area and river length are 150 km^2 and 40 km, respectively. It runs down for some distance in the mountainside with the gradient of 1:10 and then pours into the Cristobal River, passing through the alluvial fan area in the stretch of 20 km with the gradient of 1:100. It also runs down in the south drawing a gentle curve, and the shape of the basin may be compared to a long and slender rectangle.

The main tributaries of Pantaleon River include Taniluya River, Gobernador River and so on. Among these tributaries, Taniluya River with a catchment basin of 13 km^2 and river gradient of 1:10 has brought a large volume of sediment to Pantaleon River.

The upper reaches of Pantaleon River is also covered with volcanic ejecta with assorted trees, and the lower reaches have also been relatively developed for cultivation of sugar-cane, maize and cotton. Only a small area is utilized for livestock farming.

A few small villages are located along the river course and a large city, Santa Lucia, is situated on the right side of the middle reaches.

3.2 River Features

Transition of the River Course

Fig. 4-6 shows the transition of the Achiguate and the Pantaleon river courses, which were derived from the aerophotographs in 1954, 1958, 1967 and 1983 and the topographic map editted in 1960.

According to the figures, the rivers have changed their courses in a wide range. Achiguate River shifted its main course at the stretch of 16.0 km from the estuary from year to year. The maximum range of the transition at the stretch is estimated at approximately 2.0 km. The stretches of the upper reaches from 16.0 km to the road bridge had been comparatively stable before the 1960's although the course has now become unstable due to the increase in sediment load after the eruption of Fuego Volcano in 1971. The river course in the upper reaches from the road bridge forms a steep valley; hence, has been stable.

The main course of Pantaleon River has also shifted in every flood at the stretch from the confluence point to the CA-2 road bridge. The maximum range of the transition at the stretch is estimated at approximately 200 m. According to the interview result, the railway station which had once been located at the section of the existing bridge was relocated to the present place because of the transition of the river course.

Besides, the transition of the Achiguate river mouth shows that the coastline around the estuary has been extending towards offshore. During the period from 1954 to 1983, the stretch extended to about 150 m. The river mouth is sometimes closed by the sand transported by the current, wave, tide and so on, which causes inundation problem to the area around the estuary. To cope with this situation, inhabitants around the area excavate the sand closing the river mouth once a year, so that the river mouth will remain open during the flood season.

Riverbed Fluctuation

The data obtained on riverbed fluctuation are only as follows: (1) drawing of the road bridges and railway bridges, (2) aerophotographs in 1954, 1958, 1967 and 1983, and (3) the result of interviews in the field.

Although the data are not sufficient to precisely investigate riverbed fluctuations, they show that the riverbed at the railway bridge on Achiguate River had not remarkably changed during the period from 1895 to 1969, and the river had kept a narrow but deep course. The riverbed, however, has risen to the present level due to the abundant sediment load by the sediment discharge since the eruption of Fuego Volcano in 1971. (Refer to Fig. 4-7.)

The bank height in the downstream at about 20 km from the estuary is only 0.3 to 0.5 m above the riverbed; once, it had been more than 2.0 m. Furthermore, compared to the ground height at either side of the river, the riverbed is slightly higher because of sedimentation. Some sections of the river which had been buried by sediment form a portion of the cultivated land or are utilized for livestock farming.

In Pantaleon River, similar conditions were found through the field investigation at the other bridge sites, although there are a few data available to describe them in detail. Judging from the ruins of the bridge at the section of 4.0 km of Pantaleon River, it can be assumed that the riverbed has remarkably risen, because the existing riverbed almost reaches the height of the broken abutment of the bridge. The riverbed height downstream of 4.0 km is slightly higher than the ground height due to sedimentation as well as the condition of Achiguate River.

Besides the above, bank erosion condition of the rivers can be seen in some places as emphasized with the cross section at the CA-2 road of Pantaleon River shown in Fig. 4-8.

Flow Capacity

Although it is difficult to precisely compute the flow capacities because of the severe transition of the cross sections, the bankful flow capacities may be given by the uniform flow calculation method as expressed in the following equation.

$$Q = 1/N \cdot R^{2/3} \cdot I^{1/2} \cdot A \quad (R = H) \quad \ldots\ldots \quad \text{(Eq. 4-1)}$$

where,

- Q: Discharge (m^3/s)
- N: Roughness coefficient (m.s)
- R: Hydraulic radius (m); (= H: water depth)
- I: Energy slope (= riverbed gradient)
- A: Discharge area (m^2)

In this equation, the values between 0.035 and 0.050 are applied to the roughness coefficient "N" judging from the riverbed condition, and cross sectional and longitudinal survey results in this study period were used for the estimation of riverbed gradient and discharge area.

Fig. 4-9 shows the flow capacity of each section along the Achiguate and the Pantaleon river courses, together with the longitudinal profile, river width and so on. According to the results, the flow capacity of these rivers are very poor in consideration of their catchment areas, and these rivers can have only the low water discharge flow down safely.

The sections with very poor flow capacities are at 30.0 km and 16.0 km in Achiguate River with flow capacities of only 50 m^3/s and 25 m^3/s, respectively. As for Pantaleon River, the section was at 16.0 km with a flow capacity of 10 m^3/s.

Sediment Transport Capacity

As in the data on flow capacity, there were a few data for the estimation of sediment transport capacity aside from the grain sizes of the riverbed materials and their specific gravity obtained in this study.

The estimation of sediment transport capacity is sometimes made by using the experimental equations such as Brown's Formula, Sato, Ashida and Kikukawa Formula, Einsteins Formula and so on.

Among some equations for the estimation of sediment discharges, the Brown's Formula, as expressed in the following equation in which suspended load is considered, is used in this study.

$$Q_B = q^B \times B \quad \text{(Eq. 4-2)}$$

$$q^B = 10 \times \frac{U^{*2}}{(a/s - 1.0)\, gd} \quad \text{(Eq. 4-3)}$$

$$U^* = \sqrt{gHI} \quad \text{(Eq. 4-4)}$$

where,

- Q_B: Volume of sediment (m^3/s)
- B : River width (m)
- q^B: Volume of sediment in unit width of river ($m^3/s \cdot m$)
- U*: Friction velocity (m/s)
- d : Mean diameter of bed material (m)

a : Density of bed materials (g/cm^3)
s : Density of water (g/cm^3)
g : Gravitational acceleration (m/s^2)
H : Water Depth (m)
I : Energy slope of water flow (= riverbed gradient)

In this equation, the mean diameter of bed materials which is obtained by sieving test for the samples taken from the river are applied (refer to Fig. 4-10). As to the other hydraulic elements such as B, H and I, the calculation results on flow capacity are given.

Fig. 4-10 shows the obtained sediment transport capacity in case that bankful discharge is applied.

As a result, the sections with poor sediment transport capacity were detected at 30.0 km and 16.0 km in Achiguate River with sediment discharge capacities of only 0.2 m^3/s.

As for Pantaleon River, such sections were observed at 16.0 km with a capacity of 2.7 m^3/s and at 4K with a capacity of 0.9 m^3/s.

River Utilization

Since there is no organization which may administer and hence hold the record on river water utilization, the study on the present river water utilization was carried out through interviews with the residents.

River water in both the Achiguate and the Pantaleon are being utilized only for the drinking water of livestocks, watering of some fruit trees and washing clothes, while people obtain drinking water from shallow wells.

Besides, inhabitants along the river course are engaged in small fishery such as catching fish and fresh water shrimps for local consumption only. Navigation is limited only in the canal connecting Achiguate River to the sea passing by San Jose City for the transport of local products by some small wooden boats.

Riparian Facilities

There are few riparian facilities on the rivers, reflecting the fact of minimal utilization of river water.

Intake facilities were constructed in the 1960's to take in river water for use in livestock farming and the cultivation of fruit trees. Due to the rise of the riverbeds, however, the efficiency of the intake systems had been reduced and now, the intake facilities are not effectively operated for the purpose.

Gabion mattresses which are used as the only facility for flood protection in this area have come into use since the 1960's to protect bridges and/or some areas from flood damage. Some of the gabion mattresses have had effects on flood damage protection but the others have not been installed effectively and some of them were washed out by floods.

The local ring levees had been privately constructed to protect livestock farms from flood waters.

3.3 Flooding Condition and Potential Damage Area/Trouble Spot

3.3.1 Flooding Condition

Achiguate River

In the Achiguate river basin, the flooding conditions of the 1969 flood and the 1982 flood such as inundation area, flood duration, etc., were roughly known through the interviews with the inhabitants (refer to Fig. 4-11). Rough calculations were also made to know the hydrological conditions such as overtopped discharge and the water depth in the inundation area.

The inundation in both floods lasted for about one week and the flooding conditions are described as follows:

(1) 1969 Flood

In the 1969 flood, the flood discharge of 1,200 m^3/s observed at the national railway bridge point destroyed two bridges; the CA-2 road bridge and the national railway bridge. The discharge of 1,200 m^3/s flowing down and inundating the area along the river course was increased to 1,700 m^3/s by the discharge from Guacalate River.

Out of the total discharge of 1,700 m^3/s, 400 m^3/s overtopped at the section of 30 km from the estuary and flowed into the neighboring rivers of Naranjo and Suquiate in a width of 2,000 m and with a depth of 0.4 m.

The discharge of 600 m^3/s out of the remaining flood discharge of 1,300 m^3/s in Achiguate River overtopped at 20.0 km and spread over the area on the left bank side in a width of 2,800 m and with a depth of 0.5 m. Then, the overtopped discharge of 600 m^3/s reached the coastal plain situated between San Jose and the Achiguate river mouth in a width of 7,000 m and with a depth of 0.3 m. Most of the flood discharge inflicting the damages to the coastal area flowed into the sea through the Achiguate river mouth.

(2) 1982 Flood

In the 1982 flood, the discharge passed through the road bridge and the railway bridge sections without inflicting serious damage, though the flow capacity of the railway bridge section was too small compared to the flood discharge. The discharge was presumably increased after joining with the discharge from Guacalate River. It then flowed down to 30.0 km, inundating the area along the river course.

At 30.0 km, the river water overtopped and flowed into the Naranjo River and the Suquiate River inflicting damages all over the area. The inundated area was about 2,000 m wide with a water depth of 0.5 m.

The remaining flood discharge in Achiguate River overtopped at 20.0 km and spread over the area on the left bank side with the width of 2,500 m and the depth of 0.4 m. Ultimately, the overtopped discharge reached the coastal plain in a width of 7,000 m and a water depth of 0.2 m.

As in the 1969 flood, most of the floodwaters inflicting the damages to the coastal area was drained into the sea through the Achiguate river mouth.

Pantaleon River

Since the Pantaleon river basin is sparsely populated especially along the river course, the information obtained on flooding condition was very little compared to that in the Achiguate river basin. The flooding condition was then studied on the basis of hydraulic analyses by using topographic maps, aerophotographs, surveying results, etc., to augment the limited information through the interviews.

In this basin, the big floods occurred in 1969, 1971 and 1974. Inundation in all these floods lasted for more than 3 days and their flooding conditions were presumed to be as follows:

In the 1969 flood, which was reported to have the biggest discharge among the said floods, the discharge of 1,000 m^3/s flowed down to Cristobal River causing inundation along the river course, though damage was not reported in detail.

In the 1971 flood, since the river flow capacity had been remarkably reduced because of the tremendous supply of sediment caused by the eruption of Fuego Volcano, the CA-2 road bridge and the railway bridge over the Pantaleon River were washed away.

As for the 1974 flood, the flood discharge overtopped at the section of 16 km from the confluence with Cristobal River and flowed into the neighboring Pataya River where the road bridge was demolished by the diverted flood discharge. Furthermore, the remaining discharge in the river was diverted at 6.0 km to Jute River inflicting damage on some cultivated lands. It also destroyed the road bridge crossing Pantaleon River at 4.0 km.

3.3.2 Potential Damage Area/Trouble Spot

Judging from the flooding conditions described in the foregoing, the potential damage areas and/or trouble spots in the Achiguate and the Pantaleon river basins are summarized as below, and their locations are plotted in Fig. 4-12.

(1) Achiguate River

- Loss of bridges of the vital road and the railway affected by floods.

- Inundation along the Achiguate River main course for the whole stretch from the river mouth to the bridge point due to the limited flow capacity attributable to the rising of riverbeds caused by sedimentation.

- Inundation along the other river situated close to Achiguate River caused by the overtopping flows from the river at the section between 28.0 km and 30.0 km.

- Inundation in the downstream area from 20.0 km caused by the overtopping flow at the said point.

- Inundation in the estuary due to river mouth closure caused by sedimentation.

(2) Pantaleon River

- Loss of bridges of the vital road and the railway affected by floods.

- Inundation along the Pantaleon River main course due to the limited flow capacity attributable to the rising of riverbed caused by sedimentation.

- Inundation along the other rivers situated close to Pantaleon River caused by overtopping flows from the river at the points between 14.0 km and 18.0 km and between 6.0 km and 8.0 km.

4. BASIC CONCEPT FOR STUDY

4.1 Flood Control Method

4.1.1 Selection of Method

The facilities for the flood control plan are broadly divided into two categories according to objective; sediment control facilities and flood control facilities.

The study on the suitable flood control facilities is made in this sector, while the study on sediment control facilities is in the sector of Sediment Control Plan.

The following works are commonly employed as flood control methods:1/

(1) River channel improvement;
(2) Ring levee;
(3) Floodway;
(4) Impounding reservoir; and
(5) Retarding basin.

The basic idea for the works under items (1), (2) and (3) is to have the flood discharge flow down safely so as to mitigate damage to the flooding area through the construction of embankments and/or excavation of the river channel.

On the other hand, the basic idea for the works under (4) and (5) is to regulate the peak flood discharge to a safe level for the specific area by the storage function of a reservoir.

Among the above methods, the improvement of the existing river channel and the provision of ring levees are considered to be the methods applicable for this project judging from the ineffectiveness of the other methods as described hereunder.

The present river course, when simplified, forms a right angle to the ocean where it pours. Construction of floodways will not be an effective shortcut under such circumstance.

The Study Area, which is dominated by hillside slopes, is devoid of appropriate places for an impounding reservoir. An impounding reservoir, even if installed, will be made ineffective to heavy sediment output.

Flood control by retarding basin will be very difficult where the river has a steep gradient.

In this connection, the methods by training levee, channel works and groundsills, which were suggested as suitable methods in the sector of Sediment Control Plan, are included in the river channel improvement.

4.1.2 Principle for River Improvement

<u>River Channel</u>

A river channel is principally featured by the following factors; location and extent, alignment, longitudinal profile and cross section.

In this study, the foregoing factors were designed on the follwing concepts:

1/ Afforestation in the upper reaches, though effective for the control of sediment and flood runoff and desirable to be executed as a matter of principle, has not been applied to this project, because it will take around 20 to 30 years until the storage function of afforestation is assured.

(1) Location and Extent

The location and extent are in general determined by the location and value of assets to be protected in the floodplain.

(2) Alignment

New alignment basically follows the present river course since the river channels lack heavy meandering so that they may have the runoff discharge flow down smoothly. However, some stretches will be modified by smooth curves to drain the discharge safely.

The river width will be taken to the technically maximum extent, unless the existing riparian facilities hinder the extension of the river width, since the land along the river courses can be acquired easily at a low cost.

In this connection, the following equation for the relation between the river width and the discharge which is generally employed for the rivers with steep gradients in Japan is given.

$$B = 3.5 \sim 7.0 \times Q^{1/2} \quad \text{............ (Eq. 4.5)}$$

where,

B: River width (m)
Q: Design dsicharge (m^3/s)

(3) Longitudinal Profile

The longitudinal profile is so designed to assure the stability of the river channel by fixing the riverbed gradient to become steeper gradually according to the distance from the estuary. The design high water level should be kept as low as possible to avoid the enhancement of flood damage potential in case of overtopping.

In this connection, the design high water level is set below the recorded maximum flood water stage for the stretch whose gradient is relatively gentle. On the other hand, the design high water level is set below the ground height for the stretch whose gradient is very steep.

(4) Cross Section

Excavated channels, though very costly, are superior to any other mode of channel in the standpoint of safety against bank erosion or overtopping water.

In most cases, however, embankment works together with excavation channel works are applied for the improvement of river channels in case of a low velocity of water flow, because it costs less than the channel with only excavation works. Two kinds of cross section can be applied to this type of river channel; compound cross section and single cross section. Compound cross section is superior to single cross section in the point of stabilization of the river course.

The compound cross section will be applied, therefore, to the stretches with a low flow velocity and the low water channel will be planned to have a flow capacity corresponding to a 1.5-year return period flood which is commonly employed in the design of low water channels.

River channel improvement works by excavation should be provided for the upstream of the Achiguate and the Pantaleon where river water flows down at a high velocity because of a steep riverbed slope.

Riparian Facilities

Riparian facilities required for the river channel improvement plan consists of revetment, groundsill, groyne, drainage ditch and sluice, which will be installed in the following places:

(1) Revetment

Revetment having the function of bank protection is installed in the stretches subject to severe bank erosion.

(2) Groundsill

Groundsill whose function is to keep the stability of the riverbed by providing protection against scouring is provided in the stretches with a steep riverbed gradient.

(3) Groyne

The function of a groyne is to prevent scouring at the foot of the side slope by slowing down flow velocity and by accelerating sedimentation. In accordance with this purpose, groyne is provided in sections where severe erosion of the bank foot is expected.

(4) Drainage Ditch

Drainage ditch to be provided at the landside along the dike is given two functions to fulfill; one is to drain the water seeping through the dike and the other is to drain the runoff water from its landside area.

In the plan, drainage ditch is provided to the whole stretch along the dike.

(5) Sluice

Sluice is provided mainly to drain the discharge of the tributaries, as well as to take in irrigation water. In the plan, sluice is installed at the section from which irrigation water is taken in and at which the drainage canal is confluent.

River Mouth Treatment

Countermeasures against closing of a river mouth can be proposed in two methods; construction of a jetty together with excavation works and provision of a pilot channel in the sand bar. The latter method is not appropriate for the treatment of the Achiguate river mouth for the reason that the areas neighboring to the river mouth would be in a dangerous situation when the river water level rises rapidly due to river improvement works in the upper stream.

Jetty together with excavation works, though much more costly, will be installed so as to maintain a stable river mouth.

4.2 Effect of Flood Control Facility

Principle of Evaluation

It is important to know the effects of the flood control facilities which are regarded as the project benefit.

The effects may be evaluated by the lowering of the inundation water stage due to the installation of facilities from the inundation water stage without facilities.

The inundation water stage with and without facilities can be known on the basis of the flooding conditions which are identified by using a simulation model.

Simulation Model

Only a few big floods as described in the previous section have been experienced in the Achiguate and the Pantaleon river basins in recent years. Consequently, data on flood and debris flows are insufficient in quantity to assume the inundation water stage of floods of various scales for the estimation of annual sediment and flood damages. Therefore, a simulation model for sediment discharge and flood needs to be prepared so that the inundation water stage of floods in a river may be known on various scales of flood through hydrologic analysis. (Refer to Fig. 4-13.)

(1) Achiguate River Basin

The simulation model in the Achiguate river basin was drawn based on the flood data in 1969 and in 1982 and the topographical conditions of the basins. The features of this model are described hereunder.

(a) Since the section of the CA-2 road bridge has sufficient flow capacity of more than the probable discharge of 50-year return period corresponding to 1,350 m^3/s, it is assumed in the model that the river water is confined in the river channel.

As for the sediment discharge, it is also confined in the river channel.

(b) In the river stretch from 42.0 km to 28.0 km, the flood discharge temporarily overflows both banks at flood time and flows down along the river course without spreading.

The average river width of 200 m in this stretch and 400 m of the inundation width of the overflow water are given for the estimation of inundation depth by uniform flow calculation.

As for the sediment discharge, sedimentation on the riverbed depends upon the balance between the inflow and the outflow sediment volumes that are subject to the tractive force in the stretch.

In the downstream below this stretch, the transportation of sediment is so small due to the poor transportation capacity so that the sediment behavior thereabout can be neglected.

(c) The overflowing river water at 28.0 km goes down into the Naranjo and the Suquiate rivers on the left. A width of 2,000 m is applied to the estimation of inundation water depth in the inundation area.

(d) In the river stretch from 28.0 km to 20.0 km, the behavior of river water is the same as in (b). In this section, 100 m is applied to the average river width and 200 m to the inundation width of the overflowing water.

(e) The overflowing river water below 20.0 km inundates the right and left banks, and the overflowing water on the left bank spreads down on the plain area between Achiguate River and San José. An inundation water width of 7,000 m is given in this stretch.

(f) All the inundation water drains into the sea through the river mouth of Achiguate River.

(2) Pantaleon River Basin

Big floods occurred in the Pantaleon river basin in 1969, 1971 and 1974. The simulation model for the Pantaleon river basin was prepared with reference to all the data of the aforementioned floods, and its features are as follows:

(a) In the upper stream of 16 km from the confluence point with Cristobal River, river water temporarily inundates both sides at flood time and flows down along the river course without spreading.

In this stretch, the average river width of 100 m and the inundation water depth of 200 m were employed for the model.

Sand deposition on the riverbed depends upon the balance between the inflow sand volume and the outflow sand volume in the same manner as that in Achiguate River.

(b) Flood discharge is diverted at 16.0 km to Pataya River and brings about inundation on both sides along the Pataya river course. The width of the inundation was set at 1,000 m.

(c) The overflow water at 6 km from the confluence flows into Jute River with inundation on both sides along the river. In this stretch, the inundation width of 500 m was employed.

(d) In the stretch from 6K to the confluence with Cristobal River, the behavior of river water is the same as (a), and the inundation width was set at 500 m.

4.3 Evaluation Method

The assets in the Study Area have been classified into four (4) categories and given priority according to their socio-economic significance in order to make a study on the stretch and size of flood control works.

The plan of protection of the assets designated as A were evaluated only from the viewpoint of social requirements. Evaluation of both social requirements and economic viability was made for assets designated as B. As for the assets recognized to be C and D, only economic viability was assessed.

The foregoing is summarized in the following table:

Priority	Assets	Evaluation Method
A	Community in a dangerous zone	Social requirements
B	Infrastructure and Urban Area	Social requirements and economic viability
C	Cultivated Lands	Economic viability
D	Grazing Areas	Economic viability

Assets designated as A, if any in the study area, are socially required to be protected by all means. Assets designated as B should also be protected even if they are judged to have a low economic viability. For the long-term plan, the recorded maximum flood should be the basis for the determination of the flood control facilities in a concept that the maximum damage in the past be at least released. On the other hand, social requirements in the urgent plan is defined as the enhancement of living conditions against floods up to the national average.

The economic evaluation for the selection of the optimum plan was made by means of calculating the Economic Internal Rate of Return. The standard of economic evaluation (percentage of EIRR) was set at 6.5% which is equivalent to the average of the interest rates being charged by financing agencies in Guatemala.

5. LONG-TERM PLAN

5.1 Planning Condition

In the previous section, river channel improvement together with ring levee is selected as the applicable method for the flood control in the Study Area.

To study the river channel improvement and ring levee in an appropriate scale, the following conditions are given:

Stretch for River Channel Improvement

The stretch for river channel improvement is sometimes decided on the basis of the present land use which shows the assets worthwhile to be protected.

From this viewpoint, the stretches of the river channel improvement were decided as follows:

Achiguate River	From 0.0 km to 43.8 km
Pantaleon River	From 0.0 km to 22.0 km

Hydrological Condition

(1) Flood Reference Point

To provide the fundamental factors necessary for the formulation of a flood control plan, hydrological conditions regarding the recorded past floods and design floods should be identified and analyzed at a certain point called flood reference point in a river channel.

