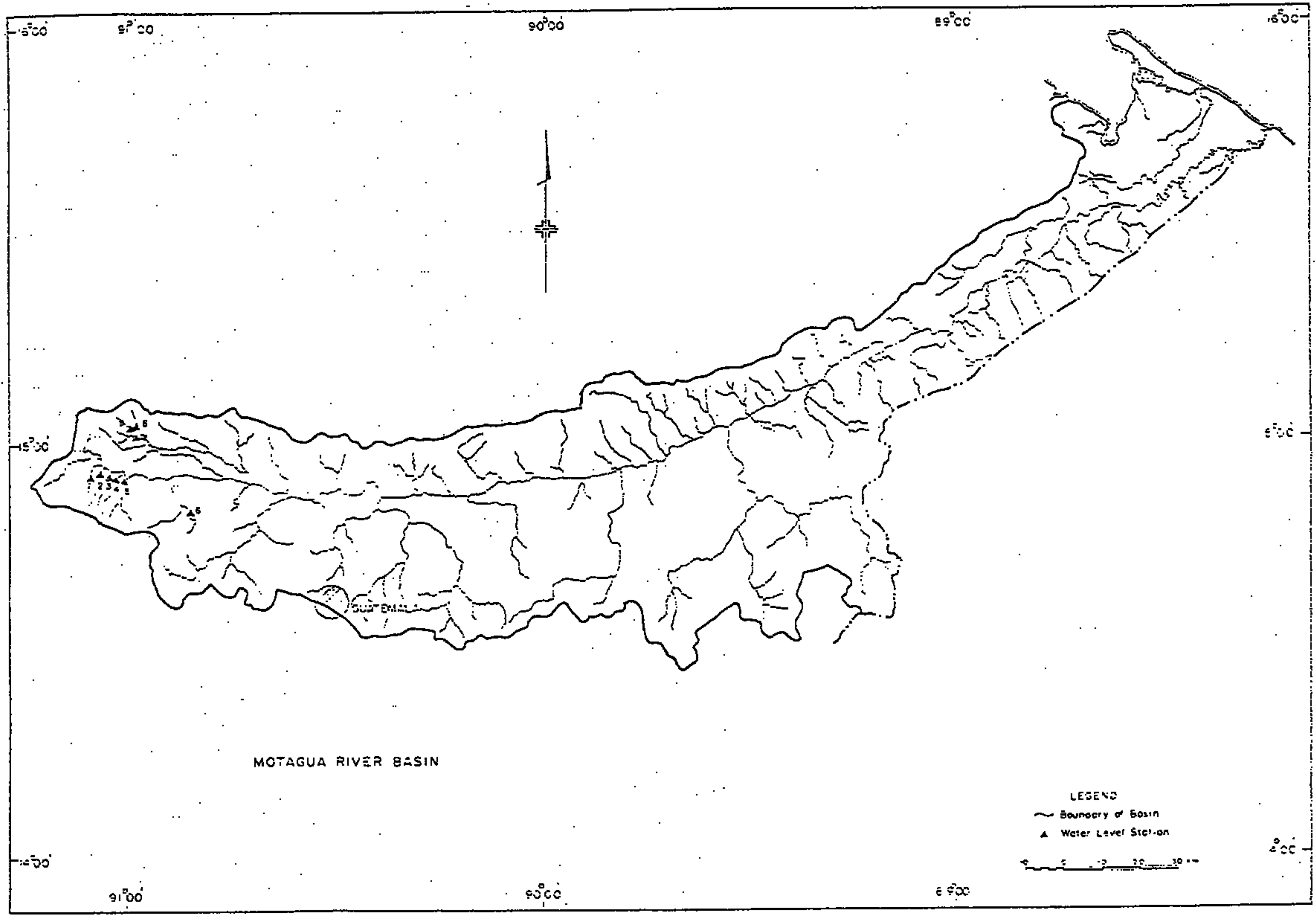


Fig. 2-5 LOCATION OF WATER LEVEL STATIONS IN GUATEMALA UNDER EMPAGUA

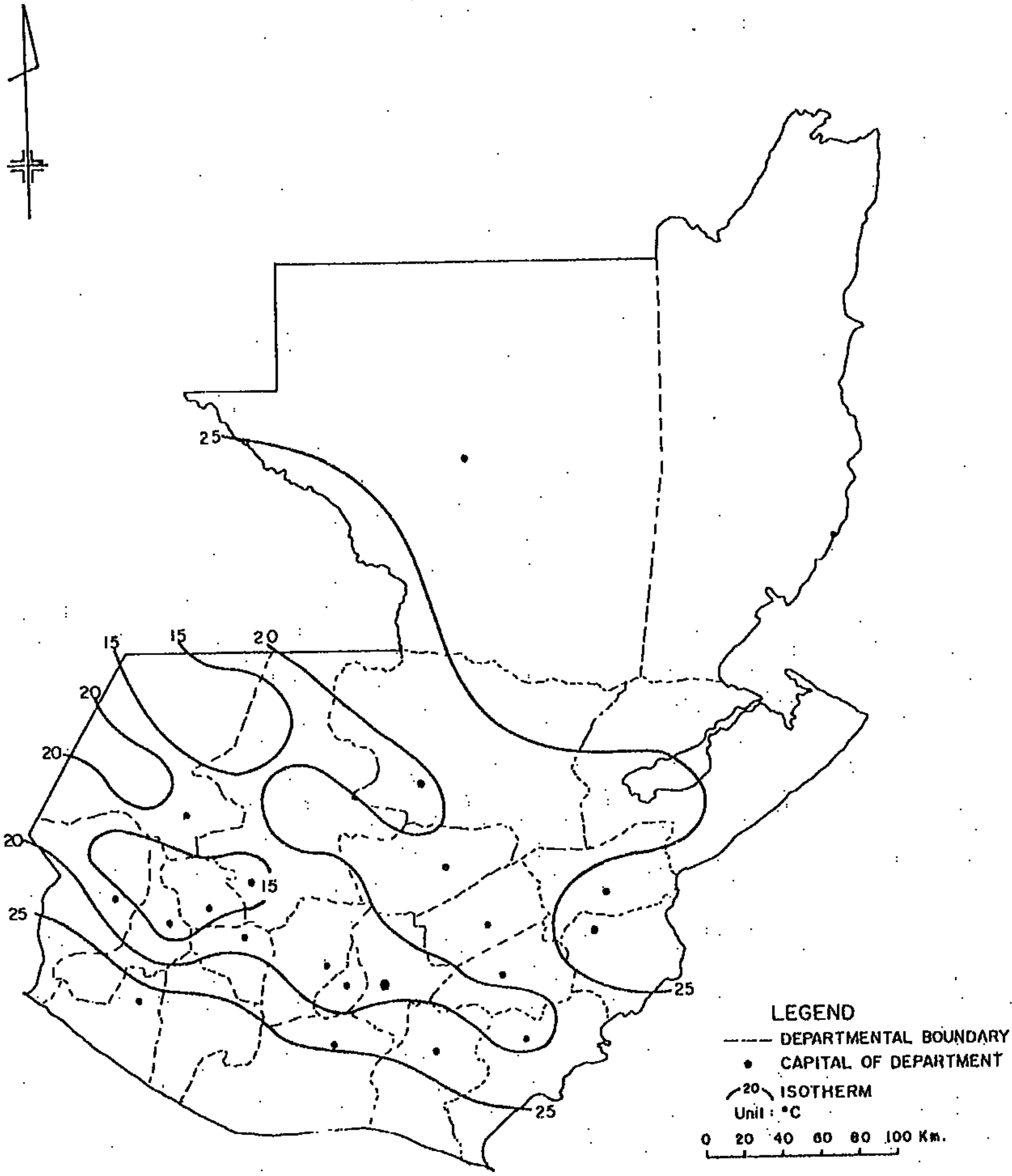


Fig. 2-6 ISOTHERM OF MEAN ANNUAL TEMPERATURE IN GUATEMALA

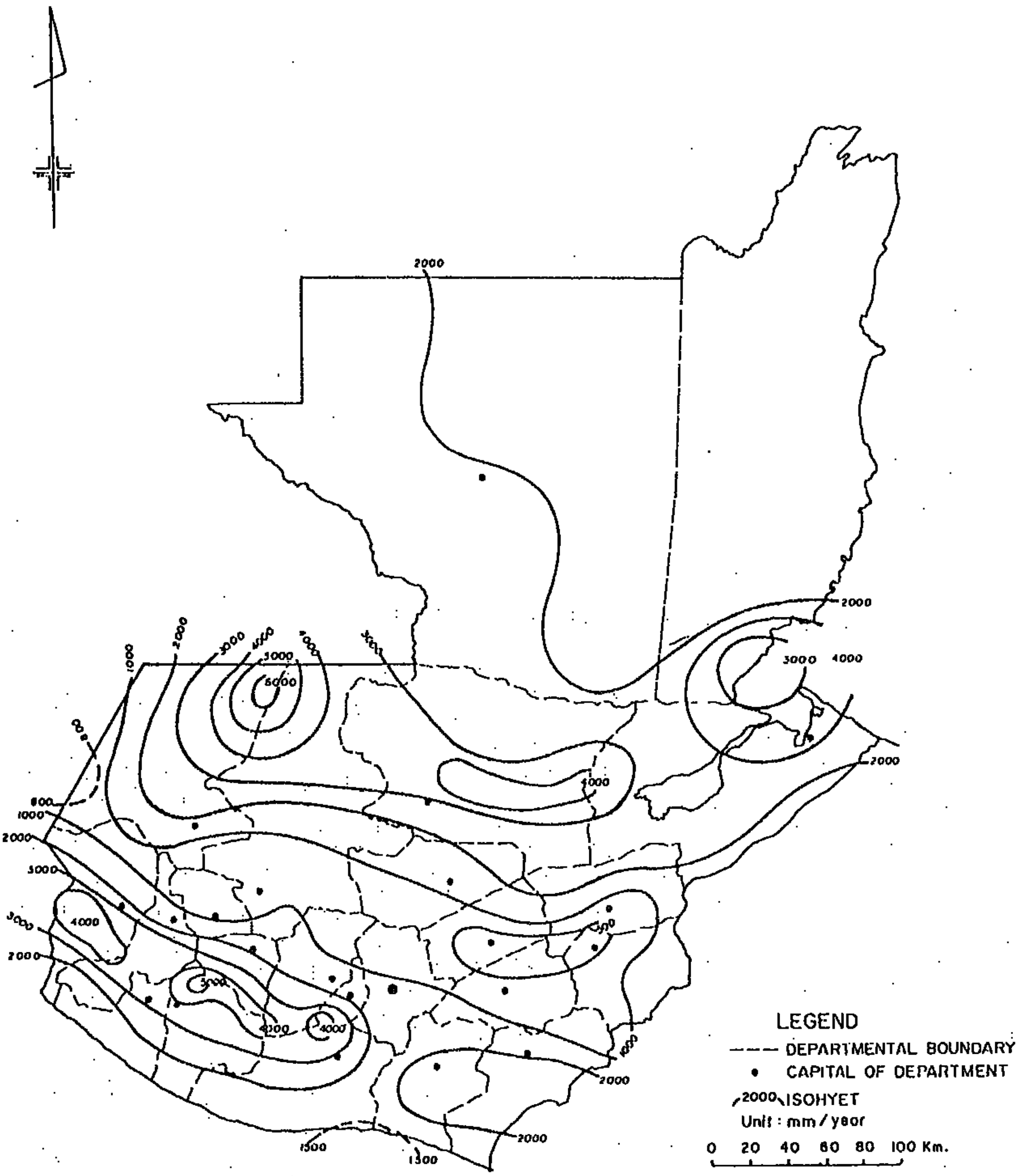


Fig. 2-7 ISOHYET OF MEAN ANNUAL RAINFALL IN GUATEMALA

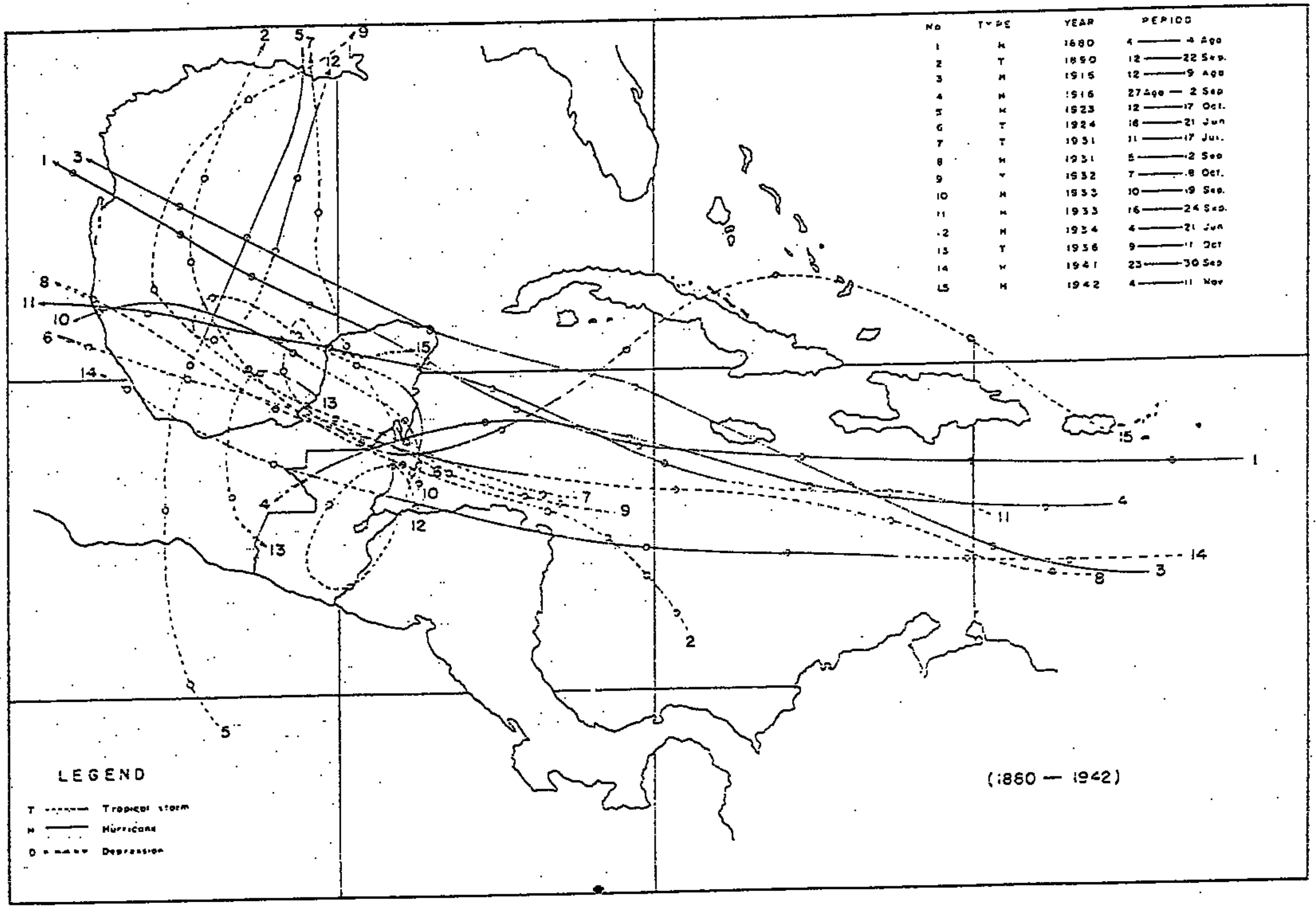
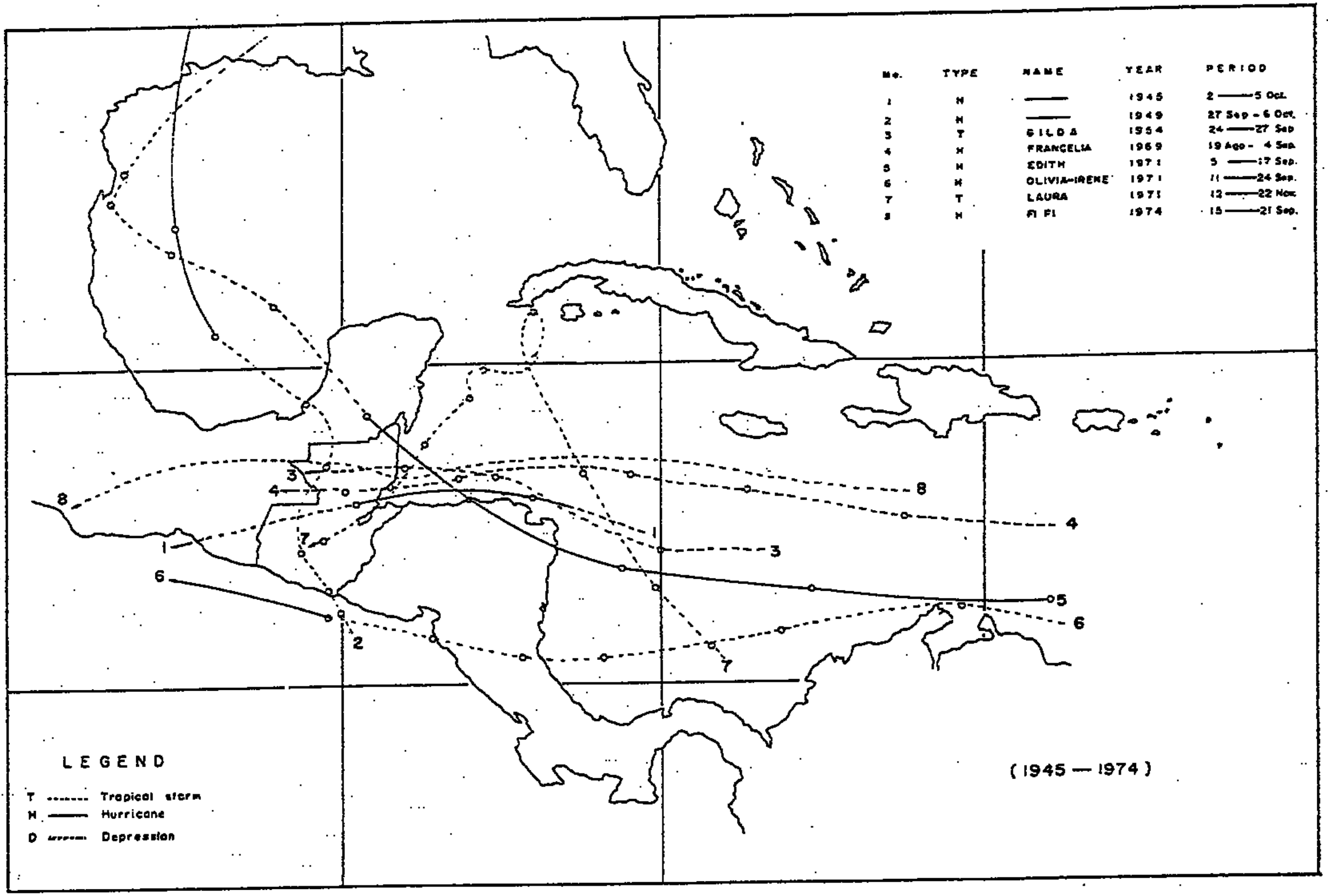


Fig. 2-8 (1/2) TRACKS OF THE TOPICAL CYCLONES FROM THE NORTH ATLANTIC OCEAN



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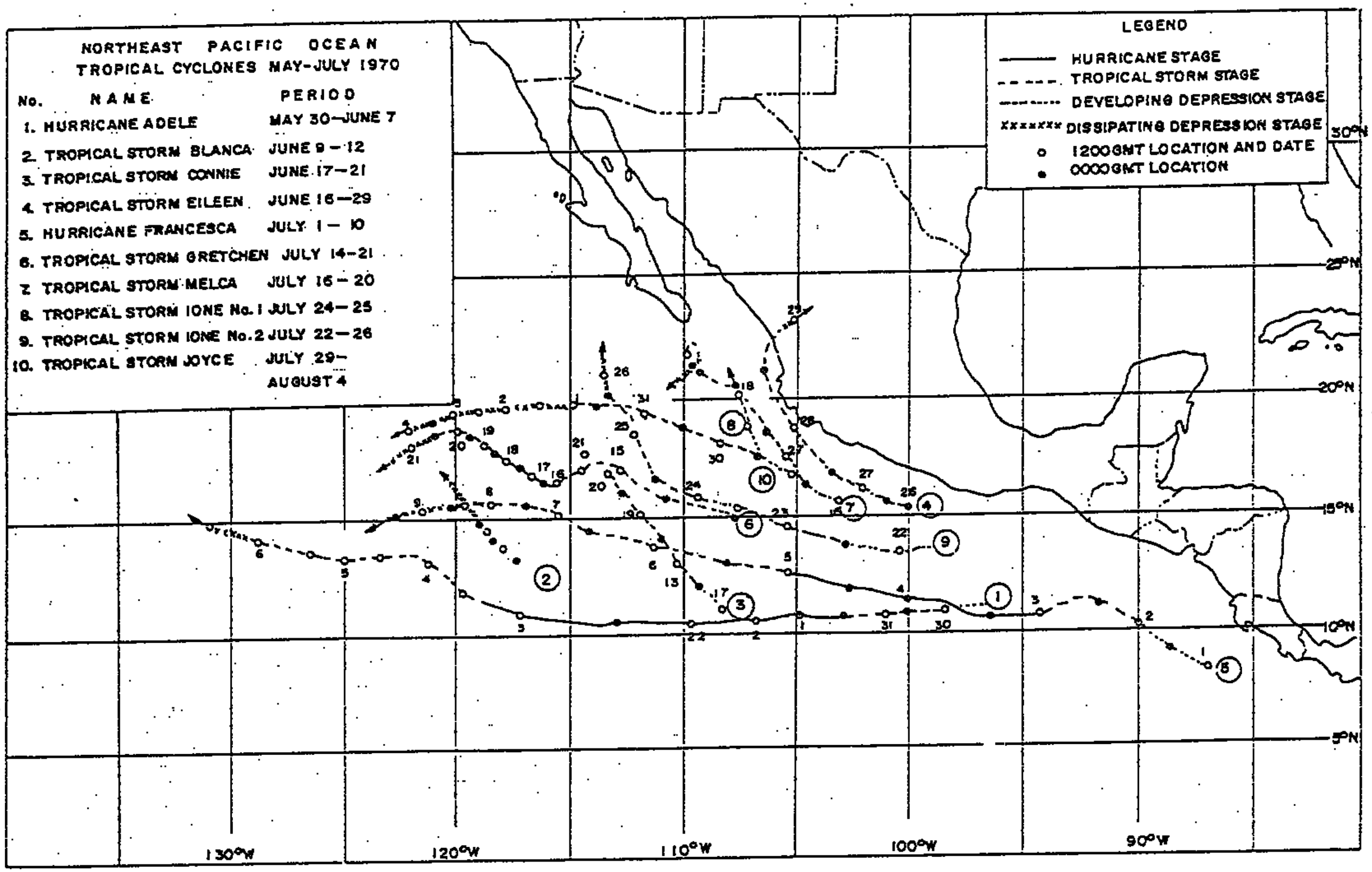

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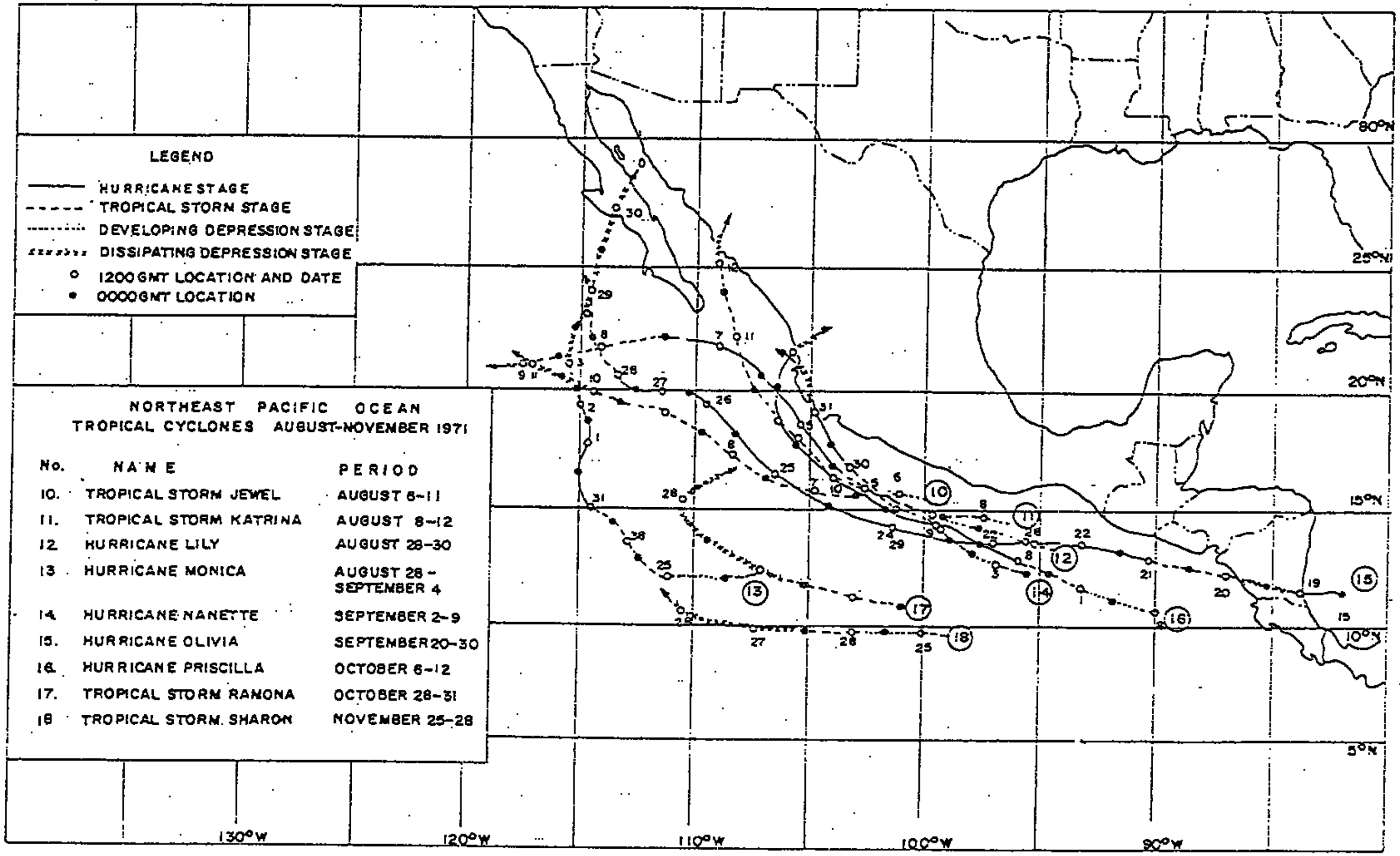

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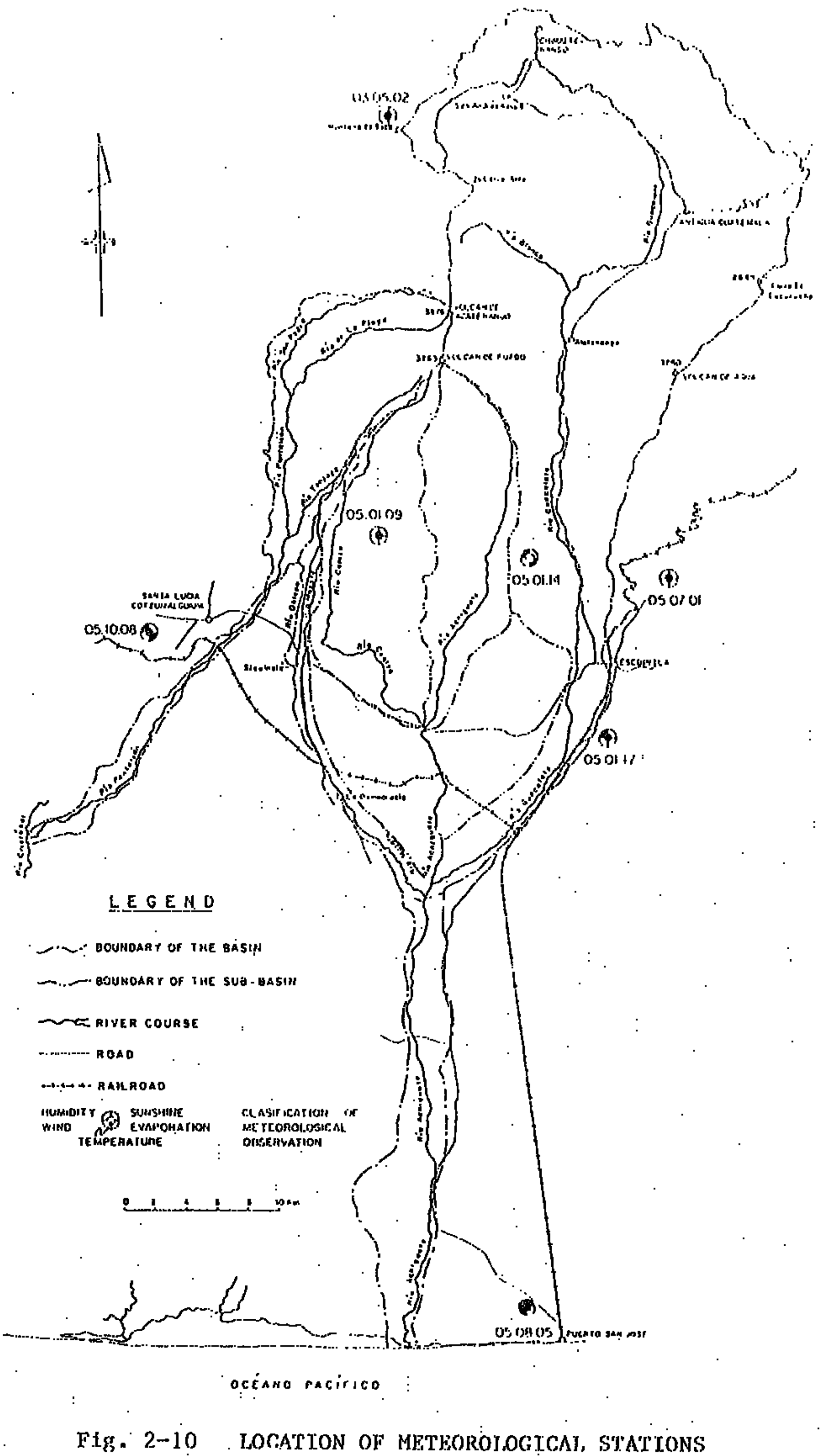


