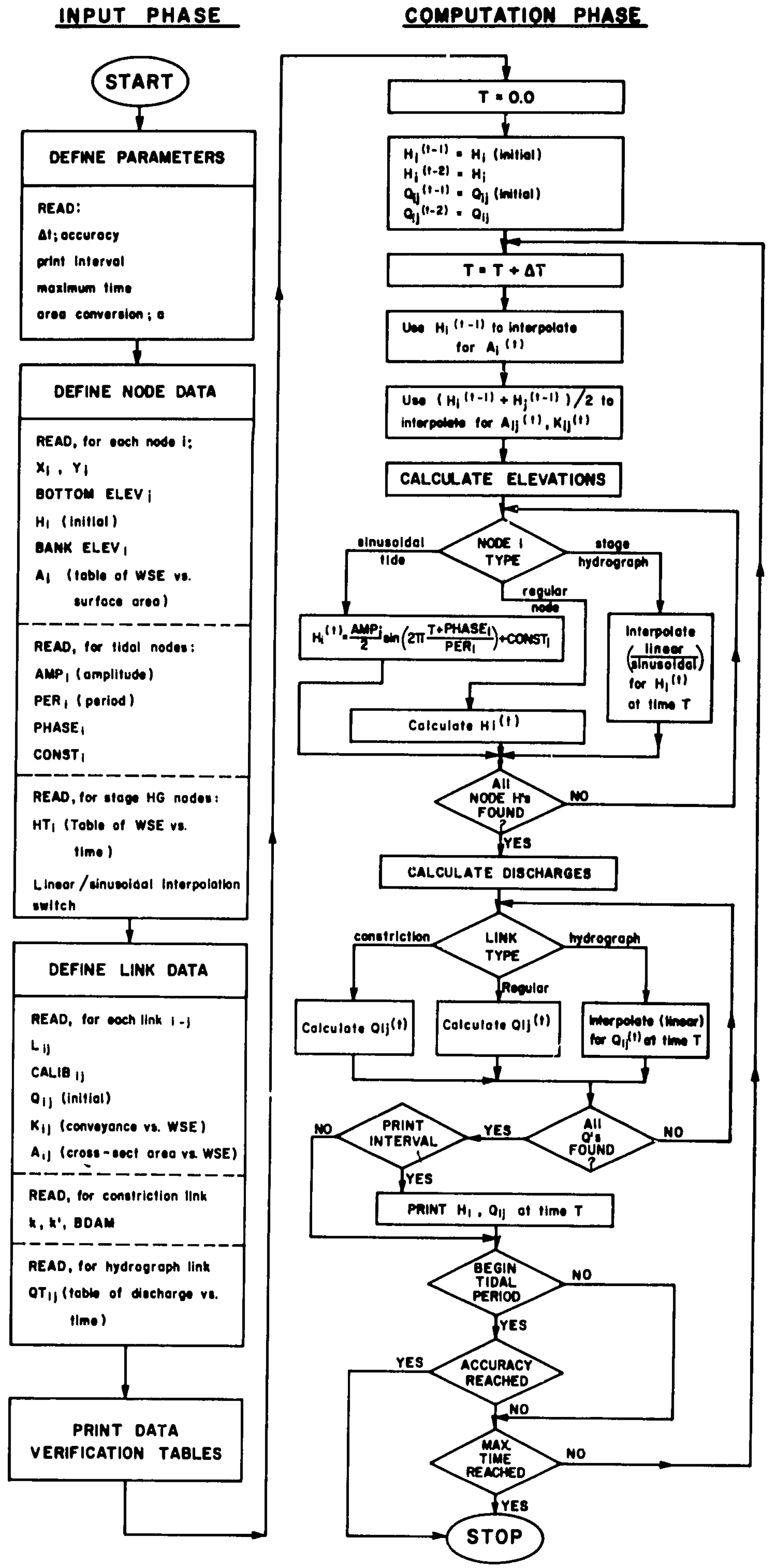
1. Balloffet, A., Cole E., and Balloffet, A. F., Dam Collapse Wave in a River, Journal of the Hydraulics Division, ASCE, Vol. 100, No. HY5, Proc. Paper 10523, May 1974, pp. 645-665.

2. Balloffet, A., One-Dimensional Analysis of Floods and Tides in Open Channels, Journal of the Hydraulics Division, ASCE, Vol. 95, No. HY4, Proc. Paper 6695, July 1969, pp. 1429-1451.

3. Orlob, G. T., Mathematical Modeling of Estuarial Systems, International Symposium on Mathematical Modeling Techniques in Water Resources Systems, Vol. 1, A. K. Biswas, ed., Department of the Environment, Canada, 1972, p. 78.

4. Ackerman, N. L., Pinkayan, S., Shi-Igai, H., Tingsanchali, T., Sahagun, V., Bicol River Basin Flood Control Investigation, Vols. I and II, Asian Institute of Technology, Bangkok, Thailand, 1975.

B-1



INPUT PHASE
COMPUTATION PHASE
START
DEFINE PARAMETERS
READ:
Δt; accuracy
print interval
maximum time
area conversion; a
DEFINE NODE DATA
READ, for each node i:
Xi, Yi
BOTTOM ELEVi
Hi (initial)
BANK ELEVi
Ai (table of WSE vs. surface area)
READ, for tidal nodes:
AMPi (amplitude)
PERi (period)
PHASEi
CONSTi
READ, for stage HG nodes:
HTi (Table of WSE vs. time)
Linear/sinusoidal interpolation switch
DEFINE LINK DATA
READ, for each link i-j
Lij
CALIBij
Qij (initial)
Kij (conveyance vs. WSE)
Aij (cross-sect area vs. WSE)
READ, for constriction link
k, k', BDAM
READ, for hydrograph link
QTij (table of discharge vs. time)
PRINT DATA VERIFICATION TABLES
T = 0.0
Hi(t-1) = Hi (initial)
Hi(t-2) = Hi
Qij(t-1) = Qij (initial)
Qij(t-2) = Qij
T = T + ΔT
Use Hi(t-1) to interpolate for Ai(t)
Use (Hi(t-1) + Hj(t-1))/2 to interpolate for Aij(t), Kij(t)
CALCULATE ELEVATIONS
NODE i TYPE
sinusoidal tide
regular node
stage hydrograph
Hi(t) = AMPi/2 sin(2π (T+PHASEi)/PERi) + CONSTi
Interpolate (linear/sinusoidal) for Hi(t) at time T
Calculate Hi(t)
ALL NODE H's FOUND ?
NO
YES
CALCULATE DISCHARGES
LINK TYPE
constriction
Regular
hydrograph
Calculate Qij(t)
Calculate Qij(t)
Interpolate (linear) for Qij(t) at time T
PRINT INTERVAL
All Q's FOUND ?
NO
YES
NO
YES
PRINT Hi, Qij at time T
BEGIN TIDAL PERIOD
NO
YES
ACCURACY REACHED
YES
NO
MAX. TIME REACHED
NO
YES
STOP

FIG. B-1

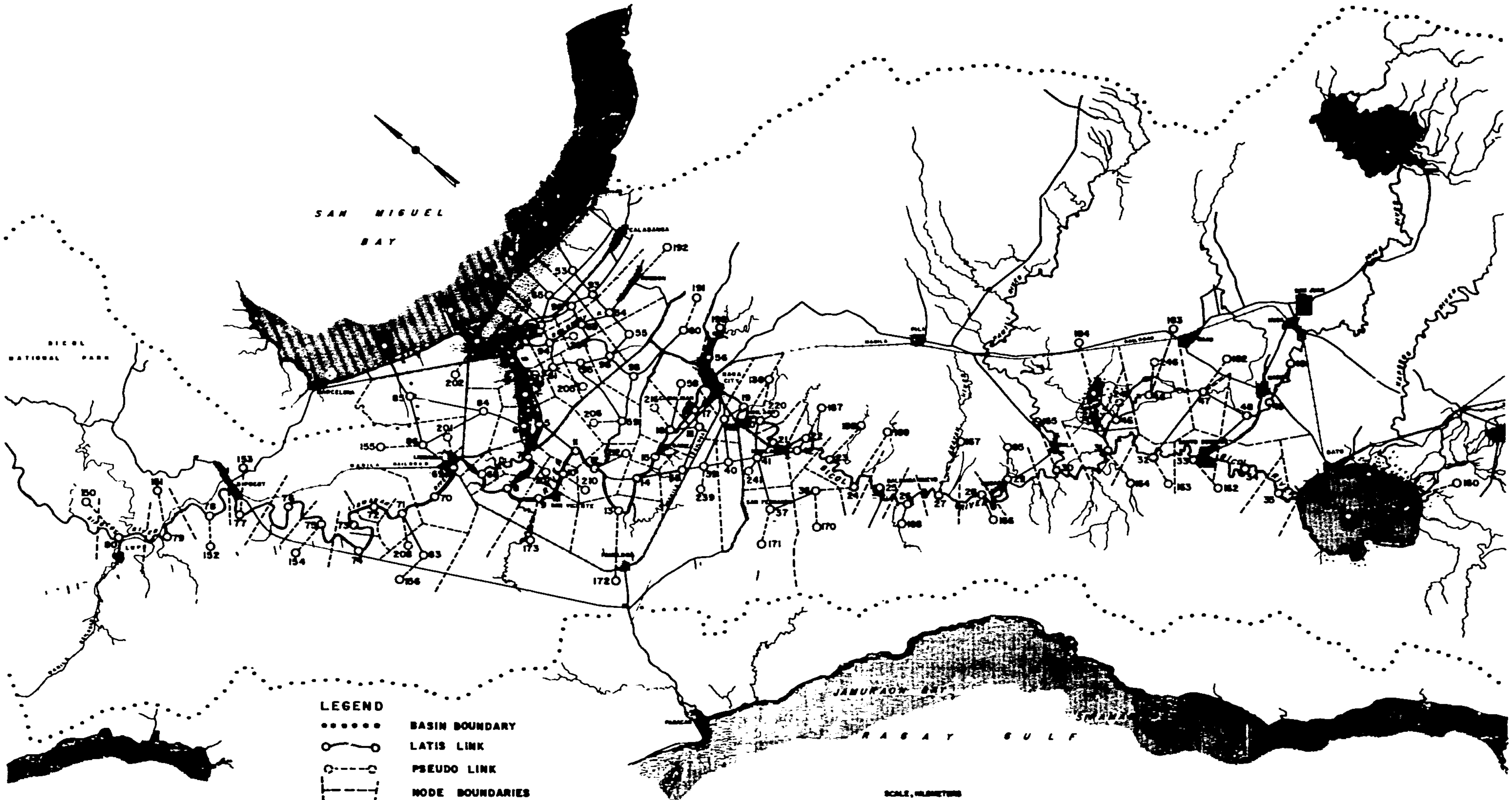

SAN MIGUEL BAY
BICOL NATIONAL PARK
JAMURAON BAY
RAGAY GULF
BICOL RIVER
LEGEND
BASIN BOUNDARY
LATIS LINK
PSEUDO LINK
NODE BOUNDARIES
SCALE, KILOMETERS

FIG. B-2

B-2

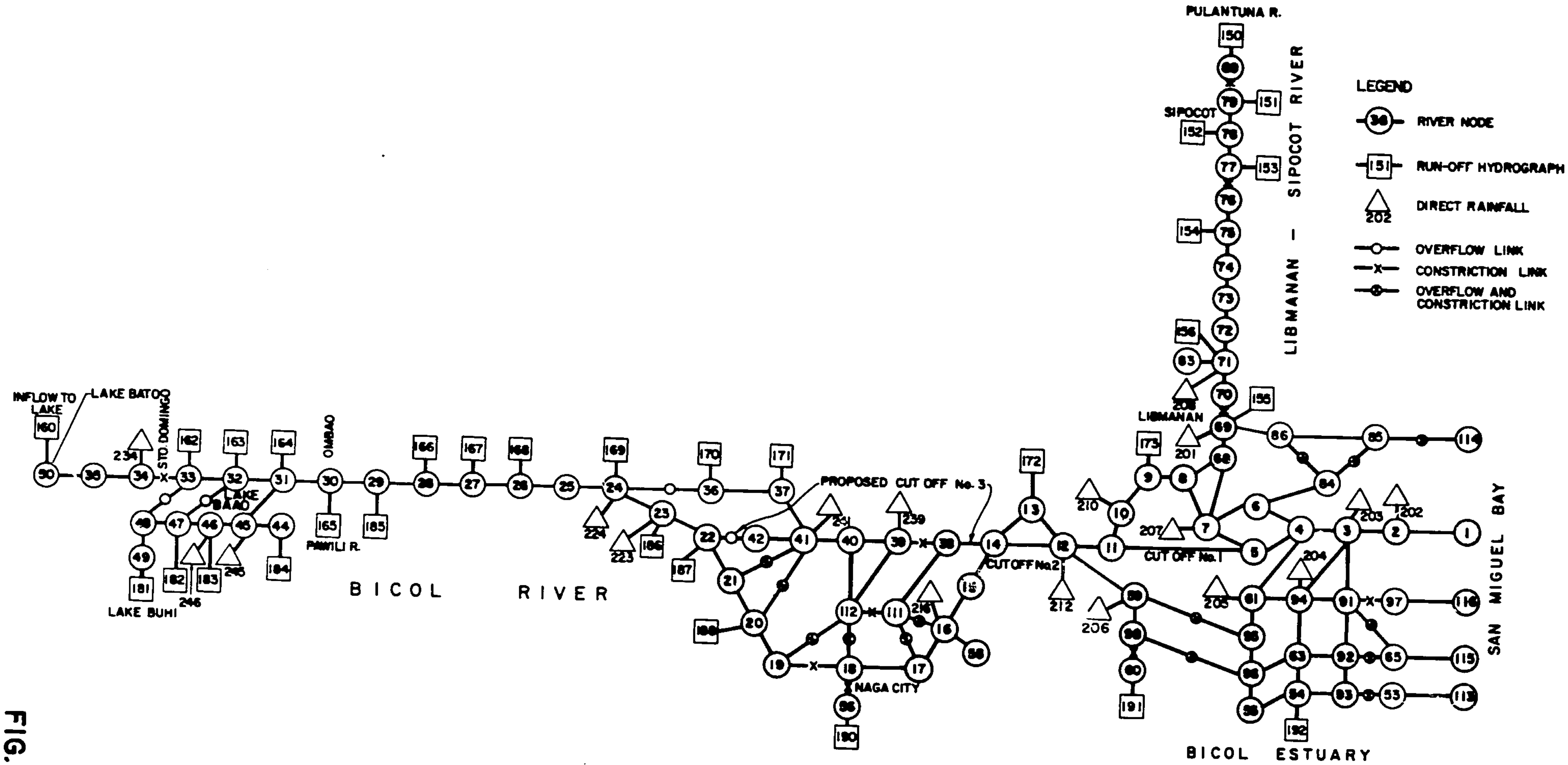
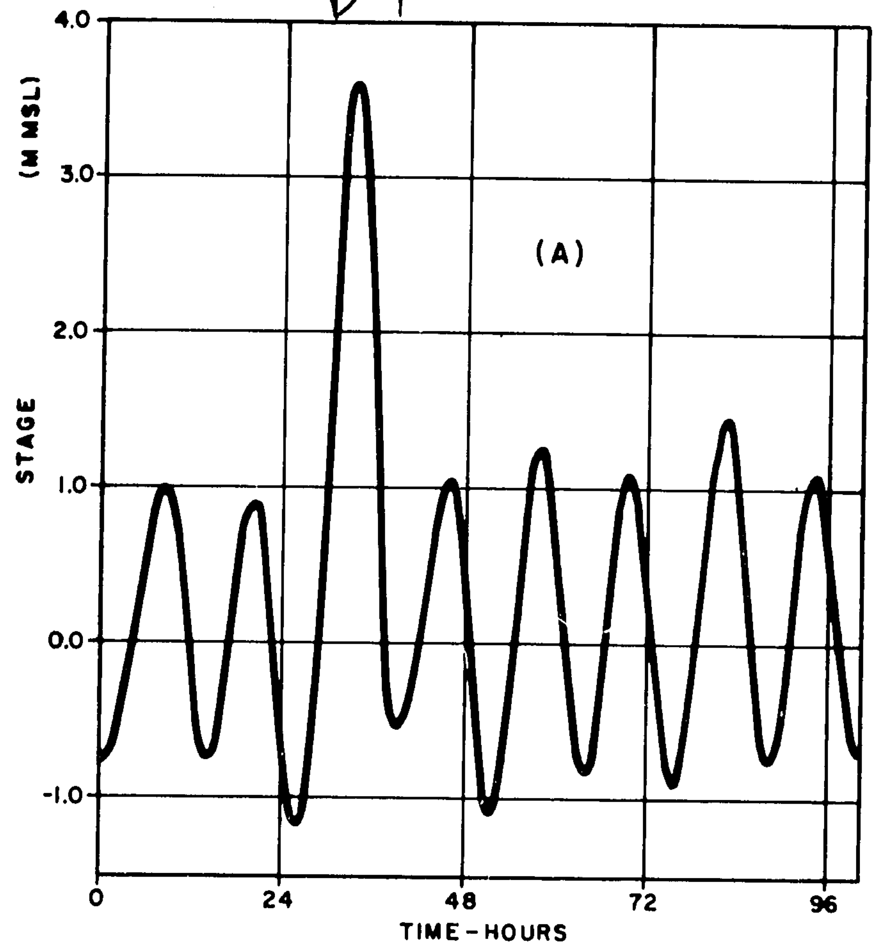

PULANTUNA R.
SIPOCOT
LIBMANAN - SIPOCOT RIVER
LIBMANAN
LEGEND
RIVER NODE
RUN-OFF HYDROGRAPH
DIRECT RAINFALL
OVERFLOW LINK
CONSTRICTION LINK
OVERFLOW AND CONSTRICTION LINK
INFLOW TO LAKE
LAKE BATO
STO. DOMINGO
OMBAO
LAKE BAAO
LAKE BUHI
PAWILI R.
BICOL RIVER
PROPOSED CUT OFF No. 3
CUT OFF No.2
CUT OFF No.1
NAGA CITY
SAN MIGUEL BAY
BICOL ESTUARY

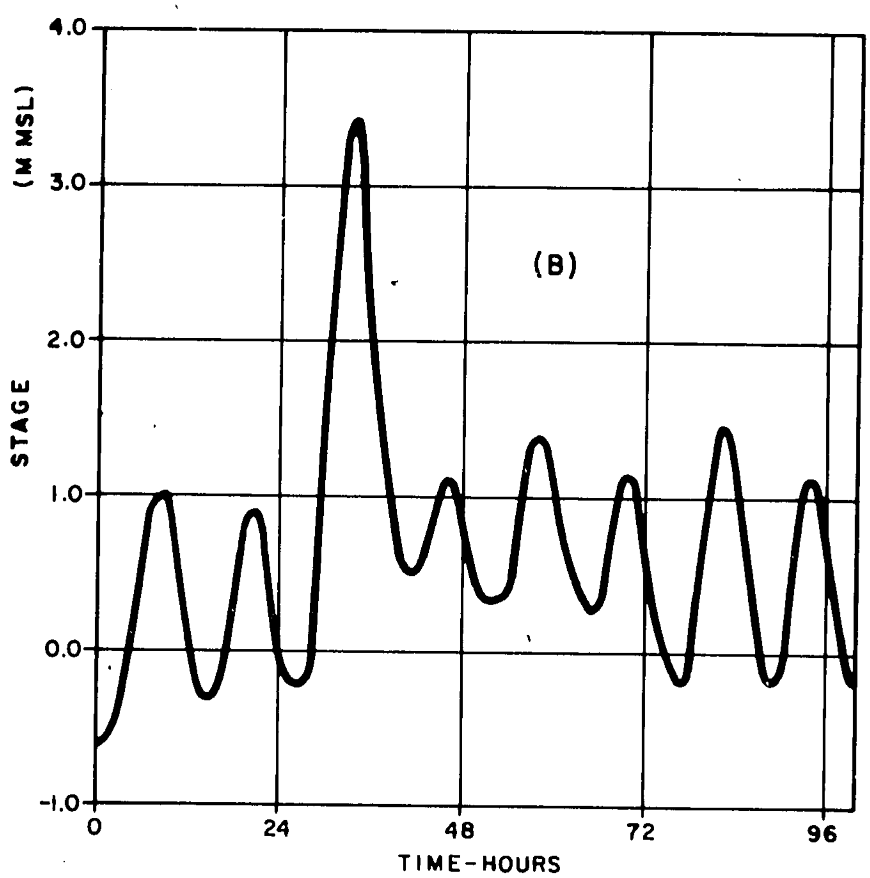
FIG. B-3

B-3

B-4



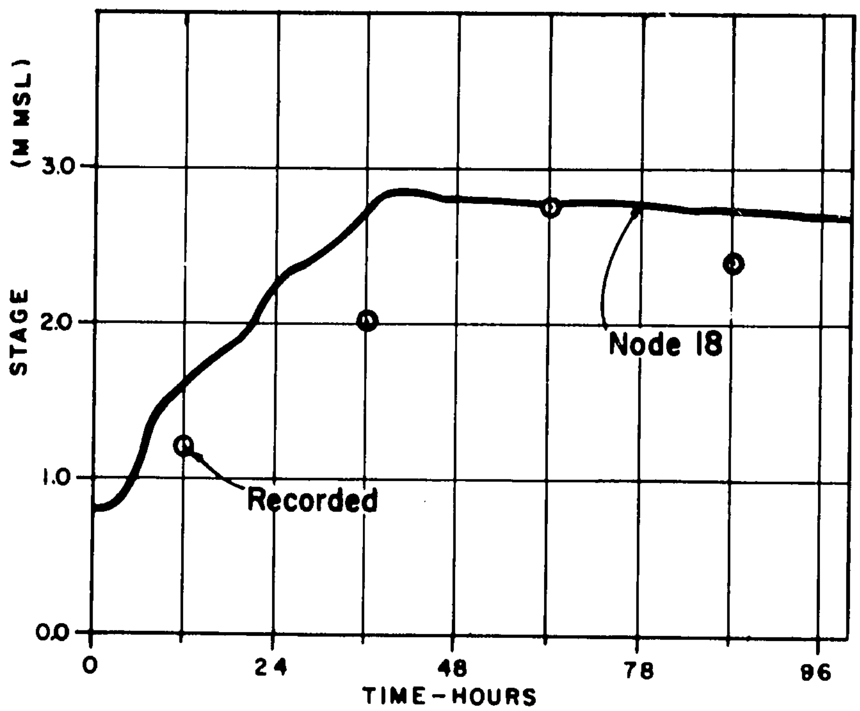
WATER SURFACE ELEVATIONS AT BOUNDARY (NODE #1)



WATER SURFACE ELEVATIONS AT BALONGAY (NODE #3)