For the Achiguate and the Pantaleon river basins, the reference points were selected in consideration of hydrological conditions, location of flood plains and especially, a conformity with the sediment control plan of the basins.

- Achiguate River Basin

Reference Point I : CA-2 road bridge
(catchment area: 205 km^2)

Reference Point II: Immediate downstream point of the confluence with Mazate River
(catchment area: 956 km^2)

- Pantaleon River Basin

Reference Point Immediate upstream point of the confluence with Cristobal River
(catchment area: 150 km^2)

The location of flood reference points is shown in Fig. 4-14.

(2) Probable Flood Discharge

In the sector of Hydrology, the probable discharges at the aforesaid reference points were calculated on various return periods and the scale of river channel improvement and ring levee were individually studied in each probable discharge.

The probable discharges on each river stretch are as follows (unit: m^3/s):

Return Period	Achiguate River			Pantaleon River
	39km-43.8km	33.24km-39km	0.0km-33.24km	0.0km-22km
50-year	1,350	1,500	1,900	1,250
30-year	1,200	1,350	1,700	1,150
20-year	1,100	1,250	1,550	1,050
10-year	950	1,050	1,250	900
5-year	750	850	1,000	750

(3) Flooding Condition

The inundation water stage which was used for the estimation of the effect of the flood control facilities was calculated on the same return period as that of the probable discharge.

In this connection, the calculation for the inundation water stage without the facilities was made by applying the probable discharge to the simulation model mentioned in Subsection 4.2. (Refer to Table 4-2.)

After the construction of the facilities, it is assumed that the target area is released from inundation.

(4) Economic Condition

In the sector of Project Economy, the future assets were firstly presumed and they are classified into the three (3) categories of B, C, and D. For the protection of each classified asset, the following stretches should be improved (refer to Fig. 4-15):

River	Asset	Improvement Stretch
Achiguate	B	0.0km-8km; 28km-30km and 39km-43km
	C	8km-16km and 30km-39km
	D	16km-28km
Pantaleon	B	18km-20km and 21km-21.5km
	C	6km-18km and 20km-21km
	D	0.0km-6km

5.2 Comparative Study

5.2.1 Study Cases

A study should be made on the selection of the target assets to be protected together with the selection of the suitable project scale.

Furthermore, a study for the selection of the suitable method should be made if the other methods except river channel improvement and ring levee can be applied.

From these viewpoints, the following cases are suggested:

River	Target Assets	Method	Return Period
Achiguate	B, C and D/1	River channel improvement	5, 10, 30 and 50-year
	B and C	River channel improvement	5, 10, 30 and 50-year
	B	River channel improvement/2; ring levee and raising of bridge	5, 10, 30 and 50-year
Pantaleon	B, C and D/1	River channel improvement	5, 10, 30 and 50-year
	B and C	River channel improvement	5, 10, 30 and 50-year
	B	River channel improvement/2	

/1 Channel improvement of the entire river course
/2 Channel improvement together with training levee

Among the above study cases, only river channel improvement is applied to the cases for the protection of the combination of assets B, C and D and assets B and C, while some other methods can be applied to the case for the protection of only assets B.

5.2.2 Study for Protection of Assets B, C and D

Since the stretch for the protection of assets B, C and D covers the whole stretch of the river, this plan is referred to as channel improvement of the entire river course.

The following river improvement works are proposed in accordance with the foregoing principle:

Achiguate River

(1) River Channel

(a) Alignment

New alignment of Achiguate River with a width of approximately 250 m which corresponds to the average width of the present river course is drawn in the stretch up to the confluence point with Guacalate River at 33.24 km from the river mouth.

The stretch between 33.24 km and 43.8 km which is the upper terminal point of the river channel improvement is drawn with a width of approximately 100 m which coincides with the possible maximum width for expansion to the length of the existing railway bridge.

This alignment is applied to the cases for every probable discharge. (Refer to Fig. 4-19.)

(b) Longitudinal Profile

The maximum excavation depth is set within 3.5 m and the maximum design high water level is below 2.0 m above the average ground height which coincides with the recorded maximum water stage. The height of the dike is designed below 3.0 m above the average ground height including 1.0 m freeboard.

The gradient of the riverbed gradually varies from 1:500 to 1:110 in proportion to the distance from the estuary, as shown in Fig. 4-16. In this case, the design high water level in the stretch up to 33.24 km is changed in accordance with the scale of the probable discharge.

On the other hand, the excavation depth in the stretch between 33.24 km and 43.8 km is changed due to the scale of the discharge.

(c) Cross Section

A compound cross section is applied to the stretch of the downstream from the confluence point at 33.24 km. The low water channel has a flow capacity of 450 m^3/s which coincides with the probable discharge of a 1.5-year return period flood.

All the gradient of slopes for high and low water channels are fixed at 1:2.

A single cross section is applied to the stretch of the upper stream from the same point. The slope gradient of channel is 1:2 in the stretch between 33.24 km and 39.6 km and 1:0.5 in the stretch from 39.6 km to 43.8 km. The standard cross section is shown in Fig. 4-17.

The flow capacity of these cross sections was calculated by using the uniform calculation method. A roughness coefficient of 0.035 which is generally employed for an improved channel with such riverbed gradient was applied to this calculation.

(2) Riparian Facilities

The riparian facilities required for the long-term plan consist of revetment, groundsill, groyne, drainage ditch and sluice. Revetment will be provided for both high and low water channels of the compound cross section in a total length of approximately 21.5 km.

Revetment in a total length of 21.12 km is provided to the channel of the single cross section and the height of the revetment is changed according to the adopted probable discharge.

Besides the 30 groundsills, 2 sections of groyne in a total length of 5,600 m, drainage ditch of 66.48 km, and 17 sluices will be installed in and along the river channel. They are fixed in number for every probable discharge.

(3) River Mouth Treatment

As the countermeasure against closing of a river mouth, construction of a jetty was selected in the previous section.

A jetty is generally designed in the stretch between the river mouth and the point where shallow water waves may be broken so that drift sand caused by broken wave may not enter the river mouth. The point can be obtained by the relation between the gradient of the seabed and the breaking depth of a shallow wave.

In this relation, the gradient of the seabed in the neighboring area was reported as 1:50 in the Feasibility

Report on the Guatemala Port Construction Project, December 1974, JICA. The breaking depth of the shallow wave was given by applying the height of a deep wave origin of the shallow wave, onto the experimental equation that was also presented in the same report.

In the present study, the same gradient and height of deep wave were employed. As a result, 280 m of jetty in the left bank is proposed against the drift sand by the wave from the southeast direction, while 380 m in the right bank is set against that by the wave from the southwest direction.

Pantaleon River

(1) River Channel

(a) Alignment

New alignment of Pantaleon River is proposed with a width of approximately 80 m which corresponds to the maximum width possible for expansion at the section of the railway bridge and the average width of the present river channel.

This alignment is applied to every probable discharge.

(b) Longitudinal Profile

The average excavation depth is set at less than 3.0 m and the design high water level is so designed to remain under the average ground height. The riverbed gradient gradually varies from 1:105 to 1:38 in proportion to the distance from the confluence point with Cristobal River (refer to Fig. 4-16).

In this connection, the excavation depth in this stretch is subject to change in accordance with the scale of the probable discharge.

(c) Cross Section

A single cross section is applied to the whole stretch, with a slope of 1:0.5. The standard cross section is presented in Fig. 4-17.

By using the uniform flow calculation method, it was confirmed that the cross section can have the probable discharge flow down safely. As in Achiguate River, a roughness coefficient of 0.035 was applied to the calculation.

(2) Riparian Facilities

Riparian facilities of revetment, groundsill and groyne will be provided for the Pantaleon river course. The whole river stretch of 22 km will be revetted, and 293 groundsills will be installed on the riverbed. These numbers of facilities were applied to every probable discharge.

5.2.3 Study for Protection of Assets B and C

Since the protection of assets B and C covers a long stretch of river course, it is most appropriate to implement the river channel improvement in the mode of partial improvements. In this respect, the works shall be as follows:

<u>Achiguate River</u>

(1) River Channel

In consonance with the planning condition as described in Subsection 5.1, Planning Condition, the target stretches for the protection of assets B and C are from 0.0 km to 16.0 km and from 28.0 km to 43.8 km.

In these stretches, new alignment will be drawn in the same manner as that of the channel improvement of the entire river course. Longitudinal profile and cross section were also designed in accordance with the study results of the channel improvement of the entire river course.

(2) Riparian Facilities

In accordance with the reduction of the stretch for river channel improvement, the number and lengths of required riparian facilities were also reduced as follows:

Total Length of Revetment (km)	:	33.12
Number of Groundsills	:	30
Section Groyne (section)	:	1
Total Length of Drainage Ditch (km)	:	42.48
Number of Sluice (nos.)	:	12

(3) River Mouth Treatment

As the countermeasure against the closing of the river mouth, a jetty was designed in the same manner as in the channel improvement of the entire river course.

<u>Pantaleon River</u>

(1) River Channel

In accordance with the planning condition as described in Subsection 5.1, the stretch from 6.0 km to 22.0 km was decided as the stretch for partial river channel improvement to protect assets B and C from flood damage.

The study results for the channel improvement of the entire river course were applied to the drawing of alignment and the design of longitudinal profile and cross section in this stretch.

(2) Riparian Facilities

In accordance with the reduction of the stretch for partial river channel improvement, the number and length of riparian facilities were also modified as follows:

Total Length of Revetment (km)	:	32.0
Number of Groundsills	:	241

5.2.4 Study for Protection of Asset B

The assets designated as B are summarized hereunder (refer to the sector of Project Economy):

River Basin	Target Assets
Achiguate	CA-2 road bridge and railway bridge; Urban Area named Finca La Trinidad (left side); and Urban Area named Finca La Barrita (right side)
Pantaleon	CA-2 road bridge and railway bridge

Possible Methods

In the previous study cases, the river channel improvement is superior to the other methods of flood control. However, as far as protection of asset B is concerned, there are several methods to release the above-mentioned assets from flood damage, as described hereunder.

(1) Achiguate River

(a) Road and Railway Bridges

Damage to the road bridge is mainly caused by severe bank erosion and/or riverbed scouring around the piers, while that of the railway bridge is due to the insufficient flow capacity of the stretch downstream of 41.7 km.

Judging from the above conditions of the bridges of the CA-2 road and the railway, three protection methods can be proposed as follows:

Method I-1	:	River channel improvement
Method I-2	:	River channel improvement together with training levee
Method I-3	:	Heightening of the railway bridge and protection works on the road bridge

Fig. 4-18 shows the location of the alternative works.

(b) Finca La Trinidad

The flood damage to this urban area is mainly caused by the overtopping floodwater in the stretch from 28.0 km to 30.0 km.

In this situation, the following methods are proposed for the protection of the area (refer to Fig. 4-18):

Method II-1 : River channel improvement

Method II-2 : Raising of CA-2 road

Method II-3 : Ring levee

(c) La Barrita

Flood damage to this urban area is mainly due to the insufficient flow capacity of the river channel in the stretch below 9.0 km.

Under this situation, the following two methods are suggested for the protection of the area (refer to Fig. 4-18):

Method III-1: River channel improvement

Method III-2: Ring levee with drainage facilities

(2) Pantaleon River

(a) Road and Railway Bridges

As in the Achiguate River, damage to the road bridge in Pantaleon River is mainly caused by severe bank erosion, while that of the railway bridge is due to insufficient flow capacity in the stretch below 19.0 km.

Judging from this condition, two methods are proposed as countermeasures as follows (refer to Fig. 4-18):

Method IV-1 : River channel improvement

Method IV-2 : River channel improvement together with training levee

Selection of Methods

To determine the most suitable method of protection for each asset among the aforementioned methods, rough calculations on the benefit and total cost based on a 30-year return period probable discharge were made. The Benefit-Cost (B/C) ratios obtained are tabulated in Table 4-3.

Based on the calculation results, the following methods are proposed:

(1) Achiguate River

(a) Protection of Road Bridge and Railway Bridge

Method I-1 is more recommendable than the other methods due to the following reasons:

- Method I-3 is more costly than the others, and the damage potential therearound will not be lowered due to no increment of flow capacity of the river.
- Training levee contained in Method I-2 will require a high replacement cost every 10 years because of its low durability, though initial investment for Method I-2 is limited to a small amount compared to Method I-1.

(b) Protection of Finca La Trinidad

Method II-1 can be recommended, although inferior to Method II-2 at the B/C ratio, on the ground that this method can equally protect the assets on either side of the river and thus makes no social problem derived from one-side protection that may be caused by the employment of Method II-2. Method II-3 is economically inferior to the other methods.

(c) Protection of La Barrita

The flow capacity of the lower channel is so small that the lower reaches are widely inundated during floodtime. Protection of this urban area by means of Method III-1 will be much more costly, because a long stretch of river channel will have to be improved. From the economic viewpoint, therefore, Method III-2 is more suitable than Method III-1 as shown in Table 4-3.

(2) Pantaleon River

(a) Protection of Road Bridge and Railway Bridge

Method IV-1 does not require so much construction cost as Method IV-2. Moreover, the training levee in Method IV-2 needs to be replaced at a high cost every 10 years. Method IV-1 is, therefore, employed for the protection of the road bridge and the railway bridge.

5.2.5 Selection of Optimum Plan

Principle of Selection of Optimum Plan

As mentioned in Subsection 4.3, the optimum plan will be selected in accordance with the evaluation method from the aspects of economic viability and social requirements.

In the selection of the optimum plan, the economic viability of the plans are firstly studied and then, the adequacy from the aspect of social requirement is confirmed.

Selection of Optimum Plan Based on Economic Viability

(1) Construction Cost

The total construction cost of each plan studied in the previous section were broadly estimated for the selection of the optimum plan based on mid-1984 prices.

The costs are summarized in Table 4-4. For the convenience of comparison among the study cases, the cost of sediment control facilities is included in these costs.

(2) Project Benefit

In this flood control project, benefits are given as the economic effect which is mainly estimated by the reduction in flood damage to the assets in the area. Since these benefits are presented in detail in the sector of Project Evaluation, only the results are summarized in Table 4-4.

(3) Economic Internal Rate of Return (EIRR)

EIRR of the plans were calculated by using the said costs and benefits on the assumption that the project life will be 30 years. The results are also included in Table 4-4.

Judging from the EIRR shown in Table 4-4, all the study cases for the protection of all the assets along the river course show too low economic viability and the study cases for the protection of assets B and C are also under similar conditions. Consequently, the plans may have little possibility for execution.

The economic viability of the cases for the protection of only asset B, likewise, show an EIRR slightly below the standard defined in Subsection 4.3.

It is, therefore, concluded that the optimum plan should not be selected on the basis of economic viability.

Selection of Optimum Plan Based on Social Requirement

Since all cases show a low economic viability, the selection of the optimum plan is made in accordance with the social requirements as described in Subsection 4.3.

In this context, the assets designated as B should be protected, in the optimum plan, from the damage caused by a flood of 30-year return period which corresponds to the recorded maximum flood.

5.3 Proposed Long-Term Plan

5.3.1 Design Discharge

The design scale for flood control was decided to be equivalent to the recorded maximum flood having a 30-year return period in both the Achiguate and the Pantaleon rivers.

The design flood discharges with 30-year return periods were determined as follows:

Flood Reference Point	Design Flood Discharge
Achiguate Reference Point I	1,200 m^3/s
Achiguate Reference Point II	1,700 m^3/s
Pantaleon Reference Point	1,150 m^3/s

5.3.2 Features of the Plan

Achiguate River

The flood control works for the Achiguate River consist of river channel improvement works in two stretches and a ring levee around the urban area of La Barrita. (Refer to Fig. 4-19.)

(1) CA-2 Road Bridge and Railway Bridge

The upper improvement stretch is 5.0 km long from 38.0 km to 43.0 km (the point of 180 m above the CA-2 road bridge) covering the road bridge and the railway bridge. This includes a transition section of 6.1 km in the lower stream. New alignment with a width of about 100 m has been arranged as smoothly as possible in line with the existing one.

The riverbed gradient is 1:110 in the stretch from 39.6 km to 43.0 km and the gradient of the transition section is 1:170. The design high water level is set at 2.45 m above the riverbed in the stretch. The depth of channel includes a freeboard of 1.0 m.

A single cross section with a bank gradient of 1:0.5 is applied to the whole stretch. The cross section of the transition portion is adjusted gradually to follow the present cross section from the standard design cross section.

The required riparian facilities are revetment and groundsills. Revetment will be provided on both sides of the channel slope for a total length of 2.3 km. Seventeen (17) groundsills with a breadth of approximately 100 m will be installed at intervals of 150 m.

(2) Finca La Trinidad

The improvement stretch extends for 6.0 km from 25.5 km to 31.5 km, including transition sections of 1.5 km in the upper stream and 2.5 km in the lower stream. New alignment with a width of 250 m will be drawn in a smooth line in accordance with the existing one.

The riverbed gradient is set at 1:300, and gradients of 1:250 and 1:340 are applied to the transition portions above and below the improvement stretch, respectively. The design high water level is fixed at 1.7 m above the ground height and a freeboard of 1.0 m is included in the height of the embankment.

A compound cross section with a bank gradient of 1:2 is applied to the whole stretch. The cross section of the transition portion is adjusted in the same manner as in the river improvement for the stretch from 38.0 km to 43.0 km.

(3) La Barrita

A ring levee will be constructed in a length of 5.0 km around the urban area of La Barrita.

The ring levee is designed with a bank gradient of 1:2 and revetment of 3.0 km long will be provided for the side facing the source of inundation water.

Drainage facilities are provided to drain the inland water of the area surrounded by the ring levee.

Pantaleon River

(1) CA-2 Road Bridge and Railway Bridge

The flood control works for Pantaleon River are composed of river channel improvement works, including revetment of the river channel in the vicinity of the CA-2 road bridge as shown in Fig. 4-20. The improvement stretch is 3.4 km starting from 18.0 km to 21.4 km. New alignment with a width of 80 m has been arranged in the same way as in Achiguate River.

The riverbed gradient is fixed at 1:38. The design high water level is set at 2.0 m above the riverbed and a freeboard of 1.0 m is considered in setting the bank height.

A single cross section with a bank gradient of 1:0.5 is applied to the whole stretch. The cross section of the transition portion is adjusted gradually to follow the present cross section.

The required riprarian facilities are revetment and groundsills. Revetment will be provided on both sides of the channel slope for a river stretch of 2.3 km. Forty-seven (47) groundsills with a breadth of approximately 80 m will be installed at intervals of 50 m.

5.4 Comprehensive Long-Term Plan

Concept of the Plan

In the preceding subsection, an optimum long-term plan was formulated in the mode of partial river improvement together with ring levee.

Since partial river improvement may cause adverse effects to the downstream of the improved section, it is necessary to complete the river improvement works covering the whole stretch of the river course. In other words, it is essential to protect comprehensively all the assets in the Study Area from the damage caused by a flood of 30-year return period, which plan may be termed as the comprehensive plan.

Features of the Plan

Since the comprehensive plan corresponds to the study case of protection for assets B, C and D, the same principle as applied to the study case is applicable to this plan. (Refer to Figs. 4-20 and 4-21.)

(1) Achiguate River

(a) River Channel

- Location and Extent

  River improvement works for Achiguate River cover all the stretch from the river mouth to 43.8 km.

- Alignment

  New alignment of Achiguate River with a width of approximately 250 m is drawn from the river mouth to the confluence point with Guacalate River at 33.24 km; thence, a width of approximately 100 m up to 43.8 km. (Refer to Fig. 4-20.)

- Longitudinal Profile

  The excavation depth is set within 3.5 m and the design high water level is designed below 2.0 m above the average ground height. The height of the dike is designed below 3.0 m above the ground height including a 1.0 m freeboard.

- Cross Section

  A compound cross section is applied to the downstream stretch from the confluence point at 33.24 km.

  A single cross section is applied to the stretch above the confluence point.

(b) Riparian Facilities

Revetment in a total length of approximately 22 km will be provided for both high and low water channels of the compound cross section. Likewise, revetment in a total length of 21.12 km is applied to the channel of the single cross section.

Aside from 30 groundsills, 2 sections of groyne in a total length of 5,600 m, drainage ditch of 66.48 m, and 17 sluices that will be installed in the ditch along the channel, will be provided.

(c) River Mouth Treatment

A jetty of 280 m long is proposed on the left bank against the drift sand by the wave from the southeast direction, while a jetty of 380 m is set on the right bank against the drift sand by the wave from the southwest direction.

(2) Pantaleon River

(a) River Channel

- Location and Extent

  River improvement works for Pantaleon River cover all the stretch from 0.0 km to 22.0 km.

- Alignment

  New alignment of Pantaleon River is proposed with the width of approximately 80 m.

- Longitudinal Profile

  The average excavation depth is set at less than 3.5 m, and the design high water level is so designed as to remain under the average ground height.

- Cross Section

  A single cross section is applied to the whole stretch.

(b) Riparian Facilities

Revetment, groundsills and groyne will be provided for Pantaleon River. The whole river stretch of 22 km will be revetted, and 293 groundsills will be installed.

Justification of the Plan

The comprehensive plan, in spite of its being the best from the technical point of view, has a very low economic viability and needs an enormous fund for its implementation. Accordingly, this plan can be hardly considered to be practicable at present.

(1) Construction Cost

The total construction cost required for the comprehensive plan, including sediment control works, is estimated to be as much as US$192 million which is broken down as follows:

River Basin	Sediment Control Works ($US\$10^6$)	Flood Control Works ($US\$10^6$)	Total Cost ($US\$10^6$)
Achiguate	11	113	124
Pantaleon	16	52	68
Total	27	165	192

(2) Economic Viability

The average annual benefit that will accrue after completion of the plan is estimated at US$8.6 million.

The Economic Internal Rate of Return (EIRR) is calculated at 2%, based on the disbursement schedule with a 10-year construction period.

6. URGENT PLAN

6.1 Planning Conditions and Principle

6.1.1 Planning Conditions

Target Assets

The long-term flood control plan has been formulated to protect the assets in the Study Area which were recognized to be socially important. This long-term plan shows a low economic viability with a relatively huge fund requirement.

An urgent flood control plan, therefore, is proposed on a more practical basis by narrowing down the target assets that would adversely affect, if seriously damaged, the socio-economic activities in a large area.

The road bridge and the railway bridge would be damaged seriously and directly by flood and sediment flow, and interruption of the transportation system would affect the socio-economy in a large area. Therefore, the target assets in the urgent plan are narrowed down to the road bridge and the railway bridge spanning the Achiguate and the Pantaleon rivers.

<u>River Improvement Stretch</u>

As in the case of the long-term plan, the improvement stretch for the protection of the aforementioned assets, including the transition section between the improvement channel and the present channel, would be as follows:

Achiguate River	:	38.0 km to 43.0 km (38.0 km - 39.75 km: transition section)
Pantaleon River	:	18.0 km to 21.4 km (18.0 km - 18.45 km: transition section)

<u>Probable Discharge</u>

As in the long-term plan, the following probable discharges were applied to the study on the river channel improvement plan.

Return Period	Achiguate River 38km - 43km (m^3/s)	Pantaleon River 18km - 21.4km (m^3/s)
30-year	1,200	1,150
10-year	950	900
5-year	750	750

<u>Flooding Condition</u>

The sediment discharge that affects inundation water stage without flood control facilities will be changed from that in the long-term plan based on the premise of urgent plan described in the sector of Sediment Control Plan. The inundation water stage without the facilities was calculated based on such premise on sediment discharge. (Refer to Table 4-2.)