Fig. 2-10 LOCATION OF METEOROLOGICAL STATIONS

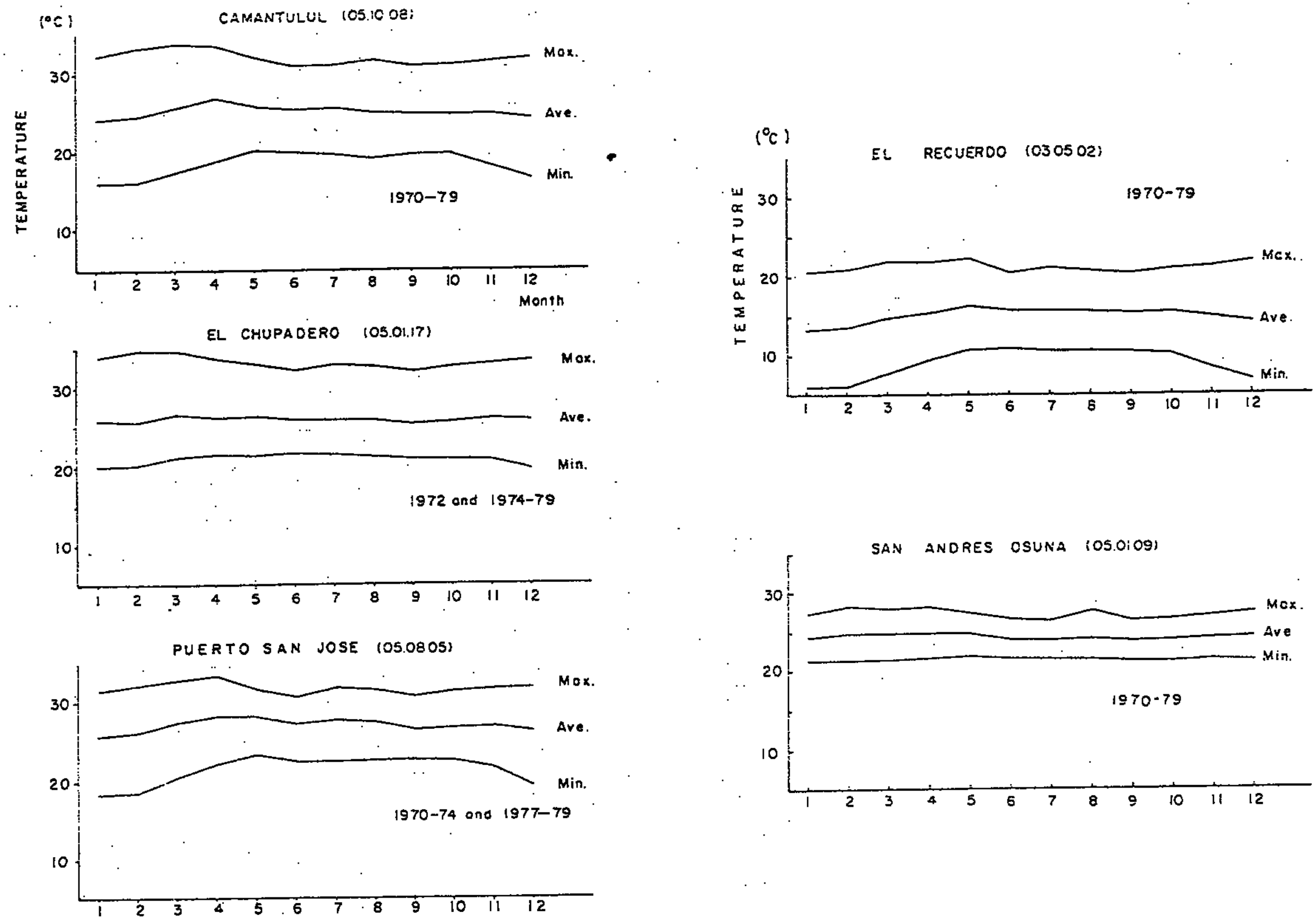


Fig. 2-11 MONTHLY MEAN TEMPERATURE

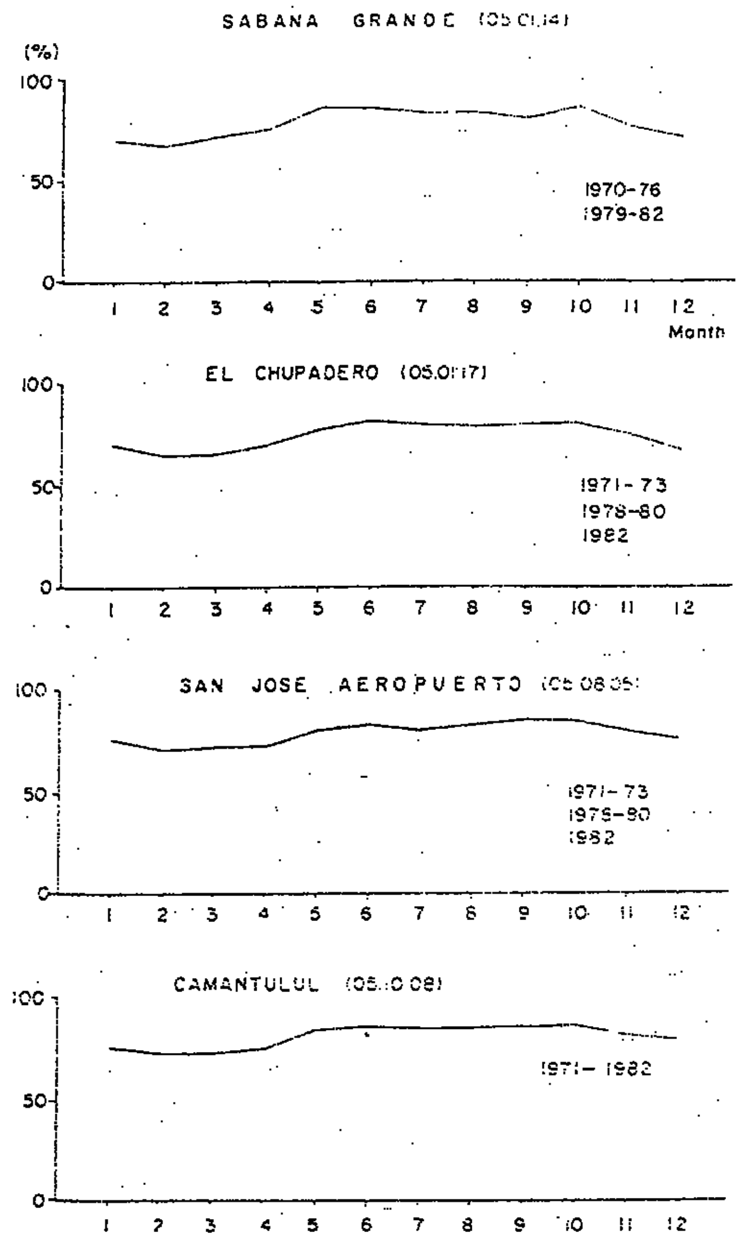


Fig. 2-12 MONTHLY MEAN HUMIDITY

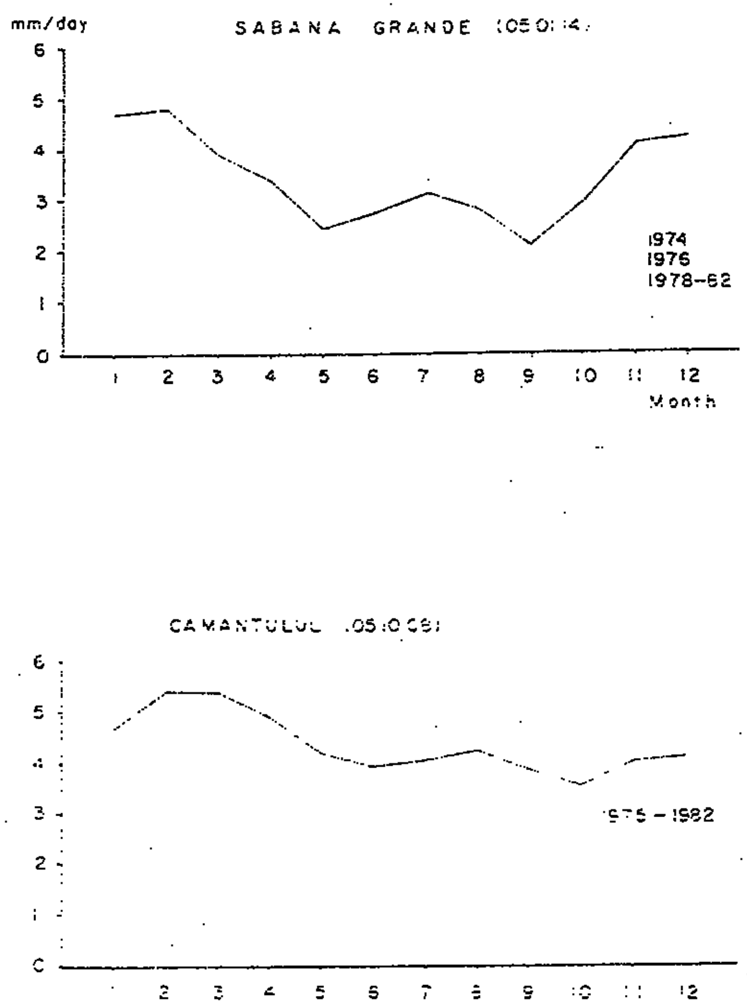
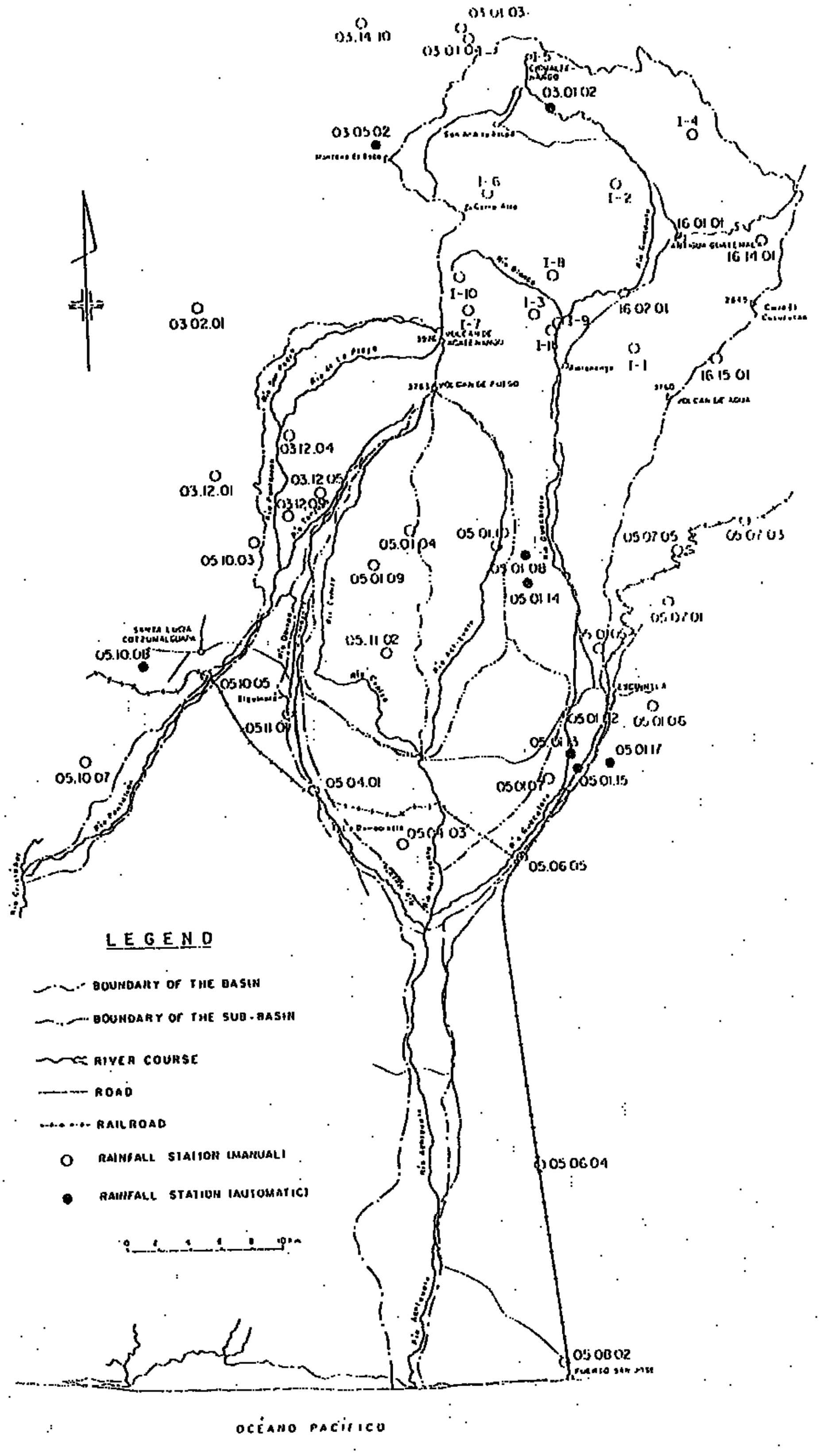


Fig. 2-13 MONTHLY MEAN EVAPORATION



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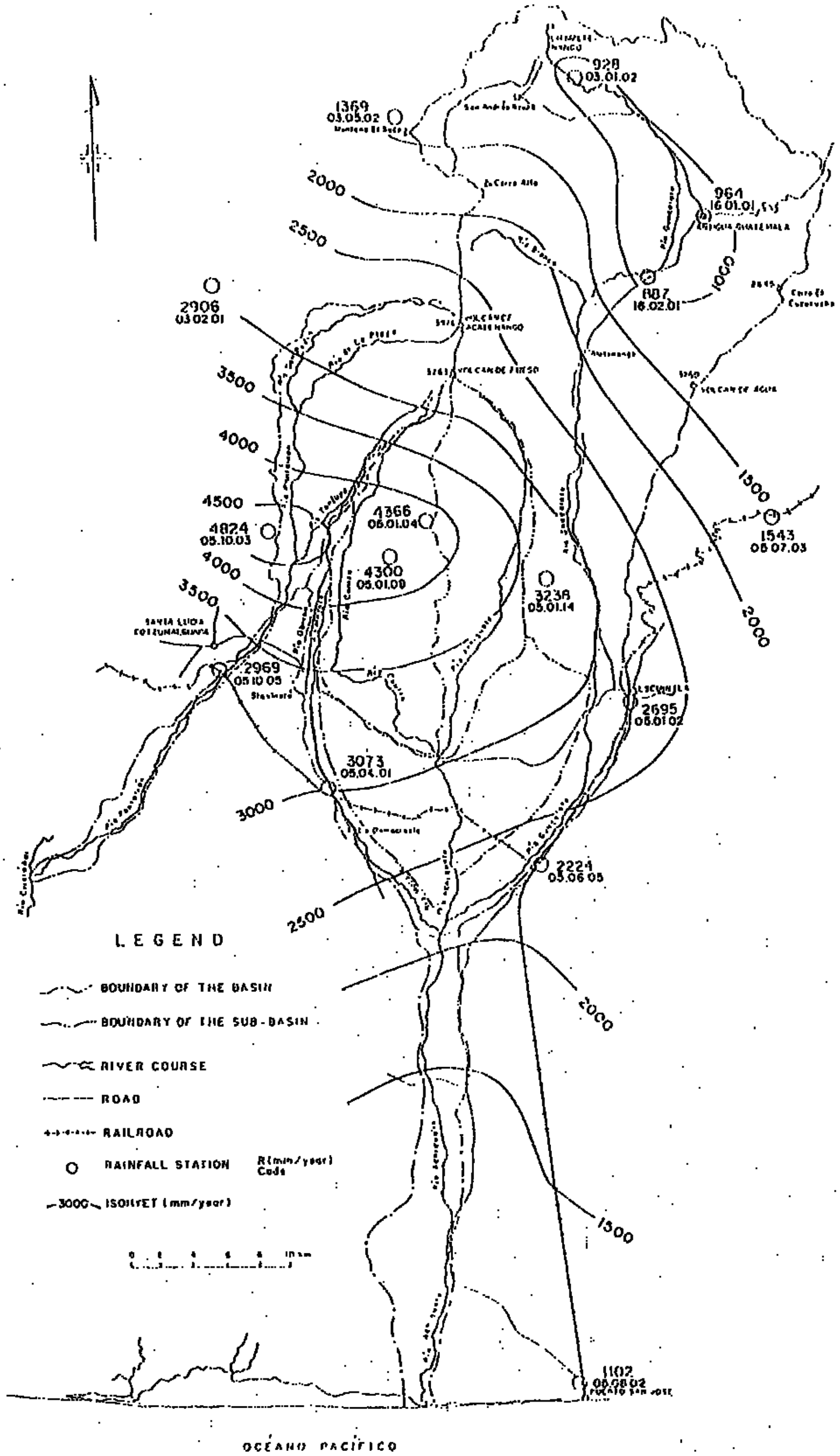

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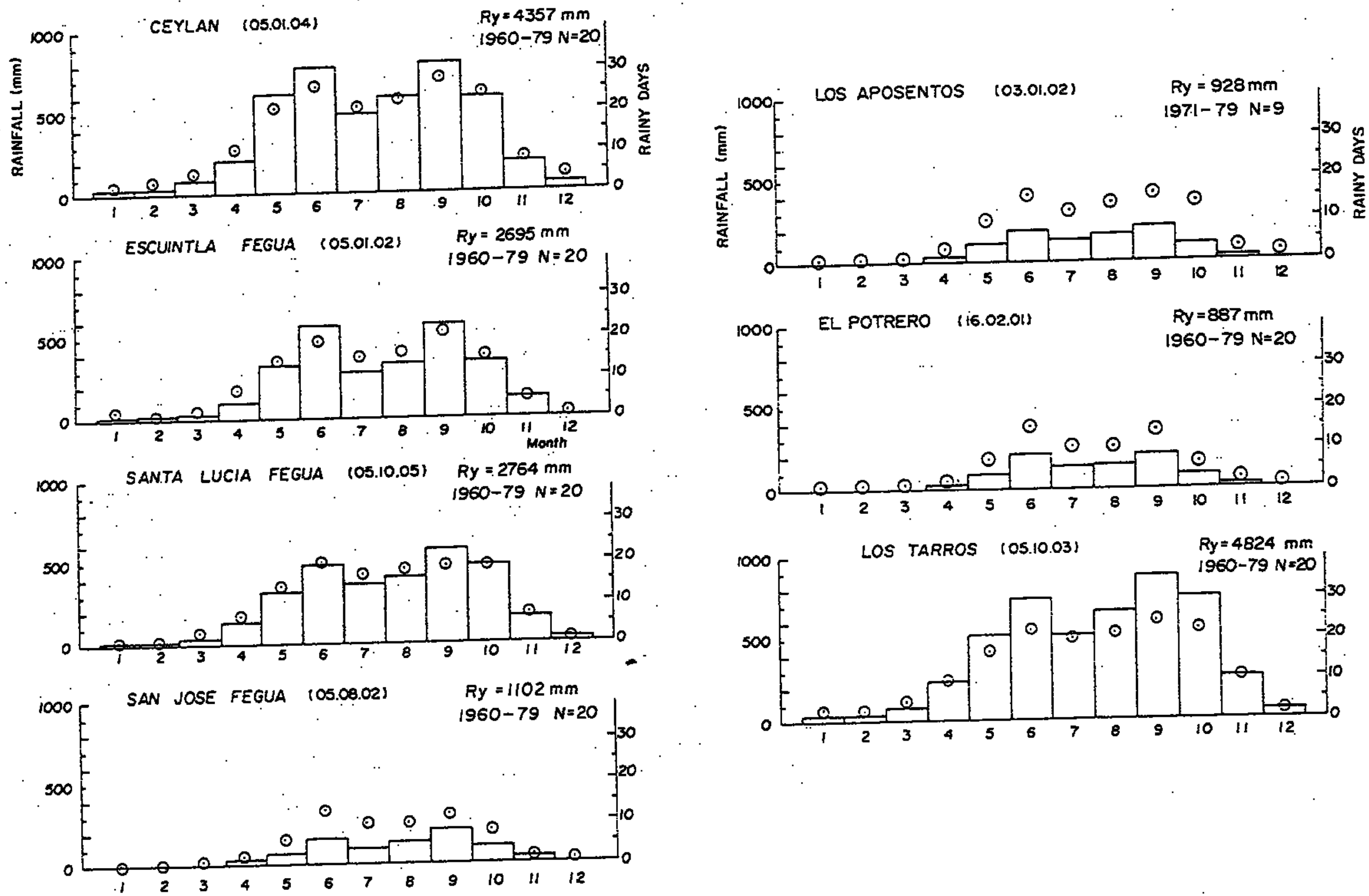
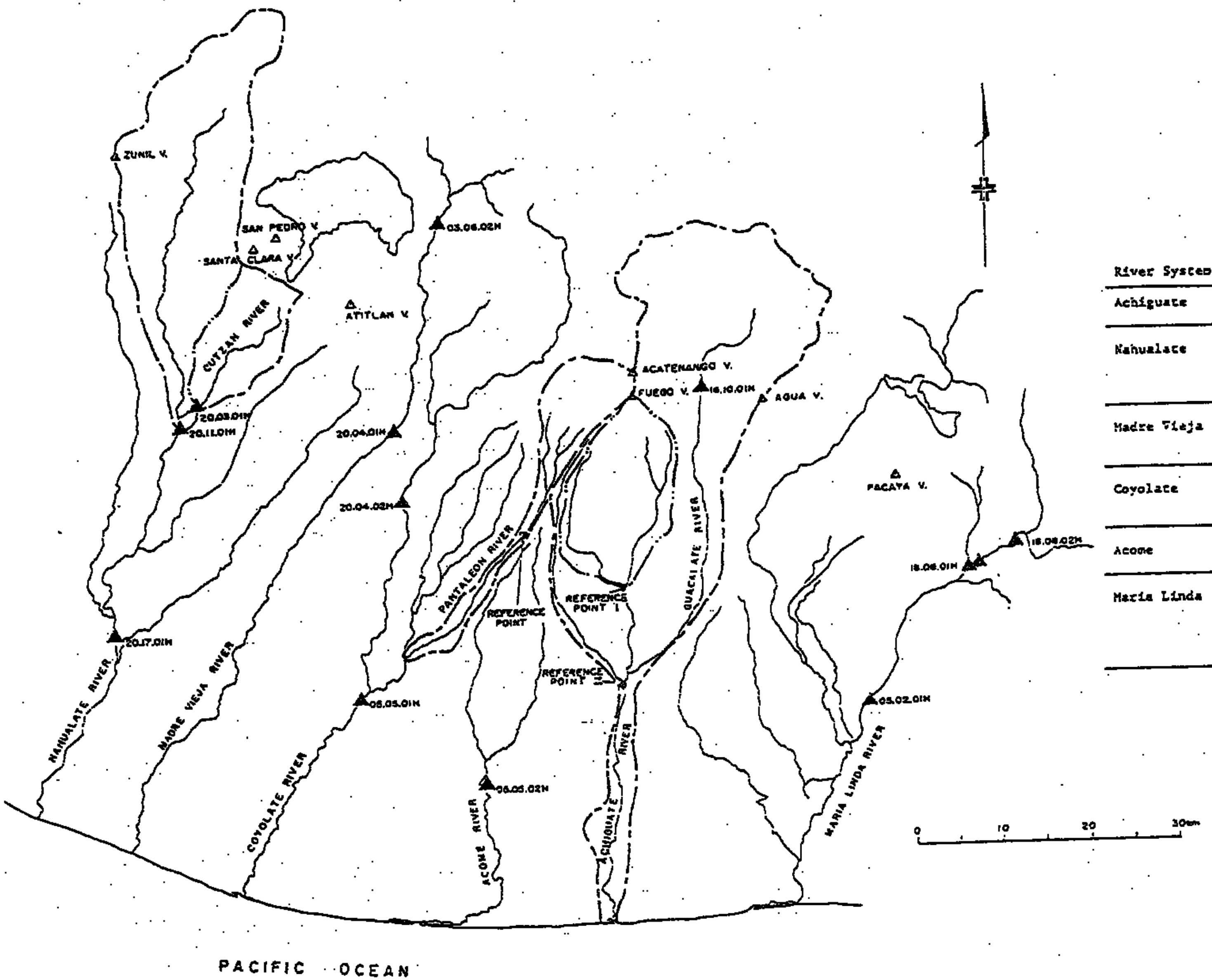


Fig. 2-16 MONTHLY MEAN RAINFALL AND RAINY DAYS



River System	Code	Name
Achiguate	16.10.01H	Alotenango
Nahualate	20.03.01H	Montecristo
	20.11.01H	San Miguel Moca
	20.17.01H	San Mauricio
Madre Vieja	03.06.02H	Panibaj
	20.04.01H	Palmira
Coyolate	20.04.02H	Puente Coyolate
	05.05.01H	Cerro Colorado
Acome	05.05.02H	La Gomera
Maria Linda	18.08.02H	Las Lomas
	18.08.01H	Agua Caliente I
	18.08.01H	Agua Caliente II
	05.02.01H	Las Guacamayas

Fig. 2-17 LOCATION OF WATER LEVEL STATIONS IN AND AROUND THE STUDY AREA

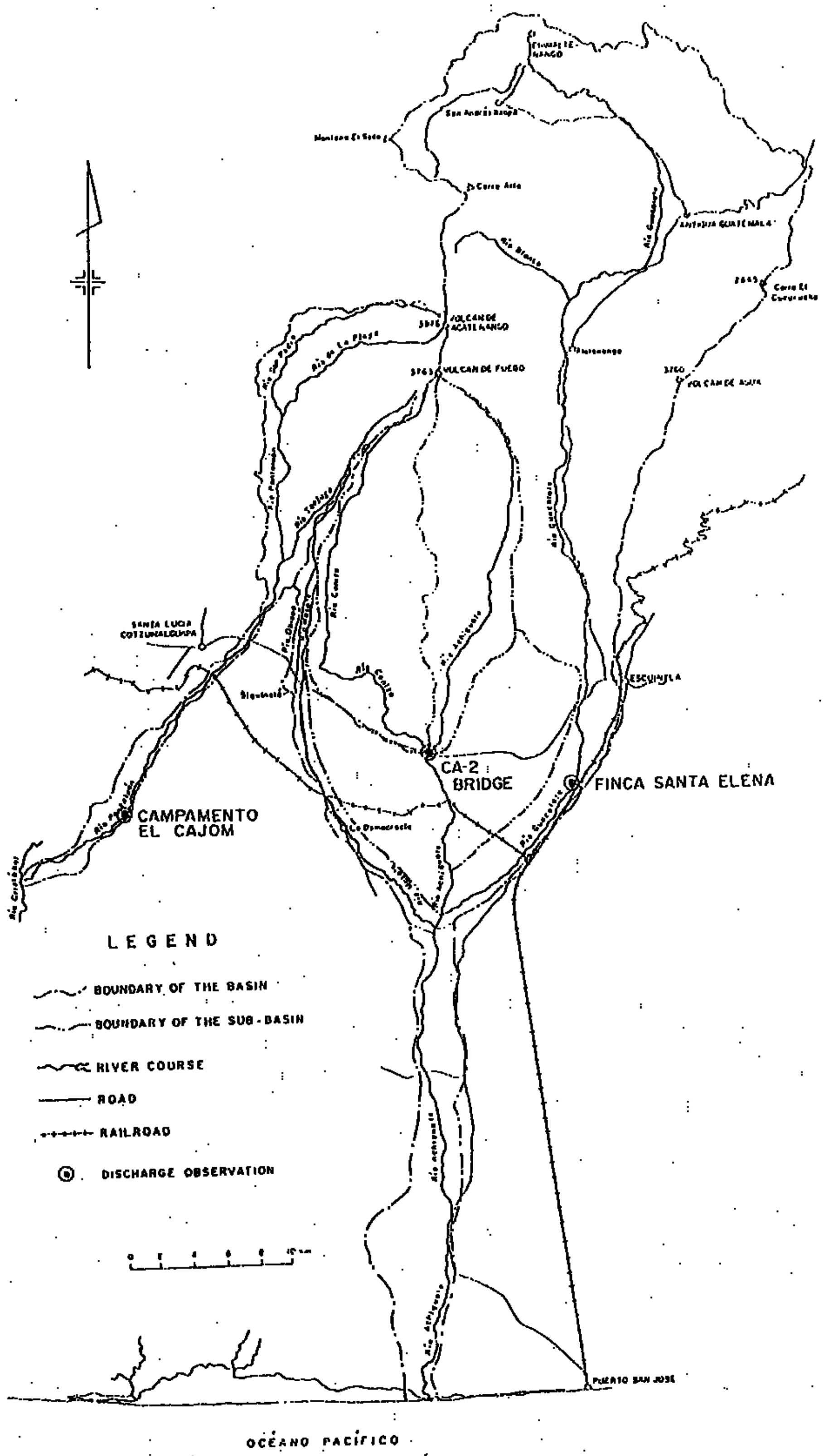
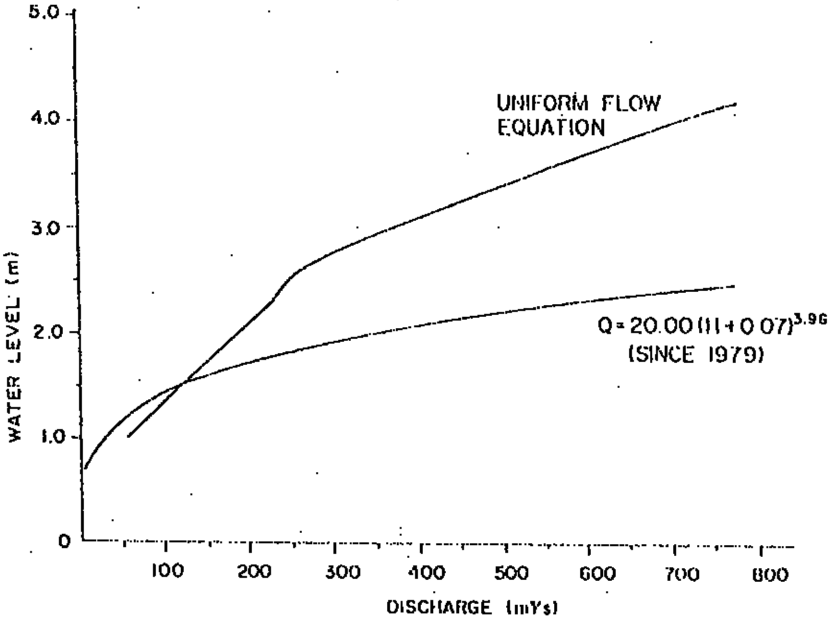
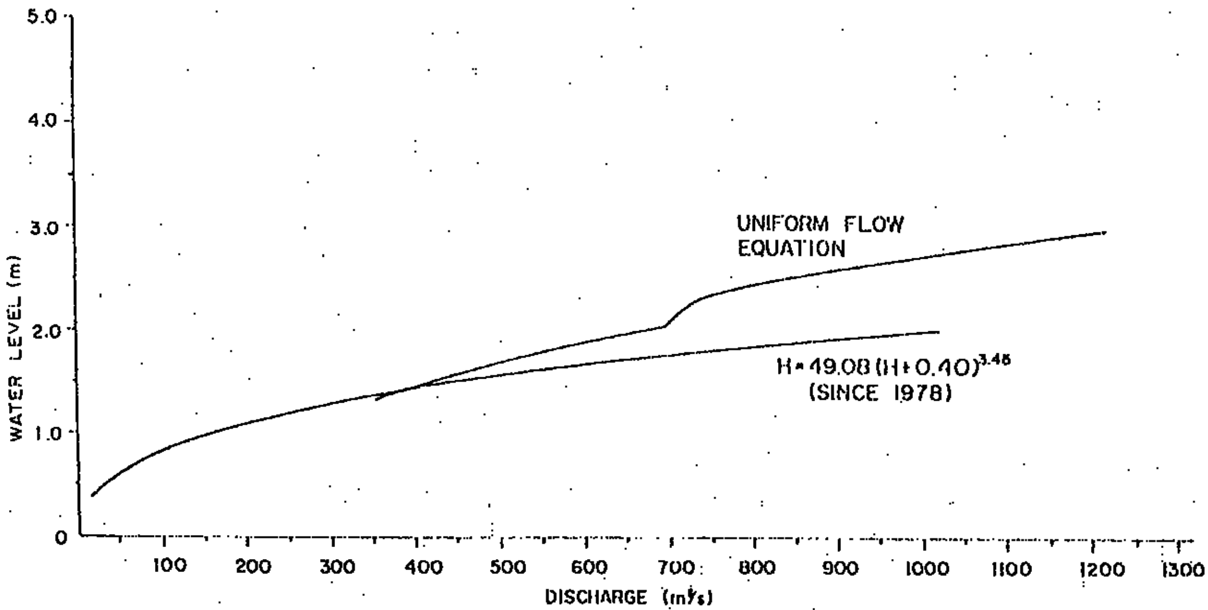