FIG. B-4

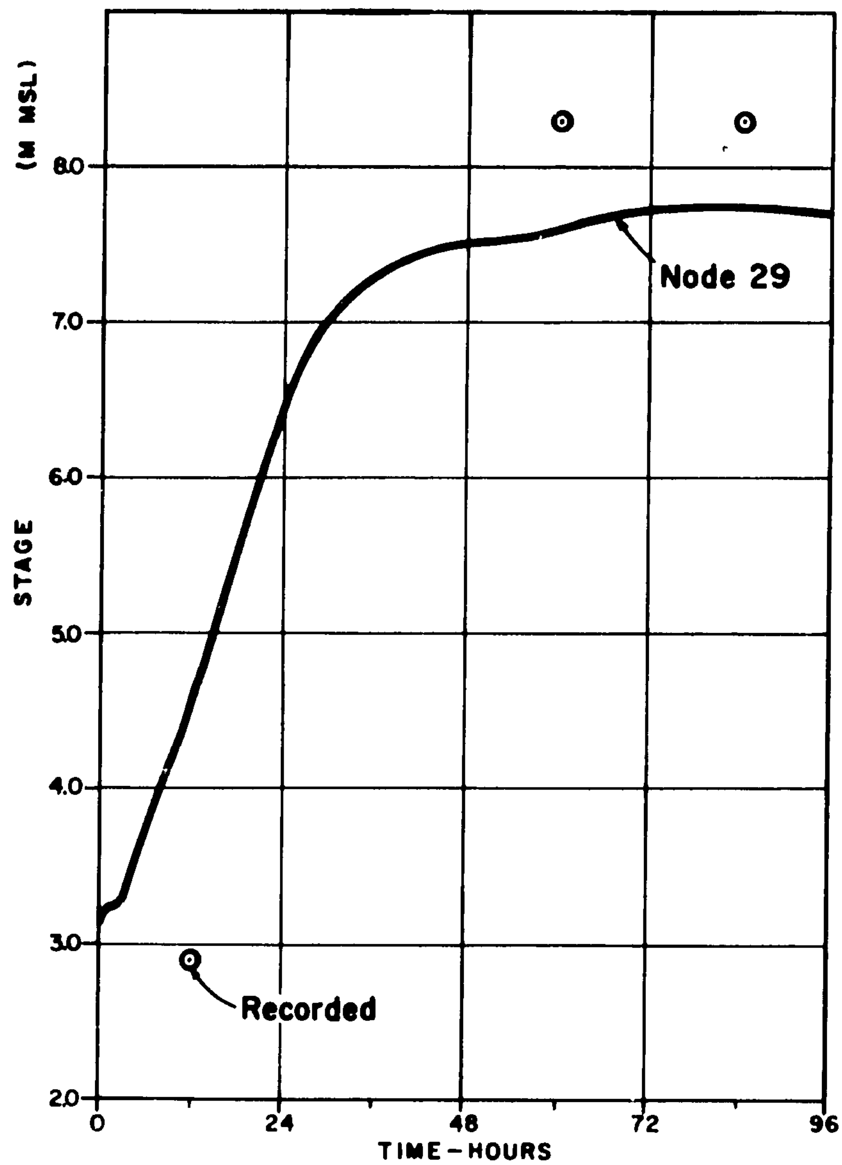
B-5



WATER SURFACE ELEVATIONS AT NAGA

FIG. B - 5

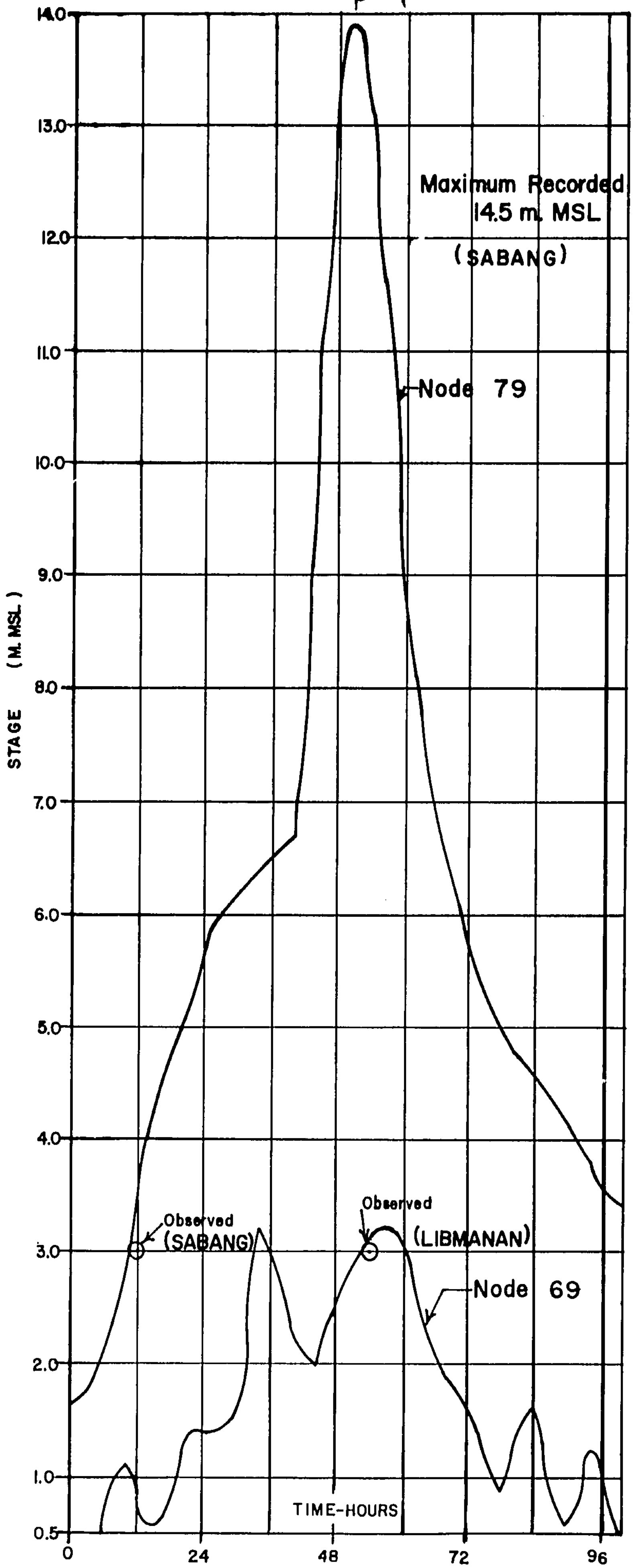
B-6



WATER SURFACE ELEVATIONS AT OMBAO

FIG. B-6

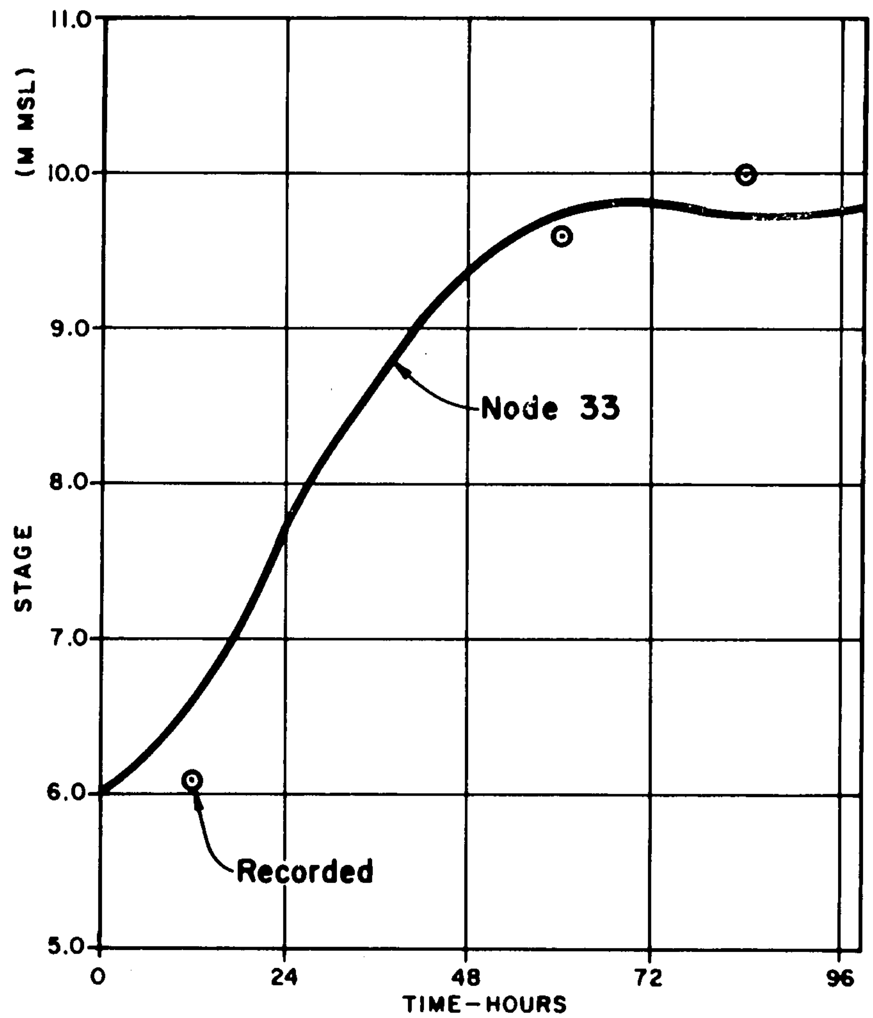
B-7



WATER SURFACE ELEVATIONS AT SABANG AND LIBMANAN

FIG. B-7

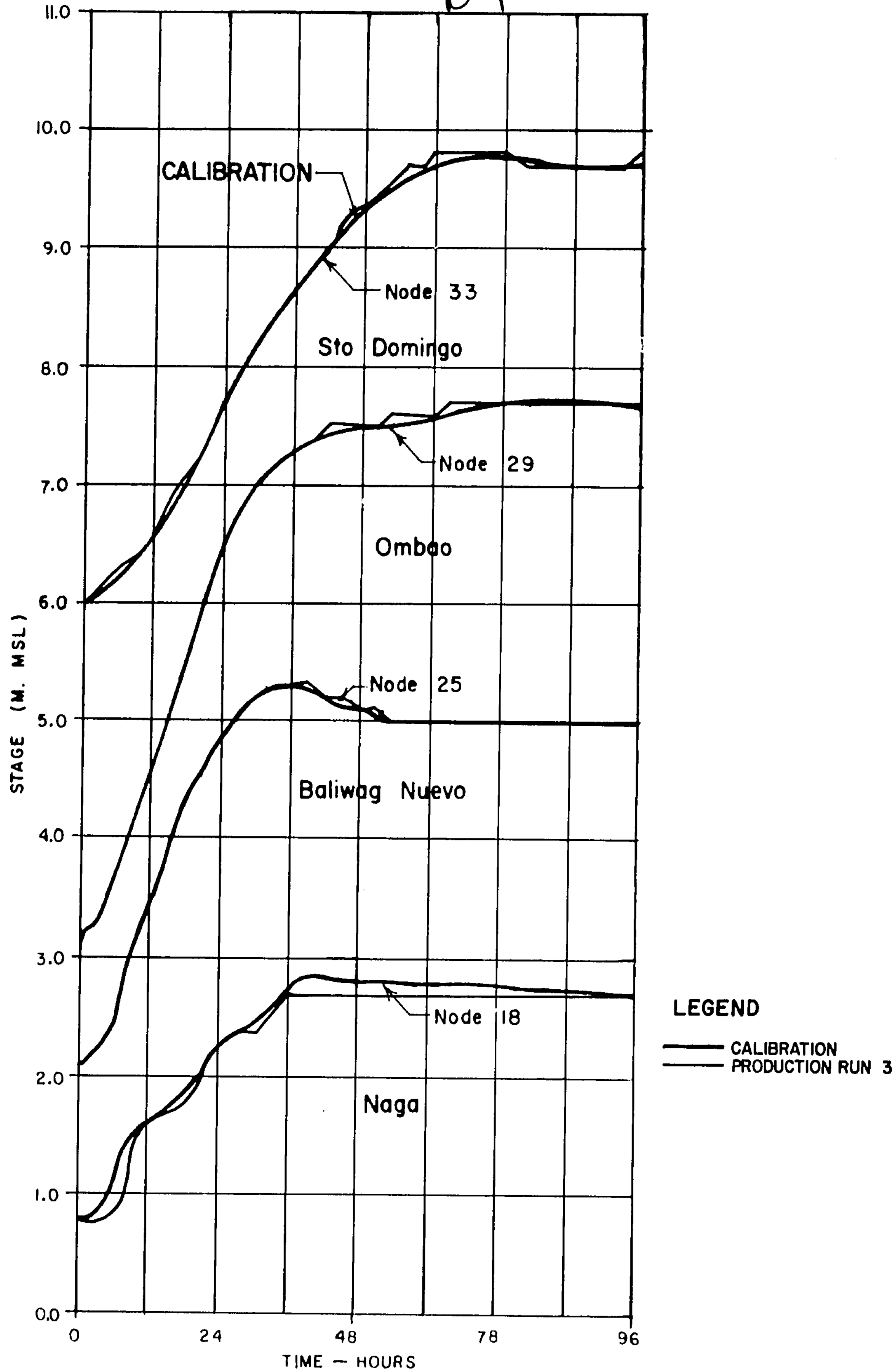
B-8



WATER SURFACE ELEVATIONS AT SANTO DOMINGO

FIG. B-8

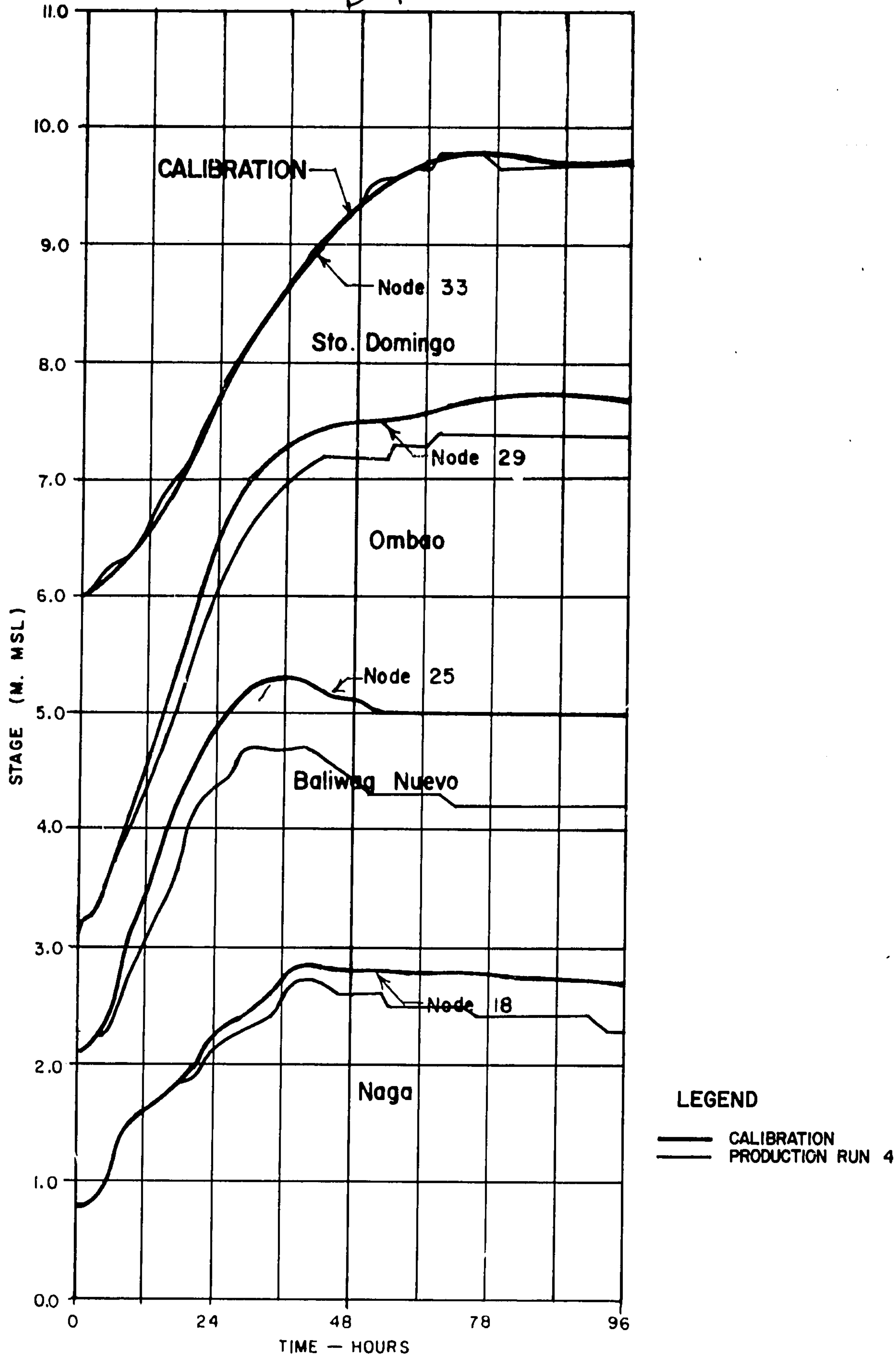
B-9



WATER SURFACE ELEVATIONS ALONG THE BICOL RIVER

Fig. B-9

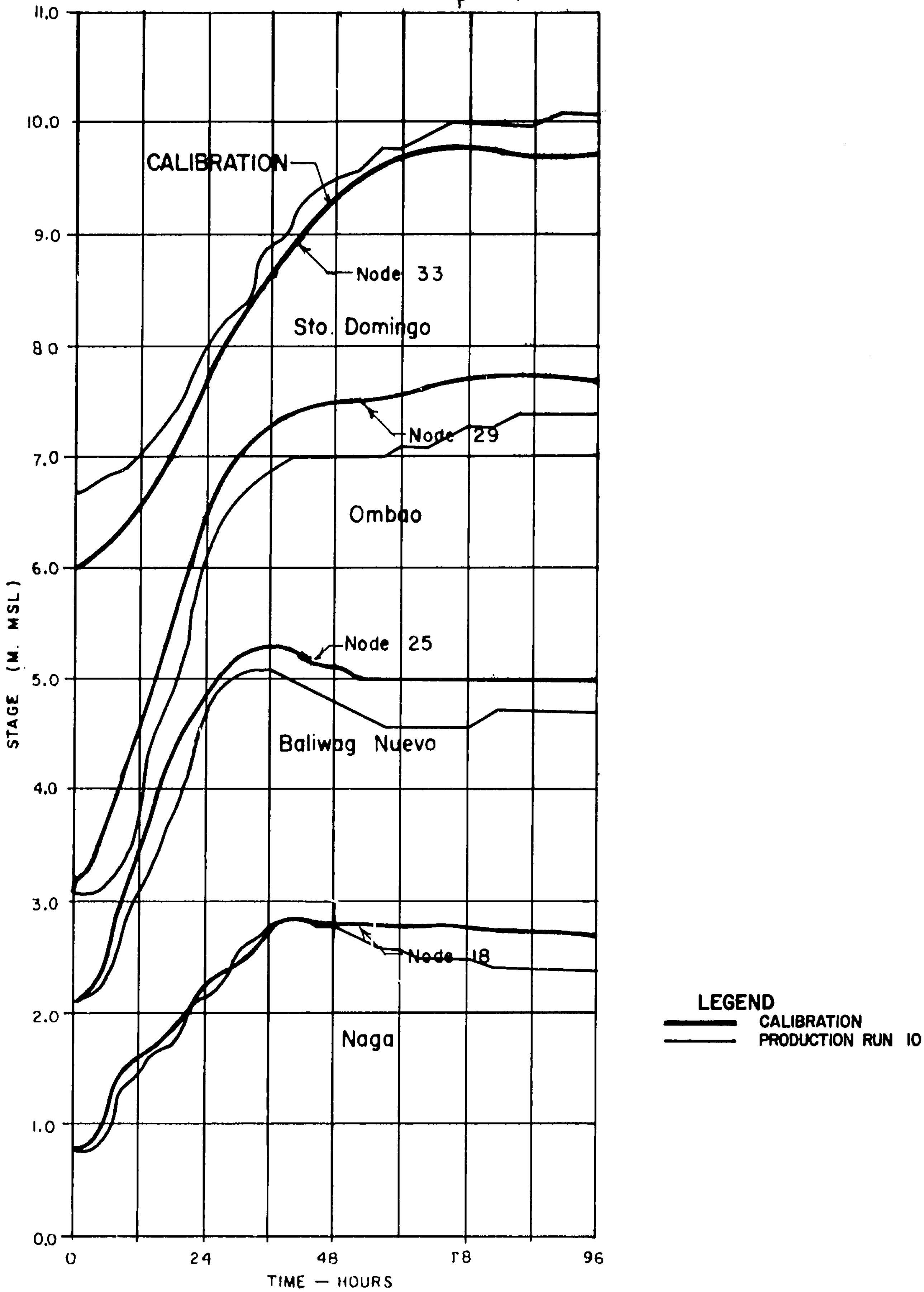
B-10



WATER SURFACE ELEVATIONS ALONG THE BICOL RIVER

Fig. B-10

B-11



WATER SURFACE ELEVATIONS ALONG THE BICOL RIVER

Fig. B-11

Appendix C
Weather Modifications
August 1976

COMPREHENSIVE WATER RESOURCES DEVELOPMENT STUDY

BICOL RIVER BASIN
LUZON ISLAND, PHILIPPINES

Appendix C

WEATHER MODIFICATIONS

August 1976

TAMS-TAE JOINT VENTURE
New York Manila

BICOL RIVER BASIN
DEVELOPMENT PROGRAM
Baras, Canaman, Camarines Sur

APPENDIX C

TABLE OF CONTENTS

Tables

APPENDIX C

WEATHER MODIFICATION

INTRODUCTION

Weather modification has advanced beyond the realm of science fiction and magic and is used in many practical applications. Specialized knowledge of the latest weather modification theories and techniques is expanding rapidly.

Experiments in weather modification in the Philippines through programs by the Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) started in 1975 in Bohol and 1976 in Central Luzon.

There are at least three types of weather modification programs: fog dissipation, rainfall augmentation and tropical storm control. The last two modes are of considerable interest in the development plans for the Bicol Basin.

RAINFALL AUGMENTATION

The progress in techniques to increase rainfall has been due to a better understanding of the processes involved in rainfall development and to technological advances in aviation and cloud seeding equipment.

Clouds are composed of water droplets and/or ice crystals formed around microscopic particles of soil, smoke, dust, etc., which are called condensation nuclei. Ice nuclei also enhance condensation and freezing of atmospheric moisture. These small, suspended droplets or ice crystals must grow many times before precipitation occurs. In many cases, natural rain does not occur even if enough moisture is available in the atmosphere, because of insufficient cloud dimensions or sizes and concentrations of cloud droplets and ice particles.

Precipitation enhancement is directly related to three basic aspects of the precipitation process: formation and growth of ice crystals at the expense of supercooled droplets; change in cloud dynamics due to release of latent heat and increase of drop coalescence.

In tropical areas ice crystal growth may be impaired, as many clouds are never colder than $0^{\circ}C$.

Some clouds have a limited vertical growth, because a stable layer lies above them. The vertical motion of the air due to a weather front, or a mountain barrier or thermal convection is not enough to break through the stable layer. Under these conditions, the cloud is not high enough to produce large amounts of precipitation. In such cases, cloud seeding may be used to increase vertical motion in the cloud, because of increased condensation of moisture around the artificial nuclei, which, in turn, releases latent heat and warms the air slightly around the new droplets. If enough droplets can be formed and frozen in a few minutes of enhanced vertical motion, the air will acquire enough energy to overcome the stable layer and the cloud will grow large enough to form precipitation.