6.1.2 Principle for Planning

Two plans are formulated for the urgent flood control; the Proposed Plan and the Alternative Plan. The proposed plan is based on the precept that the economic viability may be maximized, while the alternative plan is prepared in consideration of the following aspects: (1) technically less difficult construction method, (2) possibility of stepwise construction plan, and (3) availability of materials in the proximity of the construction sites.

The comparative study is carried out in relation to the proposed plan to determine the optimum flood control method and the optimum scale of the project from the economic and social viewpoint, because the study results for the proposed and the alternative plans may be the same.

6.2 Comparative Study

6.2.1 Applicable Methods

Achiguate River

The river improvement stretche mentioned in the preceding subsection, excluding the transition section, are subdivided into the following sections in view of their minimum flow capacities. (Refer to Fig. 4-22.)

Section	Minimum Flow Capacity (m^3/s)
39.75 km to 40.4 km	150
40.4 km to 41.7 km	1,000
41.7 km to 43.0 km	1,400

In general, several methods are considered to improve a river channel, but the applicable methods for the above-mentioned sections are limited to one or two to to their existing situations as described in the following. (Refer to Fig. 4-23.)

(1) 39.75 km to 40.4 km

In this section exists the railway bridge. Since the flow capacity of this section is small, the overflow water in this section may inflict damage to the bridge.

Widening of the river channel, embankment, or excavation to increase the flow capacity is needed; however, the railway bridge makes it difficult to widen or embank the river channel. Therefore, excavation of the channel is the only method applicable for this section.

(2) 40.4 km to 41.7 km

Since the flow capacity is insufficient for the probable discharge of 30-year return period, river channel improvement works for the probable discharge of 30-year return period in the downstream is indispensable to secure the railway bridge.

The probable discharge of up to 10-year return period may be confined in this stretch, but bank erosion is expected, which will spoil the function of the riparian facilities in the downstream including the railway bridge. Therefore, river channel improvement works for the probable discharge of up to 10-year return period is also required for the same reason as aforementioned.

There are two methods applicable for this section; excavation of the channel and provision of a training levee on the left bank. The former is suitable for keeping the section's consistency with the lower section, while the latter can make a ponding function of the existing non-use area because the area will remain intact.

(3) 41.7 km to 43.0 km

This section has a sufficient flow capacity so that works for the increment of flow capacity are not needed. It is hardly expected that bank erosion on this section will seriously affect the function of the railway bridge because of the long distance interval. However, the road bridge existing in this section, one of the target assets, should be secured to fulfill its function of transportation system. In this context, only protection works are proposed to protect the bridge from damage possibly derived from bank erosion and riverbed scouring.

As for the section between 38.0 km and 39.75 km which is established as the transition section, only channel excavation works are applied to the connection of the present channel and the improved channel.

Pantaleon River

The river improvement stretch of Pantaleon River, excluding the transition section, is also subdivided into the following sections in view of their minimum flow capacities. (Refer to Fig. 4-22.)

Section	Minimum Flow Capacity (m^3/s)
18.45 km to 19.5 km	550
19.5 km to 20.5 km	1,000
20.5 km to 21.4 km	1,300

The applicable methods for the above-mentioned sections are as described hereunder. (Refer to Fig. 4-23.)

(1) 18.45 km to 19.5 km

The situation of this section is almost the same as that of section 39.75 km to 40.4 km in Achiguate River, but in addition to the method of channel excavation, embankment (provision of a training levee) can also be applicable, because there is a suffifient clearance below the bridge girder, when sediment discharge is controlled by sediment control dams.

(2) 19.5 km to 20.5 km

River channel improvement works are needed in this section for the same reason as that of section 40.4 km to 41.7 km of Achiguate River, though the flow capacity of this section covers the flood discharge of up to 10-year return period.

Excavation of the channel and embankment (provision of a training levee) are applicable to this section to keep a conformity with the lower section.

(3) 20.5 km to 21.45 km

Protection works are solely needed to secure the road bridge for the same reason as that for section 41.7 km to 43.0 km of Achiguate River.

Besides the above, channel excavation works are applied to the transition section between 18K to 18.45 km for a smooth connection between the present channel and the improved channel.

6.2.2 Selection of Method

A study on combination of the applicable methods for each section discussed in the foregoing has been carried out for the probable discharges of 5-, 10- and 30-year return periods to select the optimum method. (Refer to Table 4-5.)

Achiguate River

The possibility of combining the applicable methods are considered in the following cases:

Case	Section	Combination of Methods
Case A-E	39.75 km to 40.4 km	Channel excavation
	40.4 km to 41.7 km	Channel excavation
	41.7 km to 43.0 km	Protection works
Case A-T	39.75 km to 40.4 km	Channel excavation
	40.4 km to 41.7 km	Training levee/1
	41.7 km to 43.0 km	Protection works

The comparative study on the above cases were conducted in consideration of the construction cost (refer to Table 4-6 and Fig. 4-24). It shows that the combination in Case A-T may be recommended for floods of 5-year and 10-year return periods, while the combination in Case A-E is suitable for the control of 30-year return period floods.

Pantaleon River

The following cases are proposed as the possible combinations of the applicable methods:

Case	Section	Combination of Methods
Case P-E	18.45 km to 19.5 km	Channel excavation
	19.5 km to 20.5 km	Channel excavation
	20.5 km to 21.4 km	Protection works
Case P-T	18.45 km to 19.5 km	Training levee
	19.5 km to 20.5 km	Training levee
	20.5 km to 21.4 km	Protection works

The construction costs of the above cases are shown in Table 4-6 and Fig. 4-24. As a result of the comparative study, the combination in Case P-E is proposed to be the optimum for any probable discharge.

6.2.3 Selection of Optimum Scale

The optimum plan can be determined in the first place by comparing the economic viabilities of the different project scales which may be presented by means of the Economic Internal Rate of Return (EIRR). The EIRRs of each project scale are given in Fig. 4-25. (Refer to Table 4-7 for details.)

As verified by Fig. 4-25, the flood control works for the Achiguate and the Pantaleon rivers should be proposed from the economic viewpoint in such a scale that the flood of 10-year return period may be controlled. It shows an IRR of 7% which is above the standard EIRR for economic evaluation (refer to Subsection 4.3).

The project scale against the flood of 10-year return period, if assessed from the point of view of social requirement, can be said to provide stabilization up to the national level in comparison to the social situation in other river basins that have been experiencing flood damage with a frequency ranging from every 3 years to every 10 years, though a few other basins are in safer conditons. (Refer to Fig. 4-1.)

6.3 Design Flood Discharge

The design flood discharge based on a 10-year return period is thus employed for the urgent flood control plan, which were fixed at 950 m^3/s and 900 m^3/s for the Achiguate and the Pantaleon rivers, respectively.

/1 Since the present river channel in the stretch between 40.4K and 41.7K of Achiguate River has sufficient flow capacity for the probable discharge of 10-year return period, riparian facilities differ with that of 30-year return period as shown in Table 4-5.

6.4 Proposed Plan

6.4.1 Features of the Proposed Plan

The urgent flood control plan is designed to cope with the design discharge of 10-year return period. As regards the riparian facilities, however, the revetment and groundsills in this plan may have to be removed and reconstructed when the long-term plan is implemented.

In this connection, revetment and groundsills in the proposed urgent plan, which are referred to as Plan A-T-10 and Plan P-E-10, should be provided at the scale of the long-term plan; namely, a 30-year return period, which are referred to as Plan A-T-10' and Plan P-E-10', because of the following reasons.

Plans A-T-10' and P-E-10' are more advantageous on the economic viewpoint than plans A-T-10 and P-E-10, though more costly in view of initial investment, when the long-term plan will be implemented in the future after completion of the urgent plan (refer to Fig. 4-26). The advantage is derived from the avoidance of double investment and duplication of construction.

The features of the proposed urgent plan in which the abovementioned idea is considered are described hereunder.

(1) Achiguate River

(a) Location and Extent

River improvement works for Achiguate River cover the stretch from 38.0 km to 43.0 km where the road bridge and the railway bridge exist.

(b) Alignment

New alignment is in principle drawn along the present river course which has no heavy meandering. The river width is fixed at 100 m based on the present width which is difficult to be widened because of the existence of the bridges. (Refer to Fig. 4-27.)

(c) Longitudinal Profile

The longitudinal profile is designed at 1:110 in the proximity of the existing riverbed gradient. The design high water level is fixed below the landside ground height to avoid augmentation of the flood damage potential. (Refer to Fig. 4-28.)

(d) Cross Section

Single cross section is applied to all the river improvement stretch. (Refer to Fig. 4-27.)

(e) Riparian Facilities

The required riparian facilities are revetment and groundsills at intervals of 150 m at the sections of 39.75 km to 40.4 km and 42.8 km to 43.0 km, and foot protection groyne on the left bank at the section of 40.4 km to 41.7 km.

(2) Pantaleon River

(a) Location and Extent

River improvement works for Pantaleon River cover the stretch from 18.0 km to 21.4 km where the road bridge and the railway bridge exist.

(b) Alignment

New alignment is drawn along the present river course and the river width is fixed at 80 m under the same consideration as in Achiguate River. (Refer to Fig. 4-27.)

(c) Longitudinal Profile

The longitudinal profile is designed at 1:38 according to the existing riverbed gradient. The design high water level is fixed in the same manner as in Achiguate River. (Refer to Fig. 4-28.)

(d) Cross Section

Single cross section is applied to all the river improvement stretch. (Refer to Fig. 4-27.)

(e) Riparian Facilities

The riparian facilities required for Pantaleon River consist of revetment and groundsills at intervals of 50 m in the stretches from 18.45 km to 19.5 km and from 21.3 km to 21.4 km.

6.4.2 Preliminary Design of Riparian Facilities

Selection of Structural Type

The riparian facilities required for the proposed urgent plan are revetment, groyne and groundsill. Revetment and groyne have the function of river bank protection against erosion, while groundsill is needed for the stabilization of the riverbed.

Each structure can be divided into four types, which are further grouped into permanent and semi-permanent according to durability, as shown below.

Function	Structure	Type	Group
Bank Protection	Revetment	(1) Concrete retaining wall	Permanent
		(2) Concrete block	-do-
		(3) Wet masonry	-do-
		(4) Gabion cylinder	Semi-permanent
Bank Protection	Groyne	(1) Non-permeable concrete	Permanent
		(2) Non-permeable wet masonry	-do-
		(3) Permeable foot protection by wooden piles	Semi-permanent
		(4) Permeable foot protection by cribs	-do-
Riverbed Stabilization	Groundsill	(1) Concrete type with concrete sub-groundsill and concrete apron	Permanent
		(2) Concrete type with apron of gabion mattress	-do-
		(3) Concrete block type	Semi-permanent
		(4) Gabion mattress type	-do-

A comparative study on the types has been conducted in consideration of the construction and replacement costs to select the optimum type in each group of structure (refer to Table 4-9). The results of the study are summarized in the following table.

Function	Structure	Group	Type
Bank Protection	Revetment	Permanent Semi-permanent	Wet Masonry Gabion cylinder
	Groyne	Permanent Semi-permanent	Concrete Cribs
Riverbed Stabilization	Groundsill	Permanent Semi-permanent	Concrete Gabion Mattress

The suitable structural types are selected for each of the river improvement sections in the proposed plan as discussed hereunder.

(1) Achiguate River

(a) 39.75 km to 40.4 km and 42.8 km to 43.0 km

Protection works are required for both right and left banks in these sections where the road bridge and the railway bridge are located. Revetment and groyne can be suggested for the bank protection as aforementioned, but the groyne is not recommendable taking into account that the concrete groyne needs a higher construction cost compared with that of the revetment, and the water flow with a high velocity may destroy or wash away the crib groyne. Therefore, revetment is applied to these sections as bank protection works.

As to the suitable type of revetment, wet masonry which has an advantage in the economical and structural points of view is applied to the proposed plan.

Groundsills are also required for riverbed stabilization of these sections to secure the bridges against the damage possibly caused by riverbed scouring. Concrete type (permanent structure) is adopted in the viewpoints of economy, durability and maintenance.

(b) 40.4 km to 41.7 km

Bank protection works should be provided on only the left bank because on the right side bank lies a hilly land adjacent to the river course. A wide high water channel extends along the left bank at the maximum width of 300 m. Therefore, revetment is not necessary and even the semi-permanent groynes are durable enough to protect the bank.

The permeable foot protection groyne made of cribs is employed for this section. No groundsill is provided.

(c) 41.7 km to 42.8 km

No river improvement works are required for this section as mentioned in Subsection 6.2, Comparative Study. Therefore, it is also not necessary to install any riparian facility along this section.

(2) Pantaleon River

(a) 18.45 km to 19.5 km and 21.3 km to 21.4 km

Bank protection and riverbed stabilization works are required for these sections being in the same situation as the sections of 39.75 km to 40.4 km and 42.8 km to 43.0 km in Achiguate River. These sections are characterized by such a steep riverbed gradient of 1:38 that flood may easily inflict a serious damage on the bank.

As for the revetment, wet masonry is also recommendable for the same reasons as mentioned in (a) of Achiguate River. This wet masonry, however, will be made stronger than that in Achiguate, taking the above river conditions into consideration. As regards the groyne, the concrete type of groyne can be employed for these sections, because the crib type of groyne may be easily washed away by the river flow with a high velocity. Hence, it follows that the applicable types for bank protection are only the wet masonry type of revetment and the concrete type of groyne. Between these two types, the wet masonry type of revetment is selected, considering its low cost and easy maintenance.

As for the groundsill, the concrete type is applied to these sections for the same reasons as mentioned in (a) of Achiguate River.

(c) 19.5 km to 21.3 km

This section does not require river improvement works as discussed in Subsection 6.2, Comparative Study, therefore, no riparian facility is needed.

Design of Riparian Facilities

The riparian facilities necessary for the proposed plan and the objective river sections are summarized in the following table and their features are shown in Fig. 4-29.

Structure	Type	River	Section
Revetment	Wet masonry	Achiguate	39.75 km to 40.4 km 42.8 km to 43.0 km
		Pantaleon	18.45 km to 19.5 km 21.3 km to 21.4 km
Groyne	Crib	Achiguate	40.4 km to 41.7 km
Groundsill	Concrete	Achiguate	39.75 km to 40.4 km 42.8 km to 43.0 km
		Pantaleon	18.45 km to 19.5 km 21.3 km to 21.4 km

(1) Revetment

The revetment of wet masonry type has a steep slope of 1:0.5 to suffer as little as possible from the damage caused by flowing stones and from the overflow caused by creeping up of water on the slope. The crest height is designed to coincide with the bank crown in order to prevent bank erosion by a water level higher than the design high water level due to water hammer action. The foundation is embedded by 1.0 m below the design riverbed, and the base concrete is placed thereunder to support the revetment considering scouring depth in the present river channel. Gabion mattresses are placed for the foot protection in a width of 3.0 m to prevent riverbed scouring at the foot of the revetment.

(2) Groyne

The groyne of crib type is made of cone-shaped cribs in which gabion cylinders are placed for its stabilization. This type has been used in Japan since time immemorial, and it has achieved the aim of bank protection. The groynes will be distributed along the bank line at intervals of 20 m.

(3) Groundsill

The crest width of the main body is designed at 1.0 m, and the foundation is embedded by 2.0 m below the design riverbed, so that the elevation of the foundation bottom is a little deeper than that of the crest of another groundsill installed in the downstream. Gabion mattresses are also placed on the downstream riverbed in a width of 6.0 m for the purpose of scouring prevention thereabout.

6.5 Alternative Plan

6.5.1 Features of the Alternative Plan

The location and extent of river improvement works, their alignment, longitudinal profile and cross section are the facilities as summarized hereunder.

(1) Achiguate River

Location and Extent	:	From 38.0 km to 43.0 km
Alignment	:	River width of 100 m
Longitudinal Profile	:	Riverbed gradient of 1:110
Cross Section	:	Single cross section
Riparian Facilities	:	Revetment, groyne and groundsill

(2) Pantaleon River

Location and Extent	:	From 18.0 km to 21.4 km
Alignment	:	River width of 80 m

Longitudinal Profile	:	Riverbed gradient of 1:38
Cross section	:	Single cross section
Riparian Facilities	:	Revetment and groundsill

6.5.2 Preliminary Design of Riparian Facilities

<u>Selection of Structural Types</u>

Riparian facilities of revetment, groyne and groundsill are also required for the alternative plan for the same purpose as mentioned in 6.4.2. The riparian structural types for this plan will be selected among the types for each structure in the same manner as in the proposed plan.

(1) 39.75 km to 40.4 km and 42.8 km to 43.0 km in Achiguate; and 18.45 km to 19.5 km and 21.3 km to 21.4 km in Pantaleon

Revetments are applied to both banks in these sections for the same reason as mentioned in 6.4.2.

Gabion cylinder type is adopted for the alternative plan in due consideration of the aspects for planning as stated in 6.1.2, Principle for Planning, though the wet masonry type has been selected for the proposed plan.

Groundsills are also required for riverbed stabilization of these sections to secure the bridges against the damage that may possibly be caused by riverbed scouring. Gabion mattress type is selected for the alternative plan based on the said principle.

(2) 40.4 km to 41.7 km in Achiguate

The permeable foot protection groyne of cribs is employed for the left bank of this section for the same reason as mentioned in 6.4.2. As in the proposed plan, no groundsill will be provided in this section.

<u>Design of Riparian Facilities</u>

The riparian facilities applied in the alternative plan are presented in the following table, together with their objective river sections. (Refer to Fig. 4-30.)

Structure	Type	River	Section
Revetment	Gabion Cylinder	Achiguate	39.75 km to 40.4 km 42.8 km to 43.0 km
		Pantaleon	18.45 km to 19.5 km 21.3 km to 21.4 km
Groyne	Crib	Achiguate	40.4 km to 41.7 km

Structure	Type	River	Section
Groundsill	Gabion Mattress	Achiguate	39.75 km to 40.4 km 42.8 km to 43.0 km
		Pantaleon	18.45 km to 19.5 km 21.3 km to 21.4 km

(1) Revetment

As to the revetment of gabion cylinder type, the slope is fixed at 1:1.5 for further easy construction. The crest height is designed at the same elevation as the design bank crown. Cylinders are also placed on the riverbed in a width of 3.0 m from the toe of slope so that riverbed lowering may not directly affect the structure.

(2) Groyne

Groyne of crib type is designed in the same precept as that for the proposed plan.

(3) Groundsill

Gabion mattresses are embedded by 1.0 m below the design riverbed. Three (3) units of mattress, each having a width of 3.0 m, are placed adjacent to each other in a total length of 9.0 m in the direction of water flow to forward the flexibility against riverbed fluctuation.

TABLES AND FIGURES

Table 4-1 (1/3) RIVERS IN GUATEMALA

NUMBER	NAME OF THE RIVER	CATCHMENT AREA	RIVER LENGTH	HORTON'S COEFFICIENTS	ALTITUDE	I.(H/C)	CITY	POPULATION
1.1	Coatán	269	18 km	0.830	2700^m-1000^m	1/10	Tacaná	37,500
1.2	Suchiate	1,064	85 km	0.147	3,000 m	1/28	Uman	------
1.3	Naranjo	1,266	90 km	0.156	2,700 m	1/33	Pajapita	9,100
1.4	Ocosito	2,024	82 km	0.301	2,200 m	1/37	Flores Costa Cuca	11,500
1.5	Samala	1,499	120 km	0.104	2,500 m	1/85	El Palmar	15,900
1.6	Sis Ican	916	70 km	0.186	1,500 m	1/47	Mazatenango	37,600
1.7	Nahualate	2,012	95 km	0.223	2,200 m	1/43	Pueblo Nuevo Tiquisate	4,000
1.8	Atitlán	548	-------	-----	--------	----	Sololá	29,200
1.9	Madre Vieja	905	100 km	0.091	2,100 m	1/46	Patulul	15,900
1.10	Coyolate	1,616	105 km	0.147	2,100 m	1/50	Sta.Lucía	65,000
1.11	Acomé	764	60 km	0.212	500 m	1/120	La Gomera	31,200
1.12	Achiguate	1,080	55 km	0.235	3,000 m	1/25	Escuintla	73,700
1.13	María Linda	2,759	80 km	0.631	1,600 m	1/80	Amatitlán	32,800
1.14	Paso Hondo	509	30 km	0.566	300 m	1/100	Chiquimulilla	30,600
1.15	Los Esclavos	2,258	110 km	0.167	2,200 m	1/50	Cuilapa	17,000
1.16	Paz	1,722	100 km	0.172	1,800 m	1/67	Quezada	11,400
1.17	Lempa(Ostúa)	2,231	95 km	0.247	1,900 m	1/50	Asunción Mita	30,400
1.18	Lempa(Olopa)	308	15 km	1,369	500 m	1/21	Esquipulas	18,800

Table 4-1 (2/3) RIVERS IN GUATEMALA

NUMBER	NAME OF THE RIVER	CATCHMENT AREA	RIVER LENGTH	HORTON'S COEFFICIENTS	ALTITUDE	I.(H/C)	CITY	POPULATION
2.1	Motagua (Zacapa)	2,471	80 km	0.386	800 m	1/100	Chiquimula	42,600
2.2	Motagua (Zacapa)	12,719	390 km	0.084	2,700 m	1/144	Morales	51,500
2.3	Dulce(Lago de Izabal)	3,448	-------	-----	-------	1/52	El Estor	23,400
2.4	Dulce(Po-lochic)	2,822	110 km	0.233	2,100 m	1/52	Tucuru	12,700
2.5	Dulce(Ca-habon)	2,248	140 km	0.115	1,800 m	1/93	Calabon	17,800
2.6	Sarstún	2,119	120 km	0.147	300 m	1/400	Sesaltui	-------
2.7	Mopan Belice	6,250	100 km	0.425	300 m	1/333	Melchor de Mencos	-------
2.8	Azull	3,450	60 km	0.958	100 m	1/600	Ixcanrio	-------

Table 4-1 (3/3) RIVERS IN GUATEMALA

NUMBER	NAME OF THE RIVER	CATCHMENT AREA	RIVER LENGTH	HORTON'S COEFFICIENTS	ALTITUDE	I.(H/C)	CITY	POPULATION
3.1	Grijalva (Cuilco)	2,274	105 km	0.206	3,000 m (900)	1/50	Cuilco	24,900
3.2	Grijalva (Selegua)	1,535	90 km	0.190	2,700 m (600)	1/43	San Sebas-tian	10,100
3.3	Grijalva (Nenton)	1,481	50 km	0.580	2,700 m (600)	1/24	Nenton	15,900
3.4	Usumacinta (Pojom)	813	25 km	1.301	2,500 m (650)	1/13	Macapoxlac	------
3.5	Usumacinta (Ixcan)	2,085	85 km	0.289	2,700 m (100)	1/43	Barillas	32,700
3.6	Usumacinta (Xaclbal)	1,366	100 km	0.137	2,600 m (100)	1/43	Nebaj	17,900
3.7	Usumacinta (Salinas)	12,156	420 km	0.069	2,700 m (100)	1/161	Sacapulas	21,200
3.8	Usumacinta (Pasión)	12,156	260 km	0.180	800 m	1/520	Chisel	17,800
3.9	Usumacinta (Usumacinta)	2,638	175 km	0.086	100 m	1/1780	San Fer-nando	-------
3.10	Usumacinta	14,335	160 km	0.560	300 m	1/530	Pasa Caba-llos	-------

Table 4-2 (1/2) INUNDATION WATER STAGE (ACHIGUATE RIVER BASIN)

(Unit: m)

Section	Extent of Inundation Water	Return Period					
		50 year	30 year	20 year	10 year	5 year	2 year
Road Bridge		Not Washed away /1					
(From 42km) to 34km	400	1.56 (1.48)	1.43 (1.35)	1.36 (1.28)	1.19 (1.14)	1.01 (0.69)	0.66 (0.62)
Railway Bridge		Washed away					
28km left (over flowed)	200	0.8	0.75	0.69	0.60	0.51	0.37
28km	400	1.6	1.5	1.4	1.2	1.0	0.65
(From 26km) to 20km	200	0.6	0.55	0.5	0.4	0.35	0.25
16km	2500	0.5	0.48	0.45	0.4	0.35	0.22
12km	400	0.42	0.40	0.37	0.33	0.29	0.19
8km	5500	0.34	0.32	0.29	0.27	0.23	0.16
4km	7000	0.25	0.23	0.22	0.20	0.18	0.13
0km	7000	0.25	0.23	0.22	0.20	0.18	0.13

/1: During the flood, the bridge falls into dangerous condition of collapse by the sediment discharge, so that transportation is interrupted, which considered flood damage.