Fig. 2-18 LOCATION OF DISCHARGE OBSERVATION POINTS IN THE STUDY AREA

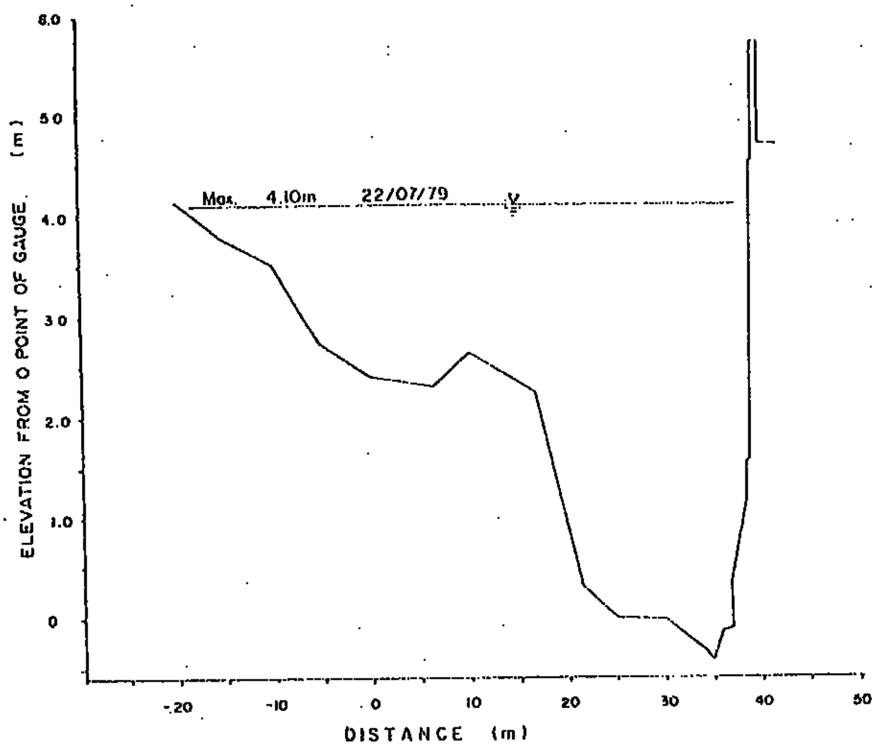


20.03.01H MONTECRISTO STATION

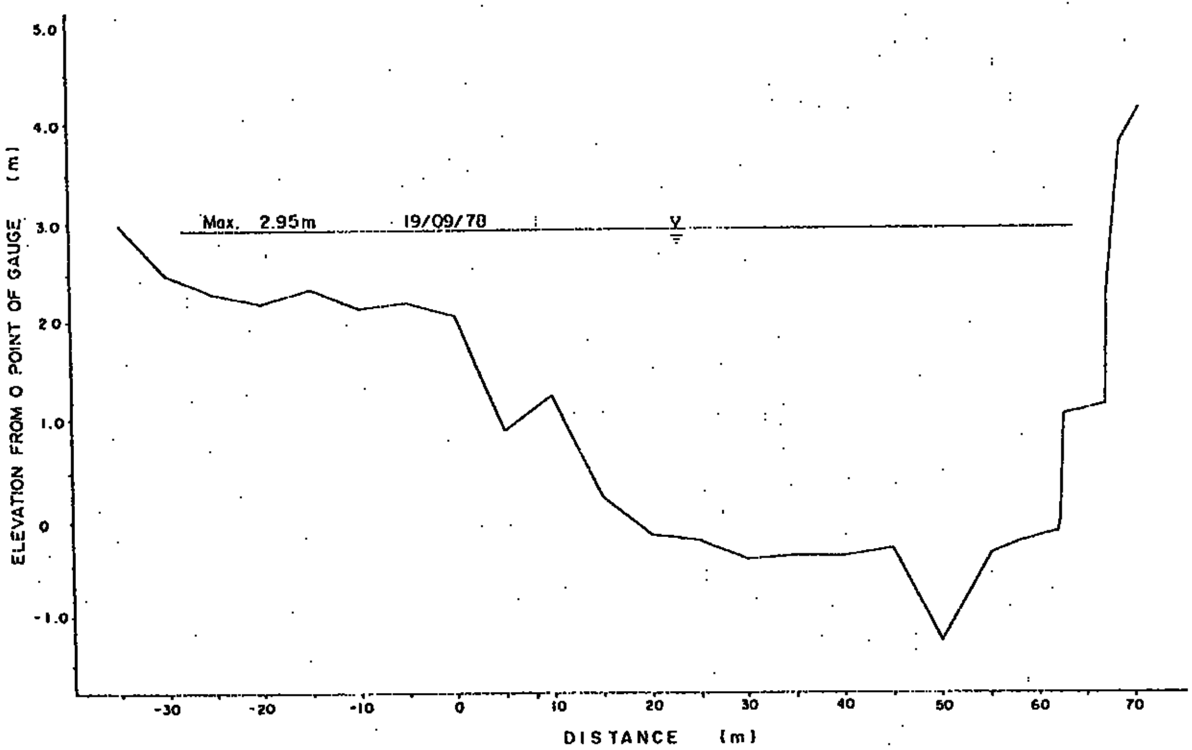


20.11.01H SAN MIGUEL MOCA STATION

Fig. 2-19 RATING CURVE AT MONTECRISTO AND SAN MIGUEL MOCA STATIONS



20.03.01 H MOTECRISTO STATION



20.11.01 H SAN MIGUEL MOCA STATION

Fig. 2-20 CROSS SECTION AT MONTECRISTO AND SAN MIGUEL MOCA STATIONS

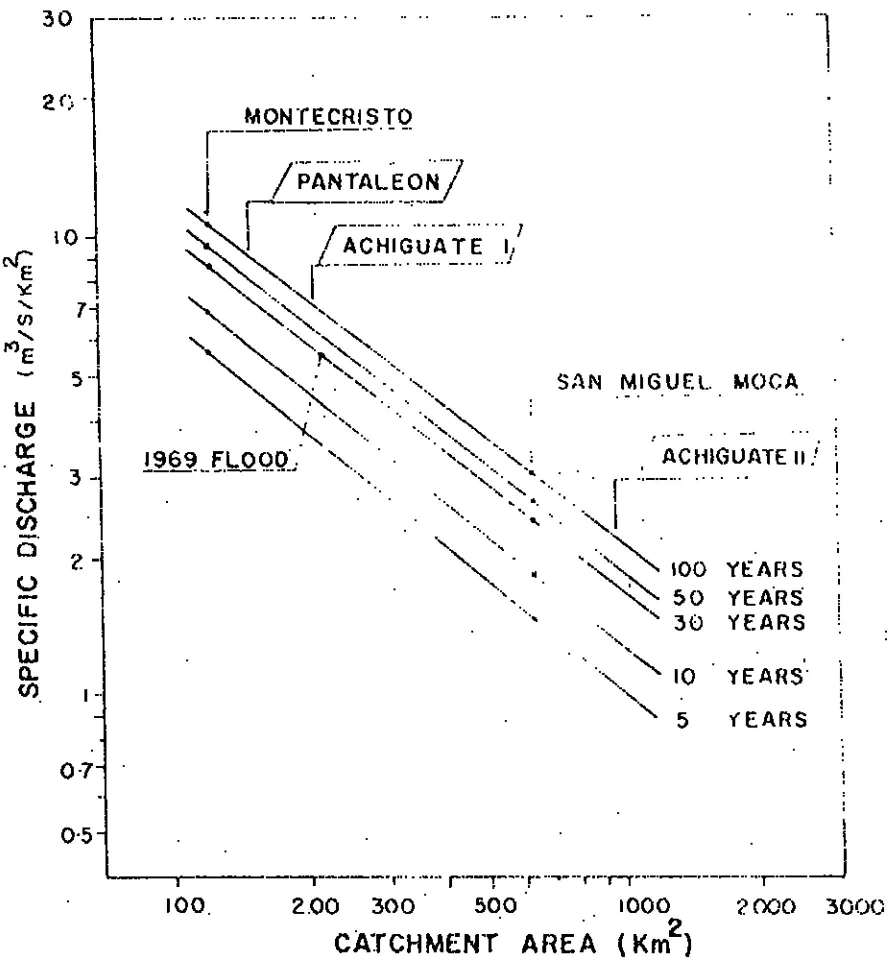


Fig. 2-21 PROBABLE SPECIFIC DISCHARGE AND CATCHMENT AREA

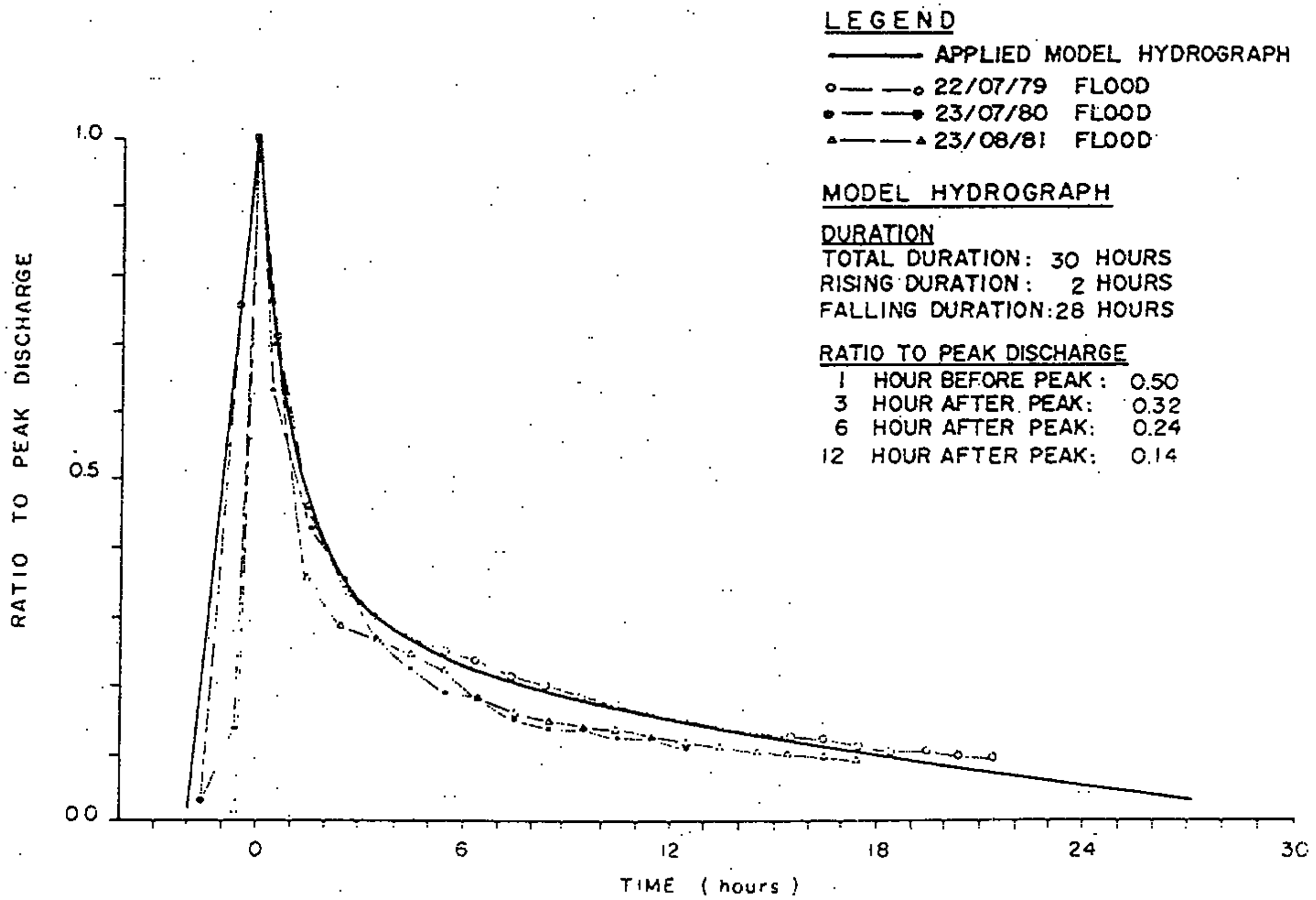


Fig. 2-22 MODEL HYDROGRAPH OF ACHIGUATE REFERENCE POINT I

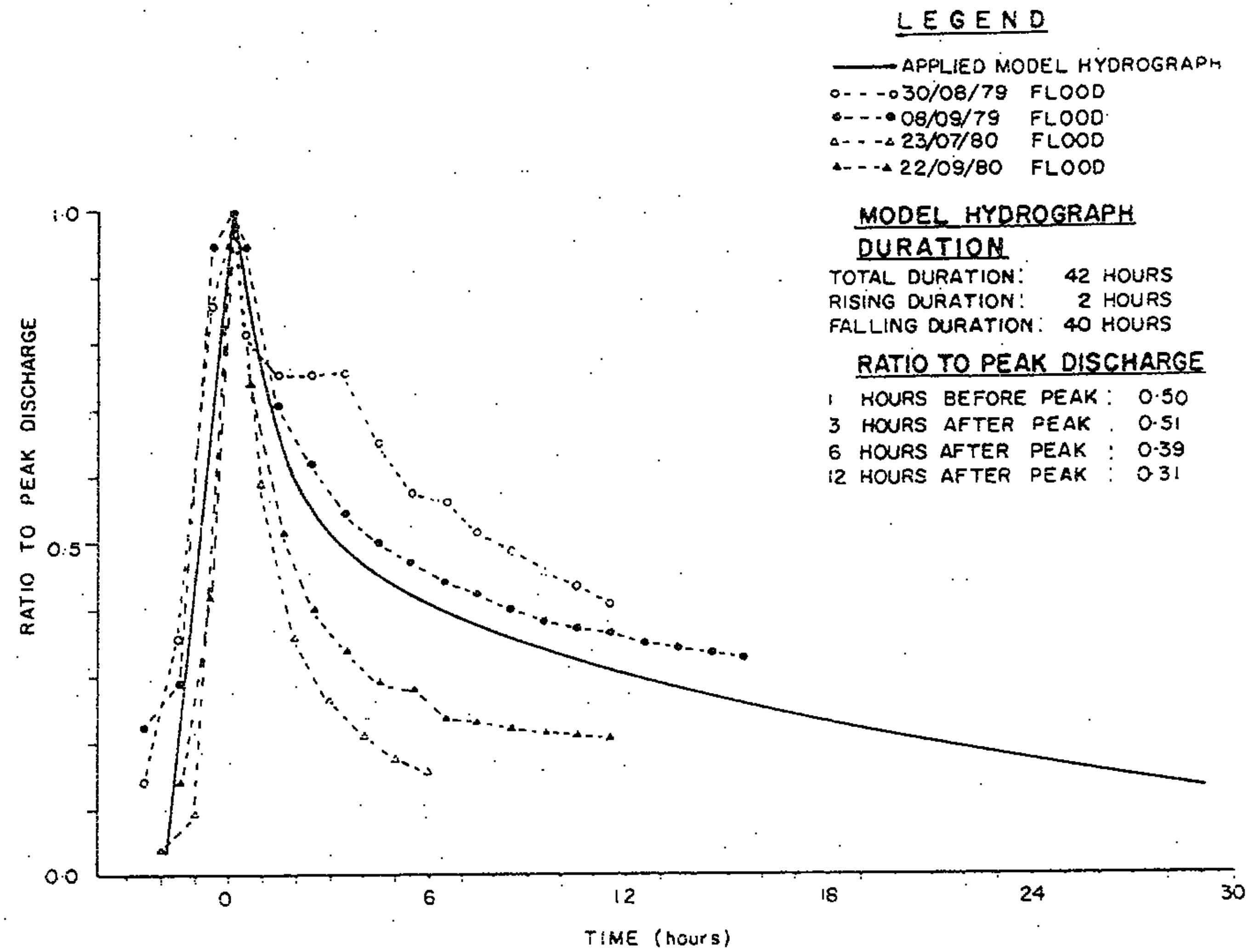


Fig. 2-23 MODEL HYDROGRAPH OF ACHIGUATE REFERENCE POINT II

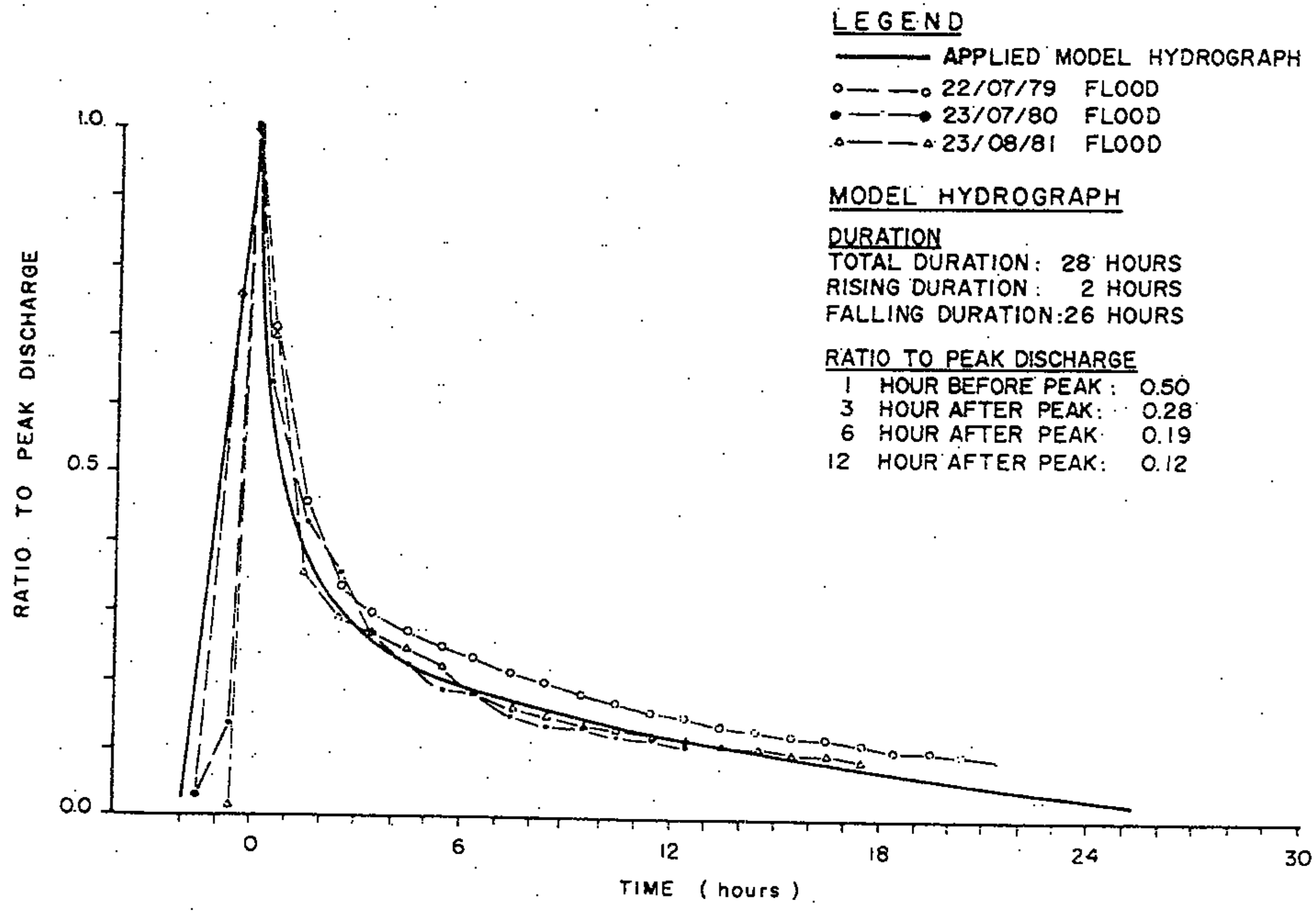


Fig. 2-24 MODEL HYDROGRAPH OF PANTALEON REFERENCE POINT

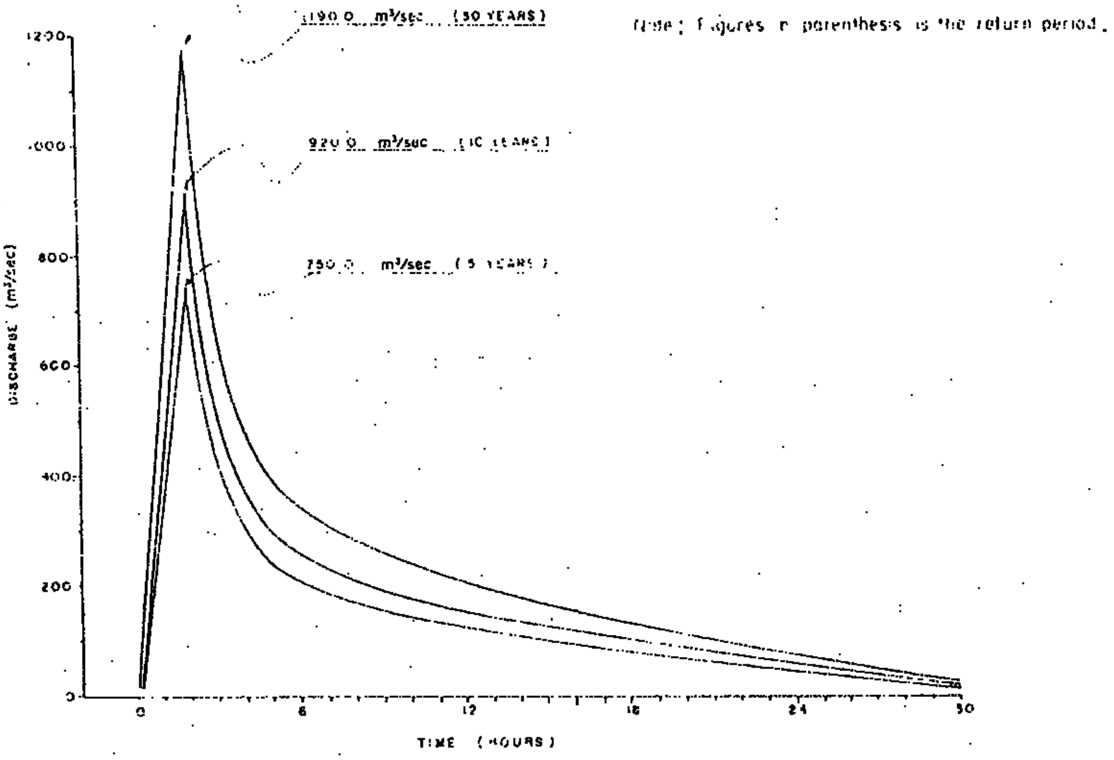


Fig. 2-25 FLOOD HYDROGRAPH OF ACHIGUATE REFERENCE POINT I

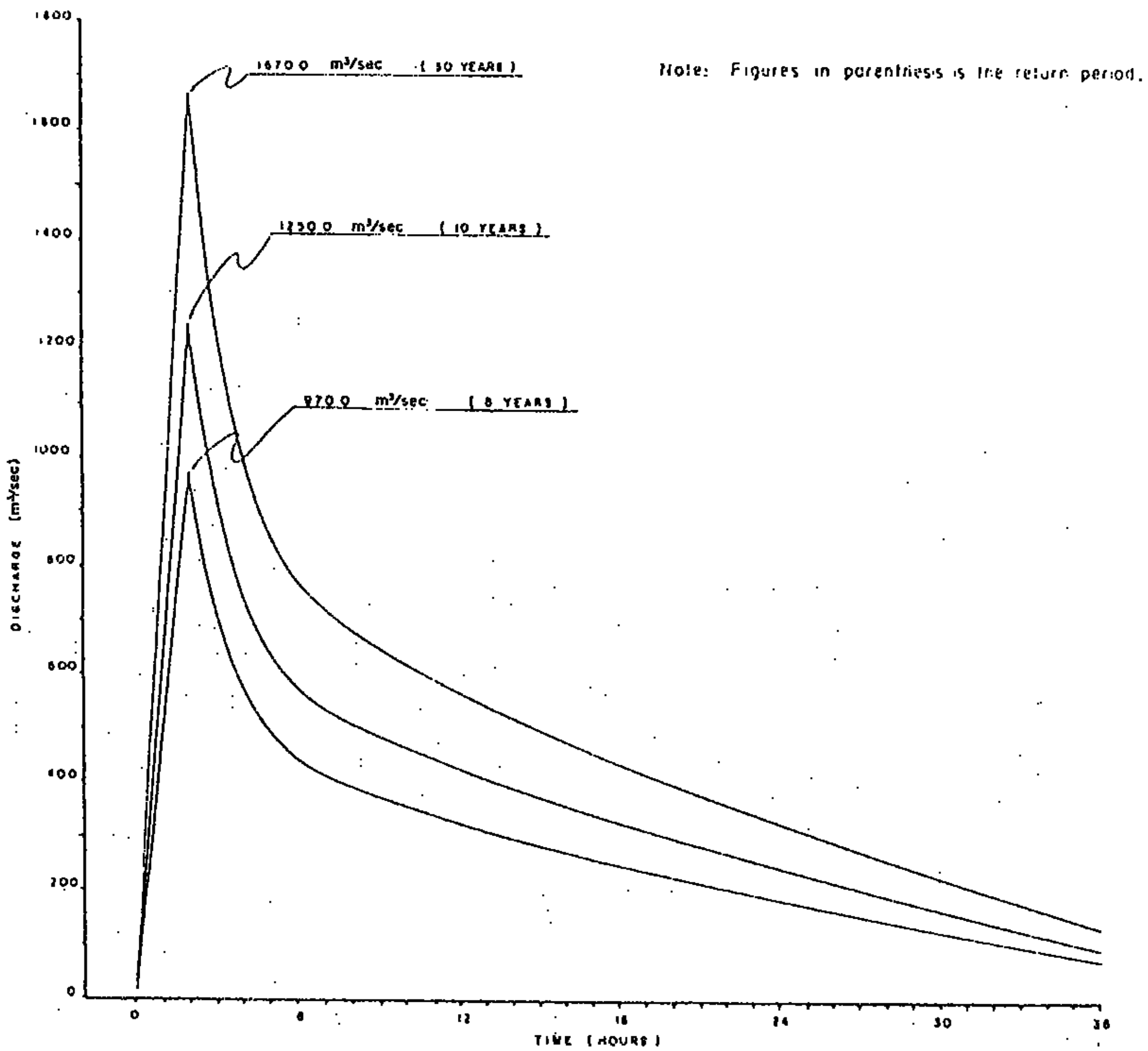
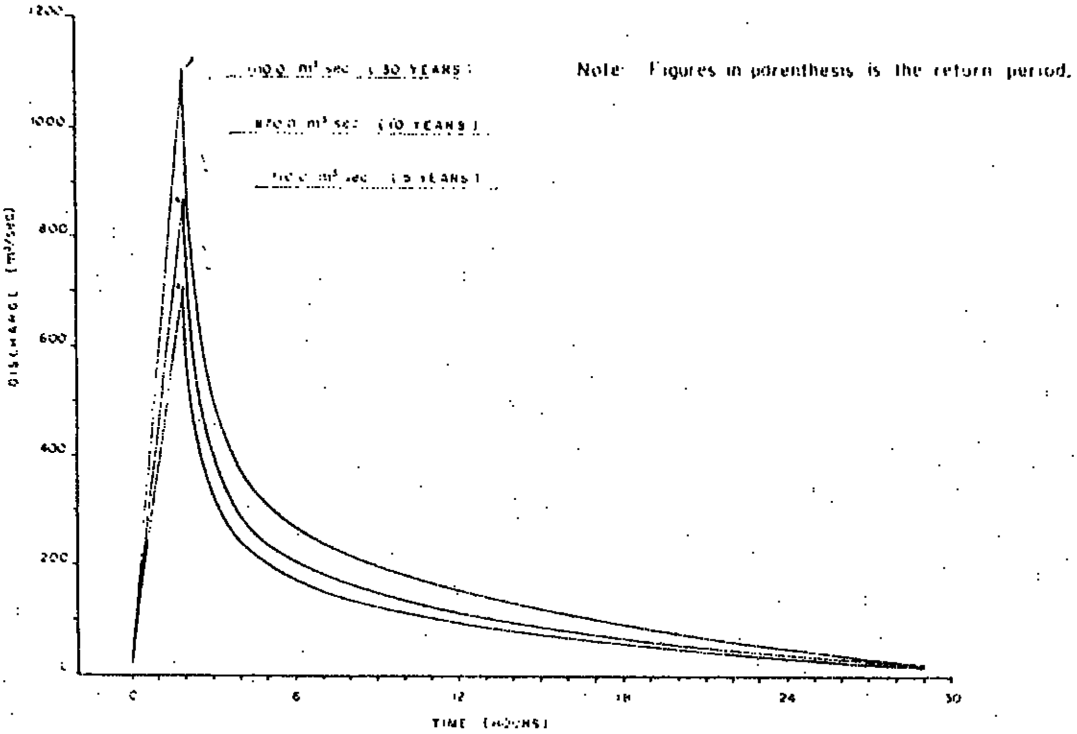


Fig. 2-26 FLOOD HYDROGRAPH OF ACHIGUATE REFERENCE POINT II



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3. SEDIMENT CONTROL PLAN

SEDIMENT CONTROL PLAN

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1. GENERAL

This report represents the results of the sediment control studies.

The objectives of the study are to grasp the sediment movements from its production to its transportation in the Study Area to formulate the optimum sediment control plan from the long-term and urgent views and to prepare the preliminary design of sediment control facilities in conjunction with the flood control plan.

The volcanic activities causing the sediment and flood damages to the Study Area are firstly reviewed under Section 2. The characteristics of sediment movement, including its balance among production, deposit and transportation, are discussed in Section 3 and the basic concepts to formulate the sediment control plan are enumerated, together with the planning conditions of the required facilities, in Section 4.

Based on the above, the optimum plans for the long-term and the urgent project were formulated through the comparative studies in Sections 5 and 6.

The preliminary design and cost estimates are presented in Sections 7 and 8.

2. VOLCANIC ACTIVITIES

Fuego Volcano is on its active stage, erupting more than 60 times since 1524 when records on its activities had been started. The recorded history of the volcano's activities in Tables 3-1 and 3-2 contains brief chronological notes on the sediment and flood damages.

Through the history of Fuego Volcano, it has been identified that the volcano has had four (4) major active periods. The volcano is supposed to be in its fourth active period which commenced with a series of ferocious eruptions in the 1950's and assumed to last for another 10 to 20 more years, judging from the behavior in the past.

The intensity of the volcanic activities are not the same throughout the so-called active period. Since 1983, it is in its rest period. Vulcanian eruptions do not last long, usually from several hours to several days accompanied by the emission of ash flows and lahar. Although it is difficult to clearly identify the beginning and the end of each cycle, it is not wrong to assume that the recurrence of the cycle is every 3 to 5 years.