Coalescence is the process by which liquid droplets grow larger by merging. Larger droplets tend to trap the smaller ones, through collision, because of different vertical velocities.

Hygroscopic agents can change the droplet size distribution when released just below the base of the cloud because they absorb water as they rise through the cloud. In a few minutes they can grow much larger than the average cloud droplet.

Clouds that are everywhere warmer than 0°C (warm clouds) apparently depend entirely on coalescence for rainfall production.

TROPICAL CYCLONE CONTROL

Air circulation around the low pressure center of a cyclone is counterclockwise in the northern hemisphere and, in addition, it presents a component toward the center produced by friction between air and ground. Consequently, this weather system results in air convergence in a spiral pattern at low levels which in turn produces a rise close to the eye. This results in expansion and cooling, and saturation of the moisture available at low elevations. Condensation ensues, which releases latent heat to the atmosphere in large quantities and this chimney mechanism is responsible for strong winds at ground elevation.

A way to modify the energy available to the cyclone would consist of reducing the moisture in the area near the center of the storm which would be partially accomplished by spreading a film over the ocean to prevent evaporation. Unfortunately, this procedure is not possible under present state of the art. Other procedures such as cooling the air near the center of the storm or modifying the divergence mechanisms at the top of the storm do not appear practicable.

On the other hand, there is hope for some success with the use of a technique that will modify the oonvective processes in the eye wall and rain bands, through enhanced water vapor condensation there. This would produce a dynamic circulation such that the influx of energy and momentum required to maintain the strength of the storm would be spread over a larger area. This is the procedure used in the Storm Fury Project of the U. S. Government, but the results so far obtained are not statistically significant.

CLOUD SEEDING EQUIPMENT

Aircraft systems deliver silver iodide (AgI) through the use of burners, flares and hoppers. Burners are used for seeding at cloud base in updrafts. Pyrotechnic silver iodide flares are manufactured by a number of companies in two types: dropping and trailing. The former are used for vertical drops in clouds of over one kilometer in depth and are similar to flare pistol cartridges. Trailing flares are similar to warning flares. Also aircraft disperse solid materials such as dry ice, dry salt or urea from hoppers.

Ground-based equipment include spray burners and ultrasonic nebulizer burners.

RESULTS OF WEATHER MODIFICATION PROGRAMS

The results of weather modification programs have been positive both to increase the available knowledge on these techniques and to obtain statistically significant increase in precipitation.

Successful cloud seeding requires natural conditions which might be called marginally conducive to rain. Atmospheric moisture and cloud formations must be such that relatively minor artificial inducement is necessary. Therefore, the precipitation that follows a cloud seeding operation might have occurred, at least in part, if no seeding had been used.

Unbiased appraisals must be based on statistical methods to obtain significant correlations between seeding and precipitation increases with respect to natural conditions.

A review of some cloud seeding programs follows.

Project Skywater.

The U.S. Bureau of Reclamation has conducted systematic rainfall augmentation programs since 1961 under the code name of Project Skywater. Three pilot projects were active in 1971 in the Colorado River Basin, in North Dakota and in the San Juan mountains in southwestern Colorado. Seeding operations begain in the latter area during the winter season of 1970-1971, after several years of equipment installation and testing. Seeding was extended over four winter seasons to obtain statistically significant results. The area covered is about 8,500 sq. km. A network of ground-based silver-iodide generators was arranged in such way that any target area might be seeded to take advantage of the most favorable events.

The North Dakota Project began operations in 1969 and was based on silver-iodide releases from airborne generators. The program operations were conducted in randomly selected days, during 75 percent of the project season. During the remaining 25 percent of the days, there were no seeding operations. Weather radars were used to monitor seedable clouds were used after being selected within the above mentioned 75 percent. A network of 88 raingages in the target area and 10 in the control areas is used.

Table C-1 shows the average change in precipitation from seven separate experiments in the United States. These results may not statistically significant for widespread application because of scarcity of available data. Therefore, the values should be considered qualitative and preliminary.

Table C-1
AVERAGE PERCENT CHANGE IN PRECIPITATION FROM SEEDED STORMS

State	Season	% Change	Remarks
California	Winter	+22	600-mb temperature, $\angle$ -14°C, 2 seasons
California	Winter	up to +300	Convective bands; 4 seasons
Florida	Summer	+300	Single cumulus clouds
Montana	Winter	+100	600-mb temperature, $\angle$ -20°C; 2 seasons

Table C-1 (cont'.)

AVERAGE PERCENT CHANGE IN PRECIPITATION FROM SEEDED STORMS

State	Season	Percent Change	Remarks
New Mexico	Winter	+44	1 season
South Dakota	Summer	+10	2 seasons
Utah	Winter	up to +200	Cloud-top temperature, $> -24^{\circ}C$; 2 seasons

Project Cold Rain

During the second half of 1970 and the beginning of 1971 rainfall through most of south Texas was well below normal. By June 1971, many Texans were experiencing the most severe drought in decades. The Bureau of Reclamation in collaboration with the Air Weather Service of the U.S. Air Force conducted a program to seed clouds, in the southern portion which had been selected for drought-relief operations. Two AWS WC-130 aircraft especially equipped to carry 208 nucleating pyrotechnic units each were used to seed a 117,000 sq. km. area of south and east-central Texas. Each pyrotechnic unit emitted 25 grams of silver iodide smoke while burning through a free fall of 3 kilometers. Towering cumulus o clouds of at least that depth have turrets topping in a temperature range below freezing. When they have a hard cauliflower appearance, they usually have large quantities of supercooled water and a youthful stage in cloud life. These clouds were selected for seeding. Normally, the aircraft penetrated the turret near its top, within the $-5^{\circ}C$ and $-10^{\circ}C$ isotherms. One pyrotechnic unit was released about every 200 m, during the traverse of the active updraft portion of the cloud.

During 35 Cold Rain missions, with over 1000 seeding penetrations into more than 250 cumulus clouds, more than 2500 pyrotechnic units were released.

Results indicated that at least during 25% of the operating days, beneficial localized increases in rainfall could be attributed to seeding operations.

The synoptic scale meteorological pattern prevailing during the latter half of June 1971 presented a considerable amount of convective activity over the operating area. The natural precipitation in the area was considerably more important than any contribution that might have been reasonably attributed to seeding operations. Thus, although the experience gained from project Cold Rain indicates that dynamic cloud seeding is effective in augmenting localized rainfall, it did not demonstrate that it is an effective measure for alleviating drought conditions.

Cloud Seeding in Southern Puerto Rico

The annual precipitation in Southern Puerto Rico is usually considerably lower than that of the northern half of the island, as it depends on convective orographic activity during the relatively infrequent southeast trade winds. In 1964-1965, a severe drought occurred south of the central mountains, with some stations reporting as little as 30 percent of normal precipitation. An agency called Lluvia Artificial Incorporada was formed including several large private concerns and government agencies. The target area was the whole south coast of Puerto Rico from Yabucoa to Mayagüez.

A network of 23 silver-iodide smoke generators was used, within the southern half of the island which is located at about 18° north latitude and is 180 km. long from west to east and about 60 km. wide, from north to south shores. Evaluation of results was obtained from 25 target raingages, located in the same southern half of the island.

Seeding was performed during 47 days for a total of 2559 generator hours.

Salt seeding was also done from aircraft flying at cloud base in areas of updrafts. Part of this seeding was done dispersing brine with a drop size of 30 microns and part through an airborne grinder dispersing solid particles of similar size in the wing tip wakes.

Dispersal was at the rate of about 0.5 kg per km of flight. Salt seeding was carried out on 35 days with a total time of 90 hours.

Natural data analyses showed that there was a strong association between target area precipitation and the number of rainy days. This association was used to obtain the average rainfall per rainy day, called specific raininess, and was used to obtain estimates of the natural rainfall in the target area. Analysis of results of four days of operations showed an increase of about 68 mm with respect to the estimated natural rainfall, a relative increase of about 13 percent. There is a strong possibility of statistical bias in the results, including the chance that all this increase could have been due to natural causes anyway. The sample of results was not large enough to prove the artificial enhancement of precipitation beyond any doubt.

Cloud Seeding in Northern Puerto Rico.

This program was conducted in August-September of 1974 for the Puerto Rico Aqueduct and Sewer Authority.

The target area was the 1300 sq. km. watershed of the Caguas Basin tributary to the Carraizo Dam and reservoir serving the City of San Juan.

In late July 1974, the reservoir was down to just over 35 percent of its present available capacity, and it was decided to attempt cloud seeding as a means to increase the inflow to the reservoir. A contract was let for cloud seeding by airplane. Fifteen seeding flights were undertaken for a total of about 23 hours, with a release of 25 pyrotechnic flares and about 1200 gm of silver iodide. These flights were accomplished in August 1974. A control, non-seeded area was established to obtain precipitation values used for comparison. This area showed an average rainfall of about 73% of the normal for August, while the operation area showed an average rainfall of 127% of the normal for August.

Since the results were obtained through a single short term program, they should only be used as indicative, until more information is obtained.

Weather Modification in India

Investigations on weather modification by cloud seeding were started in India around 1957. Experiments were made in the areas of Dehli, Agra, and Jaipur in northern India.

Salt dispersal techniques were used, using ground-based generators. The program included seeded and non-seeded days and seeded and control areas selected at random.

During one monsoon season, an aircraft was also used at Delhi for seeding at heights of 1200 to 1500 meters. Positive results were obtained as measured by statistical significance tests. Some results suggested increases of about 40% in precipitation, but since all days with continuous natural precipitation were not used for seeding, this average may have been exaggerated by 100%. In general, Indian experience seems to indicate that ground-based seeding of cumulus clouds results in increases of 10 to 20 percent of the natural precipitation.

PRELIMINARY PLAN OF CLOUD SEEDING FOR THE BICOL BASIN

A feasibility study should be made to assess the effectiveness of a cloud seeding program in the Bicol Basin. Based on the experience obtained in southern Puerto Rico, it appears that a network of about 25 ground-based burners should be used. The raingage network should be densified to a total of around 30 gages, which should be properly instrumented to avoid biased observations.

The program could be complemented with aircraft seeding during days of suitable cumulus turret formations and should be conducted at least during 3 dry seasons to obtain enough statistical information for program benefit-cost analysis.

The program would involve an interagency cooperation, probably with some expert assistance from individuals or companies specialized in these techniques.

APPENDIX C

REFERENCES

Hess, W. N., ed.: Weather and Climate Modification: John Wiley and Sons, 1974.

Howell, Wallace E. and Lopez, Manuel E.: Cloud Seeding in Southern Puerto Rico, Lexington, Mass.; W.E. Howell and Asso., Inc. 1966. (Leaflets).

Murty, V. R. and Biswas, K. R.: Weather Modification in India, Institute of Tropical Meteorology, India.

Bureau of Reclamation: Project Skywater, Atmospheric Water Resources Management Program. 1973. (Xerox Leaflets).

Appendix D
Salinity Studies
August 1976

COMPREHENSIVE WATER RESOURCES DEVELOPMENT STUDY

BICOL RIVER BASIN
LUZON ISLAND, PHILIPPINES

APPENDIX D

SALINITY STUDIES
August 1976

TAMS-TAE JOINT VENTURE

New York Manila

BICOL RIVER BASIN DEVELOPMENT PROGRAM
Baras, Canaman, Camarines Sur

APPENDIX D

TABLE OF CONTENTS

APPENDIX D

LIST OF TABLES

APPENDIX D

LIST OF FIGURES

APPENDIX D
SALINITY STUDIES

INTRODUCTION

This report presents the results of salinity intrusion studies completed to date. Recommendations are made for continuation of the field investigations as part of the overall hydro-meteorological study program during low flow periods in order to expand the data base. Conservative conclusions are reached according to existing information, regarding minimum freshwater inflows needed for control of salinity intrusion.

CONTROLLING FACTORS AND CLASSIFICATION OF SALINITY INTRUSION

Salinity intrusion occurs where rivers and sea intersect. The location over which this intersection occurs is referred to as an estuary according to the following definition: "An estuary is a semi-enclosed coastal body of water which has a free connection with the open seas and within which seawater is measurably diluted with freshwater derived from land drainage (Cameron and Pritchard, 1963)".

Salinity intrusion has two dominant characteristics: form and extent inland. The form of the salinity intrusion is varied. There can be sharp salinity gradients both vertically and horizontally or gradual salinity gradients both vertically and horizontally.

Generally, three forms of salinity intrusion are recognized and classified as follows (Dyer):

1. Highly stratified-salt wedge, i.e. with sharp horizontal and vertical salinity gradients.
2. Partially mixed, i.e., with gradual horizontal and vertical salinity gradients.
3. Vertically well mixed, i.e. with gradual horizontal salinity gradient and no or very small vertical salinity gradient.

The Bicol River Basin estuaries are all relatively narrow and would not have transverse gradients superimposed on the above schemes. These forms are not steady state phenomena: they move with the tide and change due to topographic effects.

Extent inland is the distance from the mouth of the estuary up to the section where fresh water is encountered. In the following discussions, all measurements of the extent of salinity intrusion are referred to the mouth of the Bicol Estuary on San Miguel Bay.

The form of salinity intrusion is governed by the interaction of topography, tidal range, boundary salinity, freshwater inflow and to a lesser extent, wind. Our analysis will be concerned only with low-flow conditions, which with the other effects held constant, will cause the maximum extent of salinity intrusion.

The interaction of these effects is complex. Identical tidal stages and freshwater inflows will produce different salinity forms if the boundary salinities differ. This results because the density of seawater is a function of temperature, salinity, and pressure. In an estuary, pressure,and generally, temperature effects are small compared with salinity effect on density; an increase in salinity results in an increase in density. Thus, an estuary with a high salinity boundary will tend to stratify more than if the same estuary had a lower salinity boundary

DESCRIPTION OF THE BICOL RIVER BASIN SYSTEM

The Bicol River Basin System consists of three interconnected estuaries, the Bicol Estuáry, the Libmanan-Sipocot River, and the Bicol River as shown on Fig. D-1. Each of the three estuaries is connected at Kilometer 7 by a network of three channels delineated by stations 5-6-9-8-13-5. Because of this configuration, the three estuaries were studied together in order to determine their interactions.

San Miguel Bay serves as the boundary source of saltwater for the Bicol Estuary while the head of the Bicol Estuary serves as the source of saltwater for the Bicol and Libmanan-Sipocot rivers. The word saltwater is used to indicate water that is not entirely freshwater nor is it oceanic saltwater; with salinities on the order of 35 ppt. (parts per thousand). Measurements indicate that the salinity at the mouth of the Bicol Estuary increased from 18 ppt. to 28 ppt. over the survey period (March-May 1976). This indicates that San Miguel Bay salinity is not surprisingly, affected by land runoff. San Miguel Bay could be considered an estuary too.

During the wet season, salinity intrusion extent occurs only on the

Bicol Estuary. A variety of combination of inflows on the Libmanan-Sipocot and Bicol Rivers result in salinity intrusion on these estuaries during the dry season. This study was directed toward obtaining information about salinity intrusion at low freshwater flow periods.

Table D-1 summarizes the pertinent physical factors that influence salinity intrusion on the Bicol River Basin System. The variety of ranges of tidal stages coupled with the interconnection at kilometer 7 complicates the determination of intrusion studies.

The cross section dimensions are typical values. Tidal prism values were obtained by integration of low flow LATIS model studies. These values of tidal prisms are on the same order of magnitude as the total freshwater inflow integrated over a tidal period. The monthly variation of spring and neap tidal stages affect both the form and extent of salinity intrusion.

TABLE D-1

CHARACTERISTIC PARAMETERS, BICOL ESTUARIAL SYSTEM

Location	Tidal Stage	Cross Section (Meters)	Freshwater Flow (cms)	Tidal Prism ($m^3 \times 10^6$)
Bicol Estuary	0.46-1.47	5 x 600		12
Bicol River		5 x 80	*9	21
Libmanan-Sipocot River		5 x 120	*9	

* 3-month low flow, (Appendix A.)

REVIEW OF HISTORICAL DATA

There are sporadic records of water quality measurements of the streams and estuaries in the Basin. Table D-2 presents the data related to salinity intrusion on the Bicol Estuary, Bicol River, and Libmanan-Sipocot River.

Inspection of the water quality data indicates that salinity intrusion occurs at least up to San Francisco on the Bicol River and at least up to an unknown point on the Sipocot River between Plancha and the confluence (see Table D-2). The extent of intrusion is inexact because there are no

TABLE D-2

COMPILATION OF HISTORICAL SALINITY DATA

Date	Tide m	Time	Depth Integrated Samples Salinity PPT: Balongay	San Francisco	Mabulo	Plancha	Poblacion	Discharge: Bicol cms	Libmanan/ Sipocot
19 Nov. 74		0500	0.18	0.17	0.15	0.14	0.18		
	0.94	0800	6.02	0.17	0.16	0.13	0.17		
		1100	0.97	0.16	0.17	0.16	0.16		
		1700	0.16	0.16	0.16	0.11	0.16		
19 Dec. 74		0500	7.70	0.16	0.16	0.14	0.16		
	0.94	1100	6.16	0.16	0.16	0.12	0.16		
		1400	0.20	0.16	0.16	0.12	0.16		
		1700	0.17	0.17	0.16	0.12	0.16		
21 Jan. 75		0500	2.47	0.18	0.17	0.13	0.18		
	0.85	0800	7.02	0.17	0.17	0.12	0.17		
		1400	11.05	2.54	0.17	0.13	0.17		
		1700	3.50	0.18	0.17	0.12	0.19		
13 Mar. 75		0800	26.00	7.80	0.24	0.24	0.20		
	1.12	1100	14.30	2.80	0.22	0.17	0.23		
		1400	2.99	0.50	0.22	0.18	0.21		
		1700	19.50	0.64	0.22	0.17	0.22		
16 Apr. 75		0800	5.66	1.49	0.21	0.15	0.22	16.5	67.5
	1.15	1100	27.22	6.08	0.22	0.17	0.21		
		1400	8.48	2.83	0.27	0.15	0.24		
		1700	5.66	1.17	0.28	0.14	0.21		
6 May 75		0500	22.62	5.66	0.18	0.15	0.19	27.0	64.9
	0.99	0800	14.85	2.19	0.19	0.15	0.19		
		1100	14.14	0.36	0.19	0.15	0.19		
		1400	28.28	7.07	0.19	0.16	0.20		
17 July 75		0500	3.93	0.20	0.20	0.17	0.24	43.1	107.0
	0.87	0800	2.62	0.20	0.20	0.17	0.21		
		1100	16.17	0.20	0.20	0.17	0.24		
		1700	11.09	0.20	0.20	0.18	0.20		
20 Aug. 75		0500	28.28	0.20	0.18	1.29	0.18	67.5	82.1
	1.21	0800	23.33	0.93	0.18	1.26	0.18		
		1100	7.28	0.91	0.17	0.19	0.18		
		1400	4.49	0.28	0.17	0.16	0.18		

data points in between the above stations.

The recorded salinity measurements represent vertically integrated samples taken with a sediment type sampler. As a result, the form of the salinity structure was not known at the beginning of these studies.

The water quality records for the streams of the Basin were inspected in order to determine typical freshwater conductivity levels and were used to ascertain reports of salinity intrusion up to Naga City.

Conductivity was used as a measure of salinity in previous analysis of these data by others. This interpretation may be misleading because the conductivity measurements at Naga City are due to elevated conductivities upstream rather than due to seawater intrusion.

The water quality records indicate that conductivity levels on the Talisay River are higher than those found at Naga City for identical seasons. No simultaneous data measurements could be found. Records exist for both locations, but they are for different years. It is assumed that the elevated conductivities on Talisay River are diluted by lower conductivities from other rivers which in turn determine the conductivities found at Naga City.

Water quality measurements for a number of streams in the Basin indicate that elevated conductivities are found in streams originating from carbonate rock areas and stream salinity is probably due to dissolved calcium carbonate.

These stream salinities do not render the water unsuitable for irrigation because their sodium absorption ratio (SAR) is low. On the other hand, seawater is not suitable for irrigation because of its high SAR.

Evidently, typical salinities for the Bicol River Basin streams are on the order of 200 ppm (.20 ppt) and that the historical data shows that no sea salinity intrusion has reached up to Naga City.

REVIEW OF A.I.T. SALINITY INTRUSION MODEL

The A.I.T. salinity intrusion model is patterned after a model developed by the Federal Water Quality Administration (now EPA). The FWQA model has been successfully used to model the San Francisco Bay-Delta System in the United States. The model is applicable only to vertically homogeneous estuaries. If it is applied to either partially mixed or salt wedge estuaries, the results must be carefully interpreted.

The inflow salinity selected for the studies of the AIT Report #51, was 0.0 ppt in the vicinity of Ombao. The model was then calibrated with data from various sampling locations along the Bicol River. Unfortunately, it was assumed that the salinity data at Naga City resulted from seawater intrusion and as noted elsewhere, it is due to upstream sources. To model sea salinity intrusion alone, the boundary concentration should have been 0.0 ppt at Naga City

FIELD INVESTIGATIONS MADE FOR THIS REPORT

Introduction

A salinity intrusion field study was initiated because the existing data consisted of vertically averaged point samples taken at widely spread locations (Table D-2) and the form and extent of salinity intrusion could not be determined with this data. The field study was designed to obtain all data required for correlating freshwater discharge with intrusion. Spring and neap tide conditions were selected in order to ascertain the effect of tidal range on salinity intrusion.

Knowledge of the relationship between salinity intrusion, freshwater inflow, and tidal stage is of obvious importance. Increased extent of salinity intrusion will compromise sources of irrigation water and alter existing sedimentation regimen. Impacts of proposed hydraulic structures on salinity intrusion may be assessed from these data.

In this section, a detailed hydrographic survey methodology is presented together with oceanographic field and data reduction techniques. The results of all recent field surveys are also included.

Methodology

The locations of hydrographic survey stations were selected to determine the form and extent of salinity intrusion on the Bicol Estuary, the Bicol River, and the Libmanan-Sipocot River. Because of the size of the survey area and limited boat capability, only one section could be traversed on a given day. At each hydrographic station the temperature and conductivity were determined as a function of depth and at a particular time (generally high water slack) during a tidal cycle.

Tidal predictions of time of occurrence of high and low tides for

Cabgan Island, San Miguel Bay were made with the use of "Tide and Current Tables, Philippines 1976" before scheduling a survey. These predictions are indicative of the time of occurrence of high and low tides at Balongay, Calabanga. The surveys were scheduled to coincide with the occurrence of spring and neap tides each month.

For each tidal hydrographic survey, besides temperature-conductivity-depth measurements, secchi-disc and current measurements for determining turbidity and velocity were occasionally made. Observations of tidal stage at Balongay, Mabulo, and Plancha were taken at ten-minute intervals over the survey period to determine stage-versus-time. Freshwater inflow was determined upstream of tidal effects on the Bicol River at Ombao and on the Libmanan-Sipocot River at Sabang.

It should be emphasized that other potential sources or sinks of freshwater downstream of Ombao were not accounted for in these measurements. These sources and sinks might include groundwater recharge-groundwater inflow and irrigation excess - irrigation pumping. At the time of this study these data were unobtainable.