/2: Figures in parentheses show the water stage under the condition of sediment deposition for urgent plan.

Table 4-2 (2/2) INUNDATION WATER STAGE (PANTALEON RIVER BASIN)

(Unit: m)

Section	Extent of Inundation Water	Return Period					
		50 year	30 year	20 year	10 year	5 year	2 year
Road Bridge		Not washed away					
Railway Bridge		Washed away					
(From 20km) to 16 km	200	1.16 (0.58)	0.98 (0.45)	0.88 (0.33)	0.60 (1.16)	0.32 (0.0)	0 (0.0) /2
16km Right (1)	1000	0.32	0.29	0.27	0.23	0.18	0.07
16km Right (2)	500	0.70	0.65	0.60	0.50	0.40	0.22
Pataya Road Bridge		Washed away			Not washed away		
(From 14km) to 8km		No damage					
6km Left	500	0.51	0.48	0.46	0.42	0.36	0.25
(from 6 km) to 0km	500	0.52	0.52	0.82	0.52	0.52	0.52

/1: During flood time, the bridge falls into dangerous condition of collapse due to the sediment discharge so that transportation is interrupted which is considered as flood damage.

/2: Figures in parentheses show water stage under the condition of sediment deposition for urgent plan.

Table 4-3 COMPARITIVE STUDY FOR PROTECTION OF ASSETS B

(1) River	(2) Asset to be Protected	(3) No.	(4) Method	(5) Required work	(6) Total Construction Cost x10³ US$	(7) Annual Benefit x10³ US$	(7)/(6)
Achiguate River	CA-2 road Bridge & railway bridge	I-1	River channel improvement (I)	River Course (43km - 42.8km) (41.7km - 38km)	6,050	1,280	0.21
		I-2	River channel improvement (II)	River course (43km - 42.8km) (40.4km - 38.0km) Training levee (41.7km - 40.4km)	6,140	1,280	0.21
		I-3	Heightening of railway bridge	River course (43km - 42.8km) Bridge reconstruction, Raising of approach, Railway embankment (4,000m)	11,300	1,160	0.10
	Urban area of Finca La Trinidad	II-1	River channel improvement	River course (31.5km - 25.5km)	8,350	1,030	0.12
		II-2	Raising of CA-9 road	Road raising (H=1.25m,L=2,500)	2,560	880	0.34
		II-3	Ring Levee	Embankment/ revetment (H=1.75,L=4,000m)	2,150	170	0.08
	Urban area of La Barrita	III-1	River channel improvement & training levee	River course (8km - 0km) Training levee (9km - 8km)	22,400	760	0.03
		III-2	Ring levee	Embankment/ revetment (H=1.45m,L=5,000m)	2,220	240	0.11
Pantaleon River	CA-2 road bridge & railway bridge	IV-1	River channel improvement (I)	River course (21.4km - 21.35 km) (20.5km - 18 km)	5,460	670	0.12
		IV-2	River channel improvement (II)	River course (21.4km - 21.35km) (18.3km - 18 km) Training levee (20.5km - 18.3 km)	8,180	670	0.08

Table 4-4 COST, BENEFIT AND EIRR FOR EACH STUDY CASE

Study Case	Item	Unit	Return Period			
			5 years	10 years	30 years	50 years
Protection of Assets B, C and D	Cost	($x10^3$ US$)	146,000	162,000	192,000	211,000
	Annual Benefit	($x10^3$ US$)	6,100	7,600	8,600	8,800
	EIRR	(%)	1.5	2.0	2.0	1.5
Protection of Assets B and C	Cost	($x10^3$ US$)	105,000	117,000	143,000	158,000
	Annual Benefit	($x10^3$ US$)	5,600	7,000	8,000	8,200
	EIRR	(%)	2.5	3.5	3.0	2.5
Protection of Assets B	Cost	($x10^3$ US$)	40,000	44,000	50,000	57,000
	Annual Benefit	($x10^3$ US$)	2,700	3,200	3,500	3,600
		(%)	5.0	6.0	5.0	4.0

Table 4-5 (1/2) STUDY CASES FOR URGENT PLAN (ACHIGUATE RIVER)

Case No.	Principal River Improvement Method	Return Period (year)	River Improvement Method for Each Stretch (Km)					Sediment Control Dam Site ∠1
			38.0-39.75	39.75-40.4	40.4-41.7	41.7-42.8	42.8-43.0	
A-E-5	Channel excavation	5	Excavation	Excavated channel with wet masonry and groundsills	Excavated channel with wet masonry and groundsills	No improvement	Installation of wet masonry and groundsills	A-1,C-1
A-E-10	- do. -	10	- do. -	- do. -	- do. -	- do. -	- do. -	- do. -
A-E-30	- do. -	30	- do. -	- do. -	- do. -	- do. -	- do. -	- do. -
A-T-5	Channel excavation and consturction of training levee	5	- do. -	- do. -	Foot-protection groynes only	- do. -	- do. -	- do. -
A-T-10	- do. -	10	- do. -	- do. -	- do. -	- do. -	- do. -	- do. -
A-T-10′	- do. -	10 (30)	- do. -	- do - (with a channel capacity of 30-year discharge)	- do. - (with a channel capacity of 10 year discharge)	- do. -	- do. -	- do. -
A-T-30	- do. -	30	- do. -	- do -	Foot-protection groynes and training levee with wet masonry	- do. -	- do. -	- do. -

∠1. Refet to Sector 3 "Sediment Control Plan"

Table 4-5 (2/2) STUDY CASES FOR URGENT PLAN (PANTALEON RIVER)

Case No.	Principal River Improvement Method	Return Period (year)	River Improvement Method for Each Stretch (Km)					Sediment Control Dam Site ∠1
			18.0-18.45	18.45-19.5	19.5-20.5	20.5-21.3	21.3-21.4	
P-E-5	Channel excavation	5	Excavation	Excavated channel with wet masonry and groundsills	Shaping of river channel	No improvement	Instalation of wet masonry and groundsills	P-2
P-E-10	- do. -	10	- do. -	- do. -	- do. -	- do. -	- do. -	-do-
P-E-10′	- do. -	10 (30)	- do. -	- do. - (with a channel capacity of 30-year discharge)	- do. -	- do. -	- do. -	-do-
P-E-30	- do. -	30	- do. -	- do. -	Excavated channel with wet masonry and groundsills	- do. -	- do. -	P-2 P-5
P-T-5	Construction of training levee	5	- do. -	Training levee with wet masonry and groundsills	Shaping of river channel	- do. -	- do -	P-2
P-T-10	- do. -	10	- do. -	- do. -	- do. -	- do. -	- do. -	-do-
P-T-30	- do. -	30	- do. -	- do. -	Training levee with wet masonry and groundsills	- do. -	- do. -	P-2 P-5

∠1. Refer to Sector 3 "Sediment Control Plan"

Table 4-6 COST COMPARISON FOR RIVER IMPROVEMENT METHODS

River	Case No.	Principal River Improvement Method	Return Period (year)	Construction Cost (x 10^3 US$)		
				River Improvement	Sediment Control Dam	Total
Achiguate River	A-E-5	Channel excavation	5	4,980	4,880	9,860
	A-E-10	- do. -	10	5,390	5,330	10,720
	A-E-30	- do. -	30	5,810	6,130	11,940
	A-T-5	Channel excavation and construction of training levee	5	3,470	4,880	8,350
	A-T-10	- do. -	10	3,770	5,330	9,100
	A-T-10'	- do. -	10 (30)	4,110	5,330	9,440
	A-T-30	- do. -	30	5,820	6,130	11,950
Pantaleon River	P-E-5	Channel excavation	5	2,360	2,630	4,990
	P-E-10	- do. -	10	2,490	3,000	5,490
	P-E-10'	- do. -	10 (30)	2,700	3,000	5,700
	P-E-30	- do. -	30	4,580	5,590	10,170
	P-T-5	Construction of training levee	5	3,890	2,630	6,520
	P-T-10	- do. -	10	4,310	3,000	7,310
	P-T-30	- do. -	30	7,930	5,590	13,520

Table 4-7 ECONOMIC COMPARISON FOR PROJECT SCALES

Unit: x 10^3 US$

Study Case	Construction Cost		Annual O M R Cost/1	Annual Benefit /1					EIRR
	Base Cost	Economic Cost		Railway Bridge/2	Road Bridge/3	Traffic /4	Houses /5	Total	(%)
A-T-5 & P-E-5	13,340	11,340	260	360	100	680	110	1,250	6.0
A-T-10 & P-E-10	14,590	12,410	260	420	110	800	130	1,460	7.0
A-T-10' & P-E-10'	15,140	12,870	260	420	110	800	130	1,460	7.0
A-T-30 & P-E-30	22,110	18,790	260	470	130	880	150	1,630	5.0

/1 : Economic Cost
/2 : Loss of National railway bridge
/3 : Partial damage to CA-2 road bridge
/4 : Interruption of Traffic
/5 : Damage to houses, house-hold effects and agricultural crops.

Table 4-8 COST COMPARISON FOR RIPARIAN STRUCTURAL TYPES

Purpose	Structure	Durability	Type	Description	Cost (US$) Construction	Replacement	Total
Bank Protection	Revetment	Permanent	R 1	Concrete retaining wall (n=1: 0.5) with foot- protection of gabion mattresses	470 /m	0 /m	470/m
			R 2	Concrete block (n=1:0.5) with foot-protection of gabion mattresses	480	0	480
			R 3	Wet masonry (n=1:0.5) with foot-protection of gabion mattresses	290	0	290
		Semi Permanent	R 4	Gabion cylinder (n=1:1.5)	210	420 /1	630
	Groyne	Permanent	G 1	Non-permeable concrete groyne (@ 20m)	410	0	410
			G 2	Non-permeable wet masonry groyne (@ 20m)	530	0	530
		Semi Permanent	G 3	Permeable foot-protection groyne of wooden piles (@ 20m)	110	220 /1	330
			G 4	Permeable foot-protection groyne of cribs (@ 20m)	67	133 /1	200
Riverbed Stabilization	Groundsill	Permanent	GS 1	Concrete type with concrete sub groundsill and concrete apron	120 x10^3/Unit	0x10^3/Unit	120 x10^3/Unit
			GS 2	Concrete type with apron of gabion mattresses	74	0	74
		Semi Permanent	GS 3	Concrete block type	46	92 /1	138
			GS 4	Gabion mattress type	29	58 /1	87

/1. Replacement will be carried out twice a project life (30 years), because these structures have a life of 10 years.

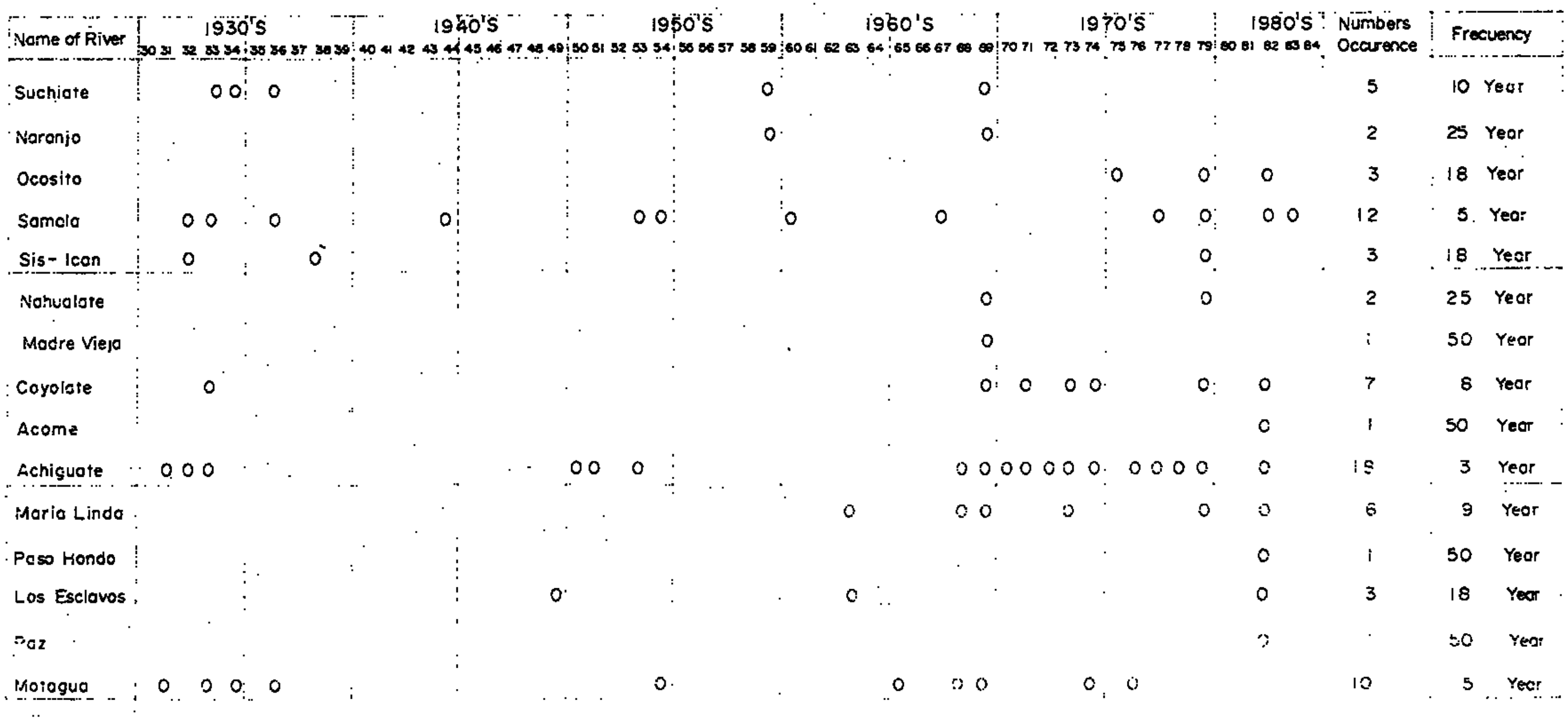
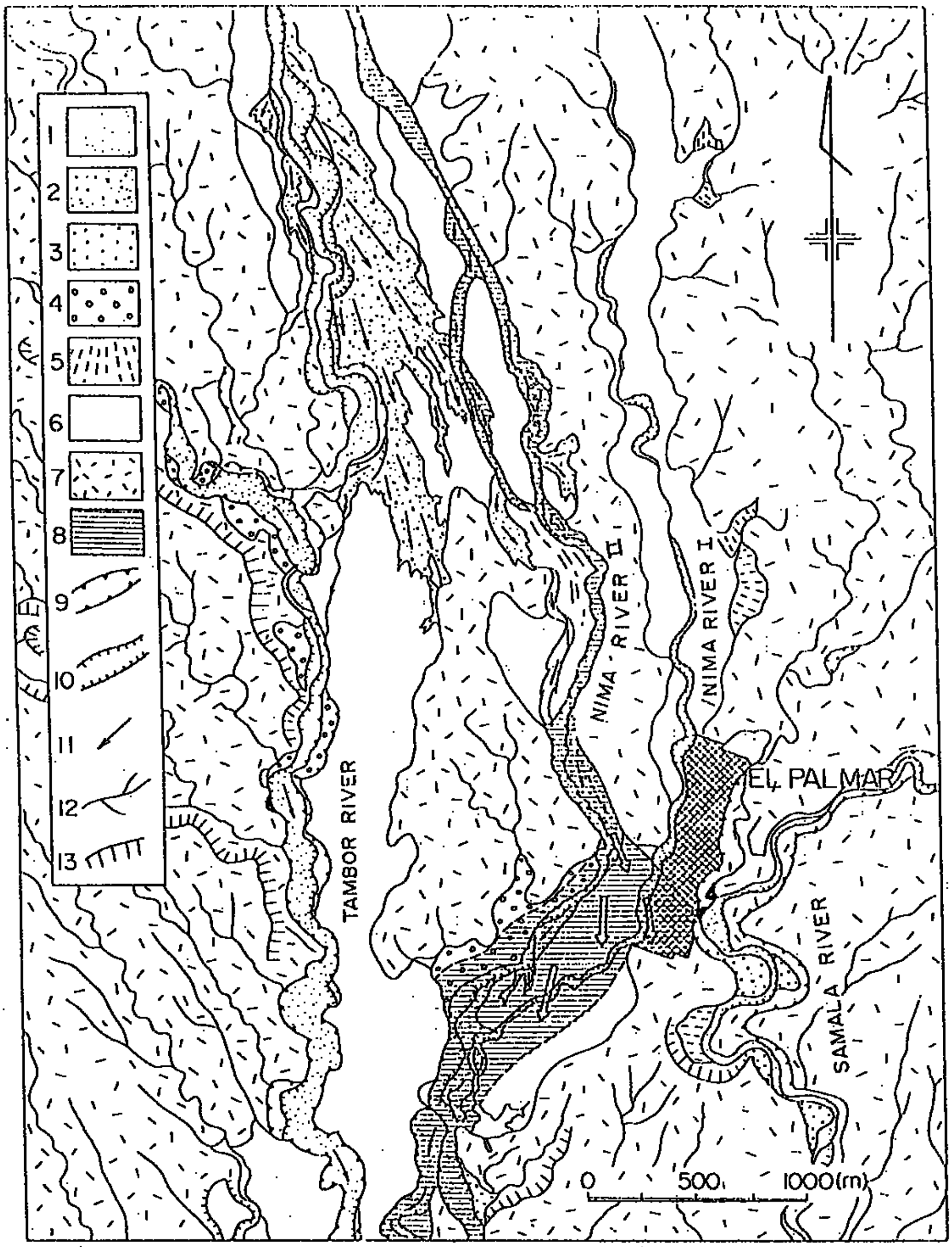


Fig. 4-1 FLOOD DAMAGE FREQUENCIES OF RIVERS IN CUATEMALA



1: Recent riverbed 2: Recent debris flow deposits 3: Lower terrace
4: Middle terrace 5: Talus 6: Volcanic fan 7: Mountain slope
8: Debris flow deposits in June – July, 1983 9: Gully (deep)
10: Gully (shallow) 11: Direction of debris flow 12: Stream
13: Cliff