The recent biggest eruption of Fuego Volcano occurred on September 14, 1971. Lava and mudflows went down the slopes to the valleys and gullies, and hit Barranca, Las Lajas and Ceniza.

3. PRESENT CONDITION OF THE STUDY AREA

3.1 Topography and Geology

The Study Area is situated on the southern slope of the volcanic belt which consists of the active Fuego Volcano and the dormant volcanoes of Acatenango, Agua and others, more specifically, at the southern foot of Fuego Volcano. Fuego Volcano which stands 3,835 m above sea level joins a twin-like mountainous formation with Acatenango which spires to the height of 3,982 m in its immediate north. These two volcanoes, as well as Agua Volcano which is standing eastward across Guacalate River, assume the shape of a conide type strato-volcano.

The Study Area may be broadly divided into three (3) areas; namely, (1) the mountainous area topped by Fuego Volcano, whose slope is steeper than 1/15 and elevation is above 700 m; (2) the spacious volcanic fan or volcanic piedmont which is spreading at the foot of the mountainous area, whose slope ranges from 1/200 to 1/15 and elevation is from 80 m to 700 m; and (3) the even alluvial plain which had been formed through gradual transformation of the volcanic fan, but is now spreading down to the seashore (see Fig. 3-1).

The processes currently taking place on the ground surface of the corresponding areas are (1) erosion, (2) transportation together with deposition and partial gully erosion, and (3) deposition.

The basement of the mountainous area consists of the volcanic rocks which belong to the tertiary miocene but prior to volcanic formation, comprising volcanic deposits such as lapilli tuff, lava flow (mainly made up of andesite and dasite), lahar sediments, volcanic conglomerates and others, in rough stratifications. This basement rock is observed in a very rugged profile often broken by ups and downs in clear topographical contrast with the newly formed volcanic body standing in the background.

The formative history of the Study Area's topography and geology down to the present is briefed in Table 3-3.

3.2 Sedimentation

The Study Area may be broadly divided into three (3) portions based on sediment condition; namely, (1) the debris production area, (2) the sediment transportation area, and (3) the sediment deposition area. (See Fig. 3-2.)

<u>Debris Production Area</u>

As has been previously stated, the mountainous area topographically corresponds to the sediment production area, and it is characterized by the fact that erosion is taking place not only of itself but also of easily erodable volcanic products that have accumulated on it. These two erosion processes combinedly contribute to an increased supply of sediment towards the downstream.

Debris/sediment produced from the volcanic eruption may be deposited in two ways; (1) volcanic ejecta falling over a wide area during the eruption and (2) volcanic ejecta containing rain water coming out of the crater and flowing down the gullies and valleys (pyroclastic flow).

Sediment production through erosion is of two (2) types; the first type being primary sediment production through erosion of mountain slopes and volcanic fans, and the second type is through re-erosion of unconsolidated sediment which are deposited on terraces, taluses, fans and river channels.

The first type of sediment production takes place through two (2) kinds of gullies; (1) the relatively wide V-shaped gully (Gully I) being etched on the slope of the central cone, and (2) the deep U-shaped gully (Gully II) formed on the pyroclastic slope of the present Fuego Volcano.

Gully I which usually develops above an altitude of 2,000 m has the basic tendency to widen itself through vertical as well as lateral erosions, even though it may happen to be refilled by volcanic products from the central cone. Gully II develops itself below an approximate altitude of 2,000 m, suffering from serious vertical erosion due to surface water and mud which flow down into it from the mountain slope.

Sediment Transportation Area

As previously stated, the mountainous area with the gradient of more than 1:15 which includes Fuego Volcano is an erosion or sediment production area as against the plain on the Pacific Ocean side with gradient of less than 1:200 which apparently belongs to the deposition area. Between these two areas is a section where the surface gradient is between 1:200 and 1:15 and whose primary function is sediment transportation. Nevertheless, sediment produced in the mountainous area are not transported straight to the deposition area on the plain. They are instead temporarily deposited or stored in two zones on their courses; one is located between the erosion area and the transportation area and the other, between the transportation area and the deposition area. Since they are not semi-permanent deposition areas but temporary deposition zones in the course of sediment movement, they may be called temporary depositing zones or storage zones.

Temporary Depositing Zone I, i.e., the storage zone between the production area and the transportation area, often assumes the topographical shape of an alluvial cone. Sediment are transported in terms of sediment flow and settle down in steep gradient (over 3°) with so many boulders gathering in precarious position but sustained by clayey soils which help in cementing the boulders together; hence, with unclear stratification. On the other hand, Temporary Depositing Zone II, i.e., the storage zone between the transportation area and the deposition area, generally assumes the shape of a fan. Sediment are transported there in traction and settle down temporarily in a gentle gradient (less than 3°) and clear stratification is observable among their principal ingredients such as pebbles, granules and sands.

The temporary depositing zones along the Achiguate and the Pantaleon rivers are located as follows:

(1) Achiguate River

(a) Along some 8.0 km upstream from the confluence with Ceniza River; and

(b) Along the interval between 1.0 km downstream of the CA-2 road bridge and the railway bridge.

(2) Pantaleon River

(a) In the neighborhood of the confluence with Taniluya River and upstream thereof; and

(b) Along the river course which extends for about 12.0 km starting from the railway bridge downwards.

The sediment transportation section along the Achiguate river course starts from the confluence with Ceniza River and ends at the large temporary depositing zone, i.e., in the vicinity of the railway bridge. Although its total length is very short, its characteristics seem to be extended toward the neighborhood of Achiguate's confluence with Guacalate River, where deposition process has already taken place and the river starts flowing in a braided manner.

In Pantaleon River, the sediment transportation section is extending from the neighborhood of its confluence with Taniluya River down to the immediate upstream of the railway bridge.

Sediment Deposition Area

There is no sediment deposition area in Pantaleon River Basin, since the deposition area is topographically considered to be below 80 m in elevation and less than 1:200 in gradient.

In Achiguate River Basin, the deposition area spreads downwards from the confluence of Achiguate River with Guacalate River. Sediment transported from the upper stream are deposited over the wide alluvial plain by floods; hence, the river channel starts meandering and becomes unstable.

In the sediment control plan, the sediment deposition area is not discussed in detail since the area may principally be protected by a river improvement from the sediment and flood damages.

3.3 Sediment Balance

Production Volume

There has rarely been a hillside landslide in the Study Area, judging from five (5) aerophotographs taken in 1954, 1958, 1964, 1967 and 1983. Sediment production volume from hillside landslide, if ever, is negligibly small compared to those from volcanic eruption and erosion.

The major causes of sediment/debris production in the area are deposition of volcanic products and gully erosion on the slope of Fuego Volcano.

(1) Volcanic Products

The volcanic ejecta deposited over the Study Area during the eruption in 1971, 1973 and 1974 were estimated at 10×10^6 m^3, 5×10^6 m^3, and 31×10^6 m^3, respectively, by R. I. Rose, Jr. (Michigan University); S. B. Bonis (IGM); et al, (Ref. 1, 2 and 3). The isopach maps for the respective eruptions are shown in Fig. 3-3.

In addition, the volcanic products in the forms of scoria flow and pyroclastic flow flowed into gullies and were abundantly deposited in the Study Area. Their volumes were also estimated at 56×10^6 m^3 and 2.6×10^6 m^3 in 1971 and 1974, respectively, while that in 1973 is negligibly small.

As for the period from 1975 to 1983, there was no record of volcanic products except the magnitude of eruption. The total volume of volcanic products deposited in the Study Area may be estimated at about 6×10^6 m^3 from the relation between the deposited volcanic products and the eruptions' magnitudes. Totally, the volume of volcanic products deposited in the Study Area from 1971 to 1983 is approximately 110.6×10^6 m^3.

Areal distribution of the above volcanic products may be derived from the ratio of sediment volume in the respective rivers as follows:

- Achiguate River System

Achiguate River	44.982×10^6 m^3
Ceniza River	$9.212 \times$ "
Total	$54.194 \times$ "

- Pantaleon River System

Pantaleon River	36.664×10^6 m^3
Taniluya River	$19.742 \times$ "
Total	$56.406 \times$ "

(2) Gully Erosion

Gullies on the slope of Fuego Volcano are presumed to have developed themselves since the volcano was formed approximately 3,000 years ago.

The total volume of gully erosion was estimated for Gully I and Gully II from the map of 1:50,000 scale as shown in Table 3-4.

The sediment produced from gully erosion from 1971 to 1983 are as follows:

- Achiguate River System

Achiguate River	639 x 10^3 m^3
Ceniza River	417 x "
Total	1,056 x "

- Pantaleon River System

Pantaleon River	808 x "
Taniluya River	1,616 x "
Total	2,424 x "

(3) Total Sediment Production Volume

Sediment production volume is summarized in the following table.

River System	Volcanic Products (10^3 m^3)	Gully Erosion (10^3 m^3)	Total (10^3 m^3)
- Achiguate River System			
Achiguate River	44,982	639	45,621
Ceniza River	9,212	417	9,629
Total	54,194	1,056	55,250
- Pantaleon River System			
Pantaleon River	36,664	808	37,472
Taniluya River	19,742	1,616	21,358
Total	56,406	2,424	58,830

Deposit Volume

From five (5) aerophotographs, it was observed that there had hardly been any sedimentation in river courses until the eruption in 1971.

Sedimentation in river courses, therefore, started after the eruption which brought a huge amount of volcanic products into the Study Area.

The total volume of deposited sediment in the area upstream of the CA-2 road bridge was determined from two aerophotographs taken in 1967 and 1983. The sediment deposit volume in each river course for the period from 1971 to 1983 were estimated as follows:

(1) Achiguate River System

Achiguate River	6,729 x 10^3 m^3
Ceniza	1,378 x "
Total	8,107 x "

(2) Pantaleon River System

Pantaleon River	1,909 x 10^3 m^3
Taniluya	6,556 x "
Total	8,465 x "

The river courses were divided into several portions from the topographical point of view and the details of the deposit volumes are in Fig. 3-4.

Sediment Balance

The sediment balance for 12 years from 1971 to 1983 was studied on the basis of production volume and deposit volume. The results of the study are shown in Fig. 3-4.

The total sediment discharge flowing down through the sediment reference points of the Achiguate and the Pantaleon rivers are estimated at 47.143 x 10^6 m^3 and 50.365 x 10^6 m^3, respectively.

3.4 Sediment Disaster

Records on sediment disaster were obtained mainly from newspaper reports since there was no investigation conducted for sediment and flood damages.

The information and data from newspaper are enumerated in Table 3-2 and summarized hereunder, although the cause of damage between sediment and flood is hardly distinguishable.

As of the time of this study, public facilities have been reconstructed and the hazard has at least been solved.

(1) Before 1969, sediment and flood damages mostly took place in areas along the course of the Achiguate and the Pantaleon rivers. Floods in the area are due to insuffifienct flow capacity.

(2) Extensive flood damage occurred on September 25, 1971, eleven days after the Fuego's eruption. The overflowing of rivers on the Fuego's slope was caused by the intrusion of volcanic products. The CA-2 road bridge across Pantaleon

River was destroyed by sediment and flood discharges, causing total traffic interruption on the highway. People in Siquinala evacuated due to the sediment and flood waters flowing into the town.

(3) The influence of the Fuego's eruption continued to work on the overflowing of the Achiguate and the Guacalate rivers at Masagua, killing one and injuring several of its inhabitants, in October 15 of the same year. Siquinala severely suffered once again due to the overflowing of Obispo River into Mazate River.

(4) Heavy rain on October 21, 1971 put Pantaleon River out of control, and Bailey Bridge was seriously damaged, together with the other two road bridges. The Pantaleon railway bridge was also washed away.

(5) The influence of the Fuego's eruption which took place on September 14, 1971 lasted over several years. A series of calamities which occurred thereafter are believed to be the results of this eruption. First came the flood damage including the washing away of houses and farms in La Democracia, which is situated to the south of Siquinala, on August 3, 1972. This was apparently due to the overflowing of Mazate River which remained untamed to give another damage to La Democracia on October 10, 1972. In August 21 of the following year, Obispo River overflowed to inflict damage to La Democracia for the third time. It was reported that deposition of volcanic products therein was abundant at that time.

(6) On October 10, 1974, Fuego Volcano erupted in a much more violent manner than the hazardous one that took place in September 1971. Although no data on its direct damage is available at present, it can be reasonably assumed that Fuego's volcanic activities in 1971 and 1974 were invariably responsible for a series of disasters occurring in the succeeding years, which are generally attributable to the rising of the riverbeds running at its foot. Among these disasters are the overflowing in the lower reaches of Achiguate River on September 29, 1975 and July 1, 1976 and the overflowing of both the Achiguate and the Pantaleon rivers on September 15, 1977.

(7) After the above incidents up to the flood on September 20, 1982, which was the latest serious one, sediment and flood damages have repeatedly taken place in the Study Area.

From the foregoing, it must now be undisputable that sediment and flood damages taking place in the Study Area are inseparably related to the Fuego's eruptions and it may be concluded that the basic cause of these disasters lies, with the only exception of the flood at San Jose Port which is partly due to inland water, in the deposition of volcanic products from Fuego Volcano.

4. BASIC CONCEPT FOR SEDIMENT CONTROL

4.1 Sediment Reference Point

In a sediment control plan, a certain location or point in the project area is to be set up in order to quantitatively estimate several kinds of sediment volume and/or discharge, such as production volume, sediment discharge, regulation volume, and so on. This point may be called sediment reference point.

Sediment reference points are usually set up on the river course which is the route for sediment discharge, and should be selected from the two viewpoints of location of target area to be protected and the sedimentation forms.

The sediment reference points for the Achiguate and the Pantaleon river basins were determined as follows:

Achiguate River Basin	CA-2 Road Bridge (Catchment Area: 205.0 km^2)
Pantaleon River Basin	CA-2 Road Bridge (Catchment Area: 115.0 km^2)

The downstream areas of the CA-2 road bridges in both the Achiguate and the Pantaleon rivers are the target areas to be protected from sediment and flood damages, together with the bridges themselves.

4.2 Probable Sediment Discharge

The formulation of the long-term plan is based on the sediment deposits that had accumulated immediately after the eruption of Fuego Volcano in September 1971, because it is the largest one experienced in the recent past. The urgent plan will be formulated to control the sediment discharge which may be produced from the sediment deposits existing as of 1983.

In consideration of the above, the probable sediment discharges were calculated in two (2) cases; one adopts the sediment condition immediately after the eruption in 1971 and the other, that in 1983.

Sediment Discharge Calculation

(1) Sediment Discharge Model

Sediment discharge at a flood time may be expressed as a function of residual sediment deposits and flood discharge/rainfall.

Sediment deposits are assumed to be stored mainly on the V- and/or U-shaped gullies in the slope of Fuego Volcano and sediment discharge is produced by the traction of water flow on such gullies' bed, i.e., sediment discharge is proportional to the square root of the amount of sediment deposits expressed as;

$$Qs \propto D^{0.5}$$

Sediment discharge also increases in proportion to three-seconds power of rainfall, that was derived from Brown's Formula, as follows:

$$Qs \propto R^{1.5}$$

From the above, sediment discharge can be formulated as;

$$Qs = C \cdot D^{0.5} \cdot R^{1.5} \quad \text{.................. (Eq. 3-1)}$$

here, Qs; sediment discharge (m^3)
D ; residual sediment deposit (m^3)
R ; rainfall (mm)
C ; coefficient

On the other hand, the sediment balance in the Study Area can be expressed by the following equation;

$$dD/dT = - Qs + I_o \quad \text{...................... (Eq. 3-2)}$$

here, I_o represents the new sediment deposit supplied by the volcanic products to the Study Area.

Equations 1 and 2 may be put together and expressed in a differential form, as follows:

$$D_i = D_{i-1} - C \cdot D_{i-1}{}^{0.5} \cdot R_i{}^{1.5} + I_o \quad \text{... (Eq. 3-3)}$$

where, D_i, D_{i-1}; residual sediment deposits at the ith and the (i-1)th step
R_i ; daily rainfall at the ith step

The interval of computation step is set to be a day, while new sediment deposit is periodically supplied at the first day of every year.

(2) Rainfall

Rainfall may be represented by that at Ceylan Gauging Station and Los Tarros Gauging Station for the Achiguate and the Pantaleon river basins, respectively.

Only daily rainfalls of more that 52.5 mm/day and 92.5 mm/day are considered to cause sediment runoff in the

Achiguate and the Pantaleon rivers, respectively, in consideration of the critical tractive force.

These minimum daily rainfalls were derived by the Iwagaki's Tractive Force Equation (Ref. 4), as follows, assuming that sediment particle sizes are 8.5 cm in Achiguate River and 20.0 cm in Pantaleon River.

$$U_*^2 = 80.9d \quad (= g \cdot h \cdot S) \qquad \text{(Eq. 3-4)}$$

Here, U_*; critical shear velocity (m/s)
d ; mean size of sediment particle (cm)
h ; water depth (m)
S ; mean river gradient
g ; acceleration of gravity (9.81 m/s^2);

and the water depth is calculated from the rational equation, as follows:

$$Q = f \cdot r \cdot A/3.6 \qquad \text{(Eq. 3-5)}$$

where, f; runoff coefficient (= 0.6)
r; rainfall intensity for a concentration time (mm/hr)
A; catchment area (km^2)

and Manning's Formula, as follows:

$$Q = B \cdot h \cdot h^{2/3} \cdot So^{1/2}/n \qquad \text{(Eq. 3-6)}$$

where, B ; river width (m)
h ; water depth (m)
S_o; river gradient
n ; roughness coefficient

(3) Residual Sediment Deposit

In addition to the foregoing, the initial residual sediment deposit which is assumed to be the sediment deposit as of 1971 are estimated at 32,428 x 10^3 m^3 and 33,862 x 10^3 m^3 in the Achiguate and the Pantaleon river basins, respectively.

The periodic sediment deposits in every year from 1972 to 1983 were calculated by taking the average of the total volcanic products in the basin. They are 2,074.7 x 10^3 m^3 for Achiguate River and 2,269.8 x 10^3 m^3 for Pantaleon River.

(4) Coefficient "C"

To calculate coefficient "C", a simulation of sediment balance in the Study Area from 1971 to 1983 was carried out.

Coefficient "C" is computed so as to make residual deposits in 1983 equivalent to those observed in the Achiguate and the Pantaleon river basins of 8,107 x 10^3 m^3 and 8,465 x 10^3 m^3, respectively.

The values of coefficient "C" are 0.0825 for Achiguate and 0.1360 for Pantaleon.

Probable Sediment Discharge

From the preceding explanation, the equation (Eq. 1) to estimate the probable sediment discharge for the long-term plan may be expressed as follows;

For Achiguate: $Qs = 0.0825 \times (32,428 \times 10^3)^{0.5} \times R^{1.5}$

For Pantaleon: $Qs = 0.136 \times (33,862 \times 10^3)^{0.5} \times R^{1.5}$

and the relation between the sediment discharge (Qs) and the daily rainfall (R) is drawn in Fig. 3-5.

The probable sediment discharge for the return periods of 5-, 10-, 20-, 30- and 50-year are tabulated in Table 3-5 (1/2).

Likewise, the equation for the urgent plan may be expressed as below and the relation is drawn in Fig. 3-5.

For Achiguate: $Qs = 0.0825 \times (8,107 \times 10^3)^{0.5} \times R^{1.5}$

For Pantaleon: $Qs = 0.136 \times (8,465 \times 10^3)^{0.5} \times R^{1.5}$

Those for the return period of 5-, 10-, 20-, 30- and 50-year are tabulated in Table 3-5 (2/2).

4.3 Sediment Control Method

Generally, there are four (4) major methods to control sediment discharge causing damages to areas along rivers, as follows:

(1) Sediment control dam;
(2) Groundsill;
(3) Training levees and channel works; and
(4) Hillside works.

Sediment Control Dam

Sediment control dams are constructed across river channels.

A sediment control dam has four (4) functions; namely, (1) trap effect, (2) regulation effect, (3) stabilization effect, and (4) sorting effect.

Among the above four functions, (1) and (2) may be quantitatively evaluated, though (1) is not considered in the sediment control plans due to its temporary nature.

The trap effect is estimated with the volume stored in a pocket of dam, which is the difference between the original riverbed and the sediment depositing riverbed with a gradient of one-half the original. (The details are in Subsection 4.4.)

Regulation effect on sediment discharge in transport is demonstrated in such phenomenon that sediment discharge at the time of flooding loses its load when it comes across the gentle slope provided by the sediment control dam. Such phenomenon is called temporary sediment storage since the sediment thus stored would be brought back to the original sediment deposit slope after being re-eroded by later medium and small scale floods. While the trap effect would lose its function once sediment is deposited to the full, regulation effect lasts almost semi-permanently.

Groundsill

The functions of groundsill may be defined to reduce the energy of water flow, to control turbulence and to prevent river bank erosion and scouring.

Groundsills are usually constructed together with revetment to stabilize the riverbed; hence, to fix a riverbed at a gentle gradient, although the structure is not expected to control and/or regulate sediment discharge.

In this study, the details of the structure are discussed in Sector 4, River Improvement Plan.

Training Levee and Channel Works

Training levee is constructed so as to confine flood discharge into a fixed river course and also to reserve a necessary cross section for flood flow. With these functions, the training levee can simultaneously protect a flood-prone area from sediment damage.

Channel works are effective to fix river courses in the sediment transportation area by its function of preventing riverbed and bank scouring.

Both training levee and channel works have no function to control and/or regulate sediment discharge. These structures are rather considered a part of the river improvement works in a sediment disaster area; hence, the details of the structures are discussed in Sector 4, River Improvement Plan.

Hillside Works

Hillside works, which consist of several and serial works such as grading, soil retaining, drainage, piling and planting works, are usually applied to keep off sediment production from a denuded area.

4.4 Selection of Sediment Control Method

Proposed Control Method

Among the four (4) methods discussed in the previous section, groundsill, training levee and channel works are discussed and planned as a part of the river improvement plan.

In the comparison between sediment control dam and hillside works, sediment control dam is much superior to hillside works in the aspect of sediment regulation and control. Moreover, the hillside works are practically ineffective in the situation that the Study Area is suffering from continuous sediment deposition by volcanic eruption and heavy persistent erosion. Therefore, the sediment control dam is proposed as the most appropriate method for the Study Area.

Planning Conditions for Sediment Control Dams

Sediment control dams are to be so planned as to effectively regulate the sediment discharge during a flood. The planning of a sediment control dam is based on the following considerations:

(1) Location

The location of dam sites is primarily selected on the basis of topographical condition and areal sediment discharge distribution so that the dam would have a large storage capacity and regulation effect.

In addition to the above viewpoint, the site nearest to the target protection area should be proposed to assure the highest sediment control effect among the suggested sites.

(2) Dam Type

Dam type is broadly classified into the following types due to the materials employed; concrete dam, cobblestone concrete dam, steel frame dam, concrete block dam, gabion mattress, and so on.

The selection of the suitable dam type will be made in due consideration of economic and technical aspects.

(3) Regulation Volume

To determine the required regulation volume of the sediment control dam, it is necessary to estimate an allowable sediment capacity, which may be defined as the sediment volume to be transported by a flood without any adverse effect on riparian structures and the area along rivers. The allowable sediment capacity are calculated by using the model hydrograph and sediment transport capacity of the river. (Refer to Sectors 2 and 4.)

On the other hand, the regulation effect of the sediment control dam will be determined as mentioned hereunder.

The surface gradient of sediment deposit is about one-half (1/2) of the original riverbed gradient, while during floods, surface gradient of deposit is somewhat steeper by about two-thirds (2/3). The increasing volume of deposit enclosed by the surfaces between the original riverbed and the surface of the 1/2 of the gradient of the former is the storage volume, and the volume of deposit enclosed by the surfaces between the above-mentioned 1/2 and 2/3 gradient is the regulation volume, which is equivalent to 1/2 of the deposit storage volume.

A storage volume is determined by the formula below:

$$V_s = n \cdot B \cdot He^2 \quad \ldots\ldots\ldots\ldots \quad \text{(Eq. 3-7)}$$

where, V_s; storage volume of sediment control dam (m^3)
n ; gradient of original riverbed
B ; mean breadth in depositing area (m)
H_e; effective height of sediment control dam (m)

Therefore, regulation volume (V_r) should be calculated by the following formula:

$$V_r = Vs/2 = n \cdot B \cdot He^2/2 \quad \ldots\ldots\ldots\ldots \quad \text{(Eq. 3-8)}$$

5. LONG-TERM PLAN

The regulation volumes for the respective recurrence probabilities were derived in due consideration of the allowable sediment discharge stipulated in Subsection 4.2. (Refer to Table 3-6.)

5.1 Dam Sites

For the location of the proposed dam sites, topographic merits for higher efficiency, topographic and geologic conditions suitable for dam sites, requirements of sediment control facilities, etc., are taken into consideration, and four (4) dam sites, including one on the Ceniza River in the Achiquate River System, and six (6) in the Pantaleon River System were selected. The location of the above-mentioned dam sites are shown in Fig. 3-6. The reasons for the selection of dam sites are given below.

(1) Achiquate River, Site A

This side is the nearest site to the target protection area, especially the CA-2 road bridge. The site is located at the narrower section which is the down-most point of the large depositing zone. The site is expected to have a high control effect.

(2) Achiguate River, Site B

The site is located at the narrower section which is the middle point of the large temporary depositing zone.

(3) Achiguate River, Site C

The site is located at the gorge which is the entrance to the temporary despositing zone.

(4) Achiguate River, Site D

The site is located at the downmost point of a large temporary depositing zone in Ceniza River Basin to have a direct protection effect.

(5) Pantaleon River, Site E

Though low in regulation efficiency, the site is located at the upstream tip of the river improvement section, so that special emphasis on the requirement of riverbed transition prevention measures is to be made.

(6) Pantaleon River, Site F

The site is located at the immediate downstream of the confluence with Taniluya River where the temporary depositing zone is spreading upward of the said confluence. The site is expected to control the sediment discharge of the zone.

(7) Pantaleon River, Site G, H, I and J

These sites are located at the narrower sections along the upstream reaches; hence, expected to have high regulation effects.

5.2 Dam Structure

Taking economical and construction efficiency into consideration, the cobble stone concrete type was selected for the main dam for all flood scales with the overflow section designed large enough to take care of a 100-year probable discharge. Also, as subdam and an apron of cobblestone concrete will be constructed for the prevention of riverbed scouring along the downstream of the dam. (Refer to Table 3-7.)

5.3 Comparative Study

It is of predominant importance to regualte completely the sediment discharge by sediment control dams during a flood. Since the scale of the required facilities is almost the same in all cases, the construction cost that may be needed as a result of a change in project scale only is investigated. The objective project scales are four (4) cases; namely, 5-, 10-, 30- and 50-year return periods.

(1) Selection of Dam Sites

Allocation of the design regulation volume to the respective dams were made in accordance with the given priority mainly based on the degree of regulation efficiency. That is, use one dam to its possible maximum effective height, and when it surpasses its maximum regulation volume, the dam next in the priority list is used. The dam sites thus selected under the respective project scales are shown in the following table, and the effective height and regulation volume as against the respective project scales at the respective dam sites are shown in Table 3-8.

The relation of the effective dam height and regulation volume at the suggested dam sites in the Achiguate and the Pantaleon rivers are shown Fig. 3-7.

Regulation efficiency is represented by the value of regulation volume per unit volume of dam body.

The relations between the regulation efficiency and the effective dam height at suggested sites on the Achiguate and the Pantaleon rivers are shown in Fig. 3-8.

Since dam body volume is a value which represents construction cost, the site having a more regulation efficiency is economically more advantageous.

The possible maximum effective height, regulation volume and selective priority mainly from the viewpoint of regulation efficiency in each site are shown in Table 3-8.

Even if sediment discharge of Achignate River is fully controlled, it is practically impossible to control the sediment load within the range of the allowable discharge without simultaneously controlling the sediment discharge of Ceniza River. Therefore, the top priority was given to Site D from the technical viewpoint. Site E on Pantaleon River is low in regulation effect and also low in regulation volume, however, it is rated as the top in priority because it is located at the uppermost tip of the proposed river improvement section.

Project Scale	Achiguate	Pantaleon
5-year	Site A, D	Site E, F, J
10	Site A, C, D	- do -
30	- do -	Site E, F, H, I, J
50	Site A, B, C, D	Site E, F, G, H, I, J

The probable sediment discharge and the regulation volumes for the respective dam sites are shown in Fig. 3-9.

(2) Construction Cost

Based on the foregoing proposed dam projects, construction costs of the dams at the respective sites under the respective probability were estimated, and the results obtained are shown in Table 3-9. The following table is a recompilation of Table 3-9.

Project Scale	Achiguate (US\$$10^3$)	Pantaleon (US\$$10^3$)	Total (US\$$10^3$)
5-year	6,400	8,000	14,400
10	8,200	9,800	18,000
30	10,700	16,000	26,700
50	14,300	21,200	35,500

5.4 Proposed Long-Term Plan

Design Regulation Volume

Based on the findings of the comparative study in Sector 4, River Improvement Plan, it was concluded that, mainly from the social aspect, the project scale of 30-year will be adopted. The total of eight dams; namely, three (3) in the Achiguate and five (5) in the Pantaleon river systems, may have to be considered, and the following table shows the design regulation volume of the respective dams. (Refer to Fig. 3-8.)

- Achiguate River System

Dam Name	Dam Site	Catchment Area (km^2)	Crest Length (m)	Dam Body Volume (m^3)	Effective Height (m)	Design Regulation Volume (10^3 m^3)
A-1	A	92.0	460	21,000	8.0	990
A-2	C	39.0	135	24,000	18.0	562
C-1	D	112.0	455	19,000	7.0	338

- Pantaleon River System

Dam Name	Dam Site	Catchment Area (km^2)	Crest Length (m)	Dam Body Volume (m^3)	Effective Height (m)	Design Regulation Volume (10^3 m^3)
P-1	E	115.0	210	7,000	5.0	60
P-2	F	107.0	392	17,000	9.0	976
P-3	H	62.0	160	17,000	11.0	235
P-4	I	61.0	190	12,000	9.0	315
P-5	J	60.0	230	44,000	18.0	1,370

Features of Sediment Control Dams

The standard construction drawings and the dimensions of the proposed dams are shown in Fig. 3-11 and in Table 3-10.

The crest width of the dam is 2.0 m, downstream gradient is 1:0.2, and the upstream gradient is between 1:0.5 and 1:1.3 in proportion to the height. The dam body is embedded 1.5 m below the existing riverbed. Also, cobblestone concrete subdam and apron will be constructed for the prevention of riverbed scouring along the downstream of the dam. The side walls of the apron is of wet masonry.

6. URGENT PLAN

The comparative study is carried out to determine the optimum scale of the project from the economic viewpoint, in due consideration of social requirement.

The regulation volumes for the respective recurrence probabilities were determined based on the probable sediment discharge and allowable sediment discharge stipulated in Subsection 4.2. (Refer to Table 3-11.)

6.1 Dam Sites

As to the dam sites under the Urgent Plan, the same sites suggested under the Long-Term Plan are considered, except Pantaleon Site E, which is planned for the main purpose of riverbed protection. In the case of the Urgent Plan, the upstream tip of the river improvement section is located on the direct upstream of the CA-2 road bridge where no suitable dam site is found, and moreover, groundsill over the full width of the river is being planned, so that the construction of the said dam may not be necessary. (Refer to Sector 4, River Improvement Plan.)

6.2 Dam Structure

Cobble stone concrete type was selected for the main dam, and the other related structures are the same as those for the long-term plan. (Refer to Subsection 5.2.)