The raw field data of temperature and conductivity were converted into salinity. Salinity is defined as "the total amount of solid material in grams contained in one kilogram of seawater when all the carbonate has been converted to oxide, the bromide and iodine replaced by chlorine and all organic matter oxidized." It is usually given in ppt or ppm (parts per thousand or per million) as a weight-to-weight ratio. In oceanic water, where all the major ions have practically the same ratio to one another, regardless of salinity, electrical conductivity is used to determine salinity rather than chemical analysis. The formula used for converting conductivity into salinity has been derived empirically by UNESCO from actual field samples of oceanic water. In estuaries, seawater is diluted by river water and, as a consequence, the ratios between the major ions differ from those found in oceanic seawater. This dilution lessens the accuracy of the UNESCO formulas for the determination of salinity in estuaries via conductivity, but their use is an accepted procedure used by estuarine researchers because the loss of accuracy is generally on the same order of magnitude as the accuracy of the measuring instrument.

The procedure adopted for converting conductivity into salinity is based on the recommendations from the Joint Panel on Oceanographic Tables and Standards (UNESCO) for determining salinity:

Given a data pair of temperature (t^oC) and conductivity (C umbos/cm) from a field data sheet, the following procedure is used:

1. Determine the conductivity (D) of a water sample whose salinity is 35000 ppm and temperature is identical with the data temperature, (U.S. Navy Oceanographic Handbook):

$$D = 1038.46\ t + 27046.1$$

2. Calculate the conductivity ratio (R_t). This is the ratio of $C/D = R_t$.

3. Determine whether the computed ratio R_t is greater or less than 0.1. If $R_t > 0.1$ skip this step and proceed to step 5. If $R_t < 0.1$ the observed conductivity ratio R_t is converted into R_{15^oC} by the following formula:

$$R_{15} = R_t + 10^{-5} R_t\ (R_t - 1)(t - 15)(96.7 - 72.0\ R_t) + 37.3\ R_t^2 - (0.63 + 0.21\ R_t^2)(t-15)$$

4. Salinity in ppt is then given by the following formula:

$$S\ ppt = - 0.08996 + 28.2972 + 12.80832\ R^2_{15} - 10.67869\ R_{15}^3 + 5.98624\ R_{15}^4 - 1.32311\ R_{15}^5$$

5. If $R_t > 0.1$, a table derived from the above formulas is used.

An H-P 65 calculator has been programmed at the Project Office to reduce the above data.

After the conductivity measurements have been converted into salinity, the data are interpreted. Interpretation of salinity intrusion can best be illustrated by means of salinity profiles. Salinity versus depth plots are prepared for a group of stations at high water slack. From these plots stratification characteristics can be observed and horizontal salinity profiles along the axis of the estuary prepared. This salinity profiles present isohalines (lines of equal salinity concentration) which give a pictorial representation of salinity intrusion form and extent.

Once these data have been reduced, additional techniques of presentation can be used. One such technique is the use of correlation between certain parameters (e.g. discharge-intrusion extent). Two objectives of a correlation are either to obtain an easily interpreted representation of the data or to use the correlation to predict the changes of salinity intrusion that would result from a variation of one of the parameters.

Because of the complex interaction of tidal range, freshwater inflow, and river configuration, a variety of correlations between these parameters is possible. This study was limited to the establishment of correlations between intrusion and tidal stage at Cabgan Island and intrusion in the Bicol versus freshwater inflow from the Bicol River. Other correlations were attempted but because of a lack of data, they were not conclusive.

The validity of a correlation increases with the available number of data points; therefore, since the recent survey results represent a total of 15 individual data points for the Bicol and Libmanan-Sipocot Rivers, which is not a large sample, it is recommended that additional measurements be obtained in the future.

Despite the short period of record, a valid preliminary correlation of freshwater inflow on the Bicol River versus intrusion was obtained along with a correlation of tidal stage versus intrusion. The correlations are presented with restrictions on their use. This is necessary because a correlation represents a combination of parameters for a specific situation. For example the intrusion correlation is valid only for distances upstream of the head of Cutoff No. One.

Surveys and Results

Table D-3 summarizes the intrusion data gathered from the recent salinity surveys. These data are used for the correlations presented at the end of this section. Descriptions of individual surveys follow below. Comments pertaining to the Libmanan-Sipocot River intrusion are not made because the discharge measurements may be erroneous. The gage at Sabang has been recently repaired and the gage zero is unknown. When these discharges are obtained, a similar analysis can be made for the Libmanan-Sipocot River.

TAPLE D-3

SALTWATER INTRUSION STUDY-SUMMARY OF SURVEYS TO DATE

Date	Area Surveyed	Type of Survey	Tidal Range (m) Cabgan Island	Stage	Q (Bicol) M^3/sec	Stage	Q(Sipocot) M^3/sec.	Length[1/] Intrusion (km) 100 PPM
12 Mar. 76	Balongay	Fixed	0.96	3.15	35.6	4.81	218.8	-
17 Mar. 76	Bicol R.	HWS-SP	1.35	3.01	30.4	4.50	138.5	14.00
16 Mar. 76	Bicol E.	HWS-SP	1.28	3.05	31.9	4.52	142.3	10.35
25 Mar. 76	Bicol R.	HWS-NP	0.76	2.61	18.3	4.47	133.4	13.70
6 Apr. 76	Bicol E.	HWS-NP	0.92	2.74	22.2	4.40	121.0	8.90
6 Apr. 76	Bicol E.	LWS-NP	0.50	2.74	22.2	4.40	121.0	3.60
7 Apr. 76	Bicol R.	HWS-NP	0.83	2.74	22.2	4.56	149.4	11.75
12 Apr. 76	Bicol R.	HWS-SP	1.18	2.60	18.0	4.30	103.3	16.20
13 Apr. 76	Bicol R.	HWS-SP	1.34	2.59	17.9	4.30	103.3	17.95
22 Apr. 76	Bicol E.	HWS-NP	0.75	2.48	16.2	4.23	90.8	11.30
23 Apr. 76	Bicol R.	HWS-NP	0.74	2.48	16.2	4.25	94.4	18.20
30 Apr. 76	Bicol E.	HWS-SP	1.21	2.45	15.8	4.31	105.0	15.65
1 May 76	Bicol R.	HWS-SP	1.20	2.50	16.5	4.26	96.2	19.3
7 May 76	Bicol E.	HWS-NP	0.41	2.50	16.5	4.25	94.4	14.15
8 May 76	Bicol R.	HWS-NP	0.89	2.54	17.1	4.25	94.4	17.1
15 May 76	Bicol E.	HWS-SP	1.47	2.59	17.9	4.40	121.0	17.0

Bicol R. = Bicol River
Bicol E. = Bicol Estuary
HWS = High Water Slack
LWS = Low Water Slack
SP = Spring Tide
NP = Neap Tide

1/ Measured from Kilometer 0+000 at the mouth of the Bicol Estuary.

September 26, 1975 Survey: A preliminary field testing of the temperature conductivity probe was made on this date. The measurements showed that the salinity wedge was excluded from the estuary under the existing flow conditions. Subsequent to this investigation, it was discovered that the conductivity probe had leaked and was rendered inoperative. It is felt however, that the measurements obtained in September are valid and useful for the correlation of intrusion versus freshwater discharge on the Bicol Estuary. The flows on the Bicol River and Libmanan-Sipocot River were respectively 38 cms and 142 cms. The tidal stage at Cabgan Island was 1.16 m. Caldwell's estimate of 640 cms required to exclude the salt wedge from the estuary compares unfavorably with these measurements.

October, November, December 1975 Surveys: During these months the conductivity probe malfunctioned and no salinity data were obtained. Tidal stage and Secchi disc data were obtained. The latter is presented in Table D-4.

Tidal stage data for these months show that high tide at Naga generally occurs two hours after high tide at Balongay and high tide at Plancha generally occurs 1-1/2 hours after high tide at Balongay. High tide at Balongay generally occurred 10 minutes after predicted high tide at Cabgan Island.

While no definite correlation can be observed from Secchi disc measurements, there is a trend for the relative turbidity to increase with location upstream. This increase is expected because the suspended sediment load tends to fall out of suspension or be diluted by seawater when travelling toward the mouth.

March 12, 1976 Tidal Current Survey: Temperature, salinity, tidal current and stage were determined on a flood tide at Station 2, Fig. D-1. Time history plots of the data are presented in Figs. D-2 and D-3.

These data indicate that the Bicol Estuary has a mixed standing wave-progressive wave tidal hydraulic form. This fact implies that high water slack conditions occur very near the time of high tide stage: a phase lag of 20 minutes is observed between the occurrence of high water slack and high tide stage. At high water slack the estuary at Station 2

TABLE D-4

SECCHI-DISC MEASUREMENT (m) HIGH WATER SLACK

Date	Station* 1	2	3	4	5	6	7	8	9
8 Oct. 75	1.22	0.76	0.76	0.76	0.61	0.30	0.30		
9 Oct. 75									
10 Oct. 75						0.23	0.23	0.30	0.30
6 Nov. 75	0.30	0.46	0.30	0.30	0.30	0.30	0.30		
7 Nov. 75						0.30	0.46	0.53	0.61
8 Nov. 75									
2 Dec. 75	0.30	0.30	0.15	0.15	0.15	0.23	0.15		
16 Mar. 76	0.75	0.25	0.25	0.30	0.20	0.25			
17 Mar. 76			0.40	0.40	0.30				

* See Fig. D-1

TABLE D-4 (cont.)

SECCHI-DISC MEASUREMENT (m) HIGH WATER SLACK

Date	Station* 10	11	12	13	14	15	16	17	18
8 Oct. 75									
9 Oct. 75				0.23	0.30	0.46	0.30	0.46	0.46
10 Oct. 75	0.46	0.46	0.46						
6 Nov. 75									
7 Nov. 75	0.61	0.61	0.76						
8 Nov. 75				0.46	0.53	0.53	0.53	0.53	0.53
2 Dec. 75									
16 Mar. 76				0.40	0.20	0.20			
17 Mar. 76				0.20	0.25	0.20	0.25		

* See Fig. D-1

is partially mixed-vertically well mixed. The temperature is uniform with depth.

The salinity versus time plot shows the well established fact that tidal flow in partially mixed estuaries changes direction earlier at the bottom layer than at the top layer. This is due to density differences between freshwater and saltwater and is called gravitational circulation. This circulation is manifested by the increase of salinity at 3 meters depth, 2 to 3 hours before an increase occurred at the surface. Phenomena of this type increase the flushing time of the estuary and thus the capacity of the estuary to assimulate waste loads.

Sedimentation is also affected by this gravitational circulation pattern. The landward bottom current tends to deposit sediment in the estuary. With relatively stable saltwedge the deposition forms at a nodal point. In partially mixed-vertically well mixed estuaries, the sediment is more evenly distributed over the estuary.

High Water Slack Surveys, March 16, 17, 1976: The surveys conducted on these dates covered the Bicol Estuary and Bicol River. It was unnecessary to survey the Libmanan-Sipocot River because intrusion only occurred on the Bicol Estuary. Spring tide occured on these dates with a stage elevation of 1.28 and 1.35 m, respectively, at Cabgan Island.

Both salinity profiles (Figs. D4a and D7b) show that the form of salinity intrusion is a function of location. The estuary proper (Stations 1-7, excluding Station 5 which is at the entrance to Cutoff No. 1) exhibits a partially mixed-vertically well mixed aspect. Cutoff No. 1 was partially mixed at Station 5 on March 16, while on March 16, Station 13, located at the other end of Cutoff No. 1, was partially mixed. The surface salinity at Station 13 was lower than the salinity found upstream at Station 14. This lower salinity surface water results from a back flow of the Bicol River into Cutoff No. 1. The natural channel of the Bicol River joins the Libmanan-Sipocot River at Station 8.

A low flow computer model study was performed with LATIS to evaluate this circulation pattern. The results indicate that at the start of ebb tide, all the Bicol River flows toward Cutoff No. 1. As ebb progresses, the flow of the Bicol goes down Cutoff No. 1 and along the natural bed of the Bicol River. Integration of the flows over one tidal cycle shows that the net flow is toward the junction of the Libmanan-Sipocot River and the Bicol River. This result is important because it shows that the Libmanan River has little effect on intrusion in the Bicol River.

It is apparent that the salinity intrusion extended up to Kilometer 14 on the Bicol River and Kilometer 10.4 on the Bicol Estuary, and did not enter the Libmanan River.

High Water Slack Survey - March 25, 1976: The neap tide survey was conducted with a tidal stage of 0.76 m at Cabgan Island (Fig. D-8a). Compared to the March 17 spring tide survey, it is apparent that the form of intrusion was altered. The March 25 survey shows that salinity intrusion extent was similar to that of the March 17 survey but it was more stratified. The freshwater discharges were respectively 30.4, 18.3 cms and the tidal stages were 1.35 and 0.76 m. It is apparent that the difference of freshwater discharge was offset by the change in tidal stage.

High and Low Water Slack Surveys - April 6, 7, 1976: The survey on the first day covered the Bicol Estuary where both high and low water slack salinity measurements were made (Figs. D-4b, D-5a). The predicted low and high water slack survey started at 0910 and ended at 1024. High water intrusion reached Kilometer 8.9. The low water slack measurements started at 1605 and finished at 1634; the intrusion reached up to Kilometer 7.6.

The form of high water slack intrusion is partially mixed-vertically well mixed. On low water slack, the form is vertically well mixed with the effects of salinity intrusion practically excluded from the estuary.

The exclusion of the salt intrusion front at low water slack tide is important because it shows that the Bicol River Basin System does not suffer from "memory" effects from previous tidal cycles, and it should be possible to control effectively the nature of salinity intrusion in the estuary.

On the second day, the survey was conducted on the Bicol River (Fig. D-8b). Tidal stage at Cabgan Island was slightly higher than on the previous day with an elevation of 0.83 m. Intrusion extent reached

Kilometer 11.75. The form of salinity intrusion on this day tended toward partially mixed.

High Water Slack Surveys of April 12, 13, 1976: Particular attention was accorded to the Bicol River on these two successive days in order to note the effects of tidal stage on intrusion (Figs. D-9a and D-9b). The tidal stage was 1.18 on April 12, and 1.34 on April 13. Freshwater discharge on the Bicol River was practically identical on each day at 18 cms. The increase in tidal stage of.16 m accounted for an increased intrusion extent of 1.8 m.

The form of salinity intrusion was vertically well mixed for both cases. It appears that in general, the spring tide intrusion forms tend toward vertically well mixed while the neap tides tend to be more stratified.

High Water Slack Surveys of April 22, 23, 1976: These neap tide surveys were undertaken with the lowest freshwater inflows to date: 16.2 cms (Figs. D-5b, D-10a). Tidal stages were 0.75 m and 0.74 m, respectively. The intrusion forms tended to be partially mixed-vertically well mixed, which supports a general trend that had been observed in previous surveys.

Intrusion on the Bicol Estuary reached to 11.3 Kilometers and 18.2 Kilometers on the Bicol River.

High Water Slack Surveys of April 30, and May 1, 1976: These spring tides have followed the general trend noted earlier of vertically well mixed forms (Figs. D-6a, D-10b). The intrusion extended to Kilometer 15.65 on the Bicol Estuary-Libmanan-Sipocot River and Kilometer 19.3 on the Bicol River.

Station 13 exhibited the occurrence of freshwater in the surface layer. The source of this water is the Bicol River which back flows down Cutoff No. 1 before it reverses to its normal downstream flow toward the junction with the Libmanan-Sipocot River.

High Water Slack Surveys of May 7, 8, 1976: The strongest stratification to date was noticed in these two neap tide surveys (Figs. D-6b, D-11a). This resulted from the general increase in boundary salinity which is apparent from comparison with the earlier surveys. The intrusion extent on the Bicol River, is still a function of freshwater discharge.

Intrusion on the Bicol River was 17.1 Kilometers and 14.5 Kilometers on the Libmanan-Sipocot River.

CORRELATIONS

As mentioned in the Section on "Methodology", a variety of correlations can be made between river discharges and intrusion extent to predict the minimum freshwater discharge needed to control salinity intrusion. Deriving these correlations is difficult because of the complicated combinations of tidal stage, freshwater discharges, channel configuration, and boundary salinity conditions that exist for the Bicol network. Extreme care must be observed on data interpretation to insure that similar situations are compared and used for predictions.

Our analysis allowed a derivation of correlations between tidal stage and intrusion and freshwater discharge and intrusion on the Bicol River. Data were not sufficient to obtain a similar correlation for the Libmanan-Sipocot River.

Fig. D-12 shows the dependence of intrusion on predicted tidal stage at Cabgan Island for two different discharges. The tidal stage at Cabgan Island was chosen for this correlation because it is a physical parameter that can be predicted from the tide tables. The lines are eye-fitted to the data points and correspond to discharges of 16.3 and 18.0 cms. The trend of these lines indicates that the higher the discharge, the more dependent intrusion is on tidal stage. This means that the further salinity moves upstream, due to less freshwater discharge, the less effect a change in tidal stage will have on intrusion extent. From the viewpoint of available irrigation water, this fact is important because it indicates that, for a given maintained freshwater inflow, irrigation diversion at a given location may need to be adjusted for the variation between spring and neaptides.

Fig. D-13 presents the correlation: natural logarithm of intrusion versus freshwater discharge on the Bicol River. Points 2, 3, 6, 8 and the location of Bo. Panoypoyan, Bula, Camarines Sur, where the river bottom goes 1 m above mean sea level, are used to draw the correlation line for a stage of 0.74 to 0.84 m. The following equation relating discharge to intrusion for this tidal stage was obtained:

$$I = e^{(-.07165Q + 4.05)} \qquad 0 \leq Q \leq 24.7 \text{ cms}$$

This correlation is limited to the head of Cutoff No. 1. This is necessary because the junction of the Bicol River and Cutoff No. 1 marks a change in river geometry which may affect the correlation.

A similar correlation can be synthesized for a spring tide of 1.47 m. By use of Fig. D-12, the intrusion of a 1.47 m spring tide (the highest predicted tide for 1976) can be obtained for discharges of 16.3 and 18 cms. These two points are denoted along with the lowest neap tide correlation points on Fig. D-13. Connecting these points gives the following equation of intrusion for this tidal stage:

$$I = e^{(-.06278Q + 4.05)}; \; 0 \leq Q \leq 18 \text{ cms}$$

$$I = e^{(-.01944Q + 3.27)}; \; 18 < Q \leq 30 \text{ cms}$$

It should be recognized that these relationships are tentative and were derived in order to give some indication of the effect of tidal stage on intrusion, which has been demonstrated in Fig. D-12.

In deriving these correlations, it was assumed that the effects of the Libmanan-Sipocot River were minimal on the Bicol River. As indicated before, preliminary low flow hydraulic computer model runs have indicated that this is the case. The net flow between the Bicol and the Libmanan-Sipocot Rivers along the Bicol River bed west of Cutoff No. 1, is almost zero, thus indicating no interaction between the two rivers.

Also, review of the data indicates that the slow change in the boundary salinity of the Bicol Estuary is not related to the extent of salinity intrusion. The dry season is of short duration and the increase of San Miguel salinity over the dry season period probably will have little effect on salinity intrusion extent. This change in boundary salinity appears, however, to alter the form of salinity intrusion from vertically well mixed to partially mixed.

SUMMARY AND CONCLUSIONS

1. The length of neap tide salinity intrusion (tidal stage = 0.74

-0.84 m) at high water slack conditions may be given by the preliminary formula:

$$I = e^{(-.07165\,Q + 4.05)} \qquad 0 \leq Q \leq 24.7 \text{ cms}$$

2. The length of spring tide salinity intrusion (tidal stage 1.47 m) at high water slack conditions is tentatively given by the preliminary formulas:

$$I = e^{(-.06278\,Q + 4.05)} \qquad 0 \leq Q \leq 18 \text{ cms}$$

$$I = e^{(-.01944\,Q + 3.27)} \qquad 18 < Q \leq 30 \text{ cms}$$

3. It is recommended that additional low-flow salinity intrusion studies be conducted in order to improve the accuracy of the above formulas. Additional surveys should be conducted at times other than maximum spring or neap tide conditions. A series of measurements every other day should be done to get a true indication of tidal stage effect on intrusion for constant freshwater discharge.

4. Preliminary review of low-flow computer model studies of the Bicol River Basin System indicates that the Libmanan-Sipocot River flow does not affect the salinity intrusion on the Bicol River. Attempts at obtaining a correlation between the Libmanan-Sipocot River flow and intrusion on the Bicol River failed.

5. The form of salinity intrusion on the Bicol River Basin System during the dry season tends to be vertically well mixed to partially mixed and to be alterered by location and tidal stage.

6. From March 12, 1976 until May 15, 1976, the boundary salinity at the Bicol Estuary mouth increased from 18 ppt to 28 ppt. The increase was not uniform because of variations of tidal stage; however, review of Figs. D-4a to D-11a shows this definite trend. This trend is probably due to an increase in salinity of San Miguel Bay resulting from the progression of the dry season.

7. The form of salinity intrusion was strongly coupled to tidal stage. More stratification occurred with neap tides than with spring tides. This results from the fact that the larger the tidal stage, the more tidal energy is available for mixing.

8. The extent of salinity intrusion was not affected by the increase in the boundary salinity; however, it appears that the salinity form tended to be more stratified.

9. It was observed during the March 12, 1976 survey that a gravitational circulation pattern exists for the Bicol Estuary. This circulation pattern will increase flushing time of the estuary and should be acknowledged in any future calculations pertaining to pollution analysis.

10. Tidal stage measurements show that the predicted tides for Cabgan Island given in the "Tide and Current Tables - Philippines 1976" occur generally 10 minutes earlier than at Balongay. Current measurements coupled with tidal stage measurements show the Bicol Estuary to have a mixed standing wave-progressive tidal wave hydraulic form. Preliminary low-flow hydraulic computer model studies support this observation.

11. The preliminary intrusion formulas given in 1, 2 can be used to predict the consequences of changes in discharge on salinity intrusion for given tidal stage conditions. Predicted tide tables can be used to formulate operational rules for irrigation diversions during the dry season.

12. Water balance studies of possible sinks or sources of freshwater in the Bicol and Libmanan-Sipocot Rivers should be completed to determine their significance on total flow and their effects on salinity intrusion.

APPENDIX D

REFERENCES

1. AIT Salinity Intrusion Report, No. 51.

2. BRBC Water Quality and Salinity Records.

3. Cameron, W. M. and D. W. Pritchard, 1963. Estuaries in The Sea (ed. M.N. Hill), Vol. 2, John Wiley & Sons, New York, 306-324.