Fig. 4-2 DAMAGED AREA OF EL PALMAR AND GEOMORPHOLOGICAL CONDITION

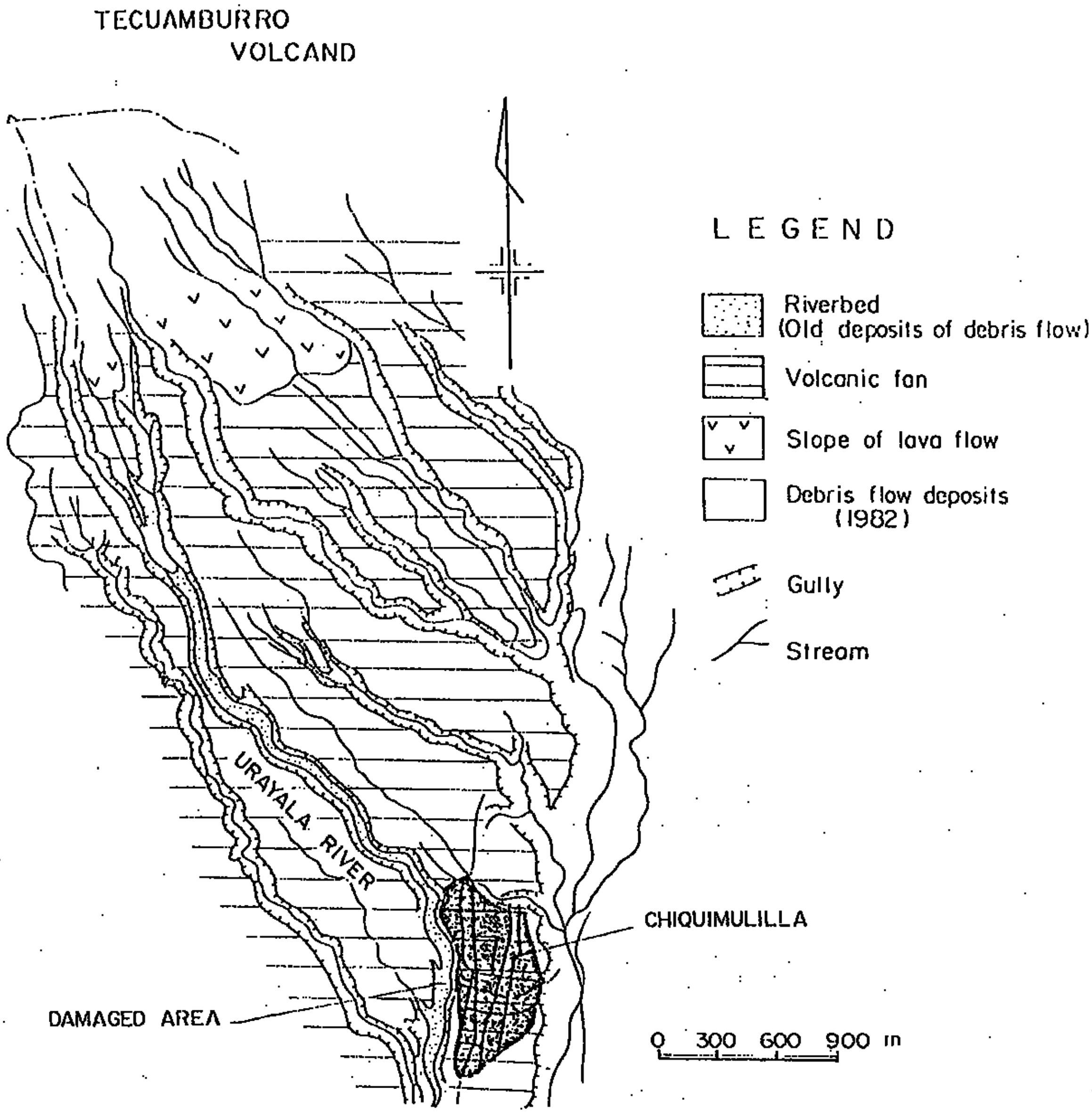


Fig. 4-3 FLOOD DAMAGE OF CHIQUIMULILLA AND GEOMORPHOLOGICAL CONDITION

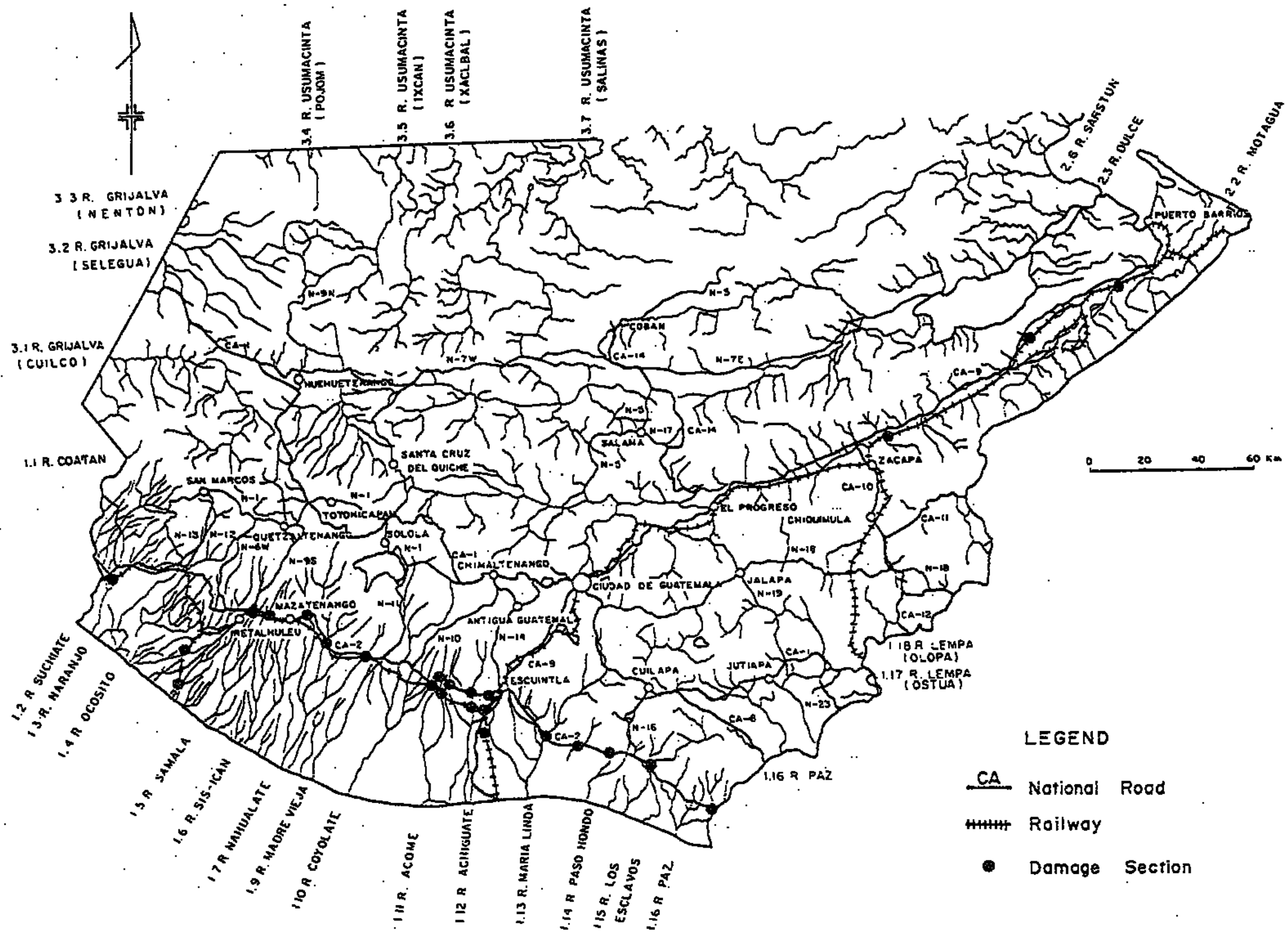


Fig. 4-4 FLOOD DAMAGE TO TRANSPORTATION SYSTEM

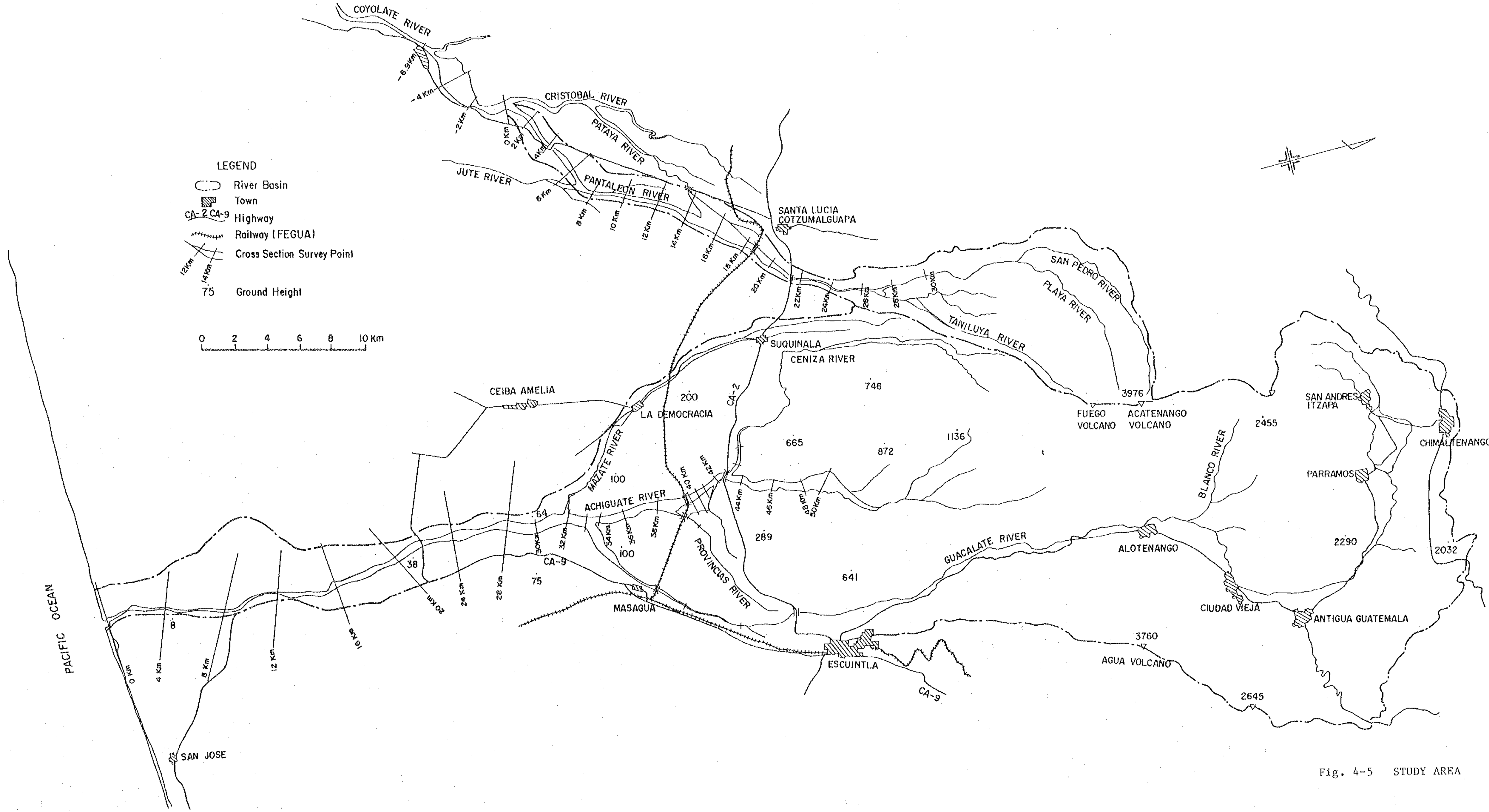


Fig. 4-5 STUDY AREA

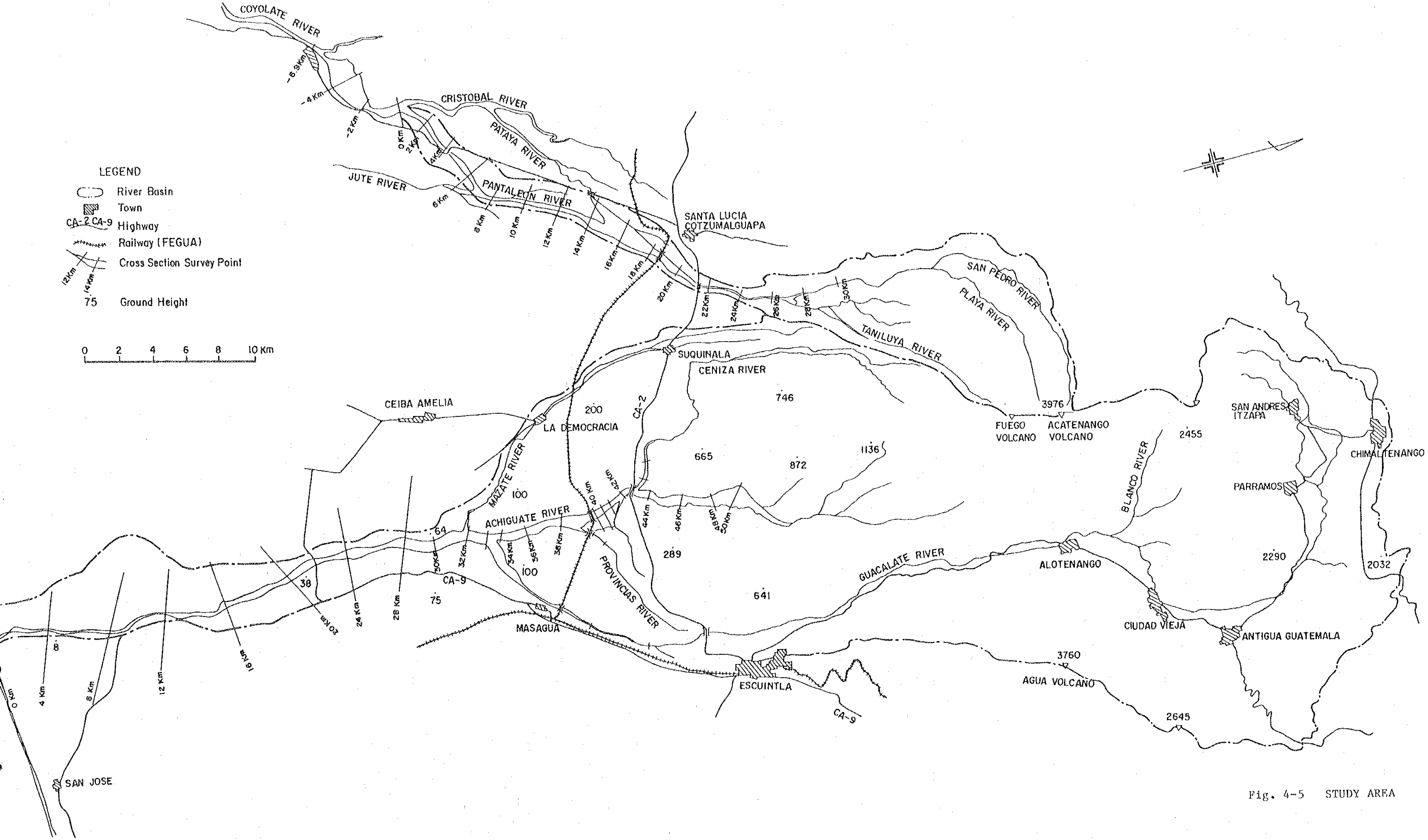


Fig. 4-5 STUDY AREA

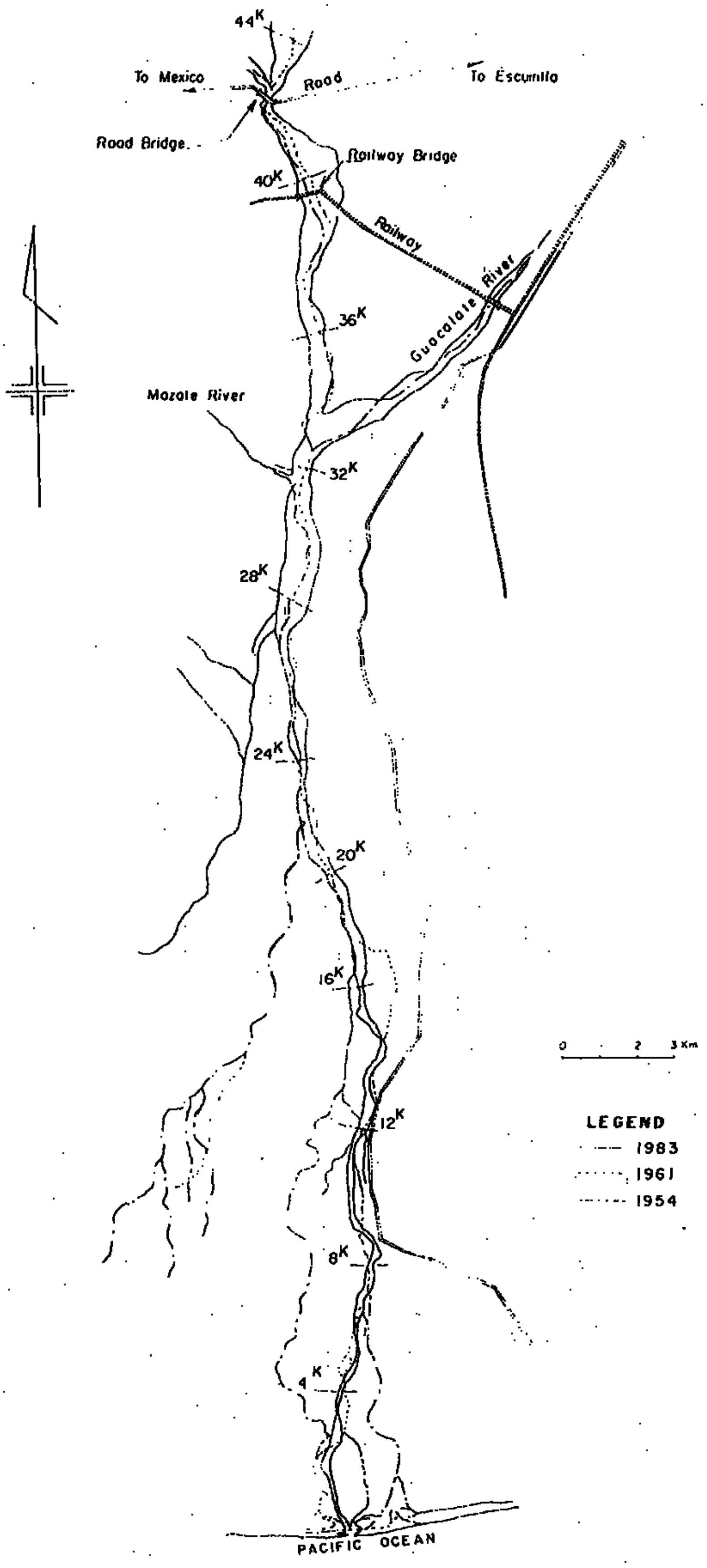


Fig. 4-6 (1/3) TRANSITION OF RIVER COURSE (ACHIGUATE RIVER)

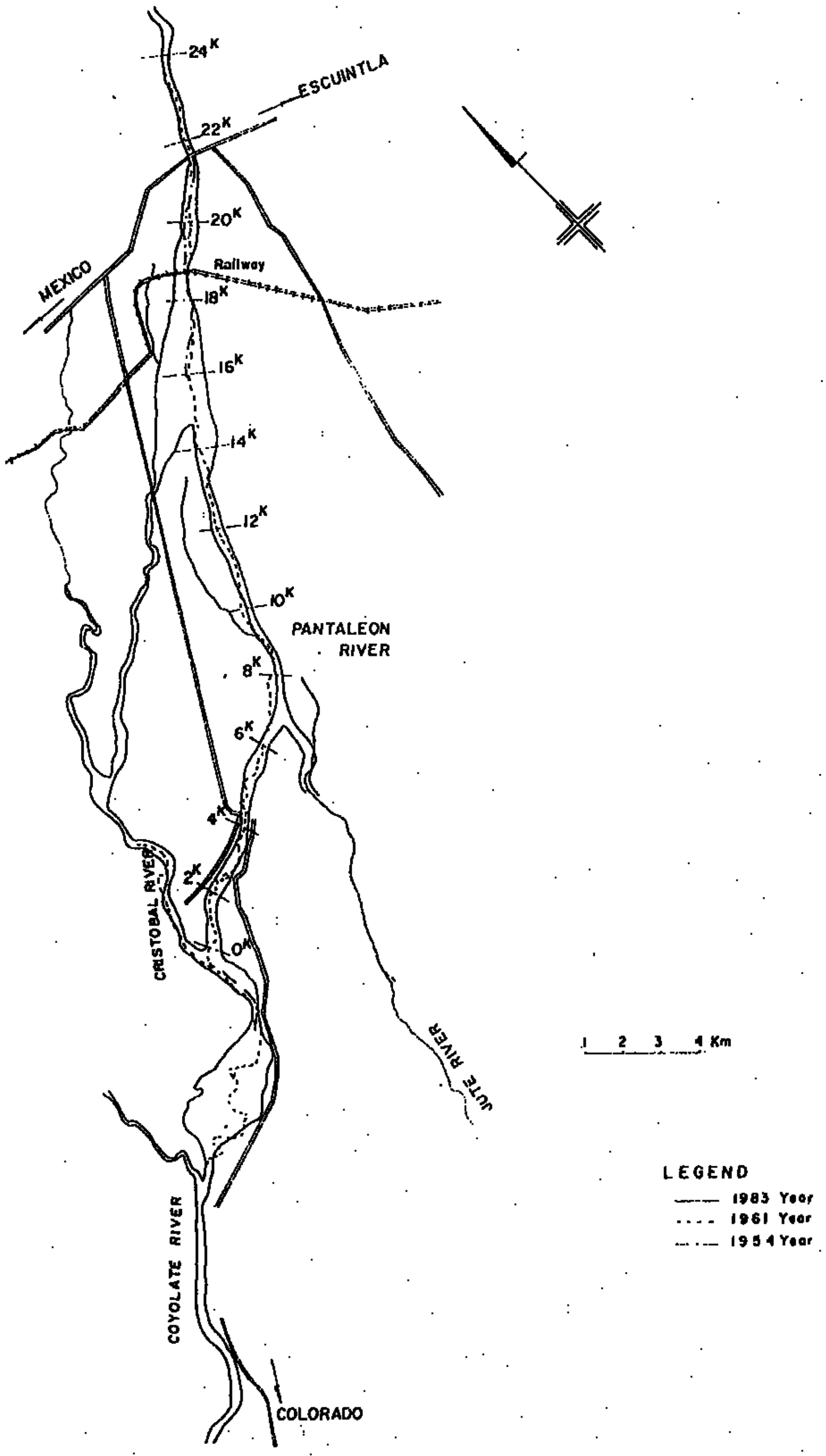


Fig. 4-6 (2/3) TRANSITION OF RIVER COURSE (PANTALEON RIVER)

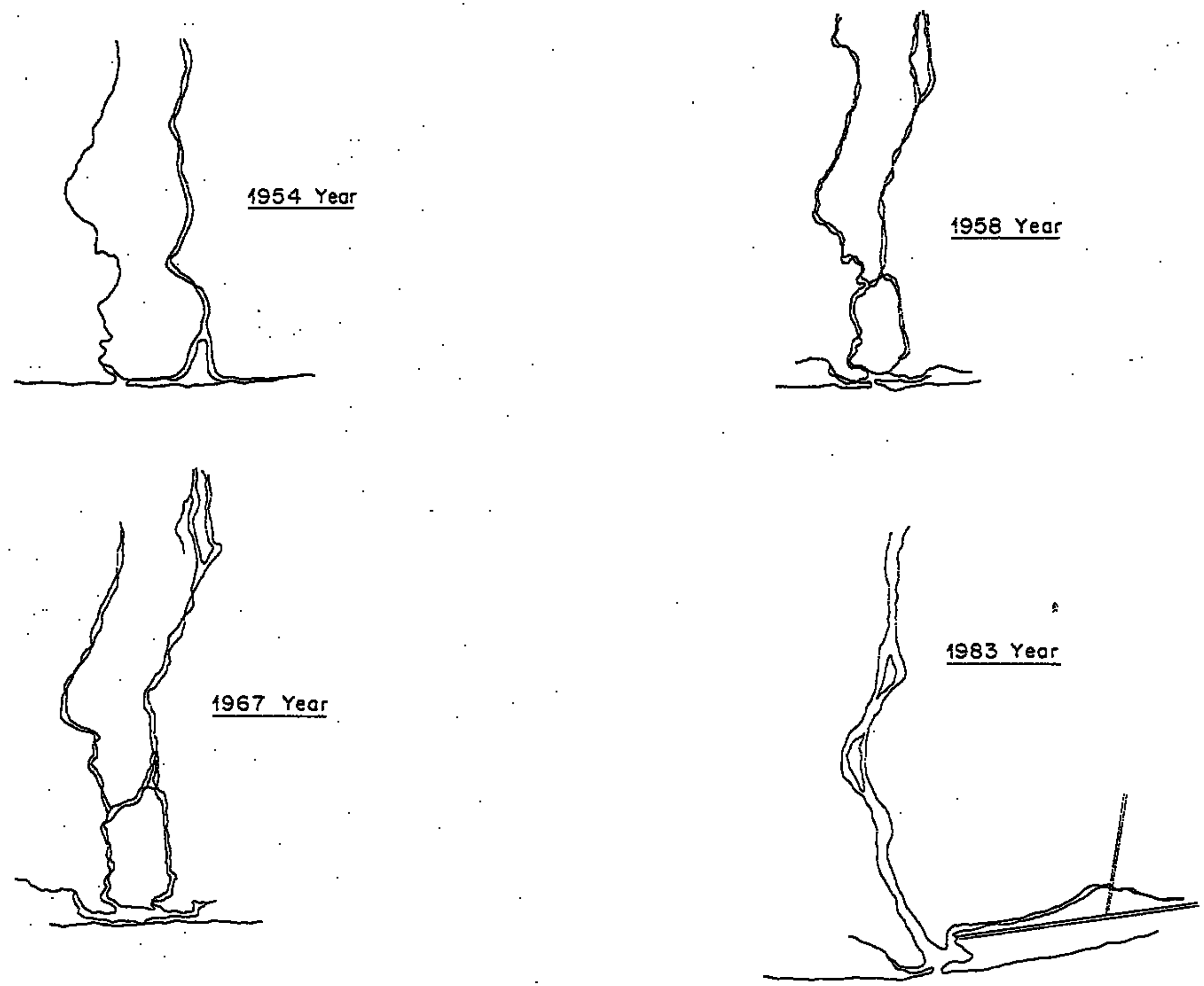


Fig. 4-6 (3/3) TRANSITION OF RIVER COURSE (ACHIGUATE RIVER)