6.3 Comparative Study

Allocation of the regulation volume to the dams in accordance with the project scale of 5-, 10- and 30-year return period was carried out and the results are shown in Table 3-12. The distribution scheme of sediment discharge for each project scale over the two river systems, the Achiguate and the Pantaleon, are shown in Fig. 3-10. The dam sites are as below.

Project Scale	Achiguate	Pantaleon
5-year	Site A, D	Site F
10	-do-	-do-
30	-do-	Site F, J

(1) Construction Cost

For the foregoing proposed dam projects, construction costs of the dams at the respective sites under the respective probabilities were estimated, and the results are shown in the table below.

Project Scale	Achiguate (US$$10^3$)	Pantaleon (US$$10^3$)	Total (US$$10^3$)
5-year	4,900	2,600	7,500
10	5,400	3,000	8,400
30	6,100	5,600	11,700

6.4 Proposed Plan

Design Regulation Volume

Based on the findings of the comparative study in Sector 4, River Improvement Plan, it was concluded that, mainly from the economic and social aspect, the project scale of 10-year was to be adopted. Under the above-mentioned conditions, the number of dams required are three (3) in total, i.e., two (2) in the Achiguate, and one (1) in the Pantaleon river systems. The design regulation volume of the respective dams are shown in the following table.

- Achiguate River System

Dam Name	Dam Site	Catchment Area (km^2)	Crest Length (m)	Dam Body Volume (m^3)	Effective Height (m)	Design Regulation Volume (10^3 m^3)
A-1	A	92	409	14,000	6.5	551
C-1	D	112	425	10,000	4.5	119

- Pantaleon River System

Dam Name	Dam Site	Catchment Area (km^2)	Crest Length (m)	Dam Body Volume (m^3)	Effective Height (m)	Design Regulation Volume (10^3 m^3)
P-2	F	107	392	17,000	9.0	976

Features of Sediment Control Dams

The sites of the sediment control dams are as shown in Fig. 3-6.

The width of the crest of the dam is two (2) meters, downstream gradient is 1:0.2, and the upstream gradient is between 1:0.45 and 1:0.65 in proportion to the height. The dam body is embeded 1.5 m below the existing riverbed. Besides, cobblestone concrete subdam and apron are constructed for the prevention of riverbed scouring along the downstream of the dam. The side walls of the apron is of wet masonry. For the construction details, refer to Section 7, Preliminary Design.

6.5 Alternative Plan

The alternative plan was formulated in consideration of (1) the possibility of stepwise construction, (2) easier construction method, and (3) availability of materials in the proximity of the construction site.

Dam Structure

Dam type is selected to be of gabion mattress which has been widely employed for river works in Guatemala for the reason that construction materials are available in the vicinity of the construction site and that the construction method is easier compared to the cobble stone concrete type. However, the height of the gabion mattress type may be limited due to the structural characteristics, i.e., the effective height should be lower than 5.0 m.

Dam Site

Due to the limited height of a gabion mattress type dam, the regulation volume of such dam must be reduced much less than that of cobblestone concrete dam in the Proposed Plan; hence, a greater number of dam sites may have to be provided. The sites were selected among the suggested sites in Subsection 6.1, Dam Sites.

The following table shows the selected sites and their features:

River	Dam Site	Catch-ment Area (km^2)	Dam Body Volume (m^3)	Effec-tive Height (m)	Design Regulation Volume (10^3 m^3)
Achiguate	A	92.0	38,000	5.0	350
	B	87.0	21,000	3.5	111
	C	39.0	9,000	5.0	90
	D	112.0	35,000	4.5	119
Pantaleon	F	107.0	23,000	5.0	370
	G	64.0	21,000	4.0	101
	H	62.0	16,000	5.0	105
	I	61.0	14,000	5.0	180
	J	60.0	18,000	5.0	220

7. PRELIMINARY DESIGN FOR THE URGENT PLAN

7.1 Proposed Plan

In the proposed urgent plan which is based on the former idea, three (3) dam sites (two in Achiguate and one in Pataleon River) are required to regulate the design sediment discharge as described in Subsection 6.3.

The sediment control dams are structurally composed of main dam, overflow section, subdam and apron, whose preliminary design has been prepared in this study as shown in Fig. 3-11.

(1) Overflow Section

The overflow section is provided at such position and direction that overflow water may easily concentrate to the center of the downstream in order to promote river channel stabilization. The size of this section is equally designed for all the dams so that a discharge of 1,250 m^3/s corresponding to a 100-year return period flood may flow down safety.

The bottom width of the overflow section and overflow depth can be obtained from the two equations given below.

$$B = \alpha \cdot Q^{1/2} \quad \text{(Eq. 3-9)}$$

where, B; bottom width of overflow section
Q; design discharge (m^3/s)
α; coefficient given in the equation below

$$Q = 2/15 \cdot C \cdot (2g)^{1/2} \cdot (3B_1 + 2B_2) \cdot h^{3/2} \quad \text{(Eq. 3-10)}$$

where, Q ; design discharge (m^3/s)
C ; coefficient of discharge (0.60 - 0.66)
g ; acceleration of grarity (9.8 m/s^2)
B_1; bottom width of overflow section (m)
B_2; water surface width of overflow section (m)
h ; overflow water depth (m)

River	Dam Name	Design Dis-charge (m^3/s)	Catch-ment Area (km^2)	(α)	Present Valley Width Bottom (m)	Present Valley Width Top (m)	Bottom Width of Overflow Section Calculated (m)	Bottom Width of Overflow Section Designed (m)	Overflow Water Depth (m)
Achiguate	A-1	1,250	92	5	50	380	177	180	2.4
	C-1	1,250	112	6	80	370	212	220	2.1
Pantaleon	P-2	1,250	107	6	90	210	212	160	2.6

(2) Main Dam

The dam foundation is embedded down to 1.5 m below the existing riverbed to assure the stability of dam body. The bedrock is a relatively dense conglomerate and it may safely be assumed that its bearing strength is about 40 t/m^2, and for the height of the proposed dam foundation, treatment is considered not required. However, it is required to carry out boring survey during the detailed design stage to fully investigate the conditions of the bedrock. Loose surface earth, about three (3) meters in depth, on both banks, is removed where the abutments are to be located to obtain sound bedrock with sufficient bearing strength and water-tightness. The crest width is designed at 2.0 m.

The slope of dam in the down stream is fixed at 1:0.2 so that the falling overflow stones may not damage the slope, while that in the upper stream is set in a range from 1:0.45 to 1:0.65 to provide endurance against any possible pressure.

The stability of a dam body against turnover and sliding, and the bearing strength of bedrock are calculated by the following formulas:

(a) Turnover

$$d = \frac{\Sigma Mx - \Sigma My}{V} \geq B/3 \quad \text{................} \quad \text{(Eq. 3-11)}$$

where, d; position along the dam base line where the combined force of dam weight and external force acts.

(b) Sliding

$S \leq f \cdot V/ H$ .... (Eq. 3-12)

(c) Bearing Strength of Bedrock

$\sigma = V/B \cdot (1 + 6e/B) <$ bearing strength of bedrock $= 40\ t/m^2$ (conglomerate) ... (Eq. 3-13)

where, f ; coefficient of friction (0.6)
V ; normal force functioning on section per unit width (t/m) H ; horizontal force functioning on section per unit width (t/m)
Σ Mx; total resisting moment on section per unit width at zero point (t·m/m)
Σ My; total turnover moment on section per unit width at zero point (t·m/m)
B ; bottom width of dam body (m)
S ; factor of safety (> 1.5)

The detailed dimensions of each dam are shown, together with those of the overflow sections, in Table 3-13.

(3) Subdam and Apron

The subdam and apron including side walls made of concrete, stone concrete and wet masonry, respectively, are designed in the downstream of dam, and they will function as scouring prevention facilities.

From the formula below, length (L) and thickness (t) of the apron may be obtained.

$L \geq 1 + X + b_2$ .... (Eq. 3-14)

$t = 0.1 \times (0.6H_1 + 3h_0 - 1.0)$

$1 = V_0 \cdot (H_1 + 0.5h_0)^{1/2}/(2/g)^{1/2}$

$V_1 = [2g(H_1 + h_0)]^{1/2}$

$X = \beta \cdot h_j$

$V_0 = q_0/h_0$

$h_1 = q_1/V_1$

$h_j = h_1/2 \cdot [(1 + 8F^2)^{1/2} - 1]$

$F_1 = V_1 / (g \cdot h_1)^{1/2}$

where, L ; length of apron (m)

g ; acceleration of gravity (9.8 m/s^2)

q_0; discharge per unit width at main dam crest ($m^3/s/m$)

β ; 4.5

l ; distance between A and B (m)

X ; distance of hydraulic jump (m)

b_2; subdam crest width (m)

V_o; overflow velocity at main dam (m/s)

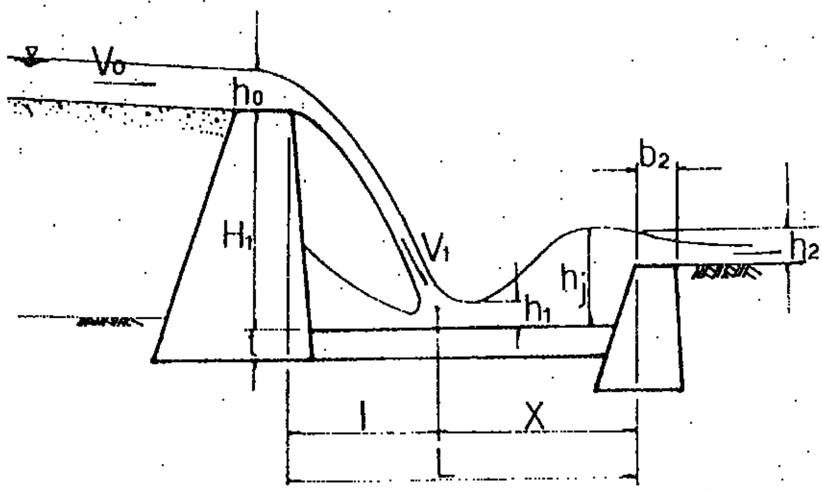
hj; depth of hydraulic jump (m)

V_1; flow velocity at point B (m/s)

h_1; super-critical flow depth before hydraulic jump (m)

q_1; discharge per unit width at point B ($m^3/s/m$)

F ; Froude number before hydraulic jump



7.2 Alternative Plan

The sediment control dams for the alternative plan, likewise, consist of main dam, overflow section, and apron, excluding sub-dam, as shown in Fig. 3-12.

(1) Overflow Section

The design of the overflow section has been prepared in the same manner as the proposed plan (refer to Table 3-13).

(2) Main Dam

The riverbed for the foundation will only be levelled off, and thereon gabion mattress will be placed. Embedding of the foundation is not necessary because the gabion mattress dam has a relatively wide bottom in comparison to its height. The dam has a crest width of 2.0 m, a downstream slope of 1:0.2 and an upper stream slope of 1:1. The downstream slope is designed steep for the same reason as that of the urgent proposed plan. Their dimensions are summarized in Table 3-13.

(3) Apron

Only the apron will be prepared by placing gabion mattress in a width of 12 m in the downstream of dam to prevent riverbed scouring due to overflow water.

REFERENCES

(1) R. I. ROSE, Jr., S. BONIS, R. E. STOIBER, M. KELLER and T. BICKFORD

Studies of Volcanic Ash from Two Recent Central American Eruptions; Bull. Volcanol (1973) Vol. 37, p. 338-364.

(2) R. I. ROSE, Jr., A. T. ANDERSON, Jr., L. G. WOODRUFF, and S. B. BONIS

The October 1974 Basaltic Tephra from Fuego Volcano: Description and History of the Magma Body; Journal of Volcanology and Geothermal Research, 4 (1978) p. 3-53.

(3) D. K. DAVIES, M. W. QUEARRY, S. B. BONIS

Glowing avalanches from the 1974 eruption of the volcano Fuego, Guatemala; Geological Society of American Bulletin (1978), V. 89, p. 369-384.

(4) YUICHI IWAGAKI

Study on Critical Tractive Force; Proceedings of Japan Society of Civil Engineering, vol. 41 (1956).

TABLES AND FIGURES

Table 3-1 (1/3) HISTORICAL ACTIVITY OF FUEGO VOLCANO (1524-1921 A.D.)

Year A.D.	Period	Intensity	Type of the Volcanic Activities: Lava Flow	Extrusion of a Lava Dome or Spine	Lahar or Nuée Ardentes	Ash (Normal Explosion)	Solfatara Fields, Vaporous	Collapse of the Volcanic Body	Damage	Remarks
1524	?					exist				
1526 -1541 ?	?					exist				
1565 ?	?					exist ?				
1575 ?	?					exist ?				
1576 ?	?					exist ?				
1577 ?	?					exist ?				
1581	26-27 Dec.	strong				exist				
1582	?		exist						Destroyed the villages	
1585	Jul. -Dec.					exist				
1586	Summer					exist				
1614	?					exist				
1623	Jan.					exist				
1629 -1632	?					exist				
1651	?					exist ?				Crater existed in the top of the volcano till 1932

* ?: Uncertainty or indetailed

(Continued)

Table 3-1 (2/3) HISTORICAL ACTIVITY OF FUEGO VOLCANO (1524-1921 A.D.)

Year A.D.	Period	Intensity	Type of the Volcanic Activities						Damage	Remarks
			Lava Flow	Extrusion of a Lava Dome or Spine	Lahar or Nuée Ardentes	Ash (Nomal Exposion)	Solfatera Fields, Vaporous	Collapse of the Volcanic Body		
1664	?					exist ?				
1668	?					exist ?				
1671	?					exist ?				
1677	?					exist ?				
1685 ?	?					exist ?				
1686	?					exist				
1689 ?	?					exist ?				
1699	?					exist				
1702 ?	?					exist ?				
1705	1-2 Feb.					exist				
1706	4 Oct.					exist				
1710	15 Oct.					exist				
1717	27 Aug. -end of the year	strong				exist				
1732	May					exist				
1737	27 Aug.	strong				exist				Crater was originated
1751 ?	?					exist ?				

(Continued)

Table 3-1 (3/3) HISTORICAL ACTIVITY OF FUEGO VOLCANO (1524-1921 A.D.)

Year A.D.	Period	Intesity	Type of the Volcanic Activities: Lava Flow	Extrusion of a Lava Dome or Spine	Lahar or Nuée Ardentes	Ash (Nomal Exposion)	Solfatera Fields, Vaporous	Collapse of the Volcanic Body	Damage	Remarks
1765	?					exist ?				
1773	?					exist ?				
1775	?					exist ?				
1799	?					exist				
1829	?					exist				
1850 ?	?					exist ?				
1852 ?	?		exist			exist				
1855	29-30 Sep.					exist				
1856	9 Jan. -7 Mar., 29-30 Sep.		exist			exist				
1857	15 Jan., 16-17 Feb.	strong	exist			exist				
1860	18 Aug.		exist			exist				
1861	21 Nov.					exist				
1867 ?	?					exist ?				
1880	29 Jun., 1-4 Jul. 20 Aug.	strong	exist			exist				
1896						exist				
1917								(Land slides by earthquakes)		Several landslides from the SW slopes of FUEGO were caused by severe earthquakes

Table 3-2 VOLCANIC ACTIVITIES AND INFLUENCES

Year	Period	Intensity	Lava flow *	Explosion of a lava dome or a spire	Lahar or nuée ardentes	Ash (normal Explosion)	Solfatara field vaporous	Other activities	Remarks	Damages caused by volcanic activities	Year & Period	Precipitation	Sedimentation or flood damage
1921–1927 1932	 21-22 Jun	 ◉	* Ashflows are easily termed "lava flow" by inhabitants. For this reason, current reports and possibly historical accounts may be misleading		○ (hot avalanches)	○	○		· Ashes fall as far as Salvador and Honduras In Guatemala City, 138 Kg tephra fell on 1m² during one hour. The top (50 ~ 80m ?) of the volcano was destroyed. and a new crater, deeply breached in NE direction, was formed. Hot avalanches came down.		1927.27 June 1927 29 July 1932 30 Aug 1932.10 Sep 1932.14 Oct 1933.11 July 1933.14 Sep 1933.22 Sep 1933. 25 Sep 1933 28 Sep 1934.8 June 1936.17 June 1936. 9 Oct		· Damages cause by the storm. serious. railway destoloyed in San Jose. in flooded. · Numerous damage in La Escuintla, due to aviolent cyclon. · damages due to rains in the road to Esquintla · Yepocapa and this sufferrs heavy damages. · San Jose is flooded. Guacalate river overflowed. · Strong hurricane raged over the city San Jose · San Jose flooded due to hevy rain. · Guacalate river overflowed. · San Jose abondoned by its inhabitants · Escuintla were panicked by a very strong cyclon. · San Jose flooded. · San Jose flooded. · San Jose flooded again.
1944 1947 1949 1953 1954 1955 1957	end of the year ? Nov 11 Apr 9 Sept July	 ◉	○ ○	○ (Lava dome) ○ (Spin)		○ (Black Scoria) ○	○		· From 1932 till 1944 observations are failing. · S & W top slopes are covered with black scoria. Crater, breached in NE direction, was filled with fresh lava up to about 20m. New lava had flown throw the deep noch of 1932 in NE direction reaching downwards halfway the mountain in slope		1949. 4 Oct 1949.14 Oct 1950. 7 Oct 1953.21 Sep 1958.30 Sep		· Flood at San Jose. · San Jose was destroyed · San Jose port flooded by torrential rains. damaged to the road. · San Jose port flooded due to the torrential rains. · San Jose port flooded.
1962 - - 1963 1966 1967	3, 6 Aug Oct 9 Nov 28,30 Sept 7 Feb 20 Apr 1 May 12.13 Aug 22.24 Apr	◉ ◉ ◉	○		○○ (Lahar)	○○ (Ash flows)		○ (Mud flows)	· Central crater: explosive activity and lahar · Strong explosive activty, central crater lava. Ash cloud estimated to 12.000 m. · Explosive activity central crater, mud flows, lava, SE flank. · Explosive activity central crater. · Ash eruption largest since 1932, lava flow · Ash clound estimated to 12,000m. · Ash eruption		1968.11 Sep 1968.18 Oct 1968. 19 Oct 1969. 5 Sep 1969.26 Sep		· San Jose flooded due to the rivermouth closing Water level reached over 1 meter. · San Jose port flooded. 5000 inhabitants evacuated. · 4000 inhabitants evacuated from San Jose. House almost submerged. This flood is due to overflow of Achiguate river. · Hurricane most heavily hits Escuintla. · 4 dead by flood. Situation were worse in Escuintla San Jose is flooded and has been evacuated.
1971	14 Sept	◎			○ (nuées ardentes)	○ (Basaltic ash, scoria ash flows)			· The 1971 event was the largest by far of all the recent Fuego activity. All observers agree that this was the most spectacular eruption of Fuego in memory (at least 70 years) The eruption consisted of large Vulcanian type eruption and of nuées ardentes which flowed down various gullays on the flanks of the cone. The most notable flows occured in Barrancos Honda, Las Lajas, and Ceniza. Eruption cloud reached over 10000m in height. · Prevailing winds deposited a 1 cm layer of ash more than 160 km to the west. Up to 3 cm size scoria was transported 8 km to the west, where the town of Yepocapa was covered with 30cm of ash.	About 20% of the roofs in Yepocapa were collapsed, including many of public buildings. Volume of ash produced this 1971 eruptions estimated to about $62 \times 10^6 m^3$	1970.30 July 31 July 1971.3 Sep 1971.25 Sep 1971.15 Oct		· Achiguate and Guacalate rivers over flowed. · Achiguate and Guacalate river damaged and lost the agricultural land. · Achiguate river and affluents overflowed in the road to San Jose in the 96 - 100km. · Several river overflowed due to eruption of the Fuego Volcano. The bridge over the Pantaleon river bridge falls interrupting the road. Siquinala is evacuated. · One dead. Several wounded and destoroyed houses due to overflowing of Guacalate and Achiguate rive in Masagua Escuintla. Siquinala suffered from the overflowing of the Obispo river.
1973	22 Feb 23 Feb 23 March (With a quiet interval from 3 to March)					○ (steam mission) ○ (ash fall, ash flows, black Scoria)			· The 1973 eruption was much less than violent and produced only a fraction of the ash volume of the 1971 eruption. · There was continuous steam emission but no explosive activity similar to the 1971 eruption. · Acatenango which is a twin of the Fuego volcano started gentle, tiny ash eruption on Nov.12. 1972, the first since 1927. Ash continued to rise in the crater, but never developed into an actual explosive eruption. · On this day, there were strong steam emissions from Fuego, and light ash fall and ash flows started the following day. In summerly, Fuego erupted ash from Feb 23 to March 2, and had renewed ash fall on March 22, and 23, for a total of 10 days of ash eruption. · Expect for a brief shower of 1 cm scoria fallen on the SE slope of the cone, most of the materials was fine sand to dust in size. The 1 cm isopach extended to about 10Km southly from the crater.		1971.21 Oct 1972.3 Aug 1972.10 Oct 1973.21 Aug		· A Bailey bridge and two other were destroyed by the Panzaleon river which overflowed again due to heavy rains. The railway. brige over the Pantaleon river was destroyed. · In La Democracia in Escuintla, the Mazate river overflowed flooding houses and lots. Mazate river overflowed flooding La Democracia. · Obispo river in Democracia overflowed due to heavy sedimentation.
1974	10 Oct 14 Oct 17-19 Oct 23 Oct – 4 Dec	◎				○ (ash fall, ash flows) ○ (ash fall, ash flows) ○ (ash fall and gas) ○ (ash fall and gas)			· The eruption began at 4 a.m. with small eruption of ash fall and ash flows · A period of intense activity began at 2 a.m. and continued to 7 p.m. A thick ash cloud rose over 7,500m above the summit, and numerous hot ash flows cascaded down the slopes of the volcanic cone. · A renewed eruption lasted from 9:45 p.m. 17 Oct. to 12 p.m. 18 Oct. The smallest of the major period of activity occured 19 Oct. and lasted for an undetermined length of time. · In the afternoon and evening, Fuego was once again in violent activity for at last 4~6 hours. Gas cloud rose 3 or more kilometers above the summit, and this episodes continued the eruptings period of intensive activity. This activity was characterized by the emission of gas and ash in a cloud reaching to 1000~2,000 m over the summit. · Since 23 Oct, the gas and ash cloud have not exceeded 1,500m in height, from 4 Dec. through 12 Dec. 12, the plume from the crater rose only a few hundred meter at most and contained almost no ash.	Winds at the time of the eruption carried the ash in a westerly direction. According to Dr Samuel Bonis who prepared the isopach map of the ash thickness, $185 \times 10^6 m^3$ of ash was produced by the 4 major eruptive episodes, about 3 times the calculated volume of the 1971 eruption.	1974.21 Sep		· The water level in San Jose rose two meters cutting all comunication was with Esquintla.
1975	28 May 23 July – 4 Aug 18 Sep and continuing 11-21 Oct					○ (ash fall, ash flow) ○ (ash fall, ash flow?) ○ (ash fall) ○ (ash fall)			· Small ash eruptions, possible ash flow · Sporadic very small ash eruptions. possible ash flows 24 July. · Increasing vapor emission followed by small airfall ash eruption Larger airfall eruptions ash falling at Antigua		1975.29 Sep 1976.11 Sep 1976 1 July		· San Jose port flooded due to overflowing of the Achiguate and Guacalate river. The Barrio Cerritos (a neighbourhood) of San Jose is completely flooded. Traffic interrupted in the 78.100 km due to the overflowing of Achiguate river. · Achiguate river overflowed in the 78, 73, 83 and 94 km of the road to the San Jose port road.
1977 1978 1979	3 Mar 19 Apr 11 Sep and continuing Jun 23 Jun 10 Feb					○ (ash fall, ash fall) ○ (ash fall) ○ (ash fall)			· Small ash eruption · Small ash eruption · Weak airfall eruptions · Light eruption · Intense activity · Intense activity		1977.17 Sep 1978. 6 Sep 12 Sep 11 Oct 1979. 1 Sep 3 Sep		· Achiguate and Guacalate rivers overflowed · At Siquinala, by damages when the river Mazate overflowed. · Mazate river overflowed · Road to San Jose with half way between 80 and 90km due to the out flood of Achiguate River. · Achiguate River flooded and road to San Jose interrupted damaging the agricultural crops. · The road to San Jose flooded in several lots by the Achiguate river.
1980	11 Jun 9 Feb								· Weak eruption · Weak eruption		1982.20 July 1983.10 Sep		· Strong rains accompanied of hurricaned winds scouring last night at Escuintla getting down trees and leaving 5 houses without ceiling. · Achiguate river flooded again. Over 5,000 inhabitants evacuated.

Table 3-3 THE FORMATIVE HISTORY OF THE TOPOGRAPHY AND GEOLOGY

(1)	Sedimentation of the tertiary volcanic rocks	Tertiary Period
(2)	Displacement of the tertiary volcanic rocks due to fault, eruption, etc.	
= = = = = = = = = = = = = = = = = =		unconformity
(3)	Effusion and sedimentation of pyroclastic rocks of the Old Fuego Volcano (formation of an extensive skirt at its foot)	
(4)	Extensive collapse (formation of a sort of cardera)	
(5)	Shaping of a central cone on the top of the Old Fuego Volcano	
(6)	Formation of cardera of the Old Fuego Volcano	Quarternary Period
(7)	Effusion and sedimentation of pyroclastic rocks of the present Fuego Volcano	
(8)	Shaping of central cone on the top of the present Fuego Volcano	
(9)	Erosion of the volcanic body resulting in the formation of the volcanic fan and the alluvial plain.	

Table 3-4 PRODUCTION VOLUME BY GULLY EROSION

Unit: $\times 10^3 m^3$

Name of Catchment	Gully (I)*	Gully (II)*	Total
Achiguate River			
(1) Achiguate River	20,250	139,550	159,800
(2) Ceniza River	18,625	85,650	104,275
Pantaleon River	19,875	585,000	604,875

* Refer to Fig. 3-2.

Table 3-5 (1/2) PROBABLE SEDIMENT DISCHARGE

(LONG-TERM PLAN)

Return Period	Achiguate River		Pantaleon River	
	Precipitation at Ceylan (mm/day)	Sediment Discharge ($x10^3m^3$)	Precipitation at Los Tarros (mm/day)	Sediment Discharge ($x10^3m^3$)
5-year	177	1,110	180	1,914
10	209	1,420	210	2,413
20	240	1,740	239	2,915
30	258	1,940	256	3,246
50	281	2,200	275	3,611

Table 3-5 (2/2) PROBABLE SEDIMENT DISCHARGE

(URGENT PLAN)

Return Period	Achiguate River		Pantaleon River	
	Precipitation at Ceylan (mm/day)	Sediment Discharge ($x10^3m^3$)	Precipitation at Los Tarros (mm/day)	Sediment Discharge ($x10^3m^3$)
5-year	177	555	180	957
10	209	710	210	1,206
20	240	870	239	1,457
30	258	970	256	1,623
50	281	1,100	275	1,805

Table 3-6 (1/2) REGULATION VOLUME (ACHIGUATE RIVER)

(LONG-TERM)

Return Period (Year)		Probable Flood Discharge ($x10^6 m^3$/flood)	Probable Sediment Discharge ($x10^3 m^3$/flood)	Allowable Sediment Discharge ($x10^3 m^3$/flood)	Regulation Volume ($x10^3 m^3$/flood)
5	Achi.		912	25	887
	Ceni.		198	5	193
	Total	14.1	1,110	30	1,080
10	Achi.		1,166	33	1,133
	Ceni.		254	7	247
	Total	17.3	1,420	40	1,380
30	Achi.		1,593	41	1,552
	Ceni.		347	9	338
	Total	22.3	1,940	50	1,890
50	Achi.		1,806	41	1,765
	Ceni.		394	9	385
	Total	24.6	2,200	50	2,150

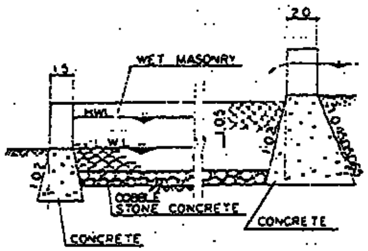
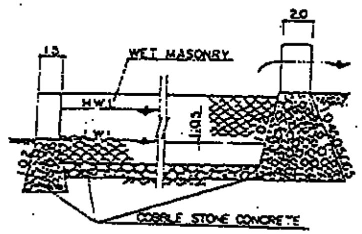
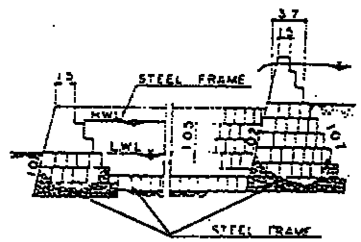
Achi: Achiguate, Ceni: Ceniza

Table 3-6 (2/2) REGULATION VOLUME (PANTALEON RIVER)

(LONG-TERM)

Return Period (Year)	Probable Flood Discharge ($x10^6 m^3$/flood)	Probable Sediment Discharge ($x10^3 m^3$/flood)	Allowable Sediment Discharge ($x10^3 m^3$/flood)	Regulation Volume ($x10^3 m^3$/flood)
5	13.3	1,914	190	3.291
10	16.3	2,413	230	2,956
30	20.8	3,246	290	2,183
50	22.9	3,611	320	1,724

Table 3-7 COST COMPARISON FOR SEDIMENT CONTROL DAM TYPES

Item		Dam Type: Concrete	Dam Type: Cobble Stone Concrete	Dam Type: Steel Flame
Section of Dam (Unit ; m)				
Base Construction Cost ($x10^3$ US$)	A-1 Dam	2,900	2, 500	4,900
	C-1 Dam	2,500	2, 200	4,400
	P-2 Dam	3,000	2, 600	5,300
	Total	8,400	7, 300	14,600

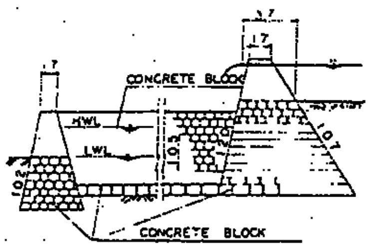
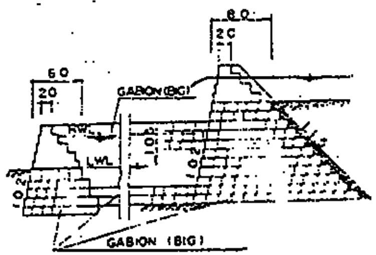
Item		Dam Type: Concrete Block	Dam Type: Gabion Mattress
Section of Dam (Unit ; m)			
Base Construction Cost ($x10^3$ US$)	A-1 Dam	3,700	3, 300
	C-1 Dam	3,100	2,900
	P-2 Dam	3,900	3, 700
	Total	10,700	9,900