4. Dyer, K. R., 1973; Estuaries, Physical Introduction; John Wiley & Sons, New York.

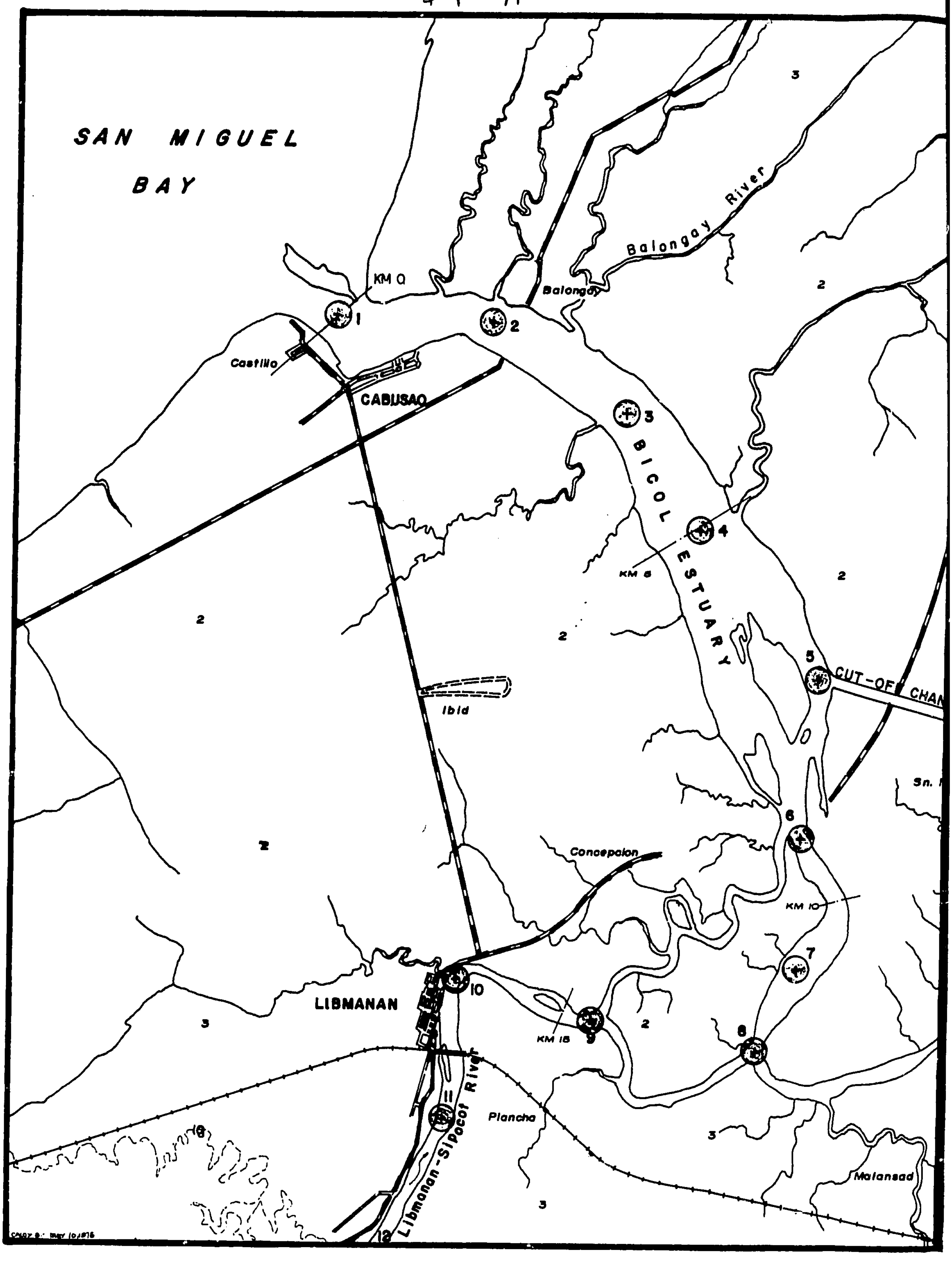
5. Pritchard, D. W., 1975; Estuarine Hydrography; Advan. Geophy. 1, 243-280.

6. Pichard, G. L., 1963; Descriptive Physical Oceanography; Pergamon Press, New York.

7. Simmons, H. B., 1955; Some Aspects of Upland Discharge on Estuarine Hydraulics; Proc. Amer. Soc. Civil Engr.; 81, No. 792, 1956.

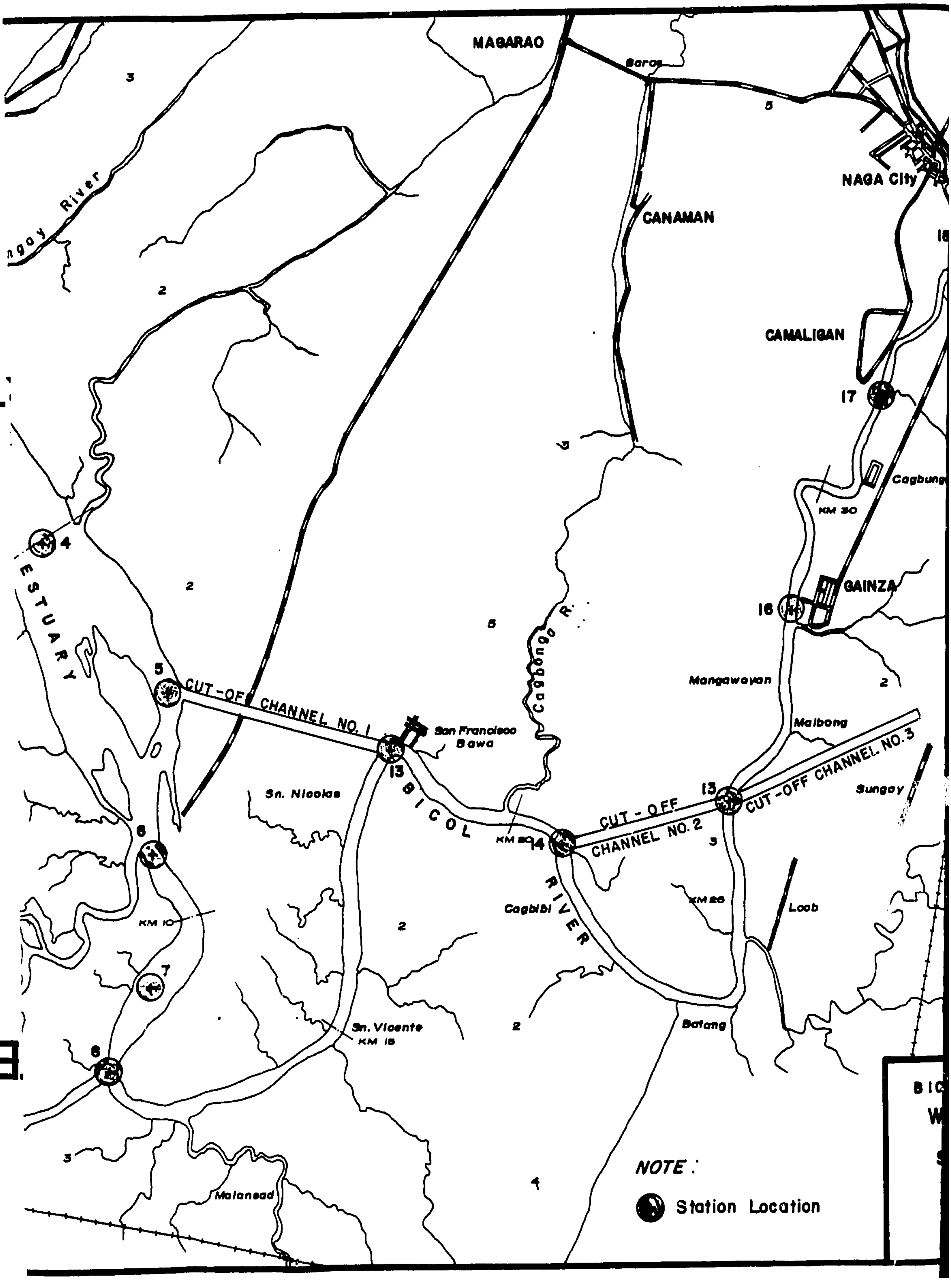
8. Tide and Current Tables - Philippines 1976, Republic of the Philippines, Department of National Defense, Bureau of Coast and Geodetic Survey.

D-1 A



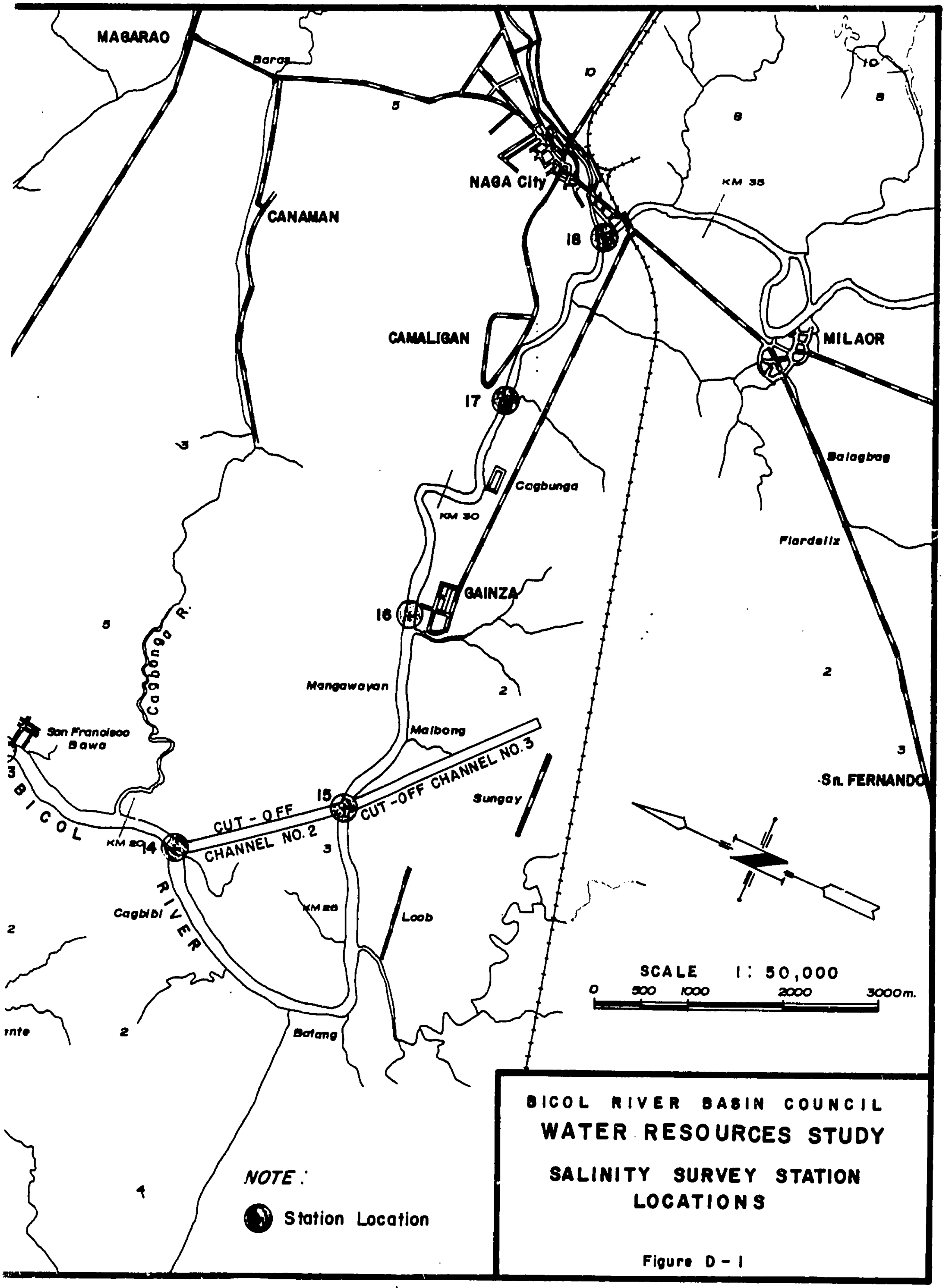
SAN MIGUEL
BAY
KM O
1
2
Balongay
Balongay River
Castillo
CABUSAO
3
BICOL ESTUARY
4
KM 5
5
CUT-OFF CHAN
Ibid
Concepcion
6
KM 10
7
8
9
KM 15
10
LIBMANAN
11
Libmanan-Sipocot River
Plancha
Malansad
12

D-1 B



MAGARAO
Baras
NAGA City
CANAMAN
CAMALIGAN
Cagbunga
KM 30
GAINZA
Mangawayan
Malbong
CUT-OFF CHANNEL NO. 3
Sungay
CUT-OFF CHANNEL NO. 2
CUT-OFF CHANNEL NO. 1
San Francisco Bawa
Cagbonga R.
BICOL RIVER
ESTUARY
Sn. Nicolas
KM 20
KM 10
KM 25
Cagbibi
Loob
Sn. Vicente
KM 15
Batang
Malansad
River
NOTE :
Station Location

D-1 C



BICOL RIVER BASIN COUNCIL

WATER RESOURCES STUDY

SALINITY SURVEY STATION LOCATIONS

Figure D - 1

SALINITY VERSUS TIME
STATION 2 at BALONGAY , CALABANGA
March 12 , 1976

LEGEND:

- - - - - SALINITY VERSUS TIME RELATIONSHIP AT 3 METERS DEPTH.

——— SALINITY VERSUS TIME RELATIONSHIP AT 1 METER DEPTH.

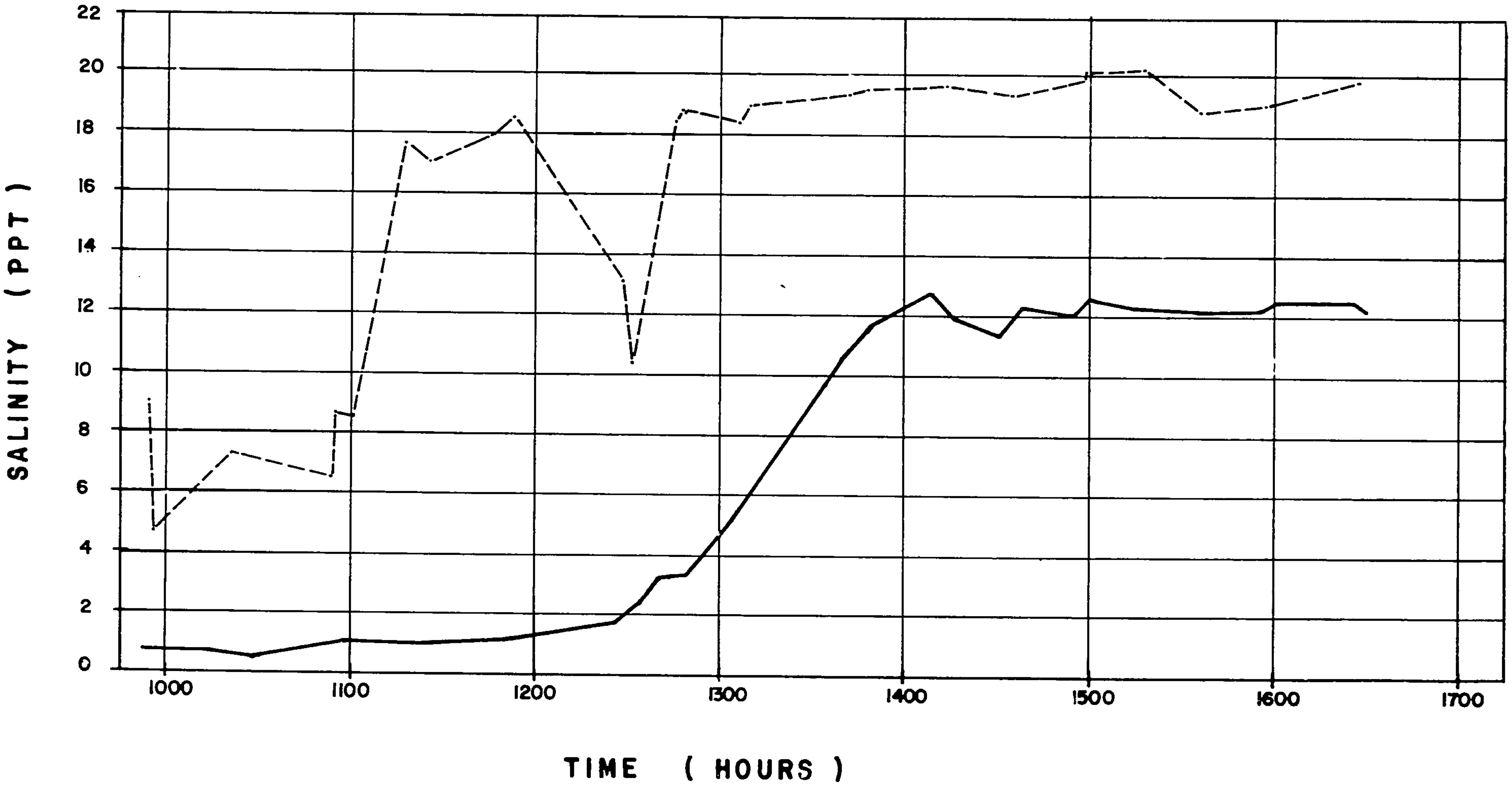


Figure D—2

D-2

COMPARISON of TIDAL STAGE versus TIME and
TIDAL CURRENT versus TIME

STATION NO. 2 at BALONGAY, CALABANGA, CAM. SUR

March 12, 1976

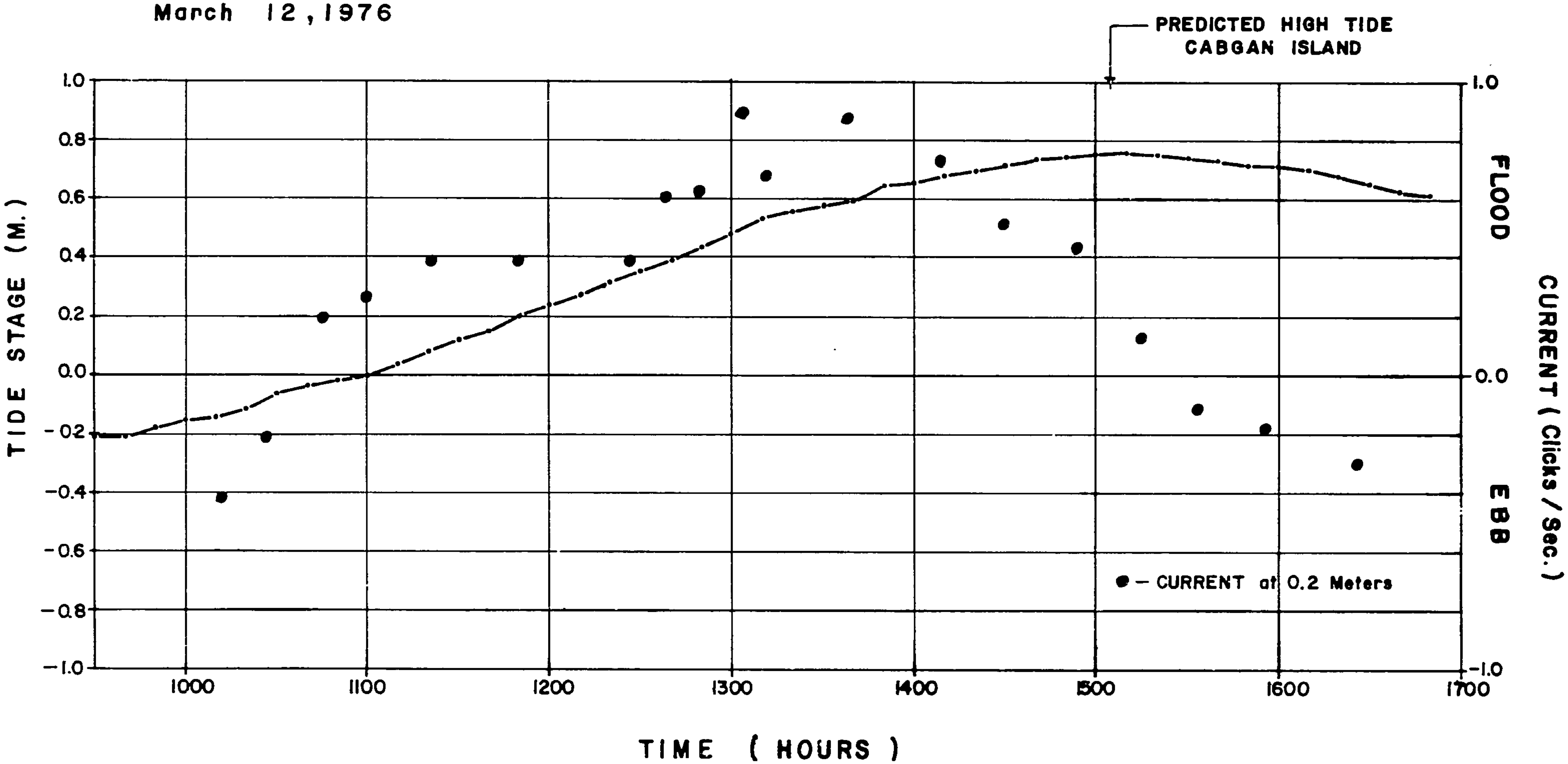
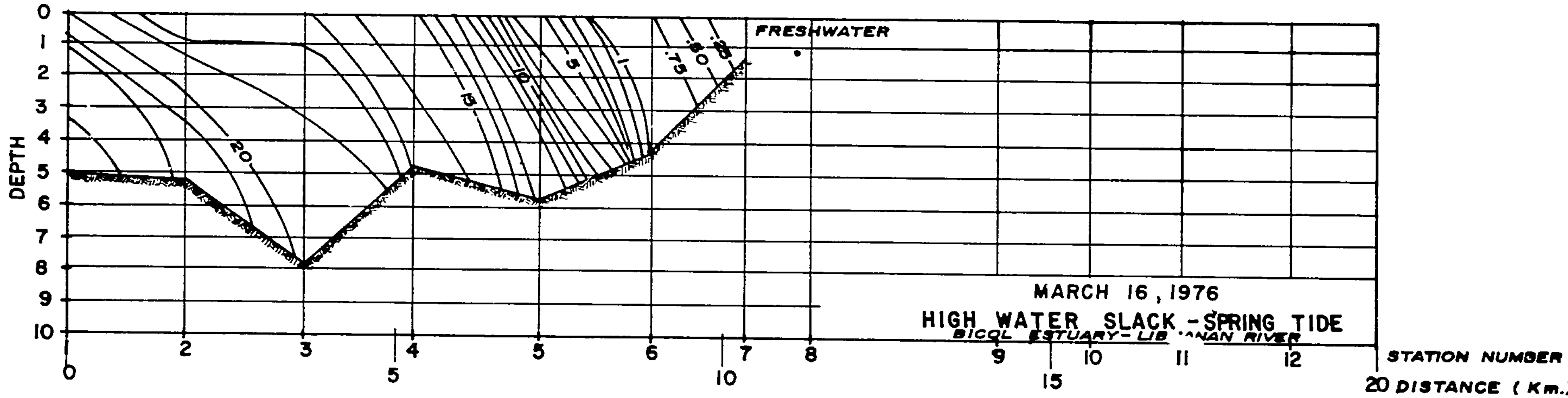


Figure D — 3

D-3



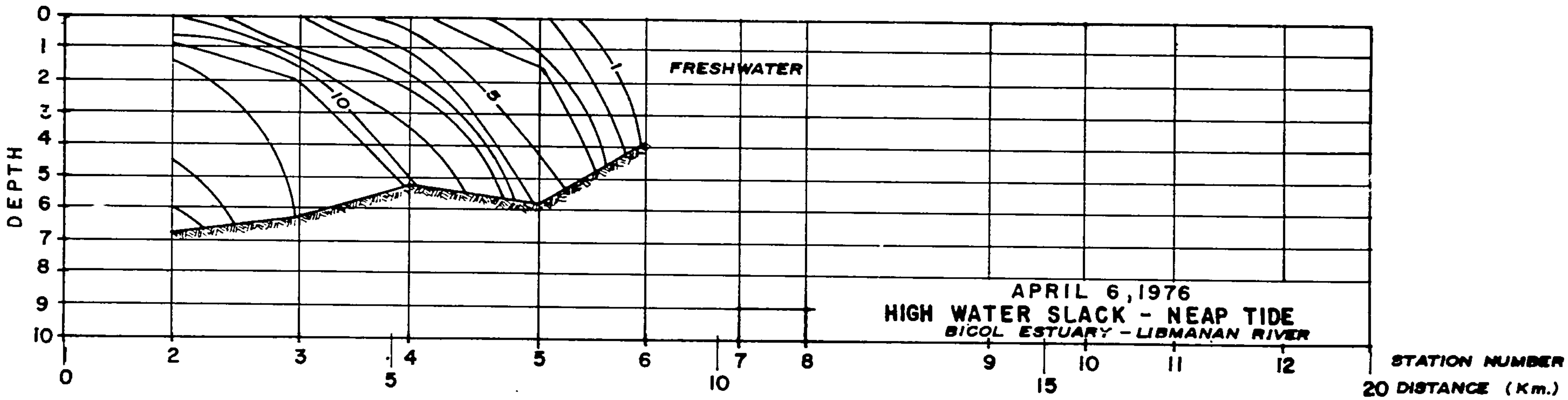
Q (BICOL R. at OMBAO) = 31.9 cu.m./sec.
Q (SIPOCOT R. at SABANG) = 142.3 cu.m./sec.
INTRUSION = 10.36 Km.