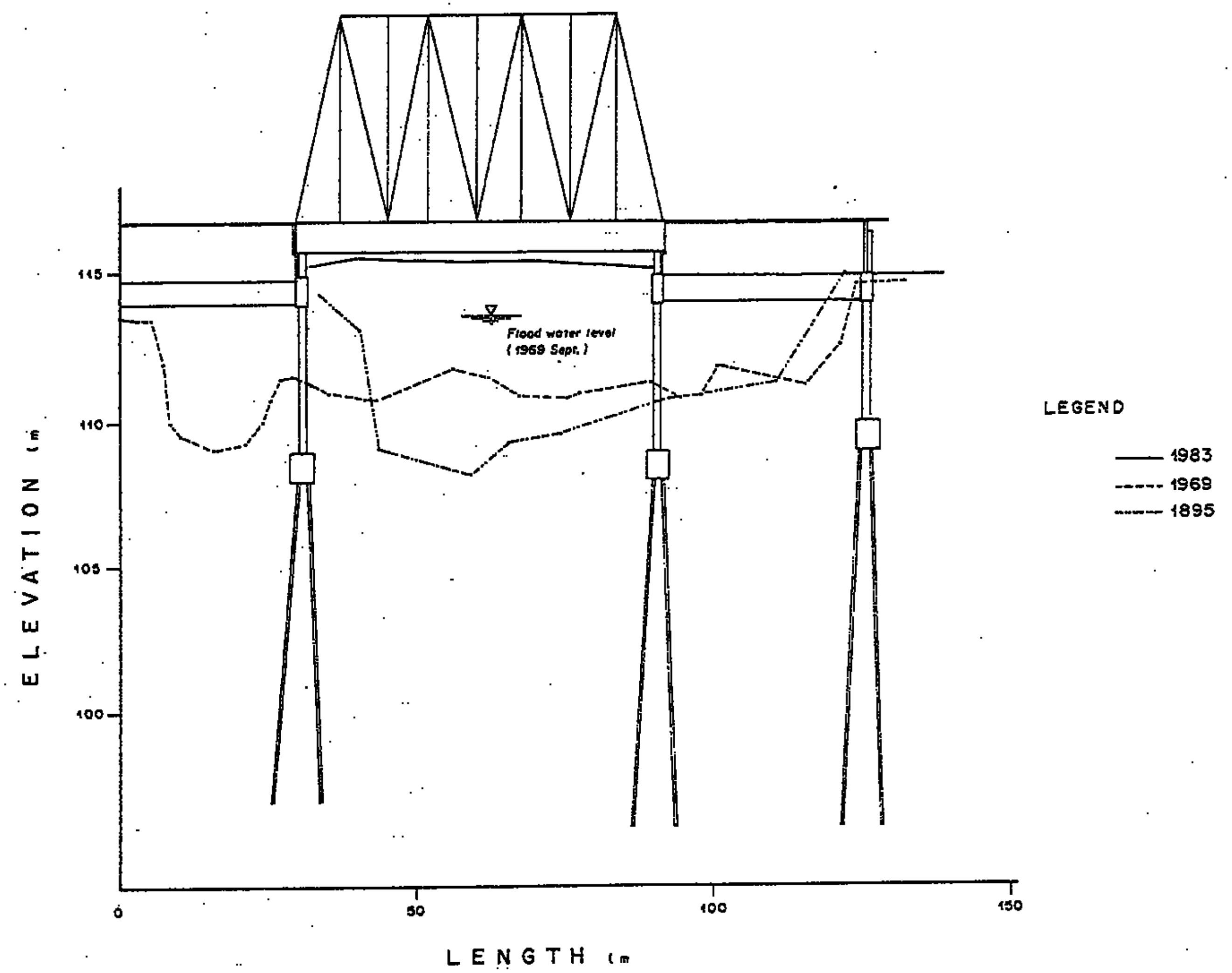


Fig. 4-7 TRANSITION OF CROSS SECTION AT RAILWAY BRIDGE IN ACHIGUATE

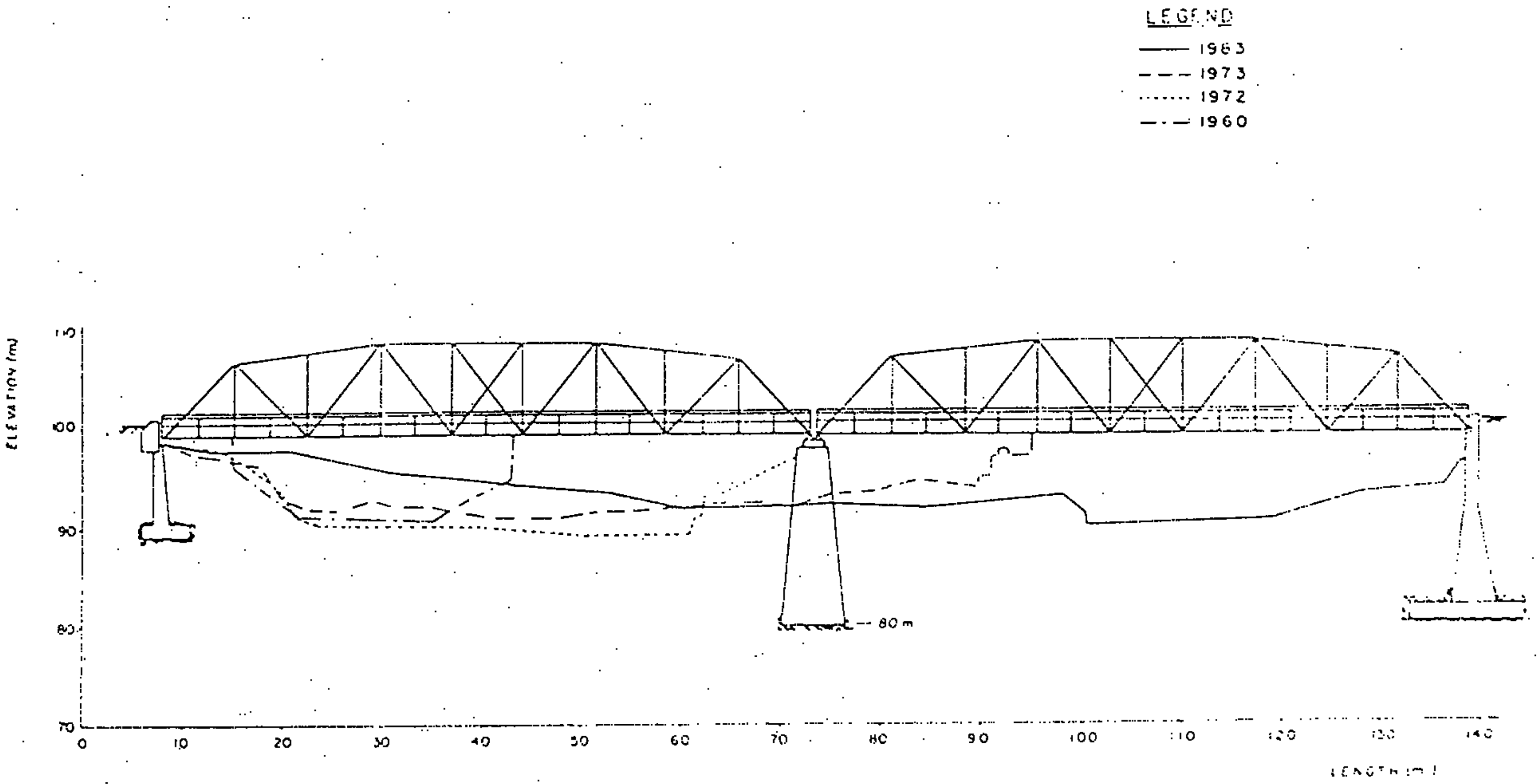


Fig. 4-8 TRANSITION OF CROSS SECTION AT ROAD BRIDGE IN PANTALEON

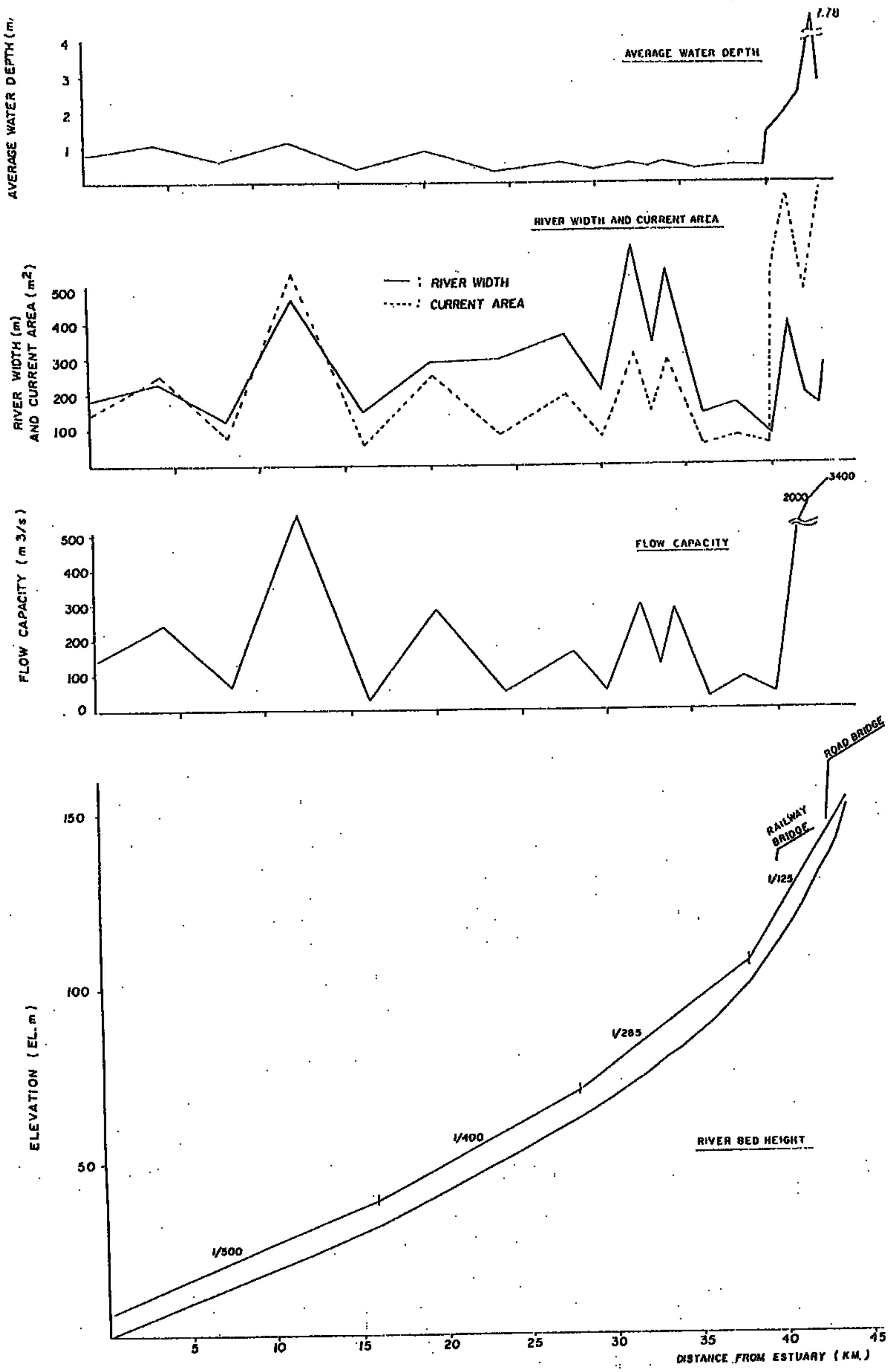


Fig. 4-9 (1/2) FEATURES OF RIVER (ACHIGUATE RIVER)

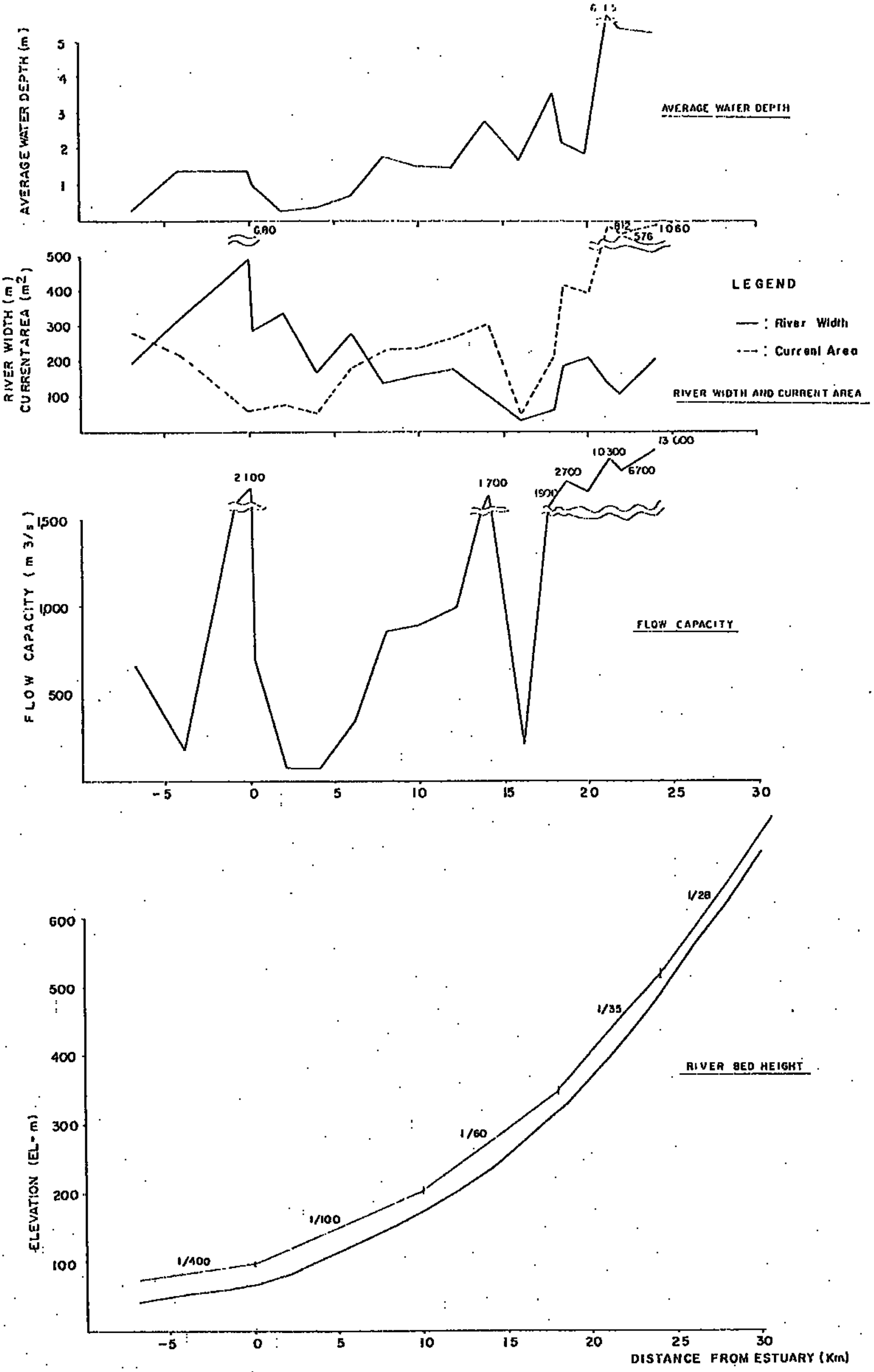
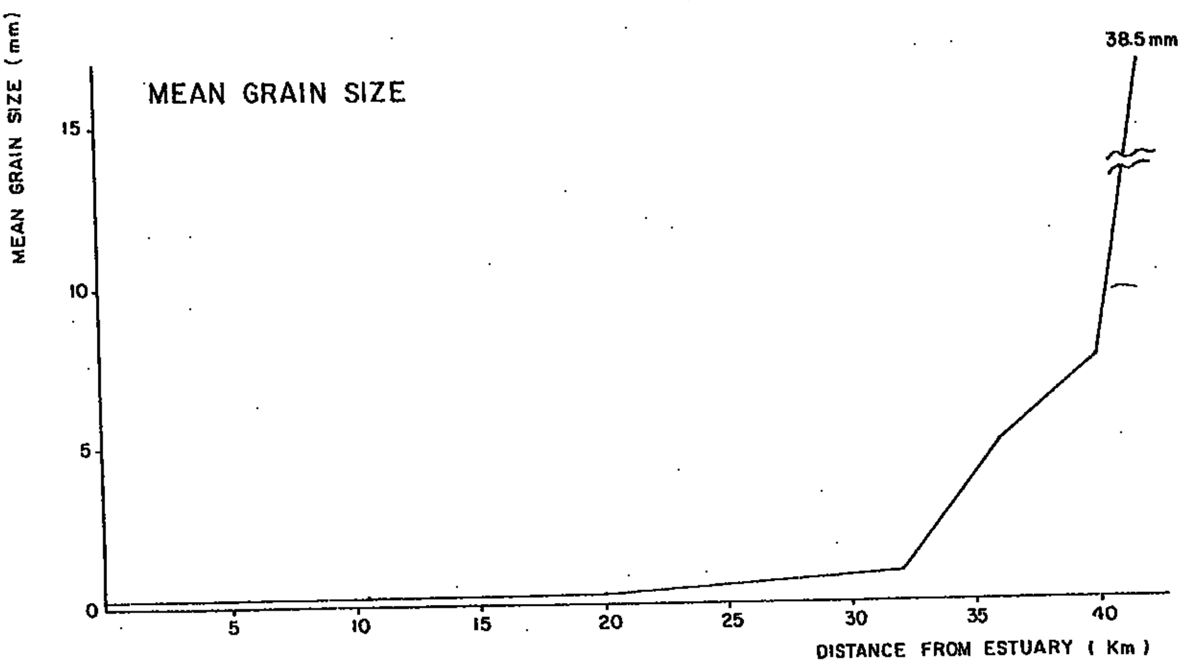


Fig. 4-9 (2/2) FEATURES OF RIVER (PANTALEON RIVER)



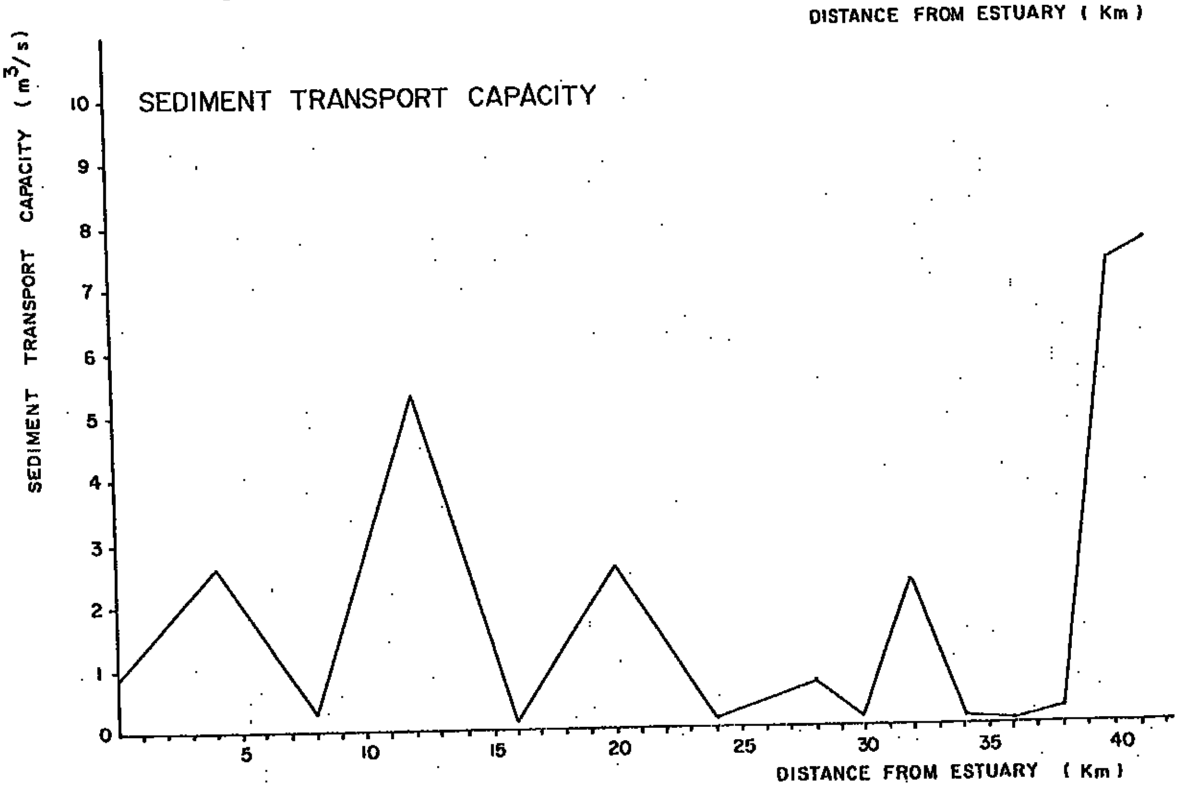


Fig. 4-10 (1/2) SEDIMENT TRANSPORT CAPACITY AND MEAN SIZE OF RIVER BED MATERIALS (ACHIGUATE RIVER)

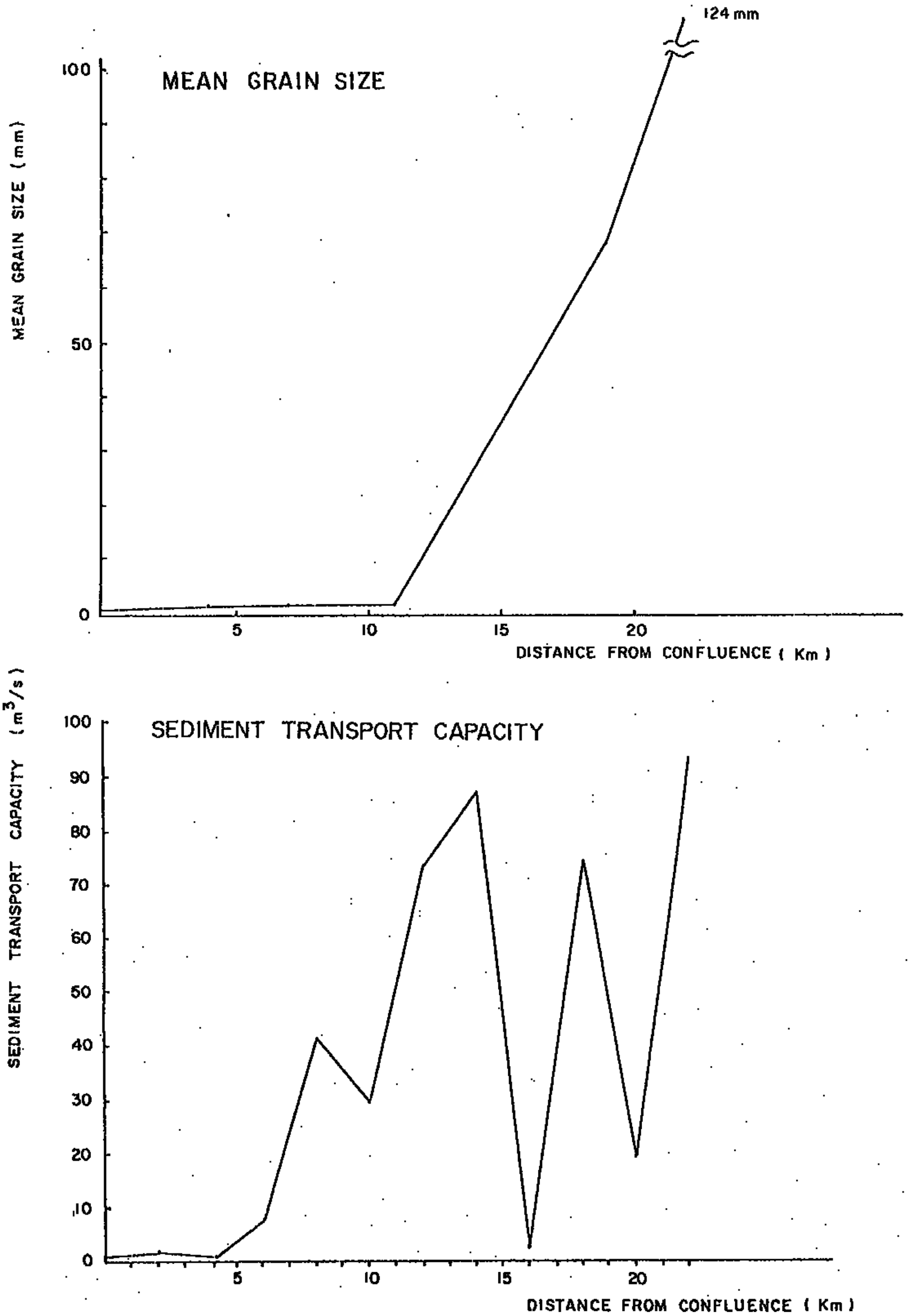


Fig. 4-10 (2/2) SEDIMENT TRANSPORT CAPACITY AND MEAN SIZE OF RIVER BED MATERIALS (PANTALEON RIVER)