Table 3-8 EFFECTIVE HEIGHT AND REGULATION VOLUME OF SEDIMENT CONTROL DAMS

River	Dam Site	Distance from River Month (Km)	Catchment Area (Km^2)	Priority of Effect for Dam Construction	Possible Maximum		Project Scale (Return-Period)							
							5-year		10-year		30-year		50-year	
					Effective Height (m)	Regulation Volume ($x10^3m^3$)	Effective Height (m)	Regulation Volume ($x10^3m^3$)	Effective Height (m)	Regulation Volume ($x10^3m^3$)	Effective Height (m)	Regulation Volume ($x10^3m^3$)	Effective Height (m)	Regulation Volume ($x10^3m^3$)
Achiguate	A	44	92	1	8.0	990	7.5	887	8.0	990	8.0	990	8.0	990
	B	46	87	4	7.5	258	-	-	-	-	-	-	6.0	201
	C	100	39	3	18.5	574	-	-	8.5	143	18.0	562	18.5	574
	D	1	112	1	8.0	505	6.0	193	6.5	247	7.0	338	7.5	385
	Total	-	-	-	-	-	-	1,080	-	1,380	-	1,890	-	2,150
Pantaleon	E	22	115	1	5.0	60	5.0	60	5.0	60	5.0	60	5.0	60
	F	26	107	2	9.0	976	9.0	976	9.0	976	9.0	976	9.0	976
	G	30	64	6	20.0	928	-	-	-	-	-	-	11.5	282
	H	33	62	5	12.0	288	-	-	-	-	11.0	235	12.0	288
	I	34	61	4	9.0	315	-	-	-	-	9.0	315	9.0	315
	J	35	60	3	18.0	1,370	11.5	688	15.5	1,147	18.0	1,370	18.0	1,370
	Total	-	-	-	-	-	-	1,724	-	2,183	-	2,956	-	3,291

Table 3-9 CONSTRUCTION COST OF SEDIMENT CONTROL DAMS

Unit: $x10^3$ US$

River	Dam Site	Project Scale (Return-Period)			
		5-year	10-year	30-year	50-year
Achiguate	A	3,400	3,700	3,700	3,700
	B	-	-	-	3,100
	C	-	1,200	3,300	3,400
	D	3,000	3,300	3,700	4,100
	Total	6,400	8,200	10,700	14,300
Pantaleon	E	1,400	1,400	1,400	1,400
	F	3,000	3,000	3,000	3,000
	G	-	-	-	5,000
	H	-	-	3,200	3,400
	I	-	-	2,100	2,100
	J	3,600	5,400	6,300	6,300
	Total	8,000	9,800	16,000	21,200
Grand Total		14,400	18,000	26,700	35,500

Table 3-10 DIMENSIONS OF SEDIMENT CONTROL DAMS

(LONG-TERM)

River	Dam Name	Dam Site	Main Dam					Overflow Section			Sub Dam		Apron	
			Effective Height (m)	Dam Height (m) Overflow Section	Dam Height (m) Non-Overflow Section (max.)	Gradient of Upstream Slope	Crest Length (m)	Design Discharge (m^3/sec)	Bottom Width (m)	Water Depth (m)	Dam Height (m) Overflow Section	Dam Height (m) Non-Overflow Section	Length (m)	Thickness (m)
Achiguate	A-1	A	8.0	8.5	11.9	1 : 0.6	460	1,250	180	2.4	4.5	7.9	29	1.3
	A-2	C	18.0	20.0	23.1	1 : 1.2	135	1,050	180	2.1	6.0	9.1	35	1.7
	C-1	D	7.0	8.5	11.6	1 : 0.6	455	1,250	220	2.1	4.5	7.6	29	1.3
Pantaleon	P-1	E	5.0	6.5	10.1	1 : 0.5	210	1,250	160	2.6	3.5	7.1	20	1.0
	P-2	F	9.0	11.0	14.6	1 : 0.65	392	1,250	160	2.6	4.5	8.1	29	1.3
	P-3	H	11.0	13.0	16.8	1 : 0.9	160	1,100	120	2.8	4.5	8.3	30	1.3
	P-4	I	9.0	10.5	14.3	1 : 0.65	390	1,100	120	2.8	4.5	8.3	29	1.3
	P-5	J	18.0	20.0	23.8	1 : 1.3	230	1,100	120	2.8	6.0	9.8	35	1.7

Table 3-11 (1/2) REGULATION VOLUME (ACHIGUATE RIVER)

(URGENT PLAN)

Return Period (Year)		Probable Flood Discharge ($x10^6 m^3$/flood)	Probable Sediment Discharge ($x10^3 m^3$/flood)	Allowable Sediment Discharge ($x10^3 m^3$/flood)	Regulation Volume ($x10^3 m^3$/flood)
5	Achi.		456	25	431
	Ceni.		99	5	94
	Total	14.1	555	30	525
10	Achi		584	33	551
	Ceni,		126	7	119
	Total	17.3	710	40	670
30	Achi.		796	41	755
	Ceni.		174	9	165
	Total	22.3	970	50	920

Achi: Achiguate, Ceni: Ceniza

Table 3-11 (2/2) REGULATION VOLUME (PANTALEON RIVER)

(URGENT PLAN)

Return Period (Year)	Probable Flood Discharge ($x10^6 m^3$/flood)	Probable Sediment Discharge ($x10^3 m^3$/flood)	Allowable Sediment Discharge ($x10^3 m^3$/flood)	Regulation Volume ($x10^3 m^3$/flood)
5	13.3	957	190	767
10	16.3	1,206	230	976
30	20.8	1,623	290	1,333

Table 3-12 EFFECTIVE HEIGHT AND REGULATION VOLUME OF SEDIMENT CONTROL DAMS

River	Dam Site	Distance from River Mouth (Km)	Catchment Area (Km^2)	Priority of Effect for Dam Construction	Limit		Project Scale (Return-Period)					
							5-year		10-year		30-year	
					Effective Height (m)	Regulation Volume ($x10^3m^3$)	Effective Height (m)	Regulation Volume ($x10^3m^3$)	Effective Height (m)	Regulation Volume ($x10^3m^3$)	Effective Height (m)	Regulation Volume ($x10^3m^3$)
Achiguate	A	44	92	1	8.0	990	6.0	431	6.5	551	7.0	755
	B	46	87	4	7.5	258	-	-	-	-	-	-
	C	100	39	3	18.5	574	-	-	-	-	-	-
	D	1	112	1	8.0	505	4.0	94	4.5	119	5.5	165
	Total	-	-	-	-	-	-	525	-	670	-	920
Pantaleon	F	26	107	1	9.0	976	8.0	767	9.0	976	9.0	976
	G	30	64	5	20.0	928	-	-	-	-	-	-
	H	33	62	4	12.0	288	-	-	-	-	-	-
	I	34	61	3	9.0	315	-	-	-	-	-	-
	J	35	60	2	18.0	1,370	-	-	-	-	8.0	357
	Total	-	-	-	-	-	-	767	-	976	-	1,333

Table 3-13 DIMENSIONS OF SEDIMENT CONTROL DAMS (PROPOSED AND ALTERNATIVE PLANS)

Plan	River	Dam Name	Dam Site	Main Dam: Effective Height	Main Dam: Dam Height (m) Overflow Section	Main Dam: Dam Height (m) Non-overflow Section (max.)	Main Dam: Gradient of Upstream Slope	Main Dam: Crest Length (m)	Overflow Section: Design Discharge (m^3/sec)	Overflow Section: Bottom Width (m)	Overflow Section: Water Depth (m)	Sub Dam: Dam heigth (m) Overflow Section	Sub Dam: Dam heigth (m) Non-overflow Section	Apron: Length (m)	Apron: Thickness (m)	Side Well: Height (m)
Proposal	Achiguate	A-1	A	6.5	7.0	10.4	1:0.50	409	1,250	180	2.4	4.0	7.4	24	1.0	5.1
		C-1	D	4.5	6.0	9.1	1:0.45	425	1,250	220	2.1	3.5	6.6	21	1.0	4.6
	Pantaleon	P-2	F	9.0	11.0	14.6	1:0.65	392	1,250	160	2.6	4.5	8.1	29	1.3	5.8
Alternative	Achiguate	A-1	A	5.0	5.0	9.0	1:1.0	404	1,250	180	2.4	---	---	12	2.0	---
		A-1'	B	3.5	4.0	8.0	1:1.0	401	1,200	180	2.3	---	---	12	2.0	---
		A-2	C	5.0	5.0	10.0	1:1.0	101	1,050	70	3.9	---	---	12	2.0	---
		C-1	D	4.5	5.0	8.0	1:1.0	424	1,250	220	2.1	---	---	12	2.0	---
	Pantaleon	P-2	F	5.0	5.0	9.0	1:1.0	276	1,250	160	2.6	---	---	12	2.0	---
		P-2'	G	4.0	4.0	8.0	1:1.0	308	1,100	120	2.8	---	---	12	2.0	---
		P-3	H	5.0	5.0	9.0	1:1.0	167	1,100	120	2.8	---	---	12	2.0	---
		P-4	I	5.0	5.0	9.0	1:1.0	170	1,100	120	2.8	---	---	12	2.0	---
		P-5	J	5.0	5.0	9.0	1:1.0	158	1,100	120	2.8	---	---	12	2.0	---

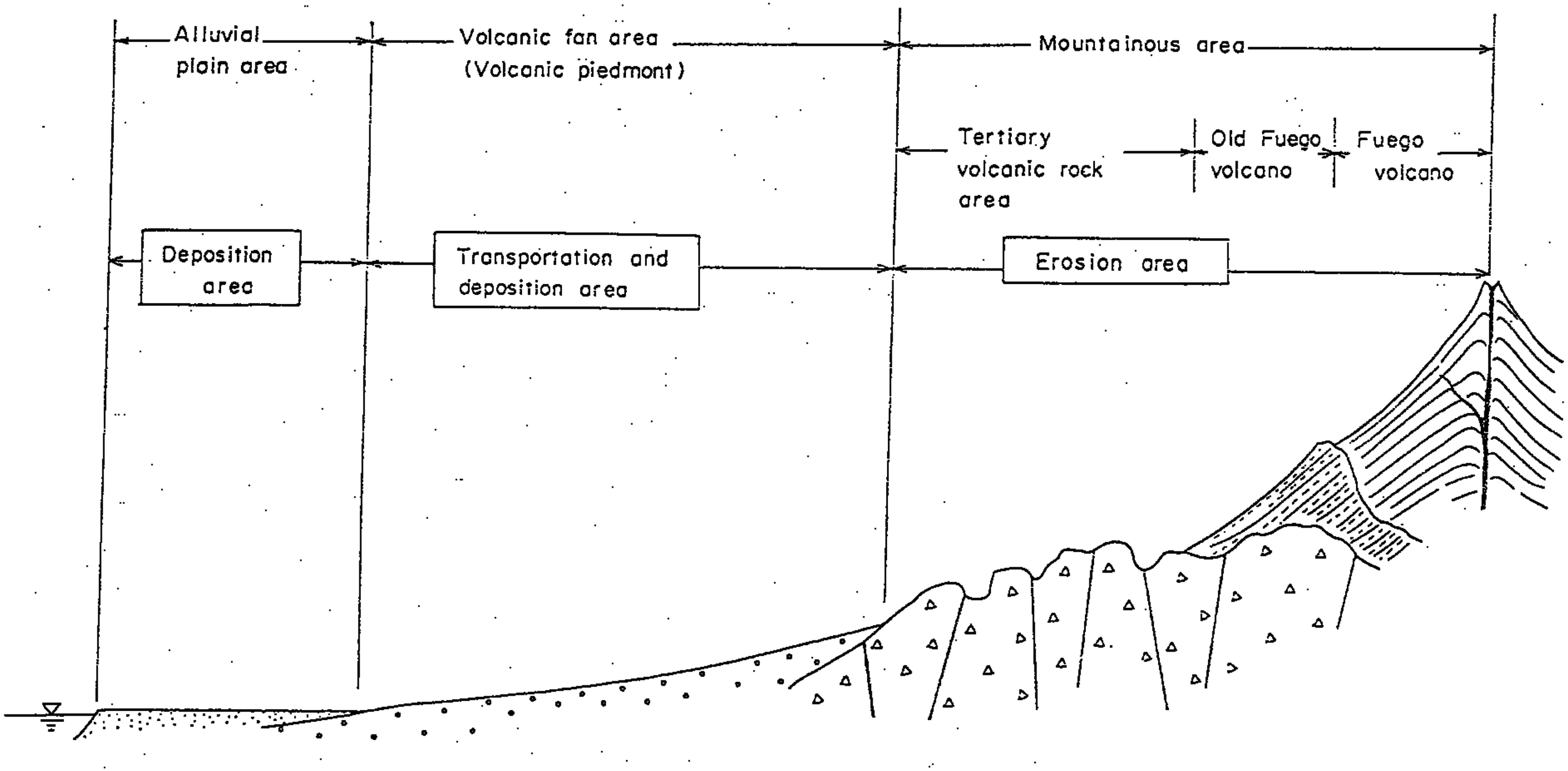


Fig. 3-1 TOPOGRAPHICAL DIVISION OF THE STUDY AREA

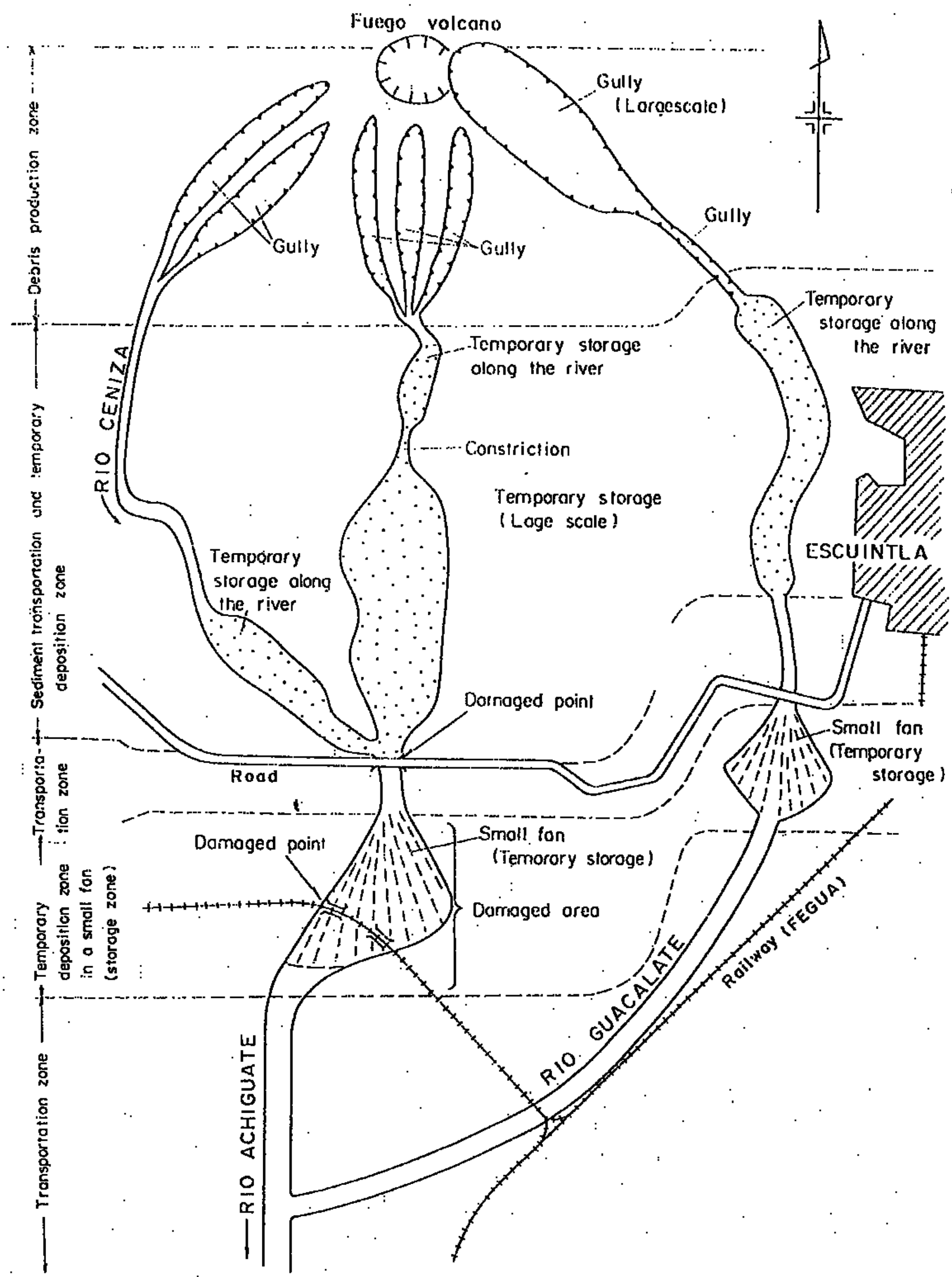


Fig. 3-2 (1/2) TOPOGRAPHY AND DEBRIS/SEDIMENT MOVEMENT (ACHIGUATE RIVER BASIN)

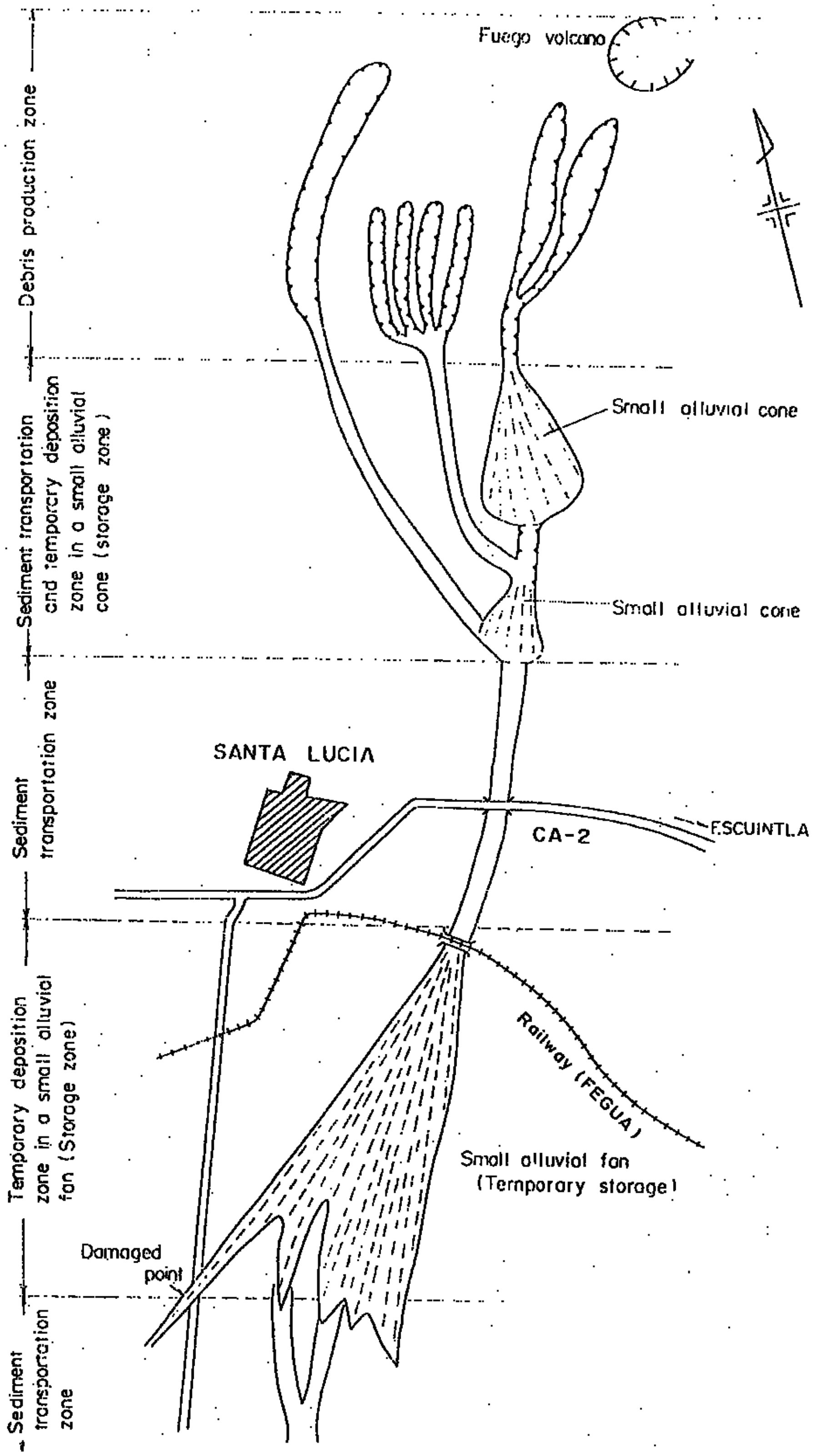


Fig. 3-2 (2/2) TOPOGRAPHY AND DEBRIS/SEDIMENT MOVEMENT (PANTELEON RIVER BASIN)

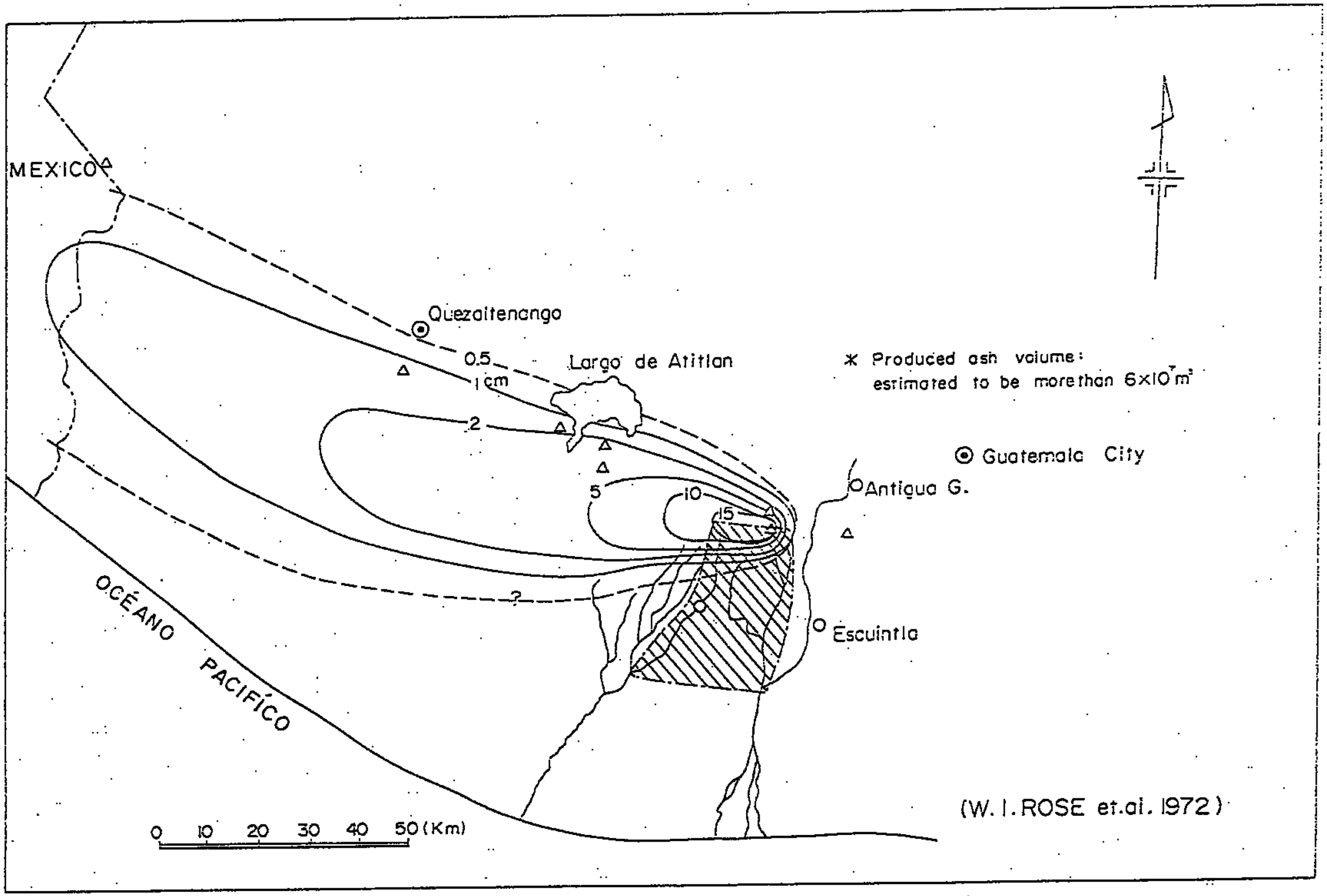


Fig. 3-3 (1/3) ISOPACH MAP OF FUEGO'S SEPTEMBER 1971 ASH BLANKET

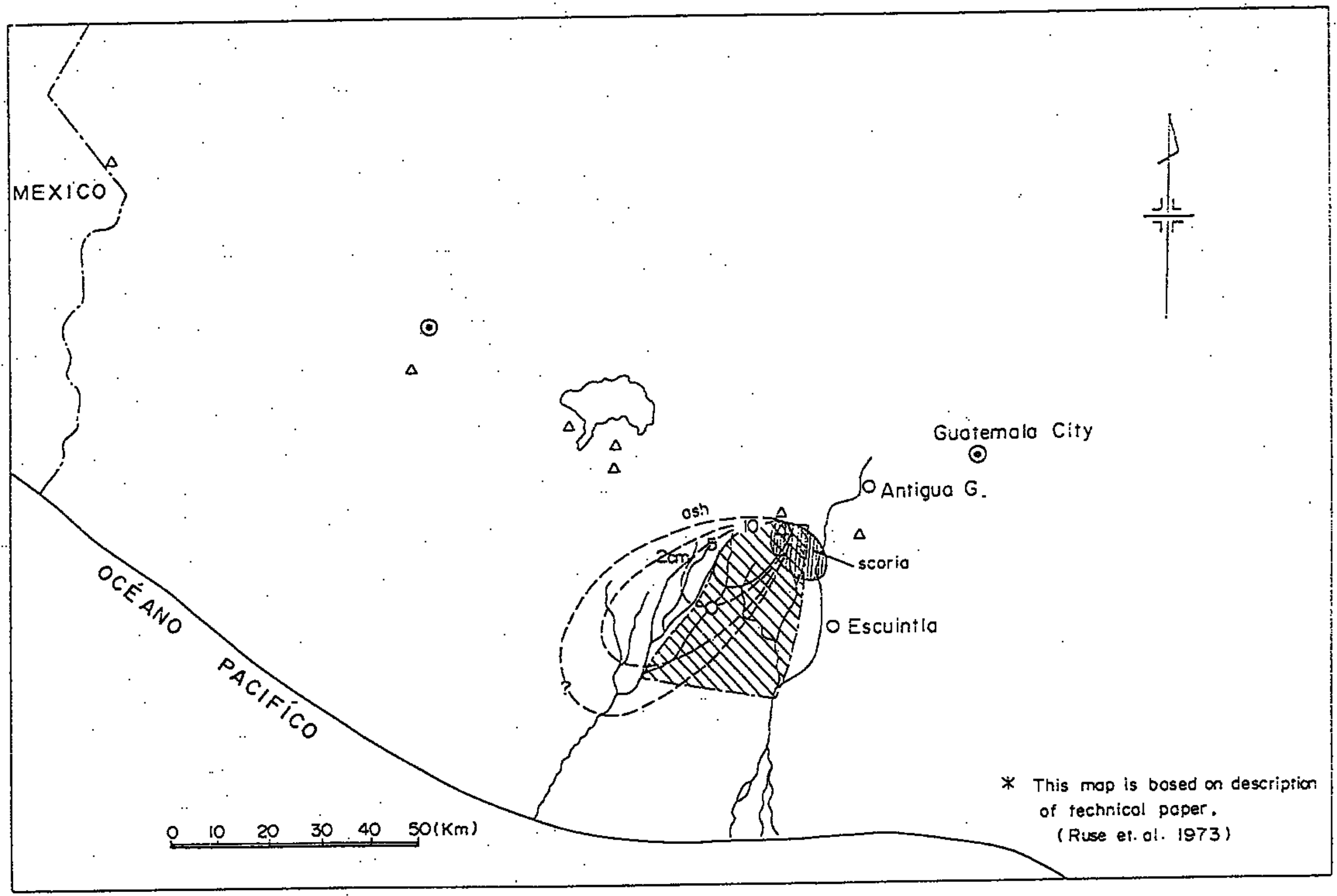


Fig. 3-3 (2/3) ESTIMATED ISOPACH MAP OF FUEGO'S 1973 ASH BLANKET

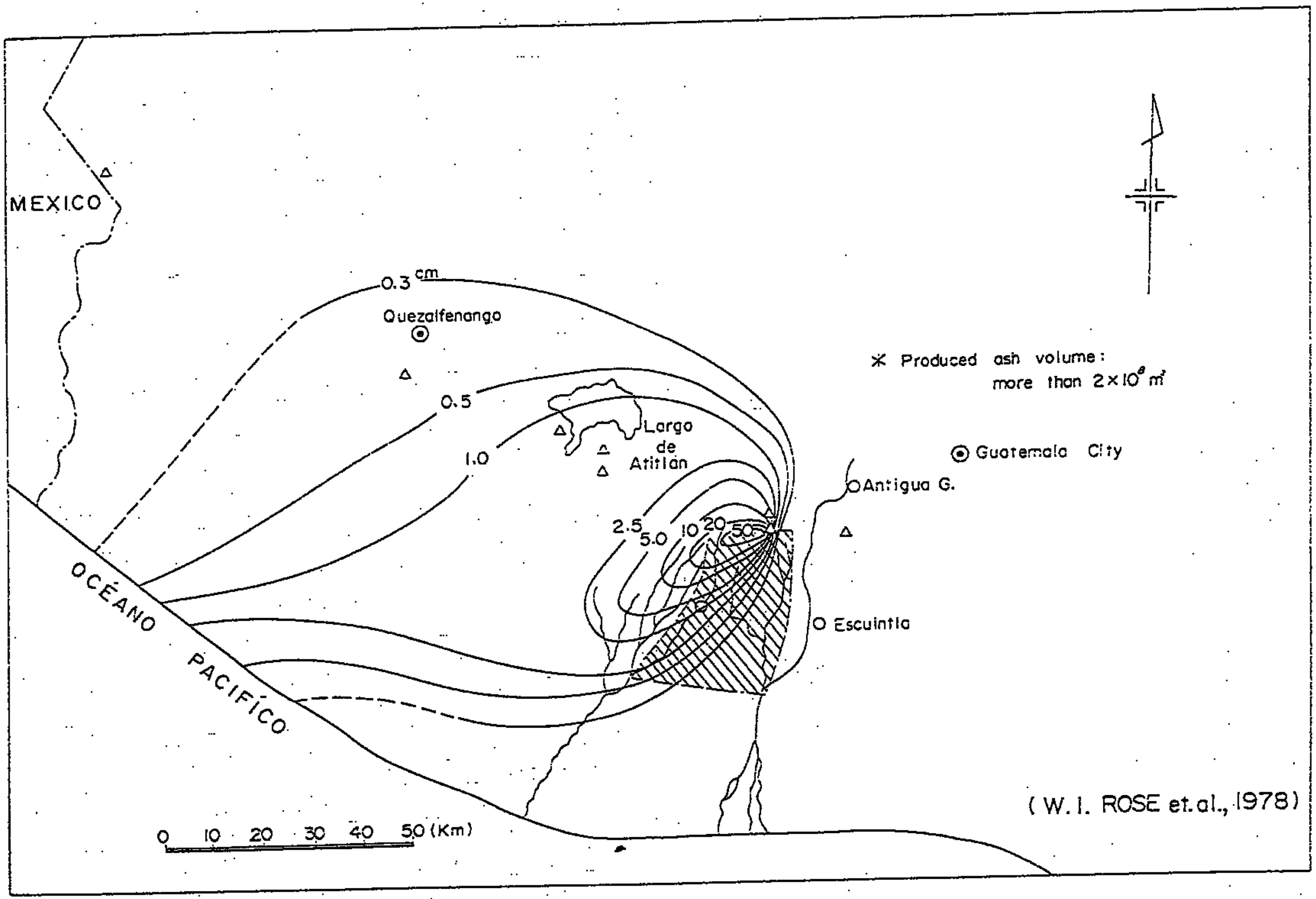


Fig. 3-3 (3/3) ISOPACH MAP OF FUEGO'S OCTOBER 14-23, 1974 ASH BLANKET

(unit : x10^{3}m^3)