TIDAL RANGE
(MSL)

Figure D-4a

BALONGAY = + 1.30 ⟶ −0.9
MABULO = + 1.34 ⟶ −0.2
PLANCHA =
CABGAN = − 0.98 ⟶ + 1.28 ⟶ 0.98

D-4



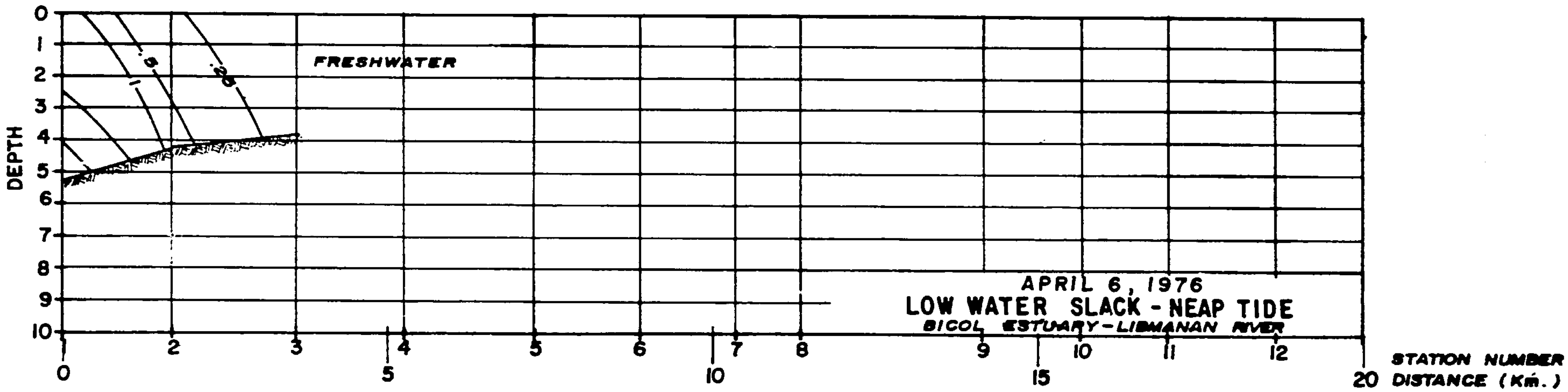
Q (BICOL R. at OMBAO) = 22.2 cu.m./sec.
Q (SIPOCOT R. at SABANG) = 121.0 cu.m./sec.
INTRUSION = 8.90 Km.

TIDAL RANGE
(MSL)

Figure D-4b

BALONGAY =
MABULO =
PLANCHA =
CABGAN = − 0.23 ⟶ 0.92 ⟶ − 0.50

FIG. D-4



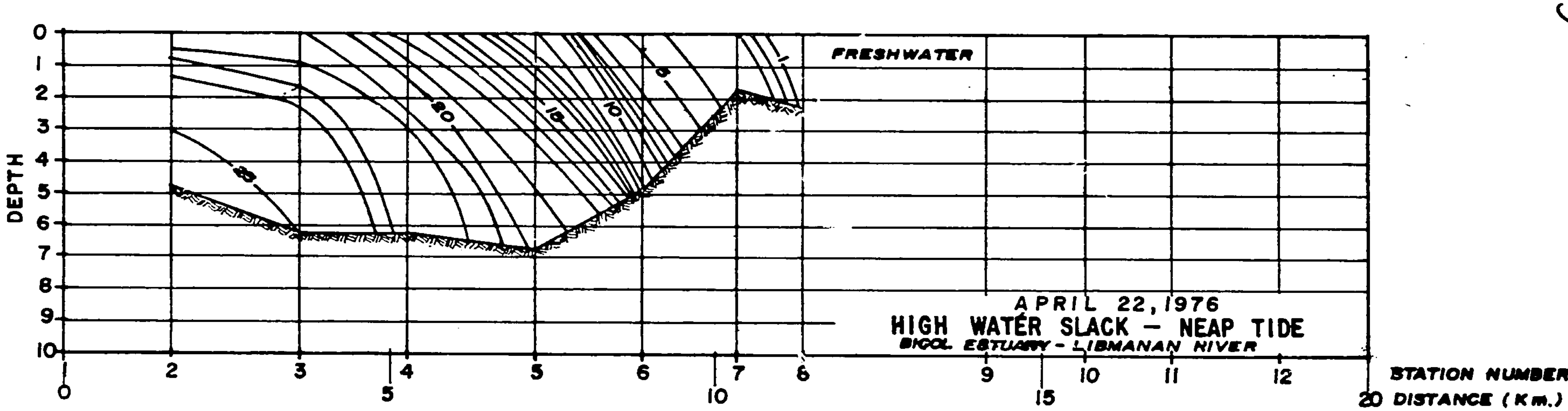
Q (BICOL R. at OMBAO) = 22.2 cu.m./sec.
Q (SIPOCOT R. at SABANG) = 121.0 cu.m./sec.
INTRUSION = 3.6 Km.

TIDAL RANGE
(MSL)

Figure D-5-a

BALONGAY =
MABULO =
PLANCHA =
CABGAN = -0.33 → 0.92 → -0.50

D-5



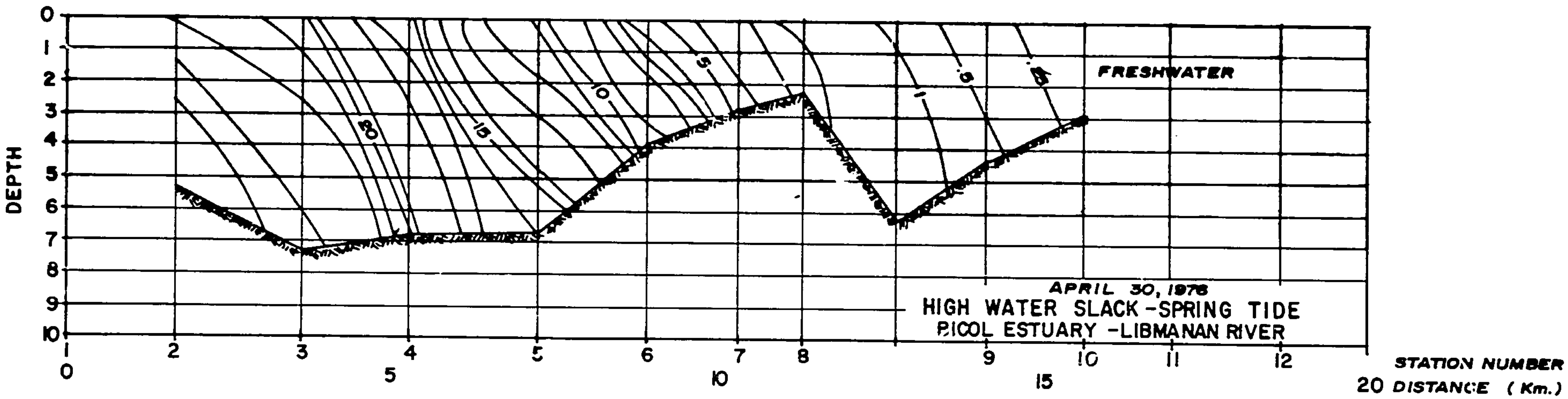
Q (BICOL R. at OMBAO) = 16.2 cu.m./sec.
Q (SIPOCOT R. at SABANG) = 90.8 cu.m./sec.
INTRUSION = 11.3 Km.

TIDAL RANGE
(MSL)

Fugure D-5-b

BALONGAY =
MABULO =
PLANCHA =
CABGAN = -0.11 → 0.75 → -0.36

FIG. D-5



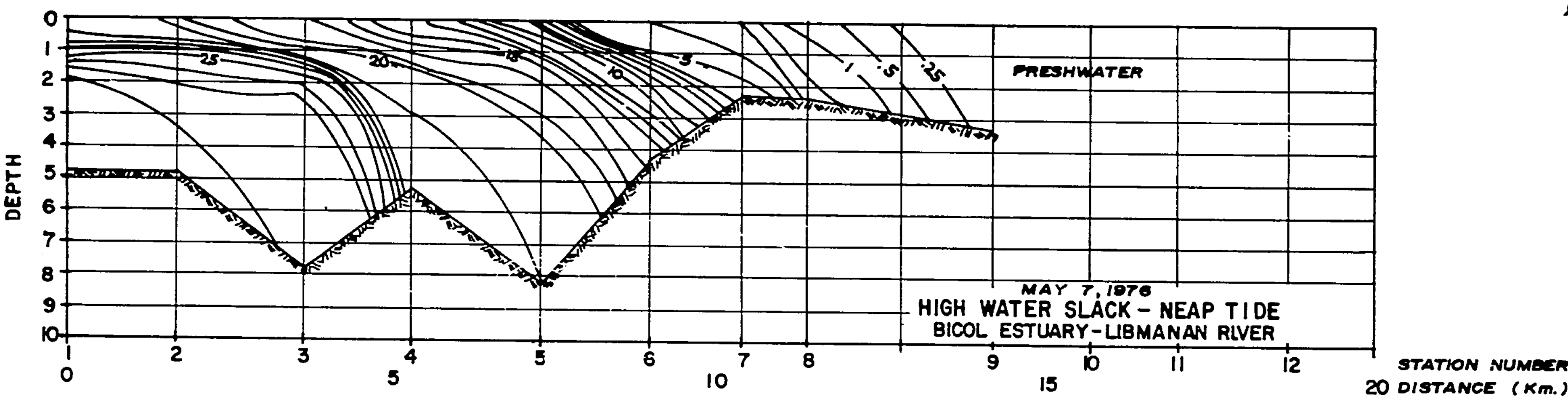
Q (BICOL R. at OMBAO) = 15.8 cu. m./sec.
Q (SIPOCOT R. at SABANG) = 105.0 cu. m./sec.
INTRUSION = 15.65 Km.

TIDAL RANGE (MSL)

BALONGAY = 1.19 ⟶ −0.86
MABULO =
PLANCHA =
CABGAN = −0.44 ⟶ 1.21 ⟶ −0.79

Figure D-6-a

D-6



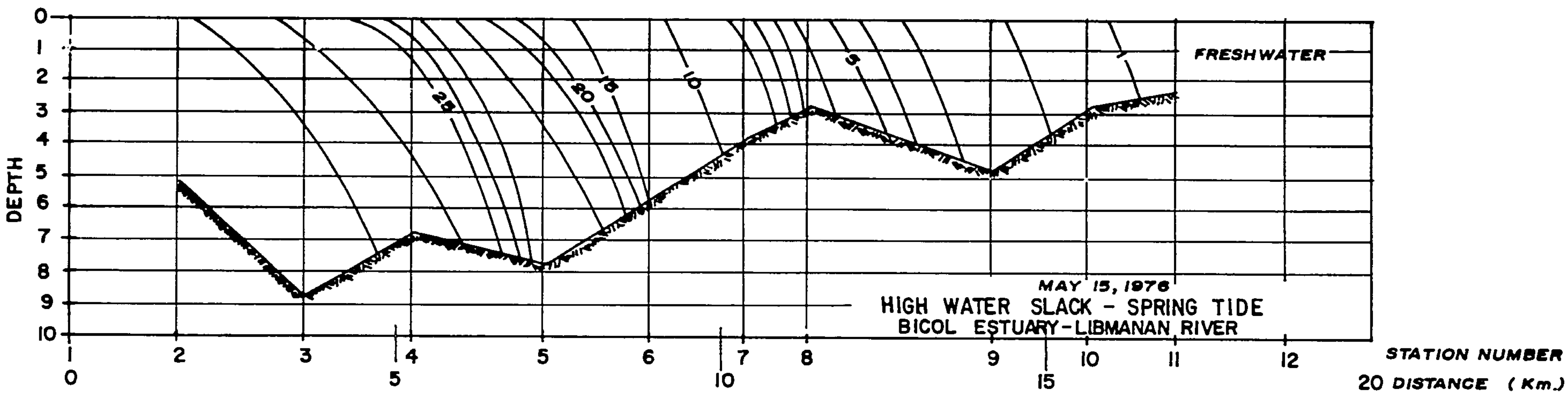
Q (BICOL R. at OMBAO) = 16.5 cu. m./sec.
Q (SIPOCOT R. at SABANG) = 94.4 cu. m./sec.
INTRUSION = 14.15 Km.

TIDAL RANGE (MSL)

BALONGAY = 0.67 ⟶ −0.52
MABULO =
PLANCHA =
CABGAN = − .12 ⟶ 0.85 ⟶ −0.41

Figure D-6-b

FIG. D-6



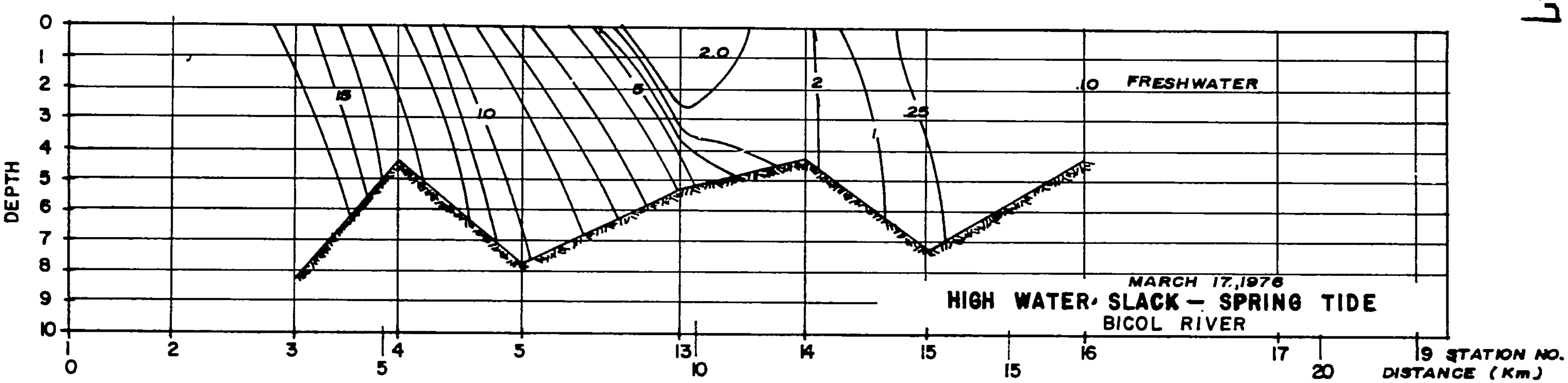
Q (BICOL R. at OMBAO) = 17.9 cu. m./sec.
Q (SIPOCOT R. at SABANG) = 121.0 cu. m. / sec.
INTRUSION = 17.0 Km.

TIDAL RANGE
(MSL)

Figure D-7-a

BALONGAY =
MABULO =
PLANCHA =
CABGAN = −.52 → 1.47 → − 1.07

D-7



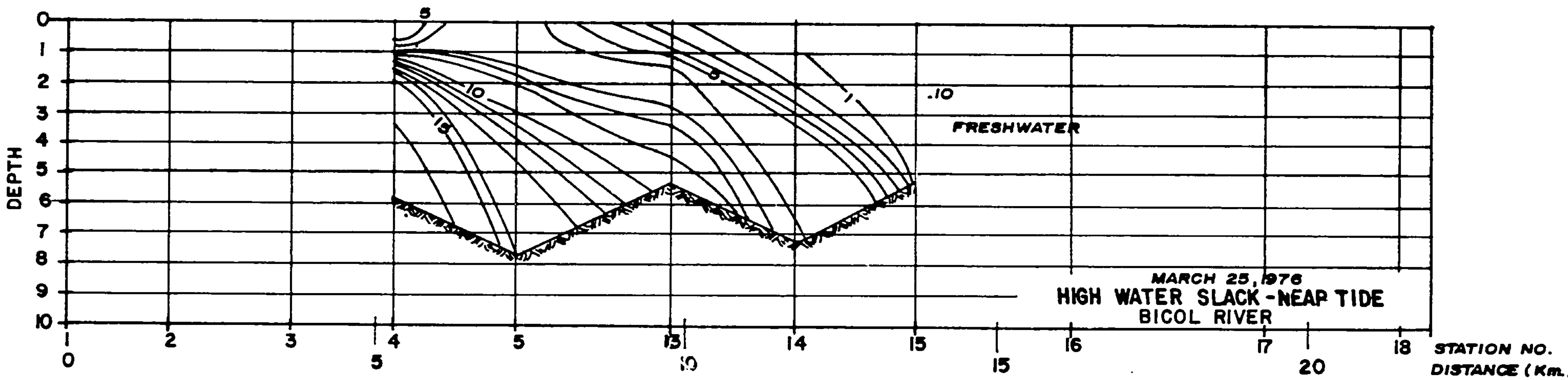
Q (BICOL R. at OMBAO) = 30.4 cu. m./sec.
Q (SIPOCOT R. at SABANG) = 138.5 cu.m./sec.
INTRUSION = 14.00 Km.

TIDAL RANGE
(MSL)

Figure D-7-b

BALONGAY = 1.35 → −0.92
MABULO = 1.37 → −0.22
PLANCHA =
CABGAN = −.98 → 1.35 → − 1.04

FIG. D-7

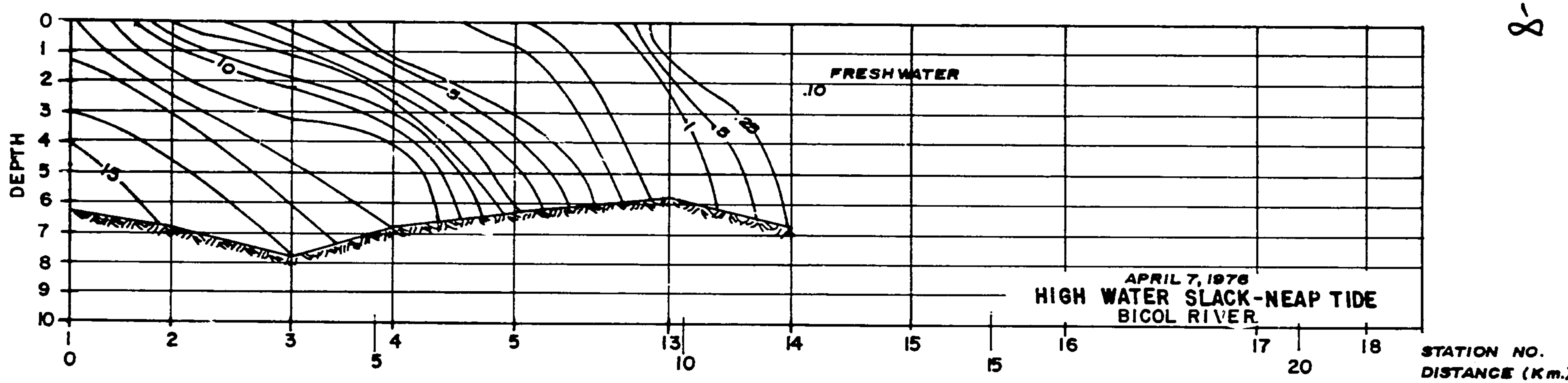


Q (BICOL R. at OMBAO) = 18.3 cu. m./sec.
Q (SIPOCOT R. at SABANG) = 133.4 cu. m./sec.
INTRUSION = 13.70 Km.

TIDAL RANGE (MSL)

BALONGAY =
MABULO =
PLANCHA =
CABGAN = −0.17 → .76 → −0.50

Figure D-8-a



Q (BICOL R. at OMBAO) = 22.2 cu. m./sec.
Q (SIPOCOT R. at SABANG) = 149.4 cu. m./sec.
INTRUSION = 11.75 Km.