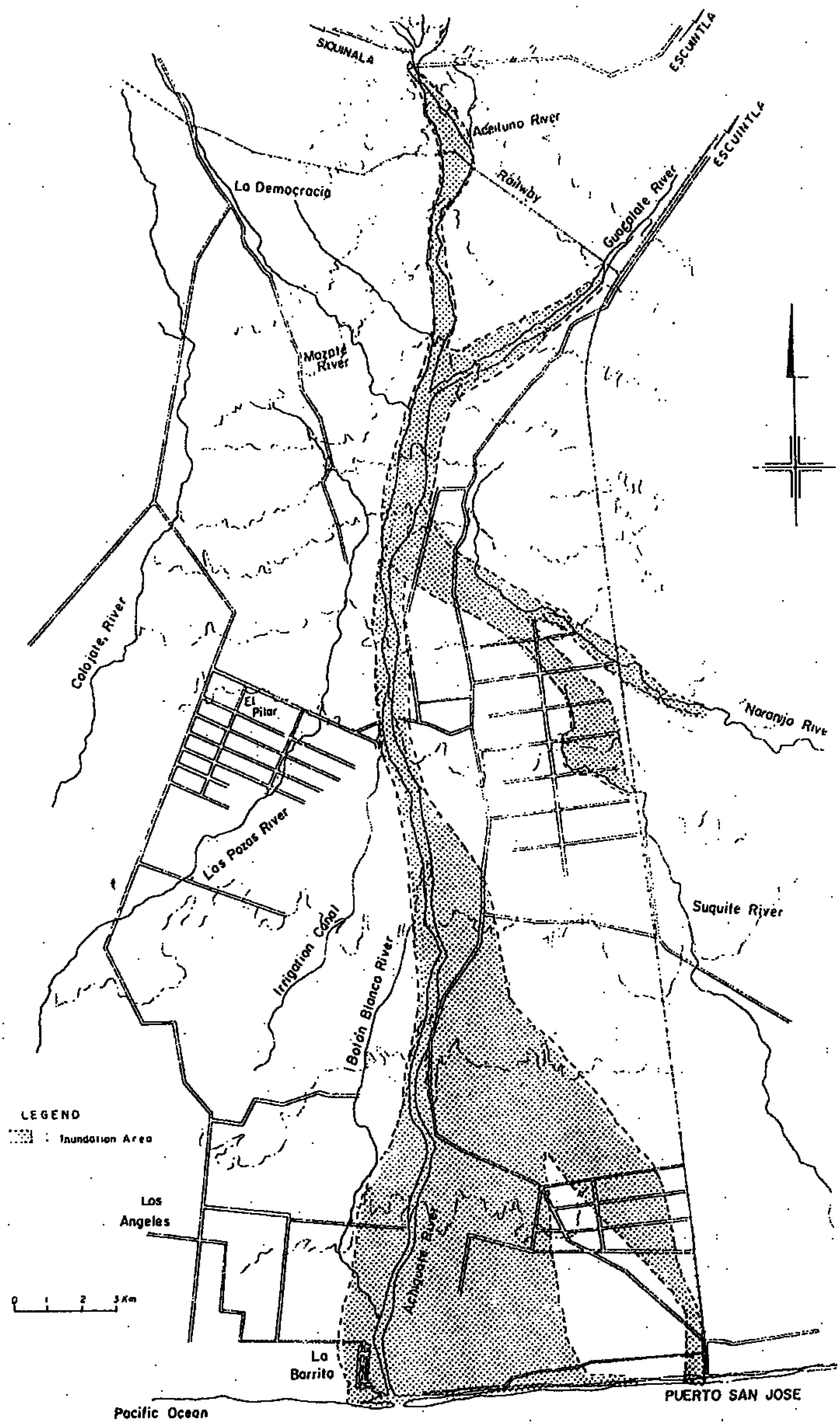


Fig. 4-11 (1/2) INUNDATION MAP OF THE FLOOD IN SEPTEMBER 1969 (ACHIGUATE RIVER)

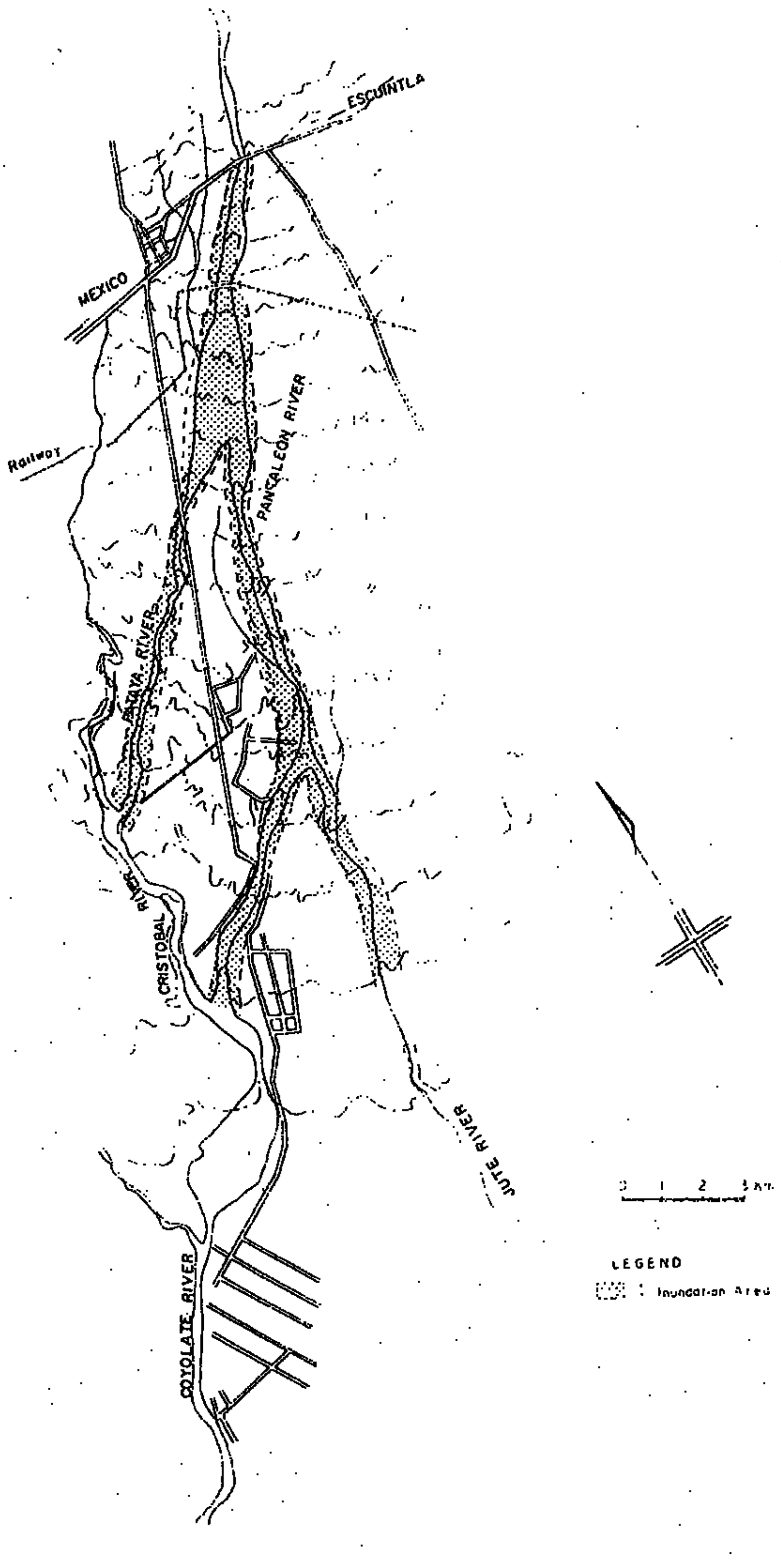


Fig. 4-11 (2/2) INUNDATION MAP OF THE FLOOD IN SEPTEMBER 1969 (PANTALEON RIVER)

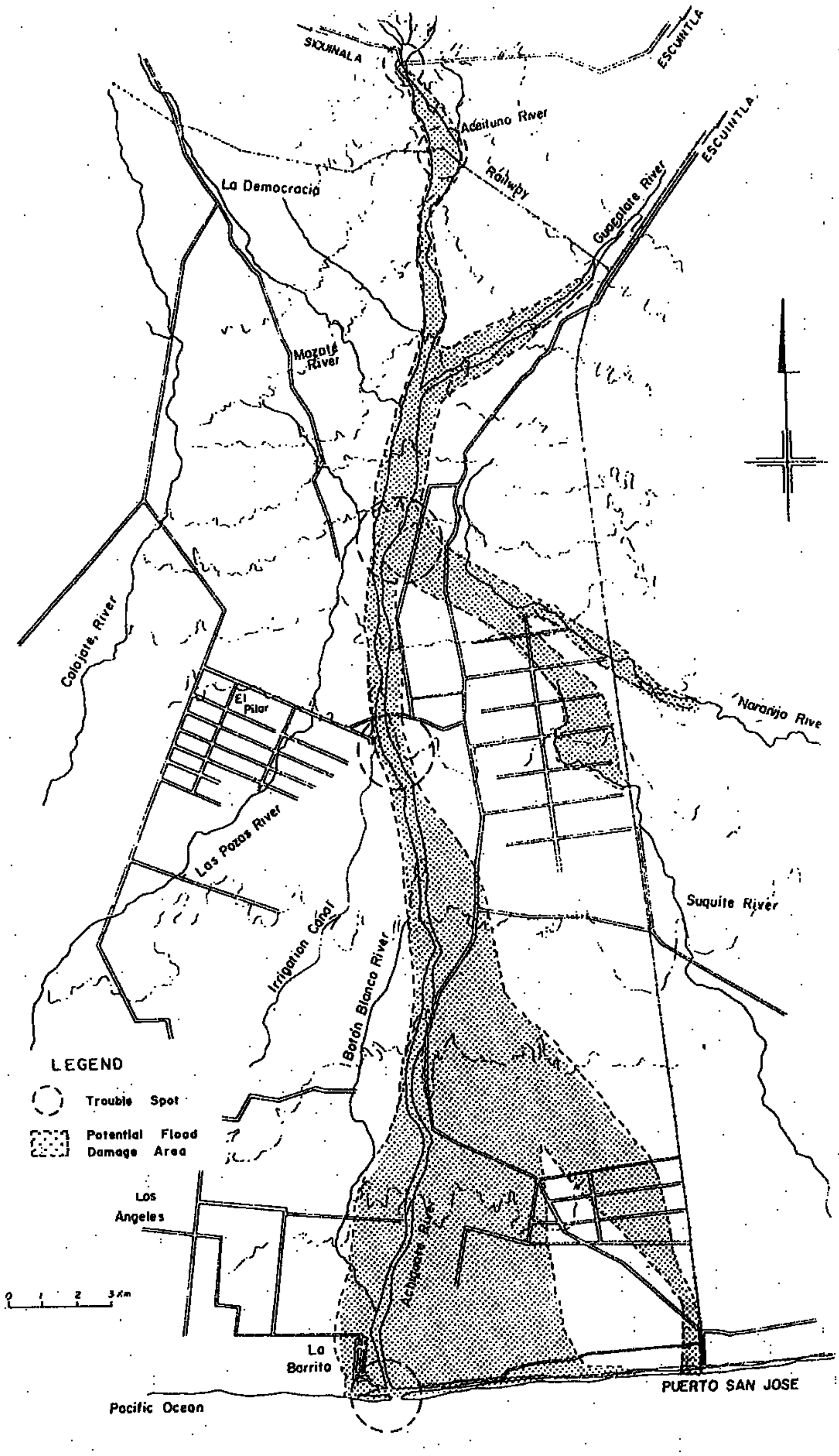


Fig. 4-12 (1/2) TROUBLE SPOT (ACHIGUATE RIVER)

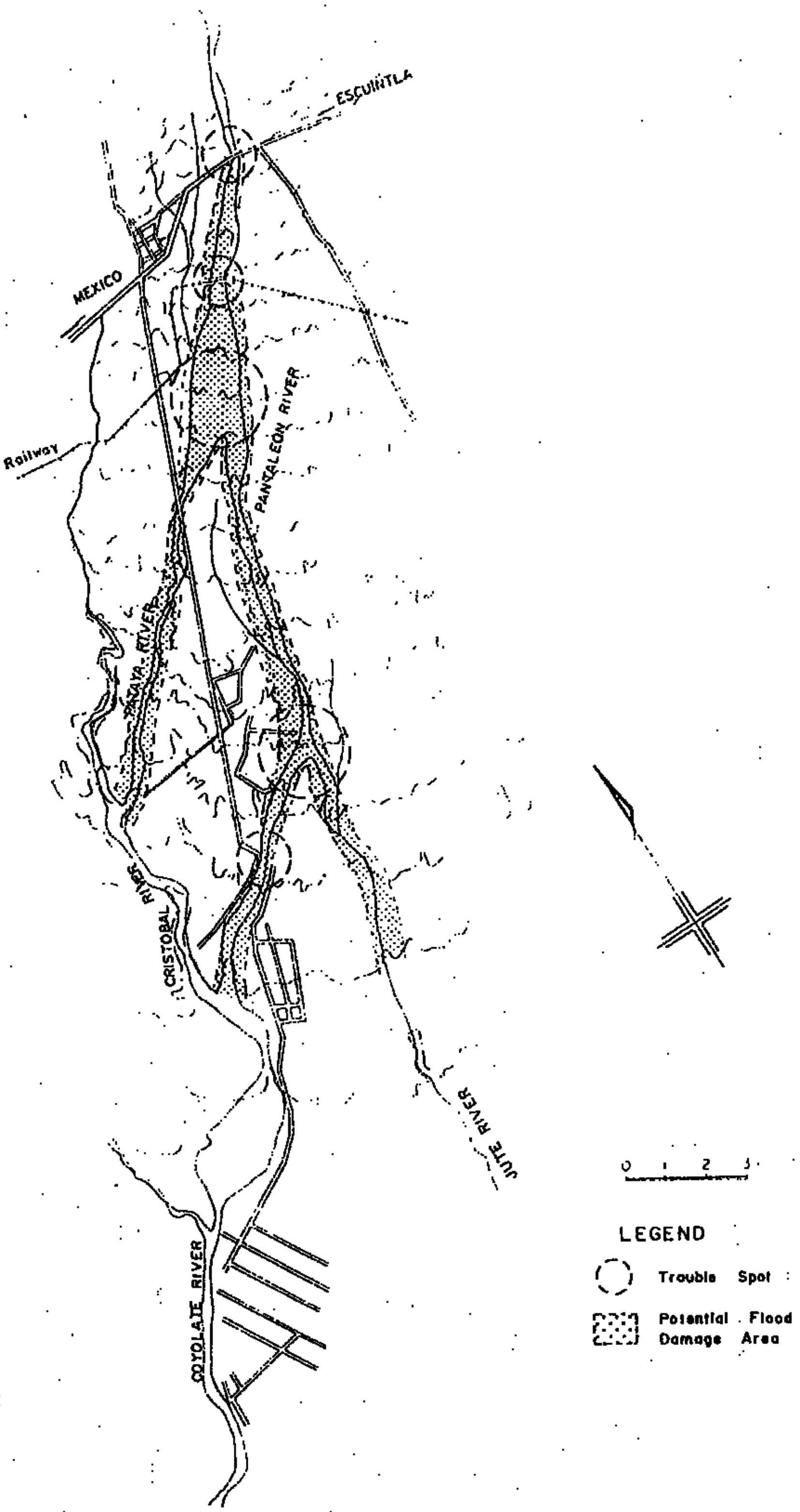


Fig. 4-12 (2/2) TROUBLE SPOT (PANTALEON RIVER)

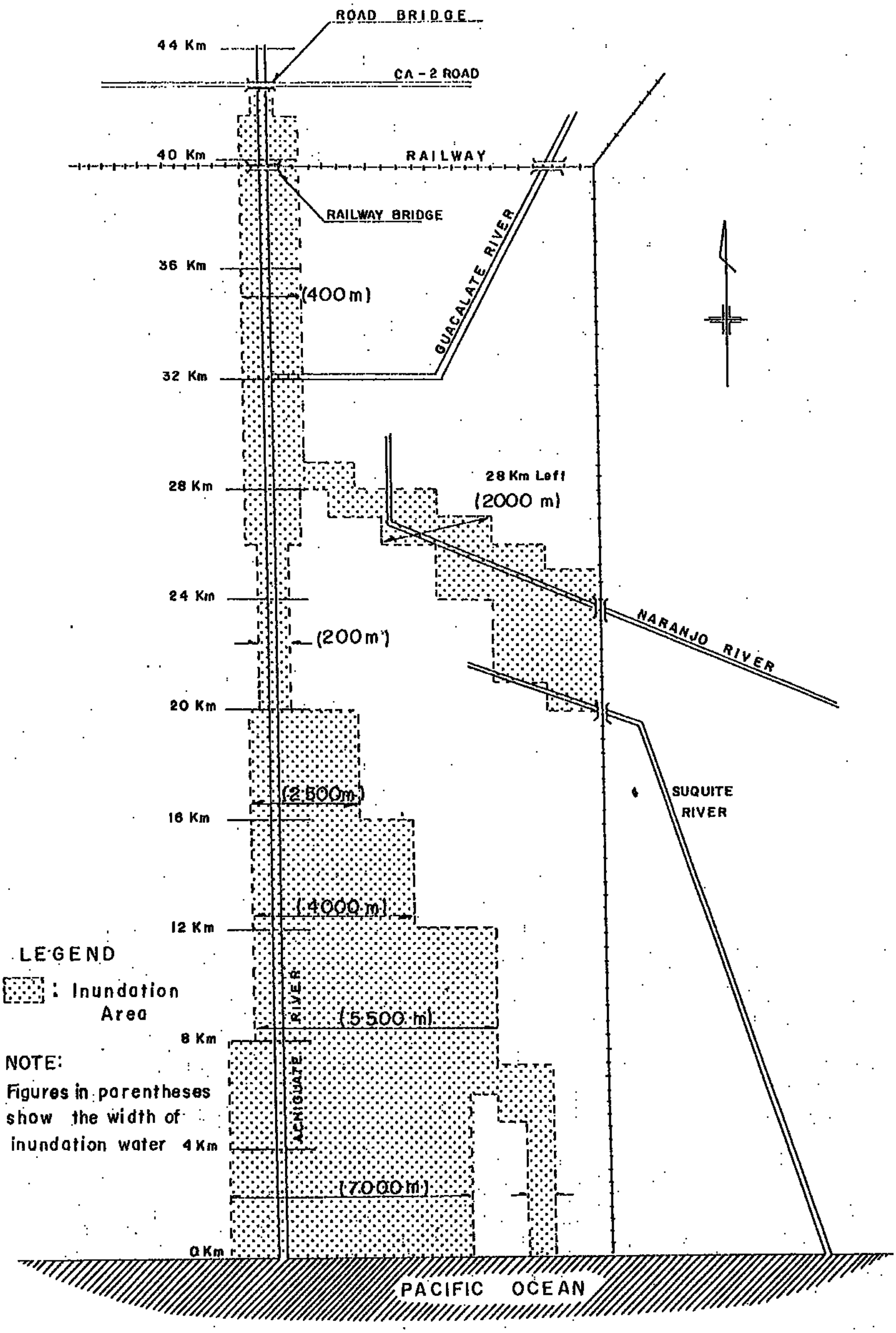


Fig. 4-13 (1/2) SIMULATION MODEL (ACHIGUATE RIVER)

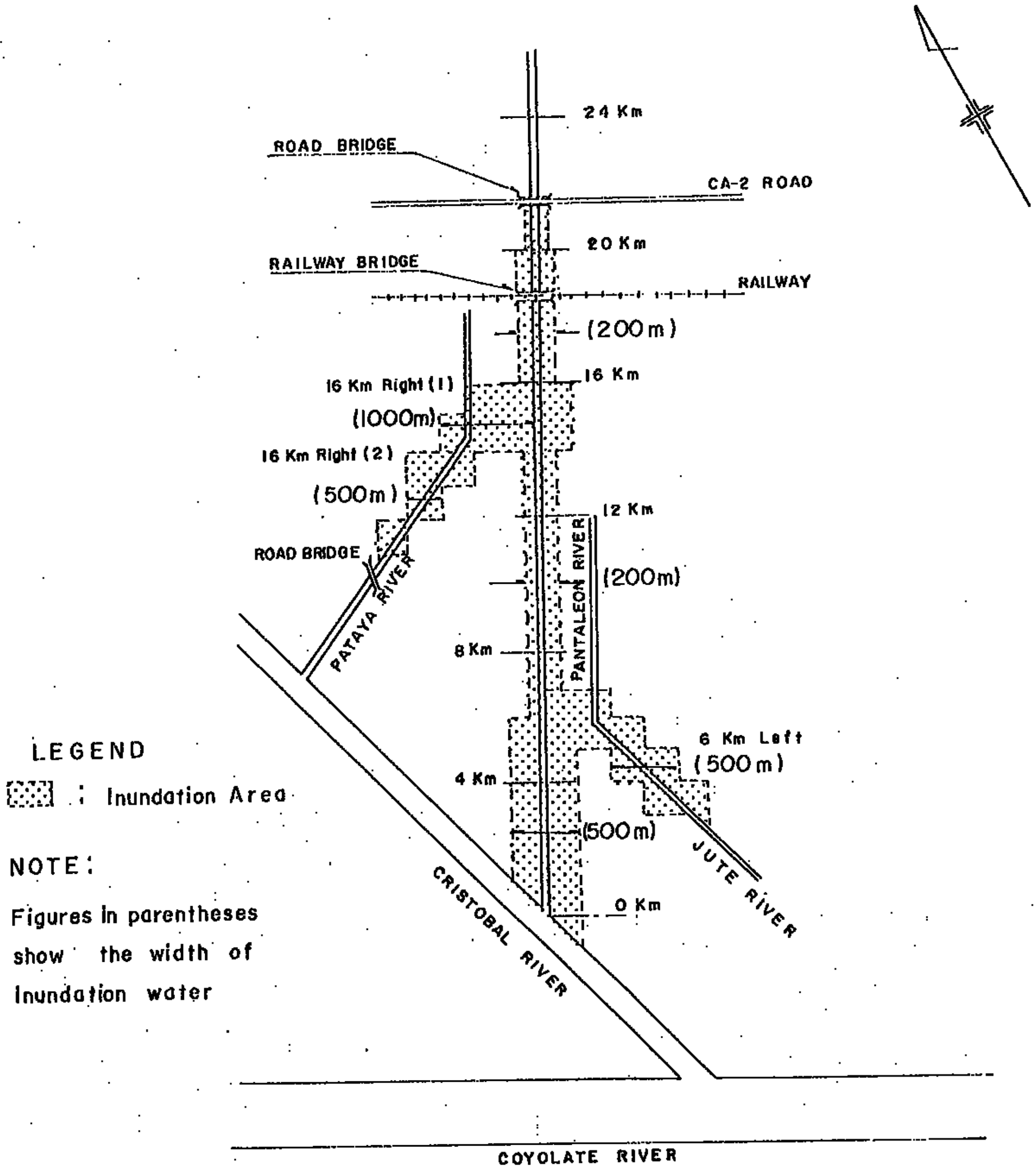


Fig. 4-13 (2/2) SIMULATION MODEL (PANTALEON RIVER)