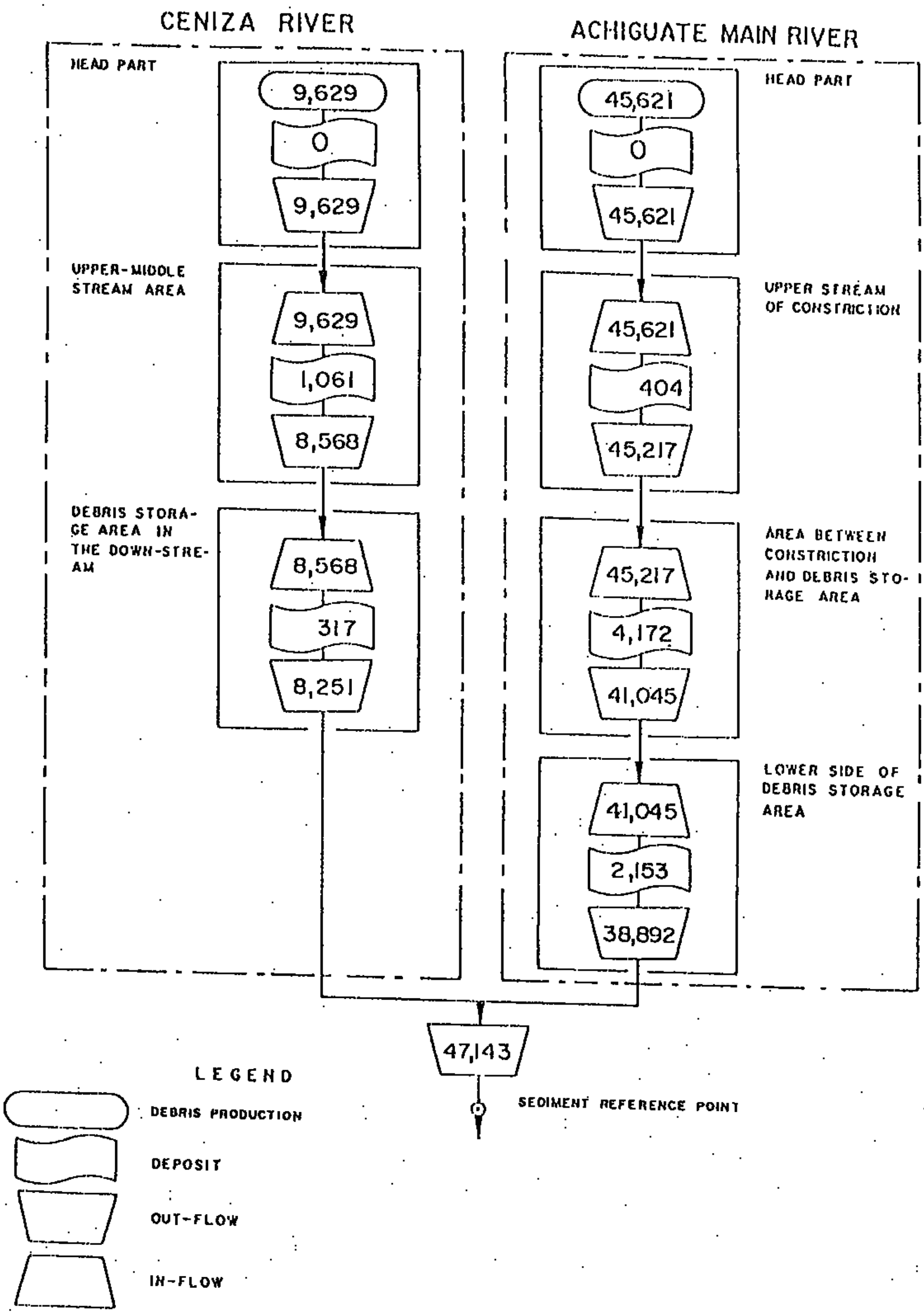


Fig. 3-4 (1/2) SEDIMENT BALANCE (ACHIGUATE RIVER BASIN)

(unit : $\times 10^3 m^3$)

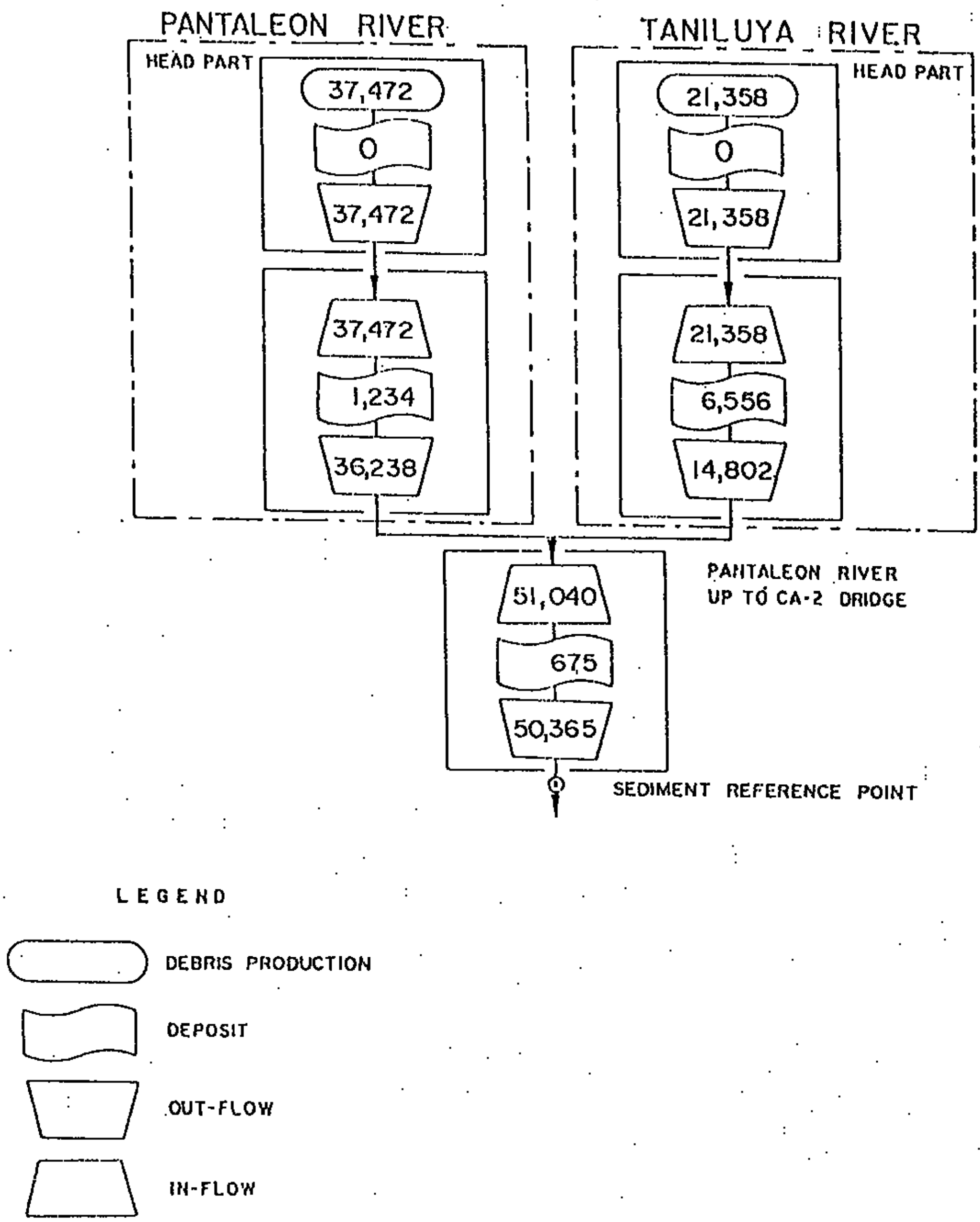


Fig. 3-4 (2/2)   SEDIMENT BALANCE (PANTALEON RIVER BASIN)

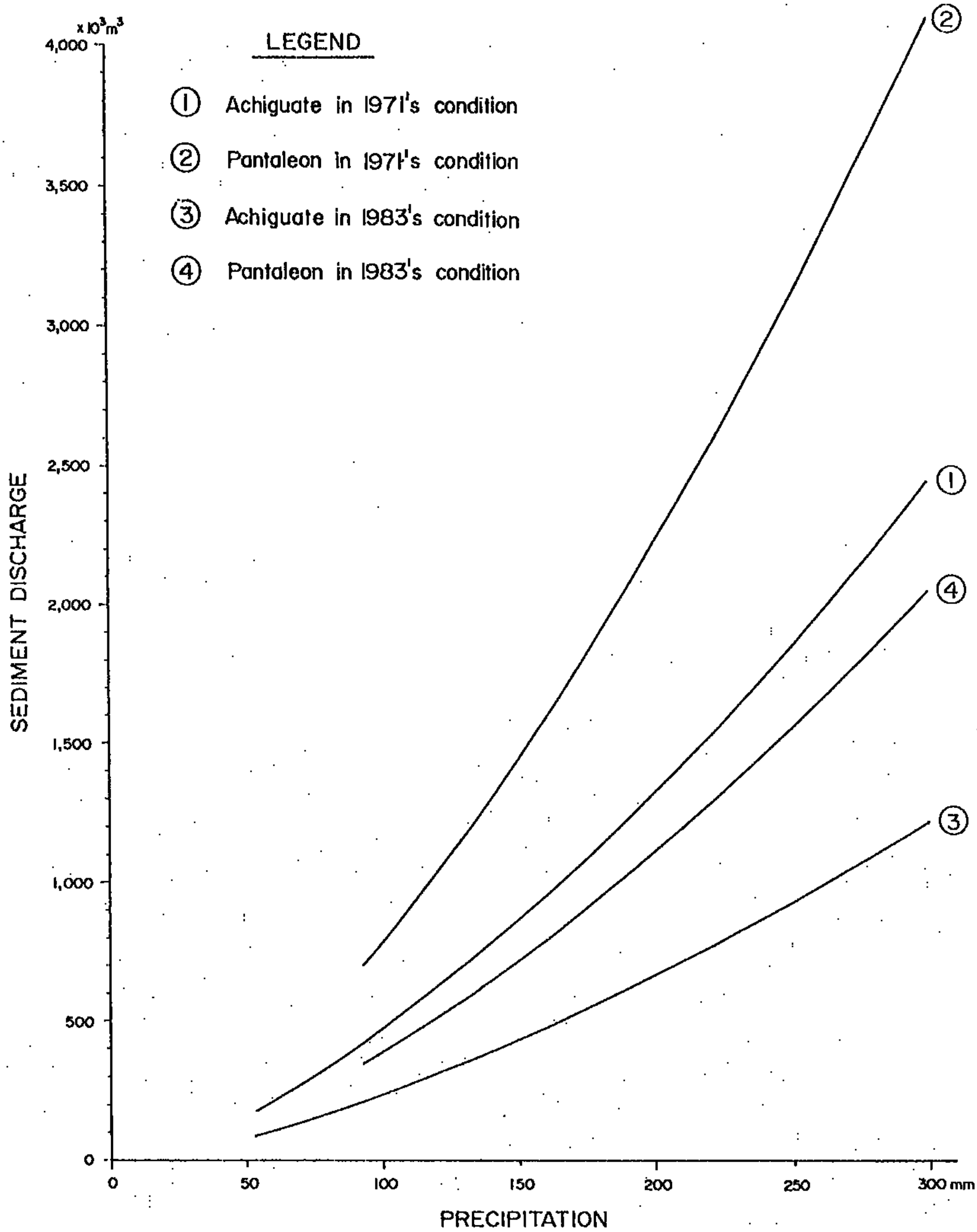


Fig. 3-5 PRECIPITATION AND SEDIMENT DISCHARGE

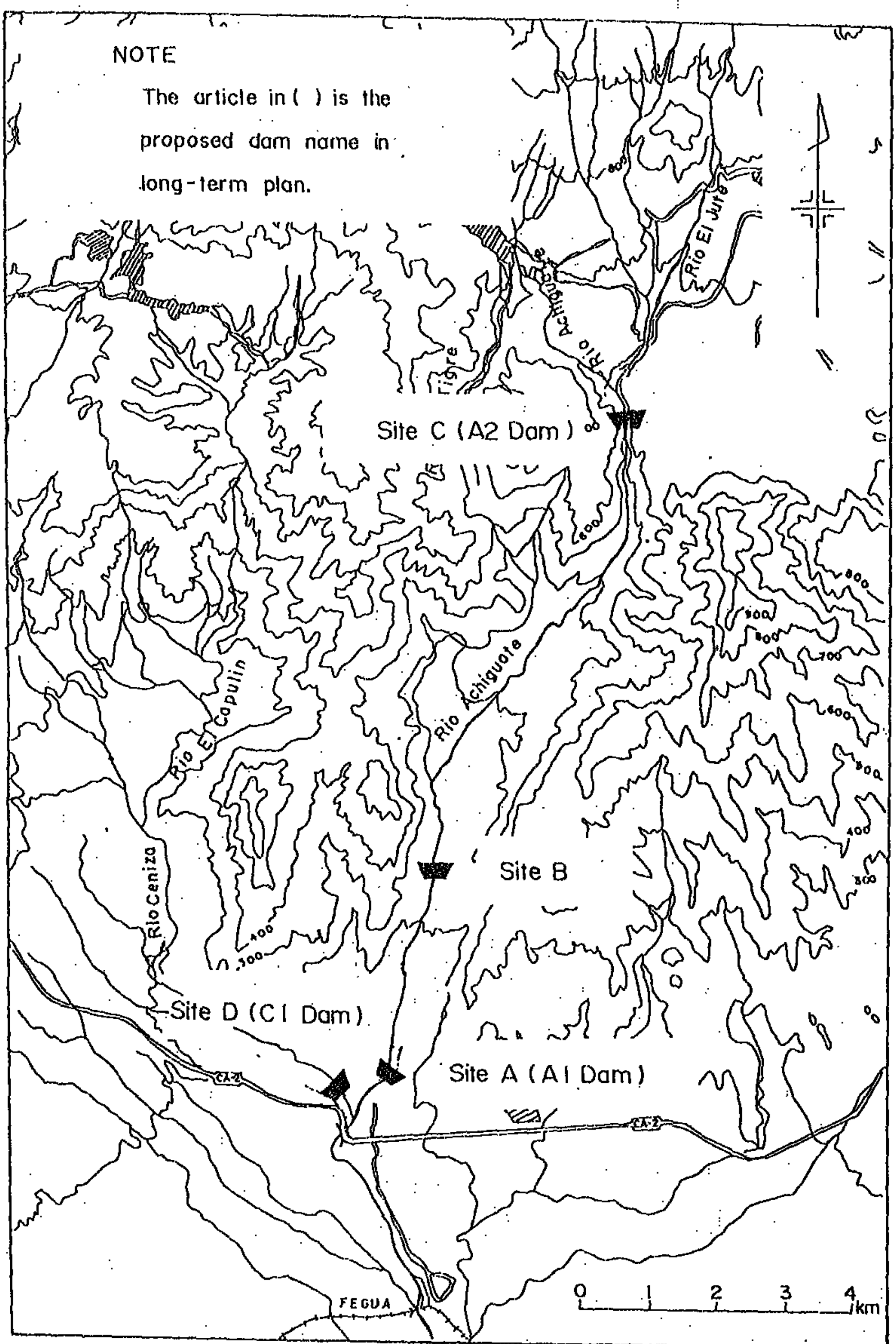


Fig. 3-6 (1/2) SUGGESTED DAM SITES (ACHIGUATE RIVER BASIN)

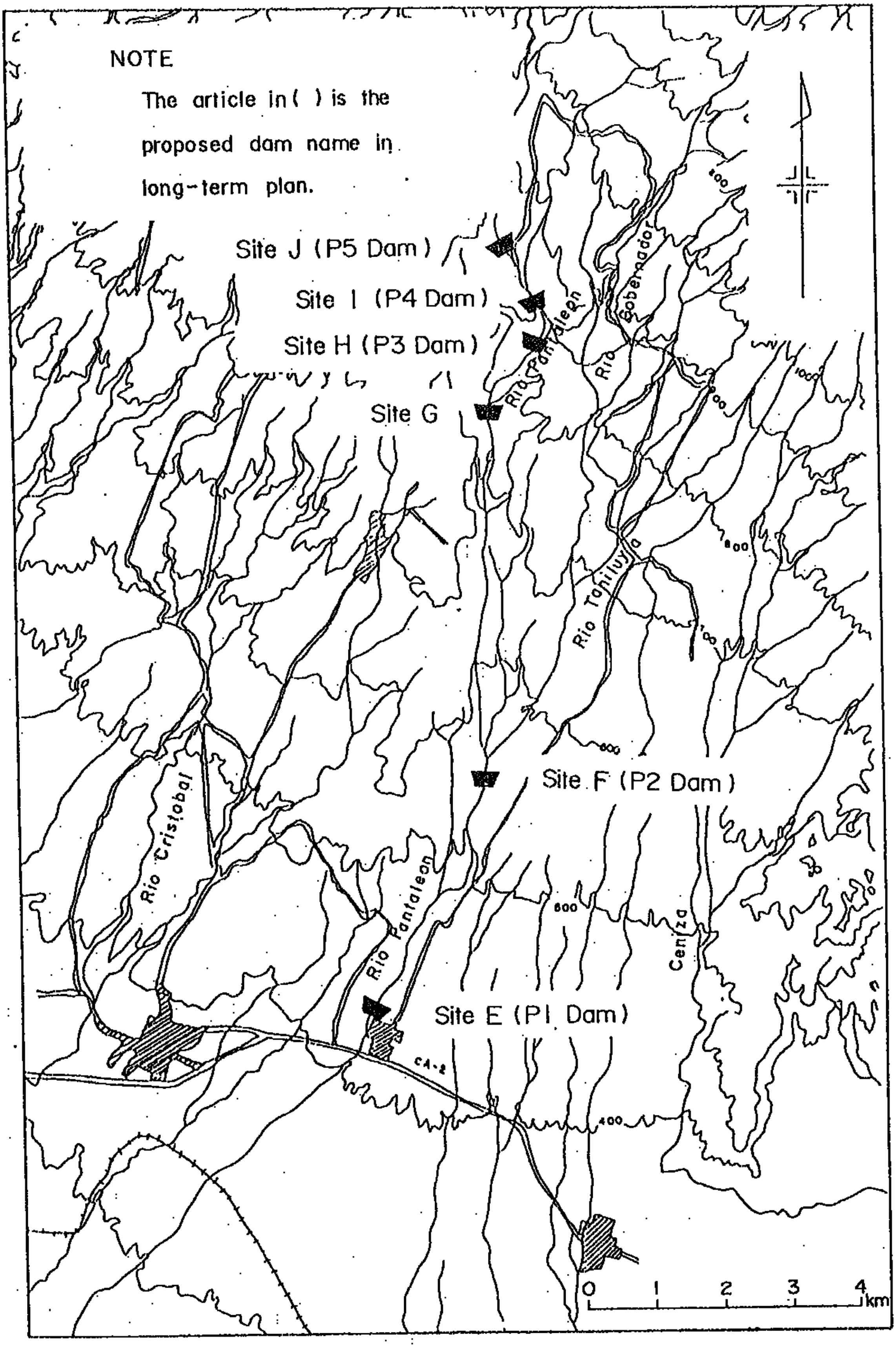


Fig. 3-6 (2/2) SUGGESTED DAM SITES (PANTALEON RIVER BASIN)

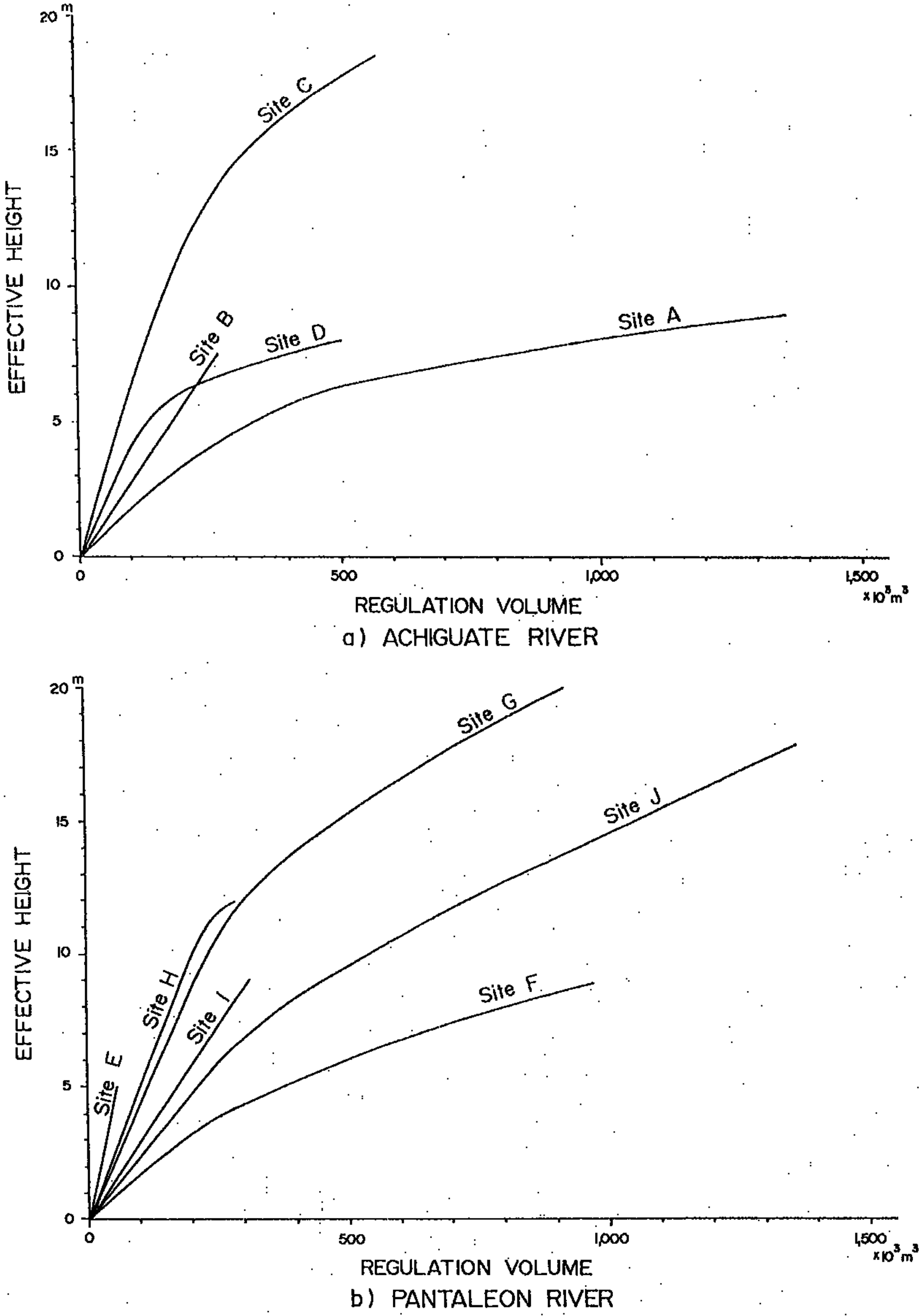


Fig. 3-7 REGULATION VOLUME AND EFFECTIVE HEIGHT

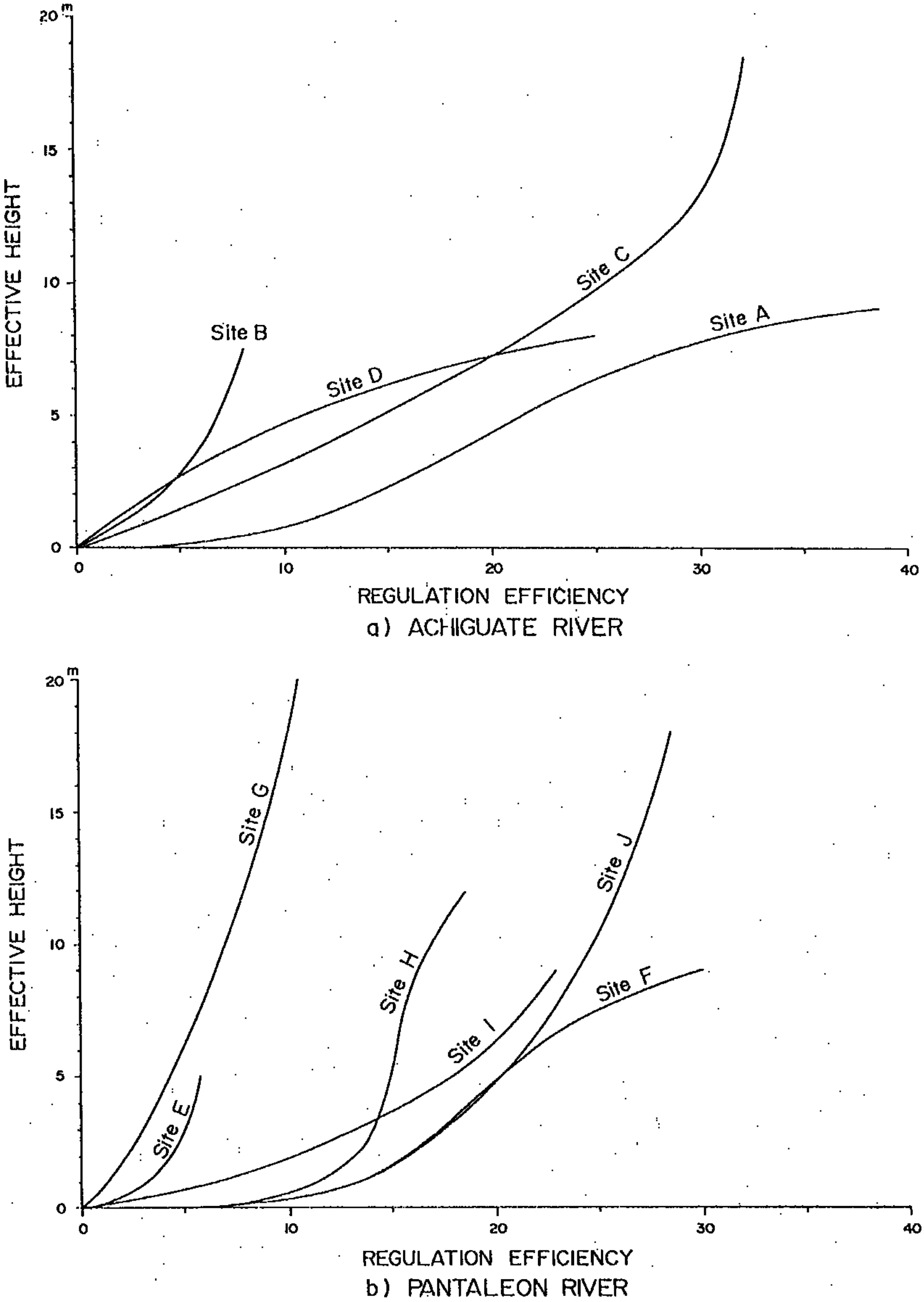


Fig. 3-8 REGULATION EFFICIENCY AND EFFECTIVE HEIGHT

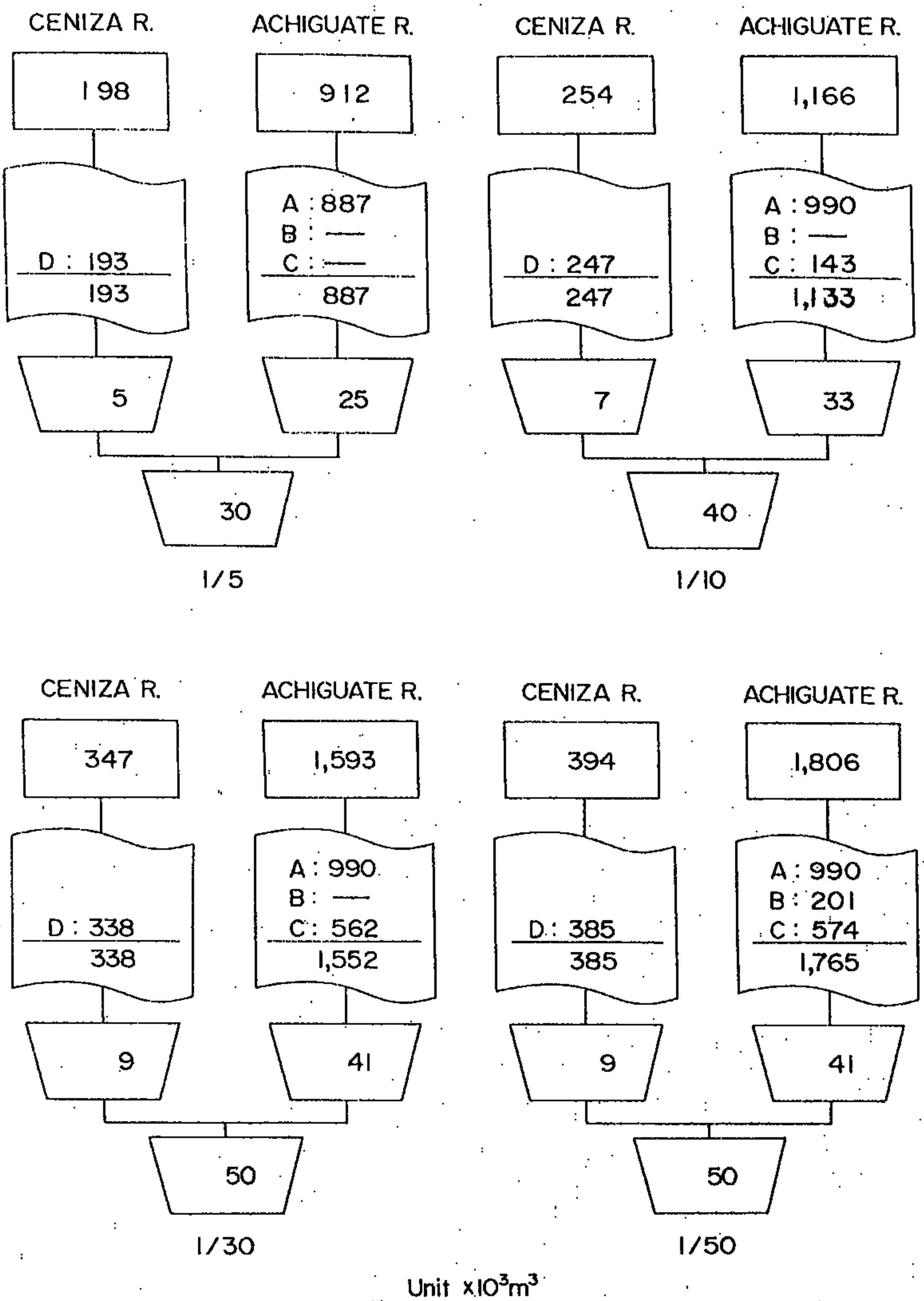


Fig. 3-9 (1/2) DISTRIBUTION OF SEDIMENT DISCHARGE IN THE LONG-TERM PLAN (ACHIGUATE RIVER)