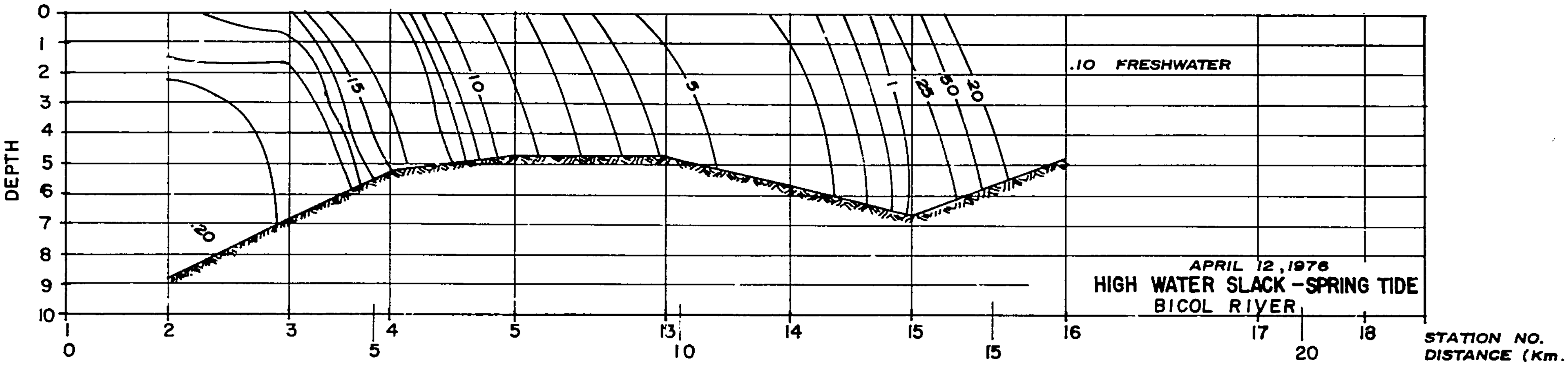
TIDAL RANGE (MSL)

BALONGAY =
MABULO =
PLANCHA =
CABGAN = −0.14 → 0.83 → −0.43

Figure D-8-b

FIG. D-8

D-8



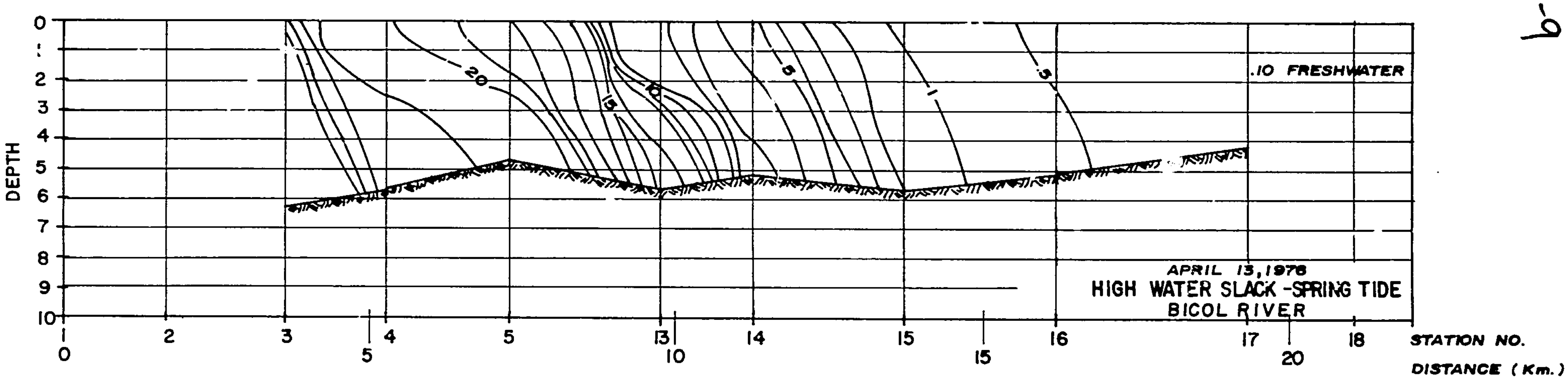
Q (BICOL R. at OMBAO) = 18.0 cu. m./sec
Q (SIPOCOT R. at SABANG) = 103.3 cu. m./sec.
INTRUSION = 16.2 Km.

TIDAL RANGE
(MSL)

Figure D-9-a

BALONGAY =
MABULO =
PLANCHA =
CABGAN = −0.71 ⟶ 1.18 ⟶ −0.75

D-9



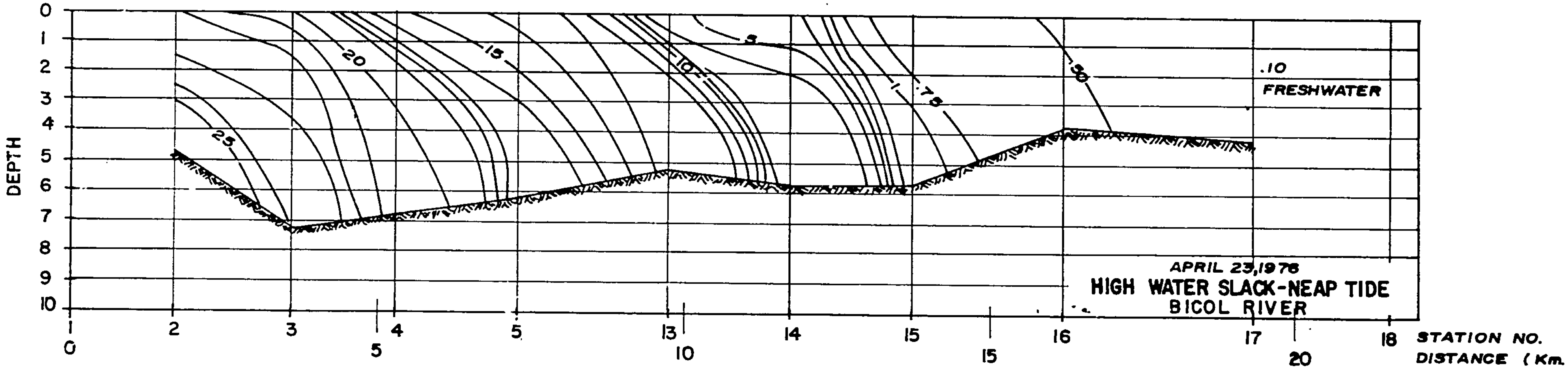
Q (BICOL R. at OMBAO) = 17.9 cu. m./sec.
Q (SIPOCOT R. at SABANG) = 103.3 cu. m./sec.
INTRUSION = 17.95 Km.

TIDAL RANGE
(MSL)

Figure D-9-b

BALONGAY =
MABULO = −0.20 ⟶ 0.80
PLANCHA =
CABGAN = −0.89 ⟶ 1.34 ⟶ −0.39

FIG. D-9



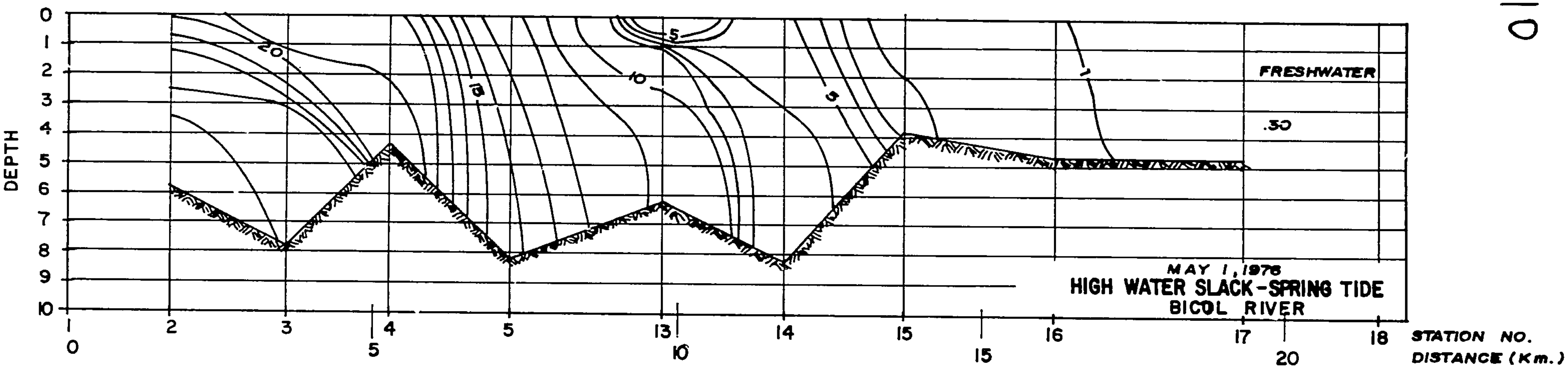
Q (BICOL R. at OMBAO) = 16.2 cu. m./sec.
Q (SIPOCOT R. at SABANG) = 94.4 cu. m./sec.
INTRUSION = 18.20 Km.

TIDAL RANGE (MSL)

Figure D-10-a

BALONGAY =
MABULO =
PLANCHA =
CABGAN = −0.17 ⟶ + 0.74 ⟶ − 0.35

D-10



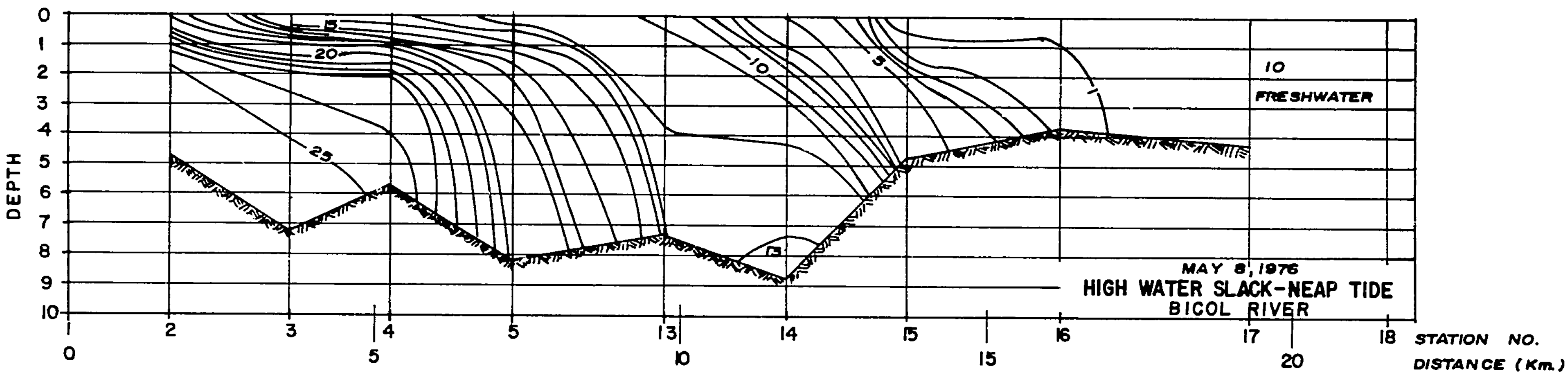
Q (BICOL R. at OMBAO) = 16.5 cu. m./sec.
Q (SIPOCOT R. at SABANG) = 96.2 cu. m./sec.
INTRUSION = 19.3 Km.

TIDAL RANGE (MSL)

Figure D-10-b

BALONGAY = 1.20 ⟶ − 0.86
MABULO =
PLANCHA =
CABGAN = − 0.41 ⟶ 1.20 ⟶ −0.80

FIG. D-10



Q (BICOL R. at OMBAO) = 17.1 cu.m./sec.
Q (SIPOCOT R. at SABANG) = 94.4 cu.m./sec.
INTRUSION = 17.1 Km.

TIDAL RANGE
(MSL)

Figure D-11-a

BALONGAY = 0.65
MABULO =
PLANCHA =
CABGAN = −0.18 — +0.84 — −0.39

D-11

FIG. D-11

INTRUSION (Km.) Versus TIDAL STAGE (CABGAN IS.)

···BICOL RIVER···

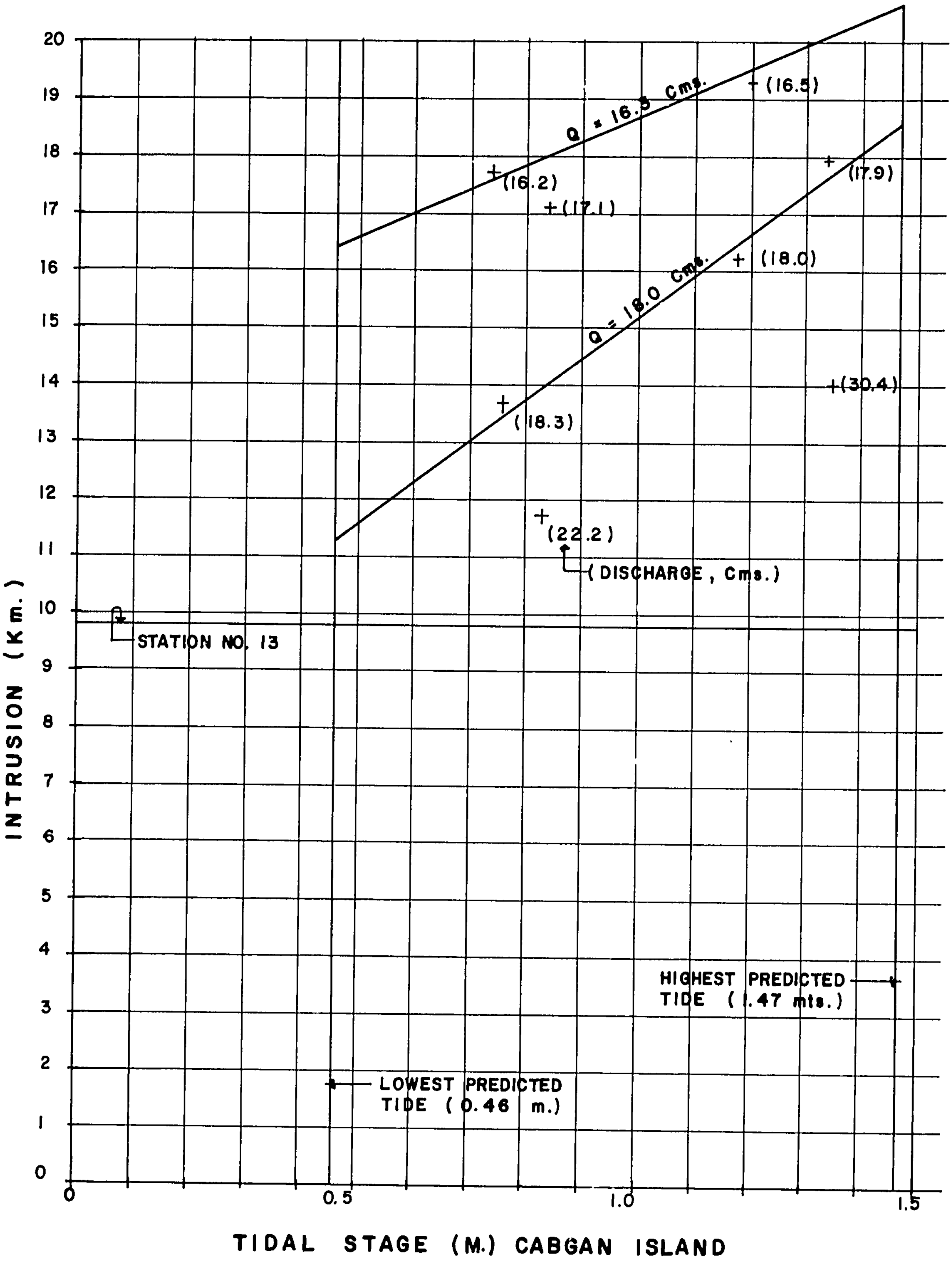
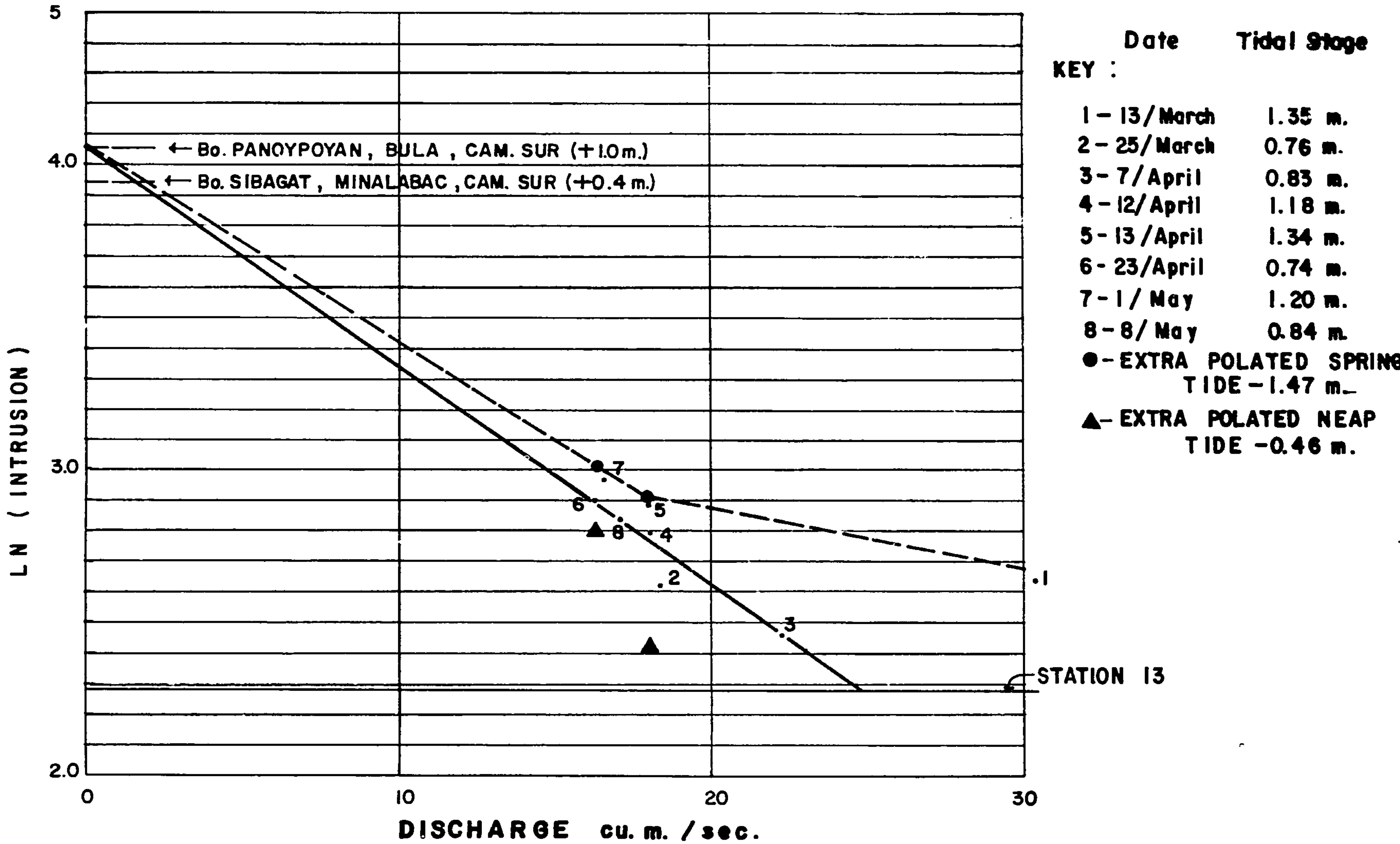


FIG. D-12

L N (INTRUSION) Vs. DISCHARGE cu. m. /sec.

··· BICOL RIVER ···



——— INTRUSION $= I = e^{(-.07165\,Q + 4.05)}$ $0 \le Q \le 24.7$ cu. m./sec TIDAL STAGE 0.74 - 0.84 m.

– – – – $I = e^{(-.06278\,Q + 4.05)}$ $0 \le Q \le 18$ cu.m./sec. TIDAL STAGE 1.47 m.

$I = e^{(-.01944\,Q + 3.27)}$ $18 \le Q \le 30$ cu. m./sec.

D-13

FIG. D-13

Appendix E
Sedimentation Studies
August 1976

COMPREHENSIVE WATER RESOURCES
DEVELOPMENT STUDY

BICOL RIVER BASIN
LUZON ISLAND PHILIPPINES

APPENDIX E

SEDIMENTATION STUDIES
August 1976

BICOL RIVER BASIN DEVELOPMENT
PROGRAM
Baras, Canaman, Camarines Sur

APPENDIX E

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX E

SEDIMENTATION STUDIES

RIVER TRANSPORT

Sediment Transport in Rivers of the Bicol Basin

Sediment samples have been collected from various streams in the Basin since 1964. The program should be continued to obtain statistically significant data for a number of stations. In addition, the river discharges corresponding to some samples were not recorded. Table E-1 presents a summary of the available information on sediment samples and their analyses.

TABLE E-1

LIST OF STATIONS WITH SEDIMENT TRANSPORT DATA

River and Location	Period of Record
Bicol, Ombao, Bula	1975
Culacling, Del Rosario, Lupi	1975
Pawili, Bula, Cam. Sur	1975
Libmanan, Plancha, Cam. Sur	1975
Pulantuna, Napolidan, Lupi, Cam. Sur	1975
Quinale, Busac, Cam. Sur	1975
Sabang, Sabang, Sipocot	1975
Bicol, Sto. Domingo, Nabua	1968-1975 (Discontinuous)
Talisay, Aliang, Ligao, Albay	1967-1975 (Discontinuous)
Yabo, Yabo, Sipocot, Cam. Sur	1964-1975 (Discontinuous)

The data for the Bicol at Sto. Domingo, Talisay at Aliang and Yabo at Yabo, were sufficient to obtain some preliminary conclusions on the annual sediment yield for these streams. Figs. E-1, 2 and 3 are log-log plots of the computed sediment transport in tons/day and the recorded discharges. Although much more information is required to confirm the accuracy of these plots, the trends are evident and allowed visual fitting of straight lines, which are considered tentative and for the sole purpose of this preliminary feasibility report.

To estimate the annual load, an integration should be made based on the daily discharges for each station, since the relationship between sediment transport and discharge is not linear. However, sample errors are probably very important, and it was decided to use mean monthly discharges instead of refining the computations beyond the accuracy of the data.

Adding the mean monthly sediment loads thus computed, the values provided by Table E-2 were obtained.

TABLE E-2

PRELIMINARY ESTIMATES OF ANNUAL SEDIMENT LOADS AND YIELDS

River, Station	Drainage Area sq. km.	Annual Load tons/sq.km.	Annual Volume**** m^3/sq.km.
Bicol, Sto. Domingo*	905	190	160
Talisay, Aliang**	90	590	490
Yabo, Sipocot***	85	980	820

* Mean monthly discharges, 1946-74 with interruptions.
** Mean monthly discharges for 1965. Discharges for following years decrease considerably, probably due to diversions.
*** Mean monthly discharges for 1971.
**** Assuming a lake deposit specific weight of 1.2 ton/cu.m.

Sediment Yields for Other Rivers in Luzon

Information provided in April 1976 by the National Irrigation Authority on sediment yields is provided in Table E-3.

TABLE E-3

ANNUAL SEDIMENT YIELDS FOR RIVERS IN LUZON

Rivers and Locations	Drainage Area sq. km.	Yield m^3/yr. sq.km.	Record
Ibulao, Hapid, Lamut, Ifugao	606	292	1972-1973
Siffu, Muñoz, Roxas, Isabela	686	292	1965-1970
Chico, Pasonglao, Tabuk	1,987	580	1963-1970
Bokod, Bokod, Benguet	48	274	1963-1969
Ambayoan, Sta. Maria, San Nicolas, Pangasinan	281	379	1963-1971
Agno, Carmen Rosales, Pangasinan	2,209	38	1964-1971
Camiling, Nambalan, Mayantoc, Tarlac	142	131	1963-1969
Pila, Pacalay, Mangatarem	126	31	1963-1971
Purac, Valdez, Floridablanca, Pampanga	118	669	1963-1971
Santor, Cuyago, Gabaldon, Nueva Ecija	89	15	1965-1972
Cabu, Cabu, Babaratnan, Nueva Ecija	143	204	1963-1972
Pampanga, San Antonio, San Leonardo, Nueva Ecija	2,851	798	1963-1972

-over-

TABLE E-3 (CONT.)

ANNUAL SEDIMENT YIELDS FOR RIVERS IN LUZON

Rivers and Locations	Drainage Area sq. km.	Yield m^3/yr. sq.km	Record
Pampanga, San Vicente, Cabiao, Nueva Ecija	3,467	441	1963-1972
Rio Chico, Sto. Rosario, Zaragoza, Nueva Ecija	1,177	167	1963-1972
Pampanga, San Agustin, Arayat, Pampanga	6,487	317	1963-1971

Comparisons

Tables E-2 and E-3 show that the loads estimated for the Bicol System are within the magnitude of those estimated for other basins in Luzon.

The load at Sto. Domingo is comparable to that of the Rio Chico at Sto. Rosario, San Leonardo, Nueva Ecija, with similar tributary area. The load in the Talisay is about three times larger than that at Sto. Domingo, which was expected both because its area is much smaller and steeper and because of the settling effect of Lake Bato and its swamps and deltas.