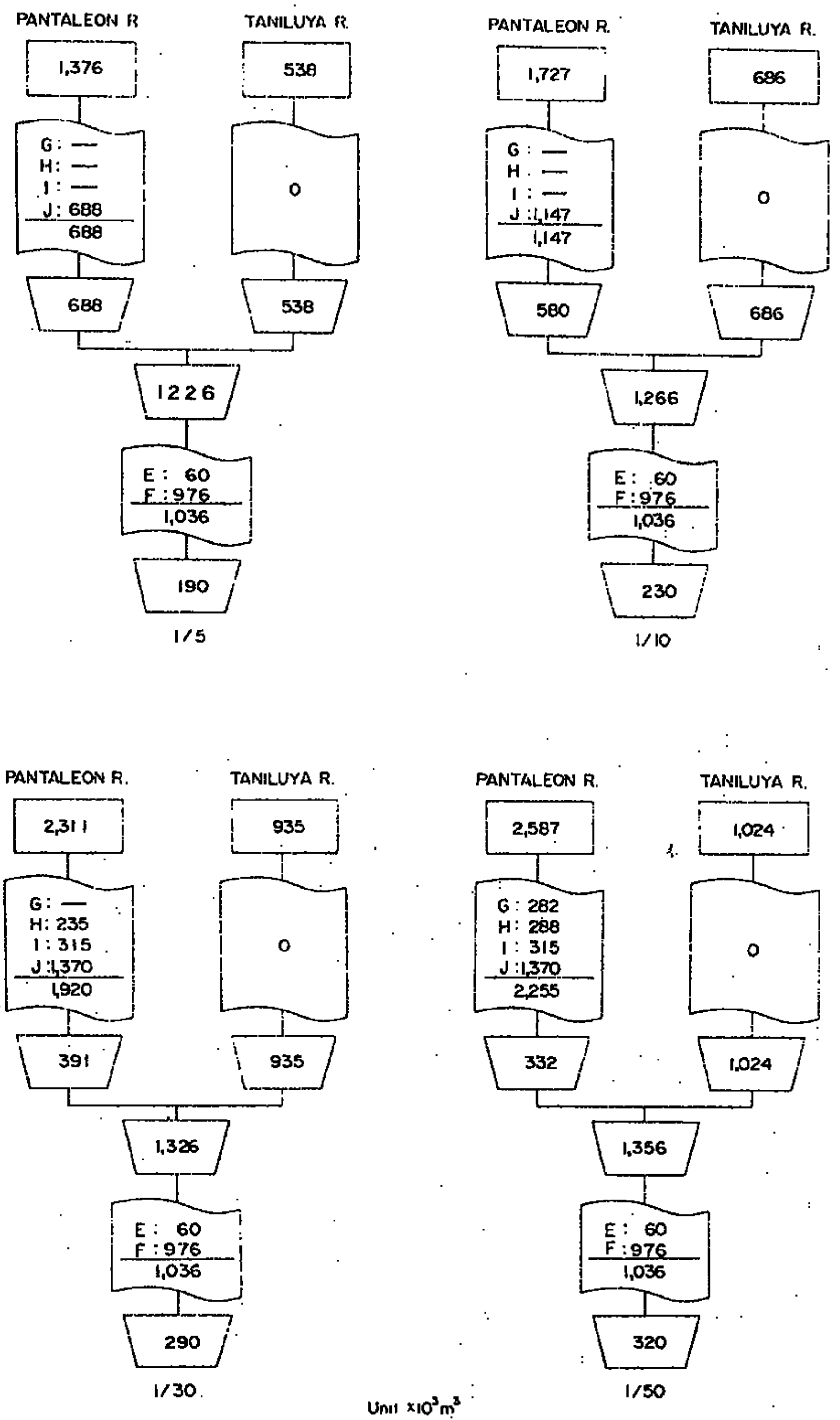
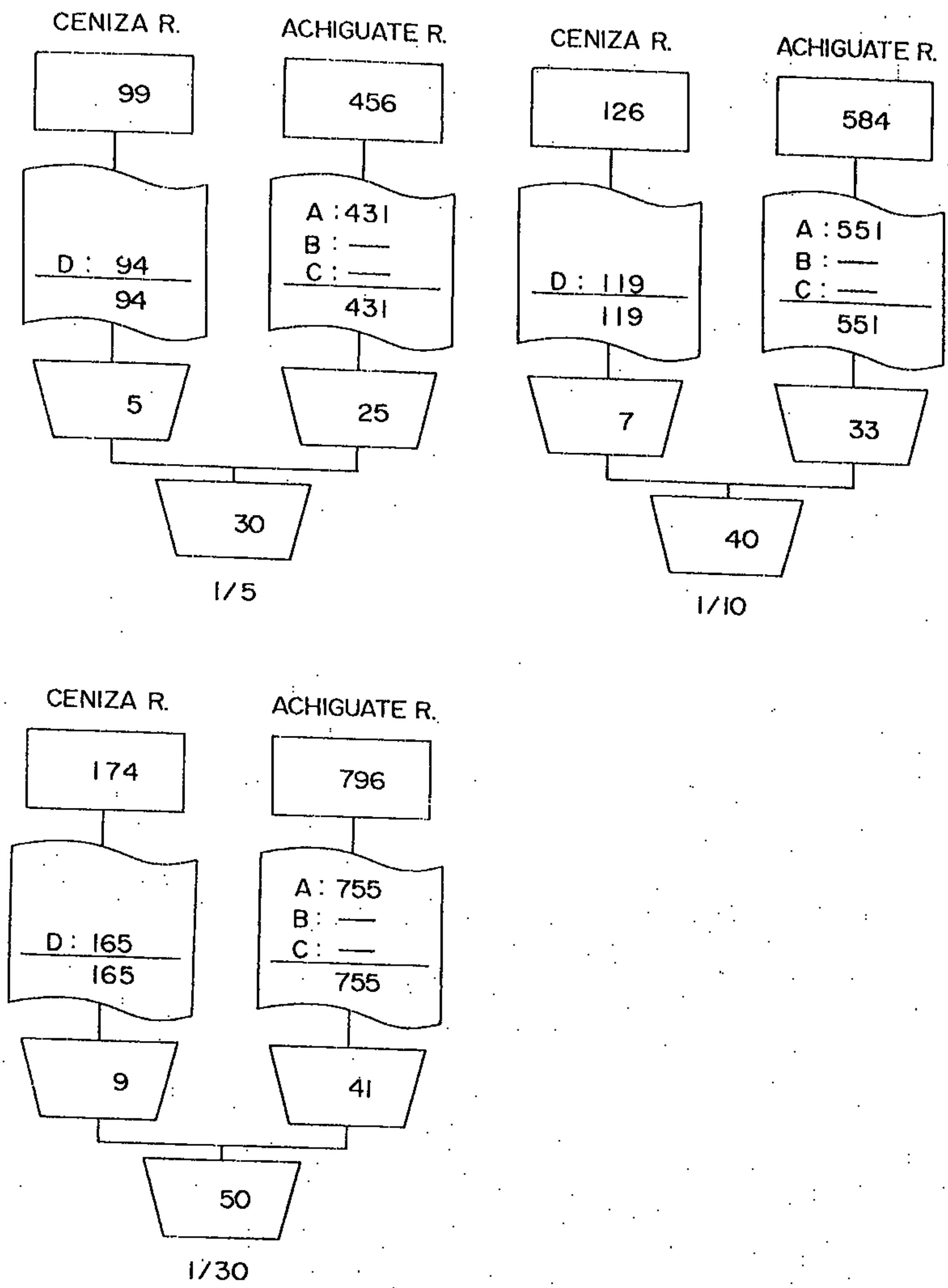


Fig. 3-9 (2/2) DISTRIBUTION OF SEDIMENT DISCHARGE IN THE LONG-TERM PLAN (PANTALEON RIVER)



Unit $\times 10^3 m^3$

Fig. 3-10 (1/2) DISTRIBUTION OF SEDIMENT DISCHARGE IN THE URGNET PLAN (ACHIGUATE RIVER)

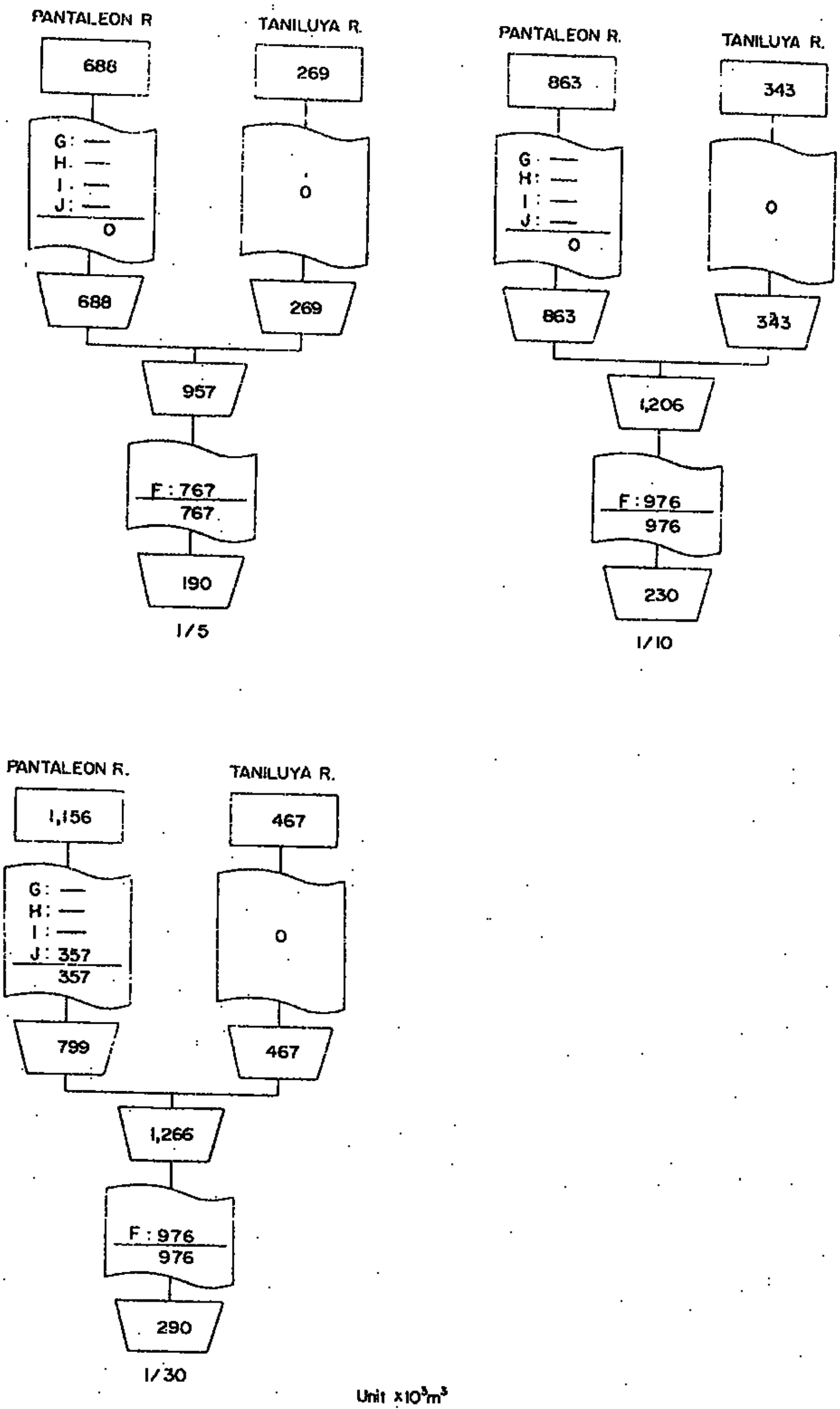


Fig. 3-10 (2/2) DISTRIBUTION OF SEDIMENT DISCHARGE IN THE URGENT PLAN (PANTALEON RIVER)

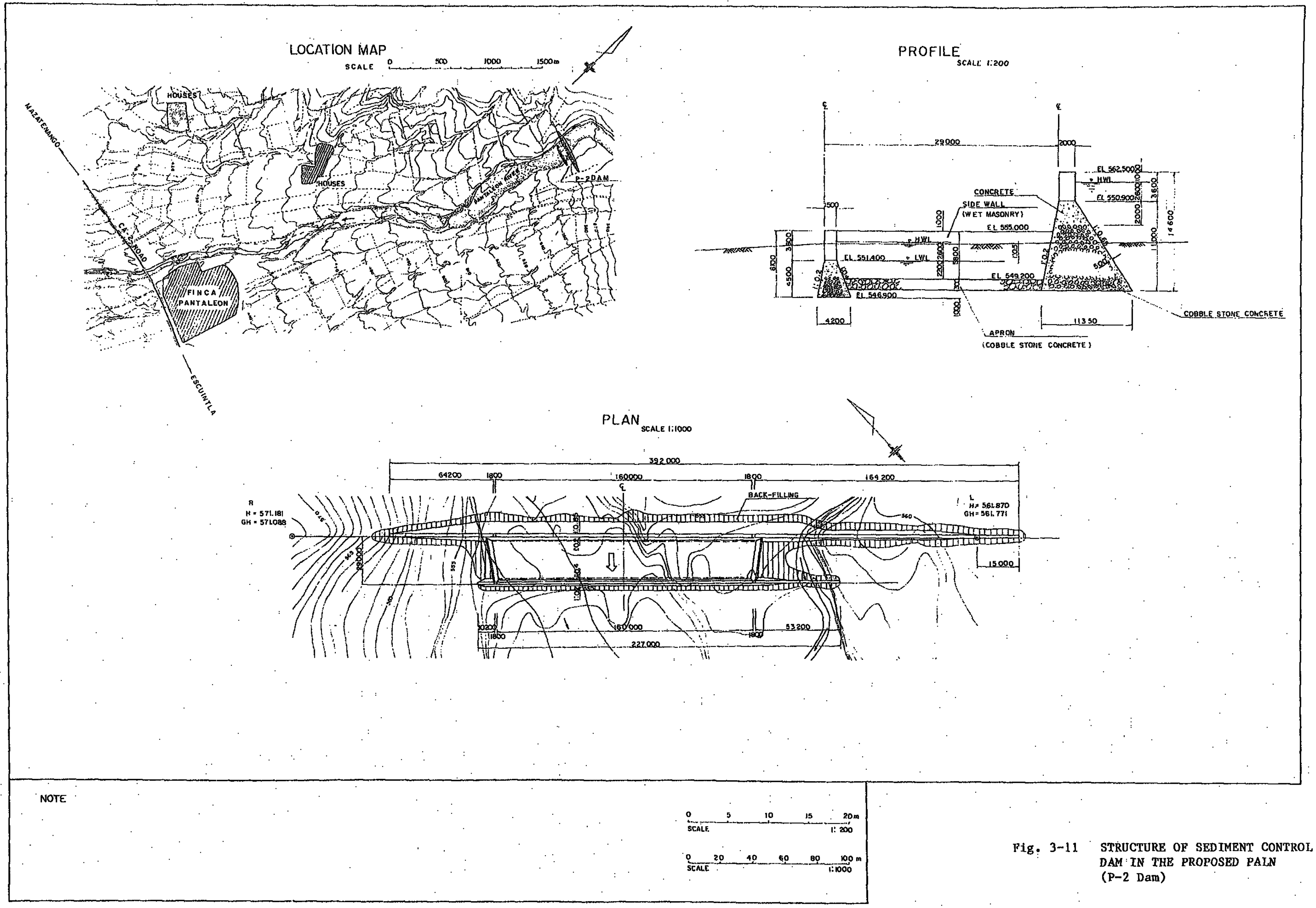
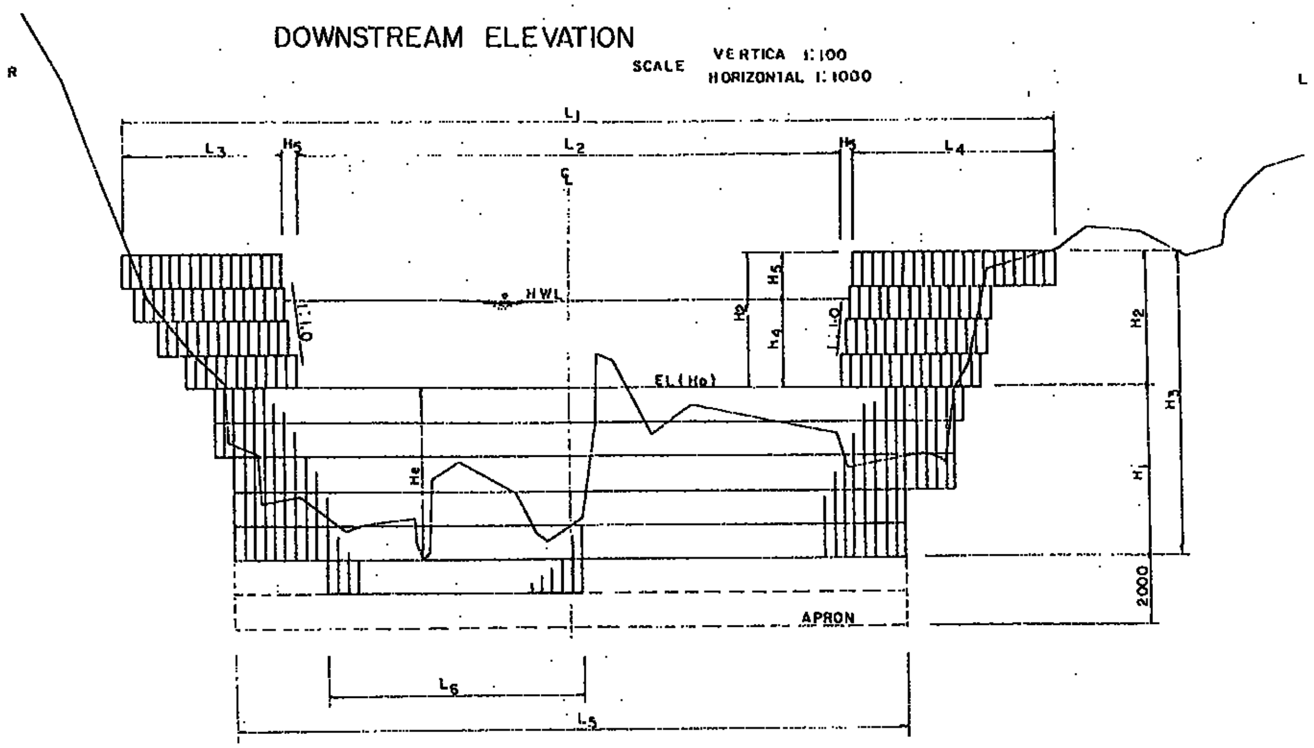
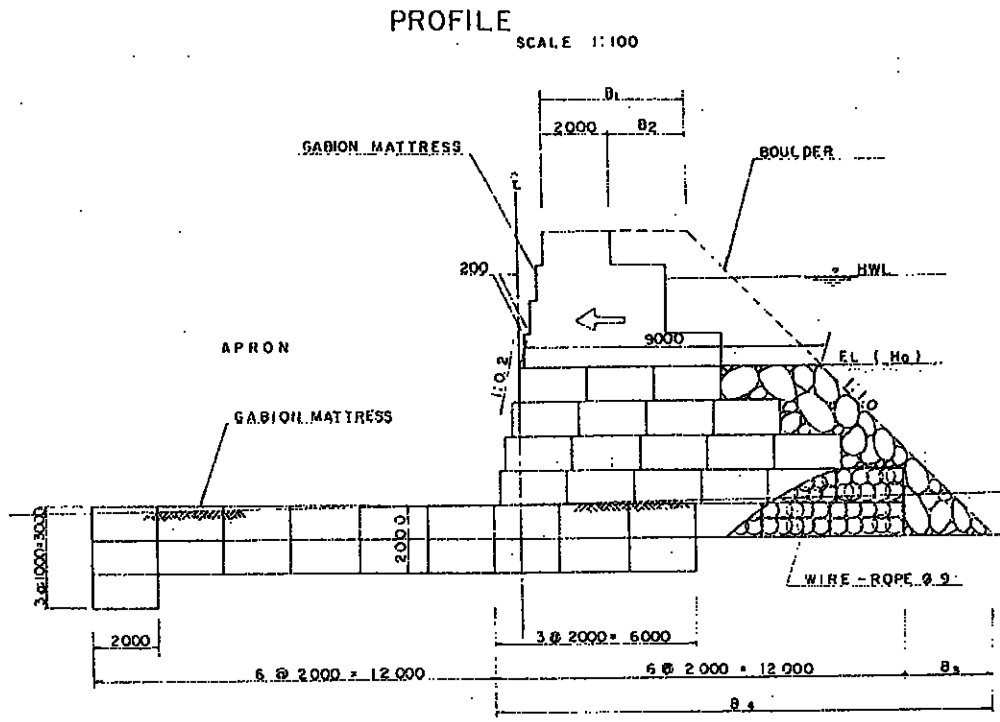
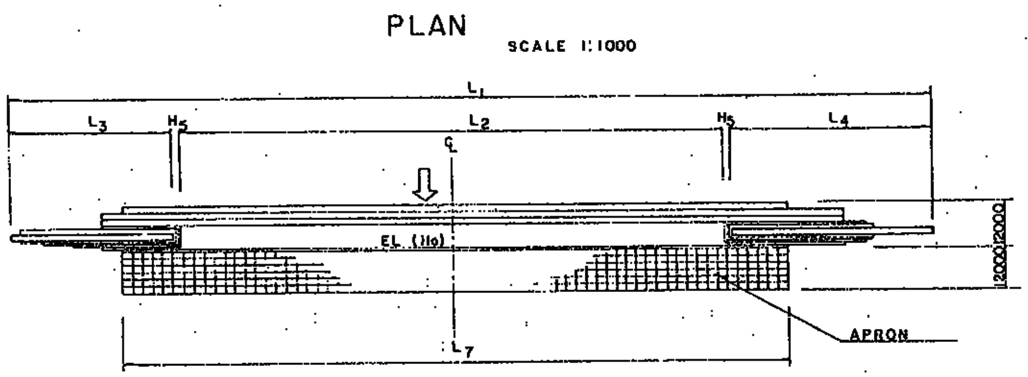


Fig. 3-11 STRUCTURE OF SEDIMENT CONTROL DAM IN THE PROPOSED PALN (P-2 Dam)







DIMENTIONS

RIVER NAME	DAM SITE	MAIN DAM LENGTH (m)						HEIGHT (m)							WIDTH (m)				APRON WIDTH (m)
		L_1	L_2	L_3	L_4	L_5	L_6	H_6	H_1	H_2	H_3	H_4	H_5	H_0	B_1	B_2	B_3	B_4	L_7
ACHIGUATE	A-1	404	180	114	102	360	111	5	5	4	9	2.4	1.6	156.8	4.2	2.2	2.6	14.6	300
	A-1'	401	180	99	114	198	75	3.5	4	4	8	2.3	1.7	213.5	4.2	2.2	1.8	13.8	249
	A-2	101	70	9	12	81	81	5	5	5	10	3.9	1.1	535	3	1	2.6	14.6	81
	C-1	424	220	87	111	330	90	4.5	5	3	8	2.1	0.9	154.6	5.4	3.4	2.6	14.6	330
PANTALEON	P-2	276	160	48	60	198	75	5	5	4	9	2.6	1.4	554.9	4.4	2.2	2.6	14.6	198
	P-2'	308	120	87	93	279	140	4	4	4	8	2.8	1.2	694.5	4.4	2.2	1.8	13.8	198
	P-3	167	120	18	21	132	132	5	5	4	9	2.8	1.2	795	4.4	2.2	2.6	14.6	150
	P-4	170	120	24	18	141	141	5	5	4	9	2.8	1.2	815	4.4	2.2	2.6	14.6	141
	P-5	158	120	12	18	141	81	5	5	4	9	2.8	1.2	855	4.4	2.2	2.6	14.6	141

NOTE

0 2 4 6 8 10m SCALE 1:100

0 20 40 60 80 100m SCALE 1:1000

Fig. 3-12 STRUCTURE OF SEDIMENT CONTROL DAM IN THE ALTERNATIVE PLAN

4. RIVER IMPROVEMENT PLAN

RIVER IMPROVEMENT PLAN

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1. GENERAL

The Study Area comprising the Achiguate and the Pantaleon river basins as identified through the comparative study on the flooding conditions of the rivers in Guatemala has long been suffering from serious sediment discharge and flood damages. To cope with this problem, long-term and urgent plans consisting of sediment and flood control works were formulated in this study.

In this River Improvement Plan sector report, the study results focusing on the flood control works are described to provide the supporting data for the study of the said plans.

In Section 2, the general feature and flood damage condition of the rivers in Guatemala are compiled as the supporting data for the identification of the significance of the Study Area. The present conditions of the Study Area is described in Section 3 based on the information obtained through the field reconnaissance. Topographic maps, aerophotographs and surveying results were also utilized to know the said condition.

Section 4 presents the basic concepts with regard to the flood control methods and the effects of flood control facilities. An optimum long-term river improvement plan is selected in Section 5 through the comparative study in due consideration of the aspects of economic viability and social requirements.

Section 6 gives the study results on the selection of the urgent proposed plan, together with the preliminary design for the required flood control facilities. An alternative plan for the urgent plan is also described in this section.

In this connection, the study results on the construction schedule and cost estimation for the urgent plan are referred to the sector on Construction Schedule and Cost Estimates.

2. RIVERS IN GUATEMALA

2.1 General Features

According to the map of basins in Guatemala issued in 1973, this country is broadly divided into 36 river basins: 18 basins for rivers flowing into the Pacific Ocean, 8 basins for rivers flowing into the Caribbean Sea and 10 basins for rivers flowing into the Gulf of Mexico. (Refer to Table 4-1.)

Among these basins, the largest is that of San Pedro River, a tributary of Usumacinta River, with a catchment of 14,335 km^2 and the smallest is that of Coatan River with 269 km^2. The longest river length is that of Salinas River of 400 km and the shortest is that of Lempa River of 15 km.

Horton's shape coefficient of these basins show that most of them are formed into relatively long and slender rectangles. The river gradients, which were estimated by dividing the difference of the altitudes at both terminals of a river by the river length, shows that most rivers in this country have steep slopes.

Achiguate and Pantaleon rivers belong to the medium range of the above features.

2.2 Flood Damage

Frequency of Flood Damage

Since the data obtained on flood damage were only the information through the interviews with the inhabitants and the past issues of newspapers, the flooding conditions in this country can hardly be known in detail. With such a limited data, however, the following conditions can be seen.

Among the aforementioned river basins, 15 basins were reported to have frequently suffered from flood damage as shown in Fig. 4-1. Achiguate River Basin ranks first in the order of frequency and Motagua, Samala, Coyolate, Maria Linda and Suchiate river basins follow with the frequency of from every 3 years to every 10 years. The frequency of flood damage reaches 10 years on the average.

Flood Damage Conditions

The reported damages to the said river basins are broadly classified into damages to community, transportation system and cultivated land.

As for the damage to community, the following river basins have recently suffered from serious damage.

(1) Samala River Basin

Samala River Basin has 1,499 km^2 of catchment area and 120 km of river length. In the upper reaches of the basin exists an active volcano, the Santiaguito Volcano, which has repeatedly erupted since 1902. During the flood of June 26, 1983 which occurred after the latest eruption, the deposited ejecta on the volcanic piedmont area flowed down into Nima II River, one of the tributaries of Samala River, and directly hit the residential area of El Palmar in the basin. (Refer to Fig. 4-2.)

In this flood, an area of about 15 km^2 was damaged by the debris flow and 150 houses were either partially or totally destroyed. As a result, 6,000 people corresponding to 35% of the total population of El Palmar were evacuated. Besides, damages on croplands of maize and beans due to the sediment which piled up to 8.0 m in the lower reaches of Samala River were also reported.

(2) Urayala River Basin

Urayala River, which is one of the tributaries of the Paso Hondo River, flows down along the border of Chiquimulilla, one of the municipalities in Santa Rosa Department in the south coastal region. This municipality suffered from severe damage and 280 inhabitants died on September 12, 1982 due to the debris flow caused by Hurricane Paul. Debris flow on Urayala River had occurred several times in the past. (Refer to Fig. 4-3.)

(3) Achiguate River Basin

In Achiguate River Basin which is a part of the Study Area, floods have frequently and seriously inflicted damage on the riparian area, especially after the eruption of Fuego Volcano in 1971 when sediment discharge with a large amount of volcanic ejecta has raised riverbeds, resulting in the reduction of flow capacity. Serious damages occurred in 1969, 1971, 1974 and 1982 and some houses, farms, roads and bridges in the area have been washed away.

The flooding condition of these floods is described in detail in Subsection 3.3.

(4) Pantaleon River Basin

Pantaleon River, a tributary of Coyolate River, has frequently brought about the damages on the riparian area.

Serious damage was inflicted by the flood after the eruption of Fuego Volcano in 1971, depositing enormous debris over the watershed of Pantaleon River and on the river course, resulting in the reduction of flow capacity. The flood and debris flow hit and destroyed the CA-2 road bridge and inflicted damages on houses, farms and so on. (Refer to Subsection 3.3.)

As regards damages to the transportation system, the CA-2 road and the national railway have frequently suffered from flood damage as shown in Fig. 4-4. Damages to cultivated lands have been reported in most of the aforementioned river basins.

3. PRESENT CONDITION OF THE STUDY AREA

3.1 River Basin

Achiguate and Pantaleon river basins are approximately located at 13°50' to 14°40' north latitude and at 90°45' to 91°10' west longitude in the southern part of Guatemala. Most of the basins administratively belong to the Department of Escuintla. (Refer to Fig. 4-5.)

Achiguate River

Achiguate River originates in the active Fuego Volcano and has a catchment area of 1,080 km^2 in total, including tributaries.

The main stream of Achiguate River, however, has a catchment area of only 216 km^2 with a river length of 55 km, which is topographically divided into two portions: the upper mountainous area of 92 km^2 and the lower alluvial fan area of 124 km^2. The transition section of both areas is located at around 40 km of the river length from the river mouth.

The river flows down on the steep slope of the mountainous area with the gradient of 1:10 and pours into the North Pacific Ocean through the fan area with the gradient of 1:200 joining some tributaries.

The main tributaries are Guacalate River, Ceniza River and Mazate River. Among these tributaries, Guacalate River which has the largest catchment basin of 629 km^2 in the Achiguate River Basin originates in Mt. El Saco and flows down in a relatively flat valley in which some cities such as Chimaltenango, Antigua Guatemala, Ciudad Vieja, Escuintla and so on, are situated. It joins with Achiguate River in the alluvial fan area after flowing down the mountainous area with a gentle slope in the stretch of 33 km.

Ceniza and Mazate rivers have catchment basins of 113 km^2 and 36 km^2, respectively. Both rivers originate in Fuego Volcano and flow down on the steep slope of the mountainside with the gradient of 1:10 to join Achiguate River in the alluvial fan area. Topographical conditions of these two rivers are similar to that of Achiguate River.

In the mountainside upper reaches of these rivers, much volcanic debris had been deposited on which assorted trees have grown, exclusive of the upper reaches of Guacalate River in which land use has been developed.

Most of the alluvial fan area in the lower reaches is utilized for livestock farming and the cultivation of sugarcane, maize and cotton. Only a small portion of the coastal area still remains as a swampy area.

In the alluvial fan area exist relatively large cities such as Masagua, Siquinala, La Democracia, and San Jose, which has one of the big trading ports in Guatemala that is located on the left side of the Achiguate river mouth. As far as residential areas along the river course is concerned, the Study Area is dotted with some villages such as Finca La Trinidad and La Barrita which are densely populated.

Pantaleon River

Pantaleon River, the tributary of Cristobal River which joins Coyolate River, originates in Fuego Volcano, and the catchment