The load in the Yabo is higher than that for the Talisay, which appears reasonable since the discharges of the former are larger.

LAKE BATO SEDIMENTATION

Trap Efficiency

The area tributary to Lake Bato is 874 sq. km. The volume of the lake of about 210 x 10^6 cubic meters at elevation 9 m MSL, is taken as index volume for sedimentation appraisal.

The mean discharge tributary to the lake may be estimated from the relationship between tributary areas and mean annual discharges for the Bicol River at about 1200 x 10^6 cubic meters per year.

Use is made of Brune's trap efficiency curves(1) to obtain an estimate of the proportion of sediment trapped in the lake per year. Since the ratio between capacity and inflow is about 0.18, it is concluded that the lake has a trap efficiency of more than 90 percent, that is, more than 90 percent of the inflow sediments are deposited in the lake.

The values of the loads given in Table E-2 do not allow making definite estimates of volume accumulations in Lake Bato. However, if the Talisay load were assumed, for the sake of discussion as being representative of the sediment inflow in the lake, the total yearly accumulation in it would be on the order of 400,000 cubic meters per year, not including the bed load deposits. It is recognized that the load from Mount Mayon must be larger than that in the Talisay, but on the other hand, a large part of the drainage area is presently occupied by swamps and the lake proper, and this would tend to compensate for the larger yields from the Mayon.

The above conclusions should be confirmed or revised with data collection in all the streams tributary to the lake.

Deltaic Formations

All coarse sediments are deposited in deltaic formations at the mouths of the lake tributary rivers. The most conspicuous delta is that of the Quinale-Naporog Rivers. Deposition of coarse sediments in the deltas produce frequent alterations of their channels during and after floods, with attendant local flooding and damages to irrigation canal intakes and levees. In all probability, none of the sand and gravel portion of the sediment load penetrates deep in the lake.

It appears that the proportion of coarse sediments in the total sediment load tributary to Lake Bato should be higher than the average because of the considerable supply of sand and gravel on the slopes of Mount Mayon and other high peaks bounding the drainage area on the west. It is estimated that probably about 15 percent of the annual sediment load is formed by coarse sediment. If the above percentage is correct, the order of magnitude of the deposits in the deltaic formations would be on the order of 60,000 cubic meters per year.

Sediment sampling should be intensified in all streams of the Bicol System and care be taken to obtain simultaneous discharges at the same stations. In particular, sediment sampling should be initiated in the Quinale and Naporog Rivers.

A comparison should be made between the economic and social convenience of continuing the present system of cleaning the channels of the Bato deltas after each flood, and other more permanent measures to avoid channel filling and changes. For example, a channelization program could be studied, which would deepen the present delta channels in advance to the occurrence of the floods, and would be subject to routine maintenance dredging.

A feasibility study of training works in the delta channels should be made, including revetments and alignment.

The present use of coarse bed sediments for concrete aggregates should be strongly promoted as a means to obtain local relief.

In regard to the lake bottom sediments, it is recommended that a sampling program be undertaken. If good undisturbed samples are taken, it might be possible to establish true rates of sedimentation in the lake. For example, if cinder layers are found in the logs and are dated to correspond to known eruptions of the Mayon, the sediment thickness between the cinders would give a very good indication of the rates of deposition.

It is recommended that use be made of the procedures of the US Bureau of Reclamation for sediment surveys in the bottom of its reservoirs.[2] A piston core sampler should be used similar to the type suitable for small reservoirs. This sampler should be operated from two boats assembled in catamaran configuration. A light A frame would be used to drive the sampler into the bottom sediment. The Bureau of Reclamation samplers have lengths of 90, 180 and 270 centimeters. These samplers may be made locally, out of standard stainless steel tubes 3-in ID, and steel rods. The US Bureau of Reclamation has standard sampler designs.[3]

REGIME THEORY STUDIES

Hydraulic Geometry Concepts

The cross-section of a river is said to be in regime if it is established by itself in movable boundaries during a long time of stable flow and sediment transport conditions. There are several theories on the relations between the main geometric parameters of the cross-section and a characteristic discharge. If changes in discharge occur, the cross sections will change to a new regime condition.

A correlation was established between discharges and the corresponding water surface elevation, cross-sectional area, depth, mean velocity and top width for several cross-sections of the Bicol System.

Usually, the mean annual discharge is taken as the regime parameter for establishing these relationships. In the case of sections subject to tidal effects, however, the mean freshwater discharge has probably much less significance than the discharges associated with the tidal motions. Table E-4 presents the estimated mean freshwater discharges for all sections. The tidal prisms should be averaged from results of the LATIS freshwater discharges for the sections subject to important tidal effects using spring and neap tide conditions.

Table E-4 presents such correlation for different rivers and stations.

TABLE E-4

HYDRAULIC GEOMETRY BICOL SYSTEM

River and Place	Drainage Area sq. km.	Q Mean (cms.)	Cross Section Parameters for Q Mean Stage WSEl.* (m)	Area (sq.m.)	Depth (m)	u(m/s)	Width (m)
Bicol, Sto. Domingo	905	40.6	5.9***	220	5.5	0.19	53
Bicol, Ombao	1,630	72	3.9	80	3.6	0.96	30
Bicol, Baliwag	1,720	77.4**	1.5	159	4.4	0.49	63
Bicol, Naga	1,930	86.8**	0.75	380	6.3	0.23	110
Culacling, Lupi	64	2.8	4.05	2.5	0.9	1.10	5.4
Sipocot, Sabang	447	39.8	3.5	60	1.8	0.66	47
Aslong, San Isidro	12	1.3	9.9	1.4	0.3	0.93	4.7
Pawili, San Roque	540	24.4	1.55	30	1.2	0.81	40
Libmanan, Plancha	596	206**	1.0+	530	4.6	0.39	174

* WSEl = Water surface elevation.
** Estimated through drainage area relationship. Tidal effects.
*** From calibration run. Mathematical model. (Average Nodes 33.34).

The regime formulas may be expressed as follows:(4)

Width: $W = C_w Q_m^a$

Depth: $D = C_d Q_m^b$

Velocity $\bar{u} = C_u Q_m^c$

In which C_w, C_d, C_u, a, b, c, are empirical constants. These equations may be applied in a downstream direction of the same river and, if the physiographic characteristics do not change, the same constants will be applicable for all sections. This was done for the Bicol System, using the values given in Table E-4 but the values obtained for the constants proved unrealistic. It was concluded that the physiographic characteristics of the system are not homogeneous. In fact, the Bicol is controlled by a narrow stretch in the vicinity of Ombao, which has an entirely different physiography than the rest of the system. The lower portions of the system are subject to tidal effects, and therefore, the mean discharge governing the geometry of the cross-section is different from the mean fresh water flow, as stated above. In addition, the portion of the basin located upstream of Ombao has a marked lacustrial character.

The regime relationships may in turn, be used to estimate the order of magnitude of possible changes if the characteristic discharges are changed. For this, it is required to estimate the values of the exponents. From results of studies made in the humid United States, it is estimated that the exponent in the width relationship is the smallest: on the order of 0.1. This means that once a cross-section is in regime, its width will change relatively little with the discharge. The depth and the velocity exponent are both on the order of 0.45.(4)

If the discharge at a particular cross-section were reduced to 50 percent, for example, the width would be reduced by 7 percent and the depth and the velocity would both be reduced by 27 percent.

Consequently, if Cutoff Channel No. 3 were constructed to proportions able to reduce the flow at Naga by say 50 percent, reductions in depth on the order of 27 percent would be expected there. If, due to scour during floods, the cutoff cross-section were enlarged to convey most of the discharge, then sedimentation would decrease the depth of the present channel in proportion to the 0.45 power of the discharge approximately.

COASTAL SEDIMENTATION

Physiographic Description

The entire southern portion of San Miguel Bay has muddy tidal flats and mangrove forests. There appears to be relatively little sand contribution from the Bicol, the Barcelonita estuary or the littoral itself. Chart 14223 of the US Hydrographic Office shows that the 3-fathom (5.5 m) line is located 5 km off shore the mouth of the Bicol Estuary.

Reiterated aerial reconnaissance showed that there are suspended sediments transported from Barcelonita toward the Bicol and further to the west. Muddy bars parallel to shore are exposed during low tide.

At the mouth of the Bicol, there is an important normal bar probably enhanced by the fresh water-saltwater interface. Depths in the Bicol Estuary upstream of the bar and in the lower Bicol River reach 5 m below MSL, while low-tide depths on the bar are on the order of 1 m. There is a short bar parallel to and opposite the west shore protrudes beyond the end of the east shore.

The normal bar has been dredged to facilitate navigation of shallow draft, but siltation occurs rapidly and maintenance dredging is required. Fishing vessels must wait for the high tide to negotiate the bar.

Proposed Study of Navigation Improvement

It is proposed to study the feasibility of reducing the inlet cross-sectional area with spur jetties at the inlet. Furthermore, channelizing parallel jetties would lead the discharge out to the bar location. The reduction of cross-sectional area would increase velocities which in turn would increase scour and would keep a channel open across the bar into deeper water. This should reduce the need for maintenance dredging. The channel would be designed according to present inlet stability theory.

Results from the recent salinity intrusion studies indicate that deepening the inlet would not adversely affect salinity intrusion with the above described scheme because the inlet and lower portions of the Bicol Estuary have a vertically well mixed salinity condition and the above scheme should not change it.

The spur and channelizing jetties would be designed based on the inlet stability theory, according to empirical data. There is a relationship between the spring tidal prism and the minimum cross-sectional area for a stable inlet, expressed as follows:(4)

$$A_c = 8.0 \times 10^{-4} P_s^{0.85}$$

A_c: Minimum cross-sectional area

P_s: Spring tidal prism

A typical spring tidal prism for the Bicol is 21×10^6 m^3. The above expression gives a minimum cross-sectional area of 1000 m^2 as necessary for a stable inlet. The present cross-sectional area is on the order of 2500 m^2.

The difference in size between a stable inlet and the Bicol cross-sectional area implies that there is moderate littoral drift and wave activity, due to the short fetches in San Miguel Bay.

A reduction of the cross-sectional area in size to that corresponding to a stable inlet would increase the velocity enough to scour the inlet without maintenance dredging. In addition, the channelizing jetties would direct the flow across the bar and produce a channel of suitable depth. The inlet should not be made too small, to avoid velocities beyond acceptable vessel operation.

Additional soundings should be made to study the deposition of sediment at the mouth of the Bicol Estuary. The entrance to the Estuary was recently dredged; soundings in this vicinity should be taken to determine the rate of sedimentation at the mouth.

It is suggested that fishing vessels make a report of wave heights and directions for use in design of any anticipated coastal works in the region.

In the actual design of the project, it should be determined whether the spur jetties can be anchored in the mangrove areas.

Mathematical hydraulic model studies should be made to determine whether the inlet structure might adversely affect flooding upstream on the Bicol River and also to obtain values of the resulting maximum velocities.

APPENDIX E

REFERENCES

1. Vanoni, Vito A., Editor - American Society of Civil Engineering, Sedimentation Egineering. New York, 1975. Page 590.

2. Ibid. page 361.

3. Ibid. page 362.

4. Graf, Walter H., Hydraulics of Sediment Transport, McGraw-Hill Book Co. New York, 1971. Page 254.

5. Moes, J., Stability of Small Estuary Mouths, XVI Congress of the International Association for Hydraulic Research, Sao Paulo, Brazil, 1975.

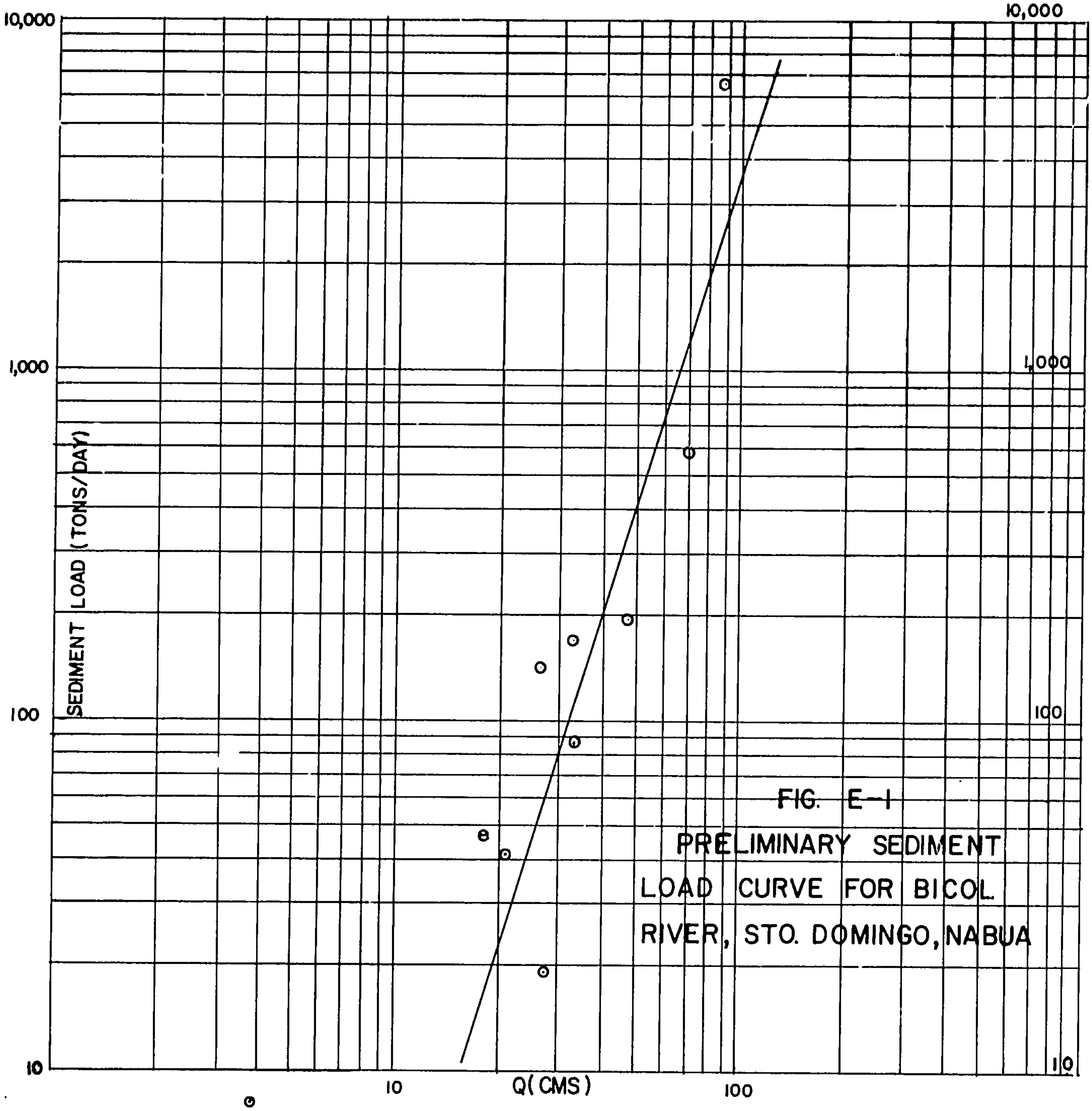


FIG. E-1
PRELIMINARY SEDIMENT LOAD CURVE FOR BICOL RIVER, STO. DOMINGO, NABUA

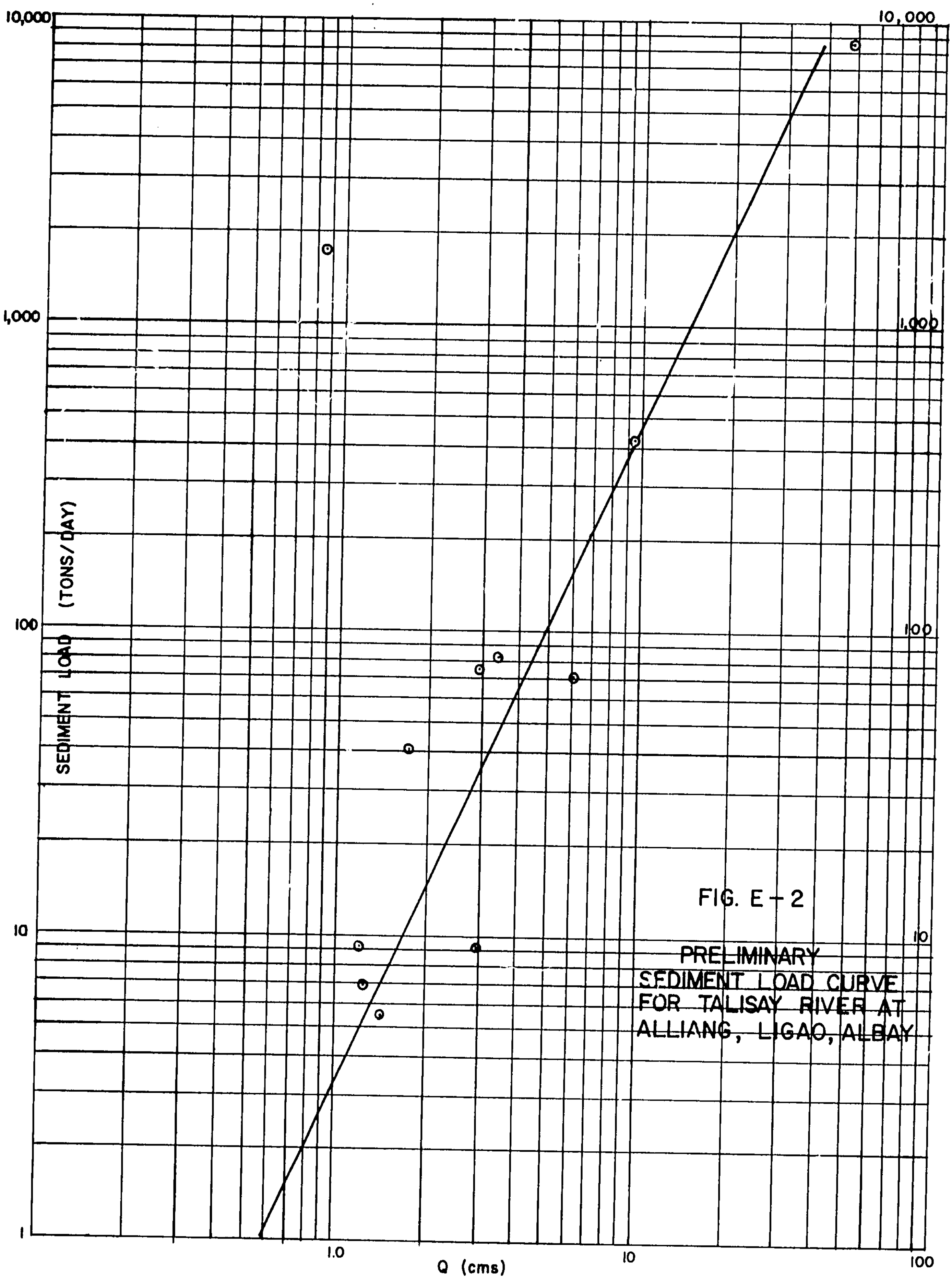


FIG. E-2

PRELIMINARY SEDIMENT LOAD CURVE FOR TALISAY RIVER AT ALLIANG, LIGAO, ALBAY

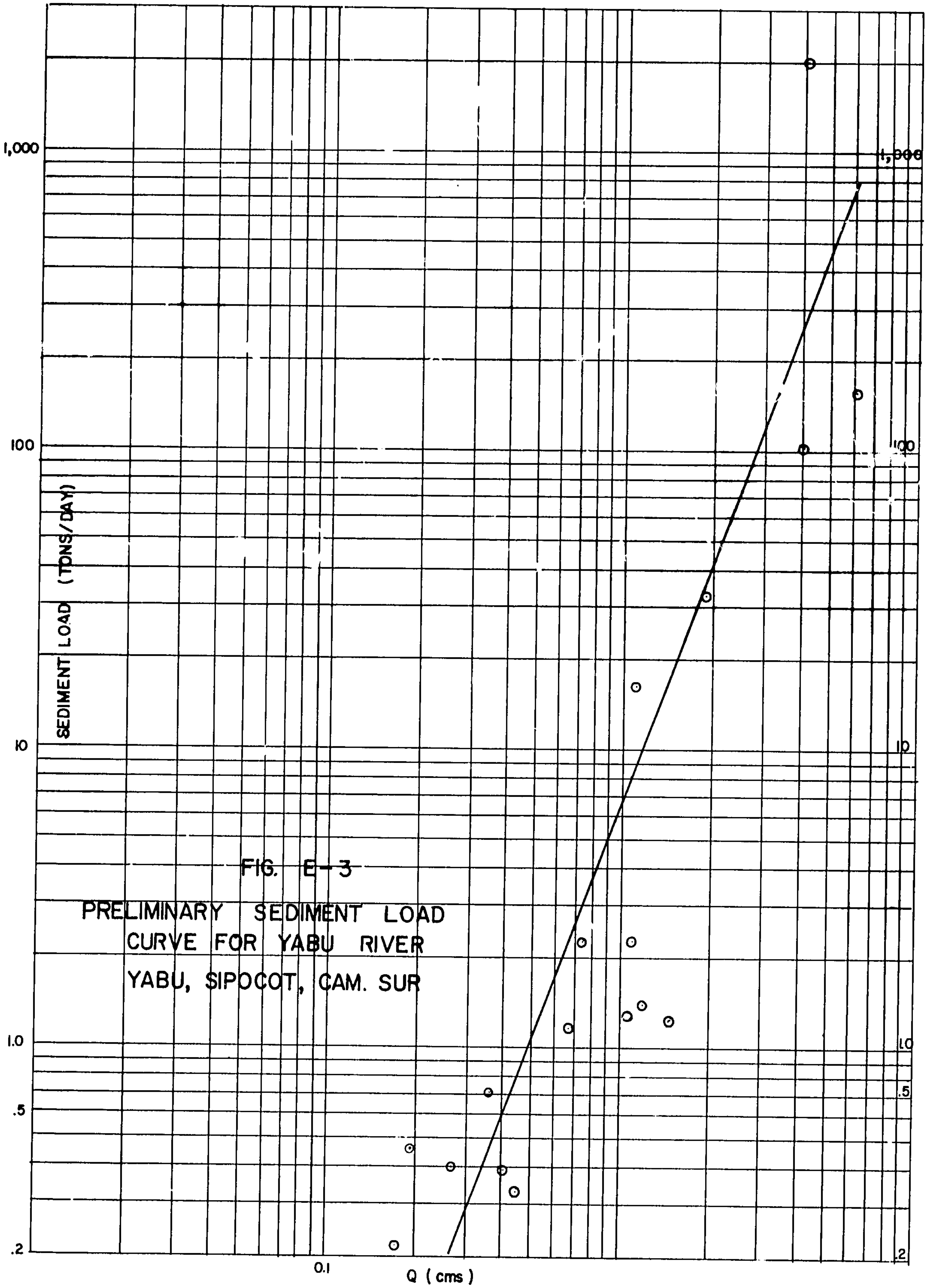


FIG. E-3

PRELIMINARY SEDIMENT LOAD
CURVE FOR YABU RIVER
YABU, SIPOCOT, CAM. SUR