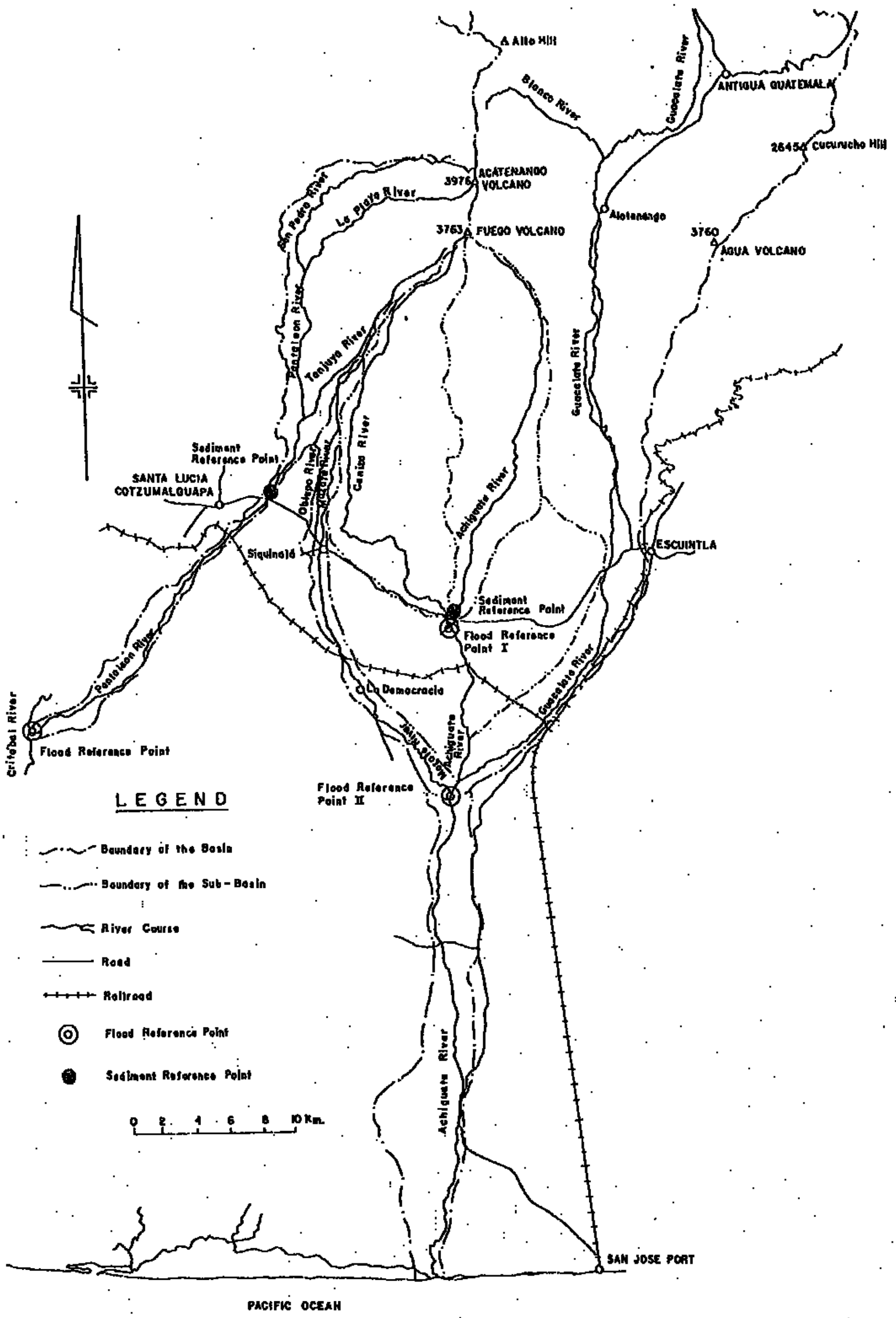


Fig. 4-14 LOCATION OF REFERENCE POINTS

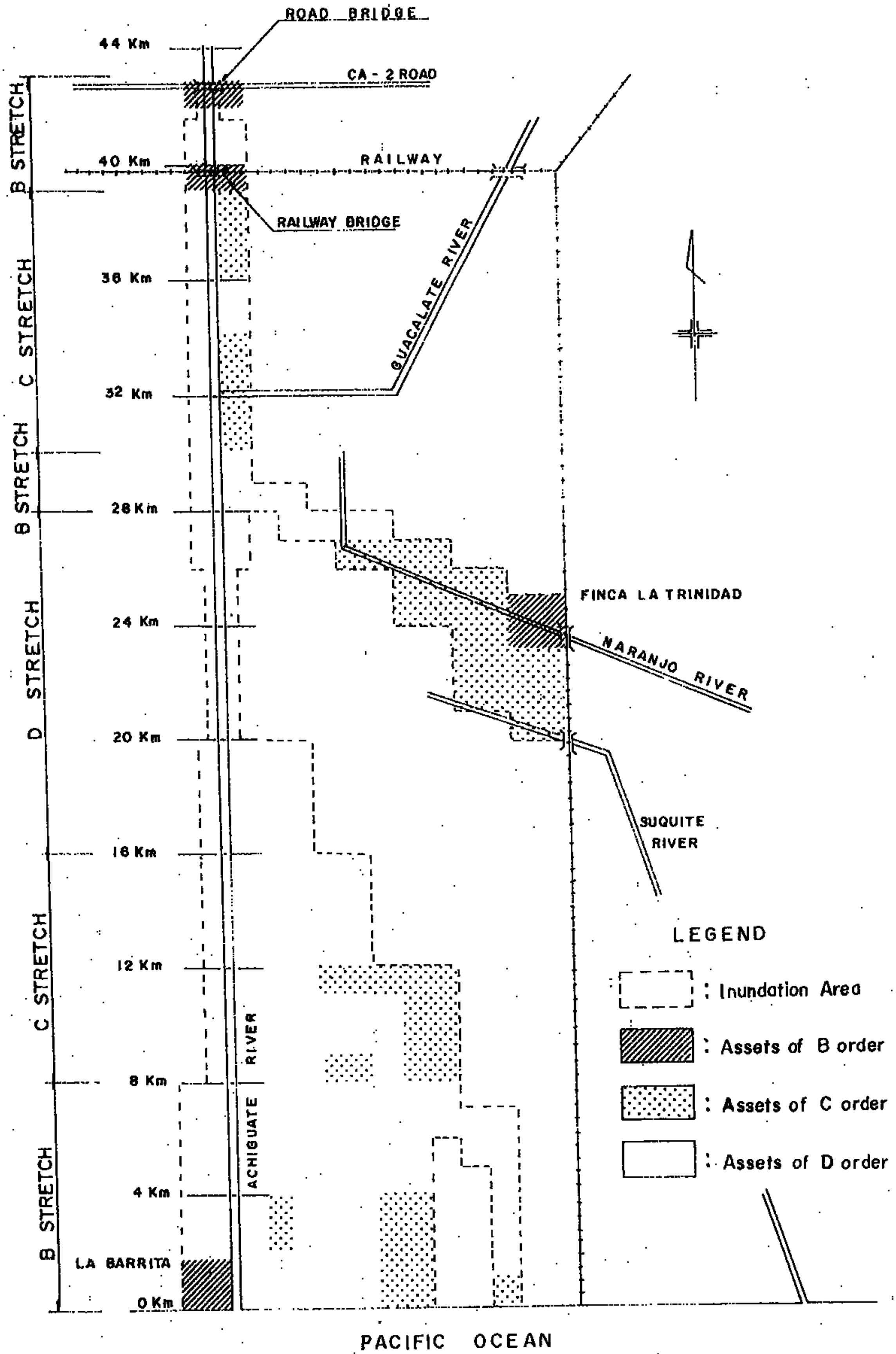


Fig. 4-15 (1/2) CLASSIFICATION OF ASSETS (ACHIGUATE RIVER BASIN)

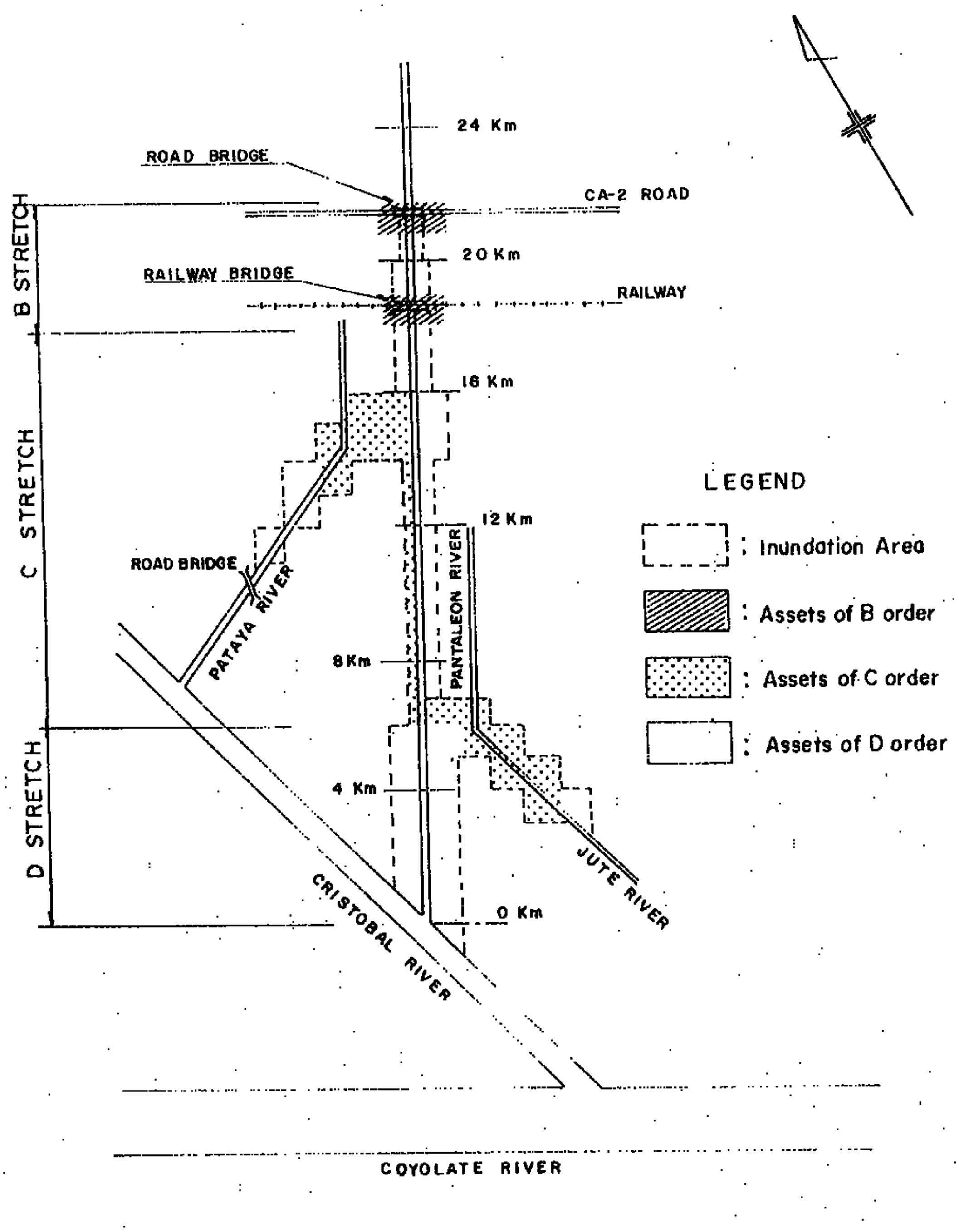


Fig. 4-15 (2/2) CLASSIFICATION OF ASSETS (PANTALEON RIVER BASIN)

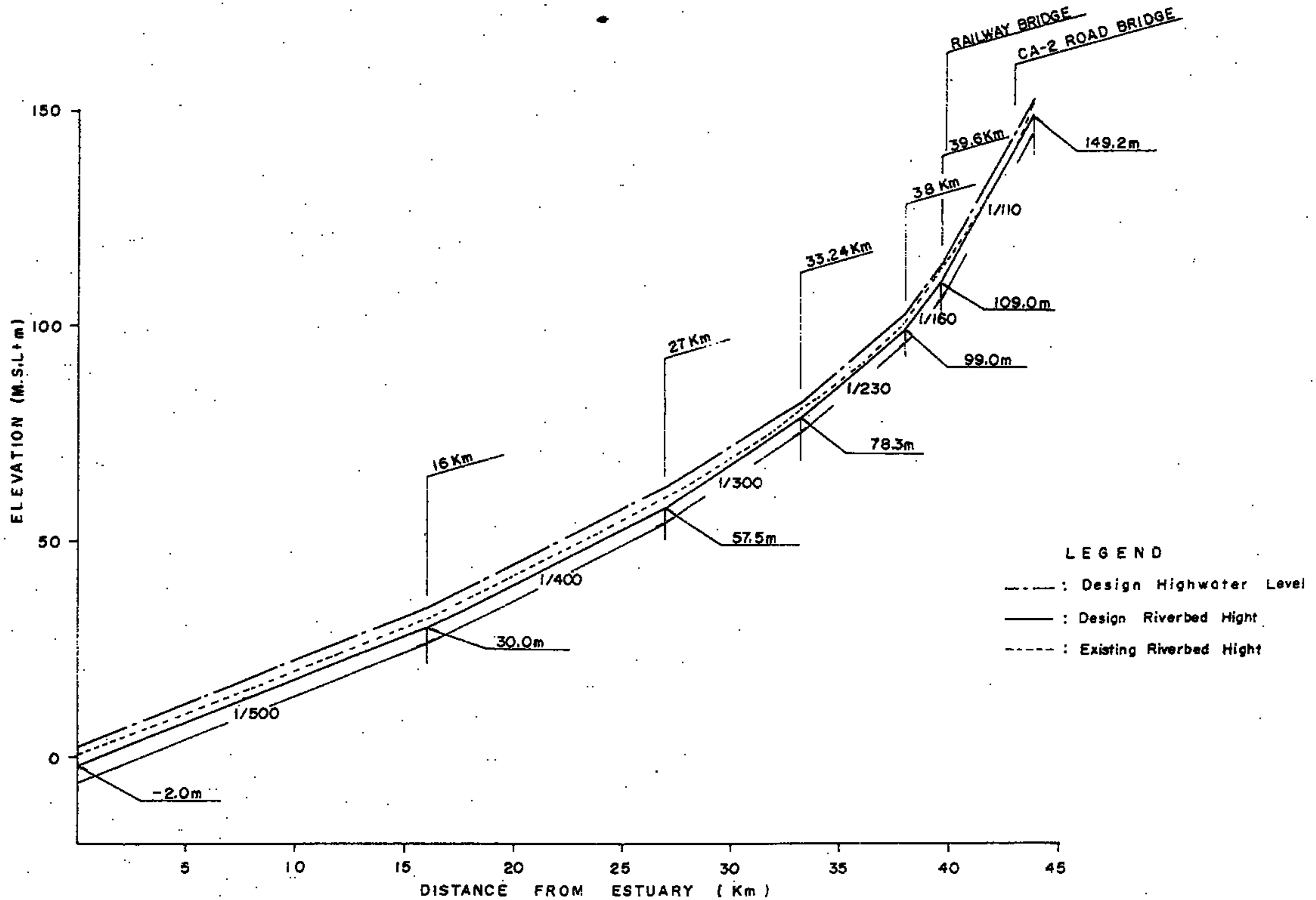


Fig. 4-16 (1/2) LONGITUDINAL PROFILE (ACHIGUATE RIVER)

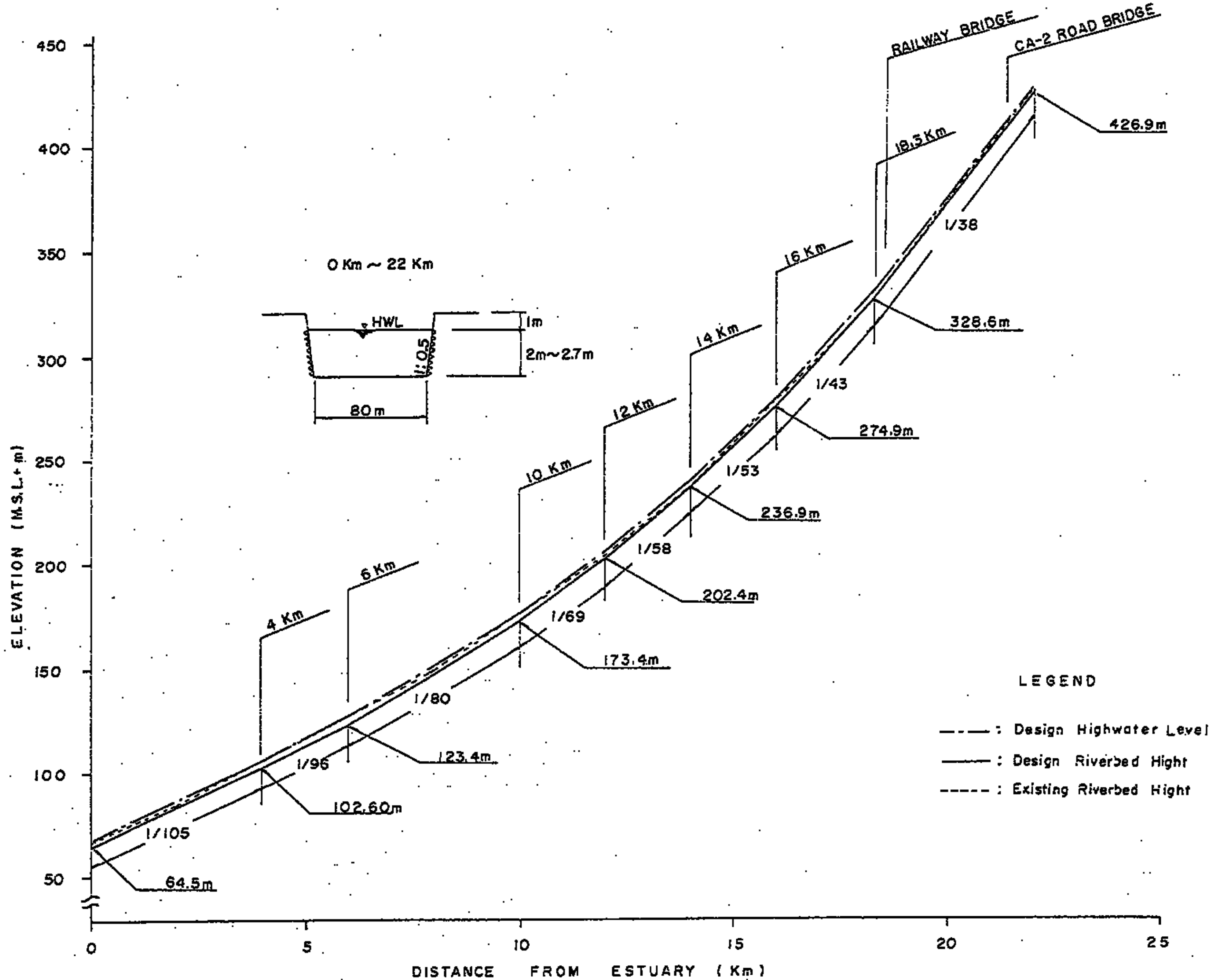


Fig. 4-16 (2/2) LONGITUDINAL PROFILE (PANTALEON RIVER)

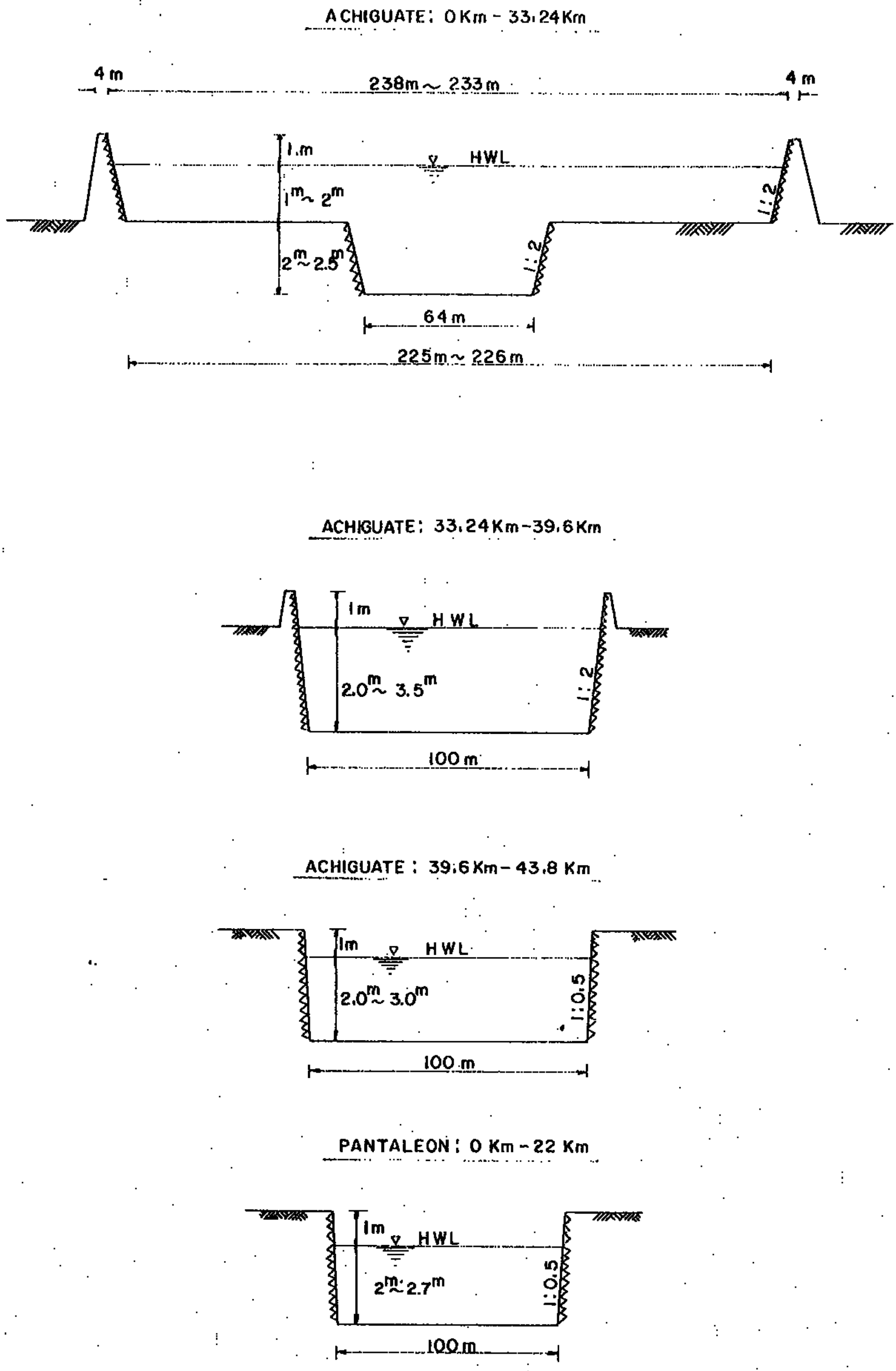


Fig. 4-17 STANDARD CROSS SECTION

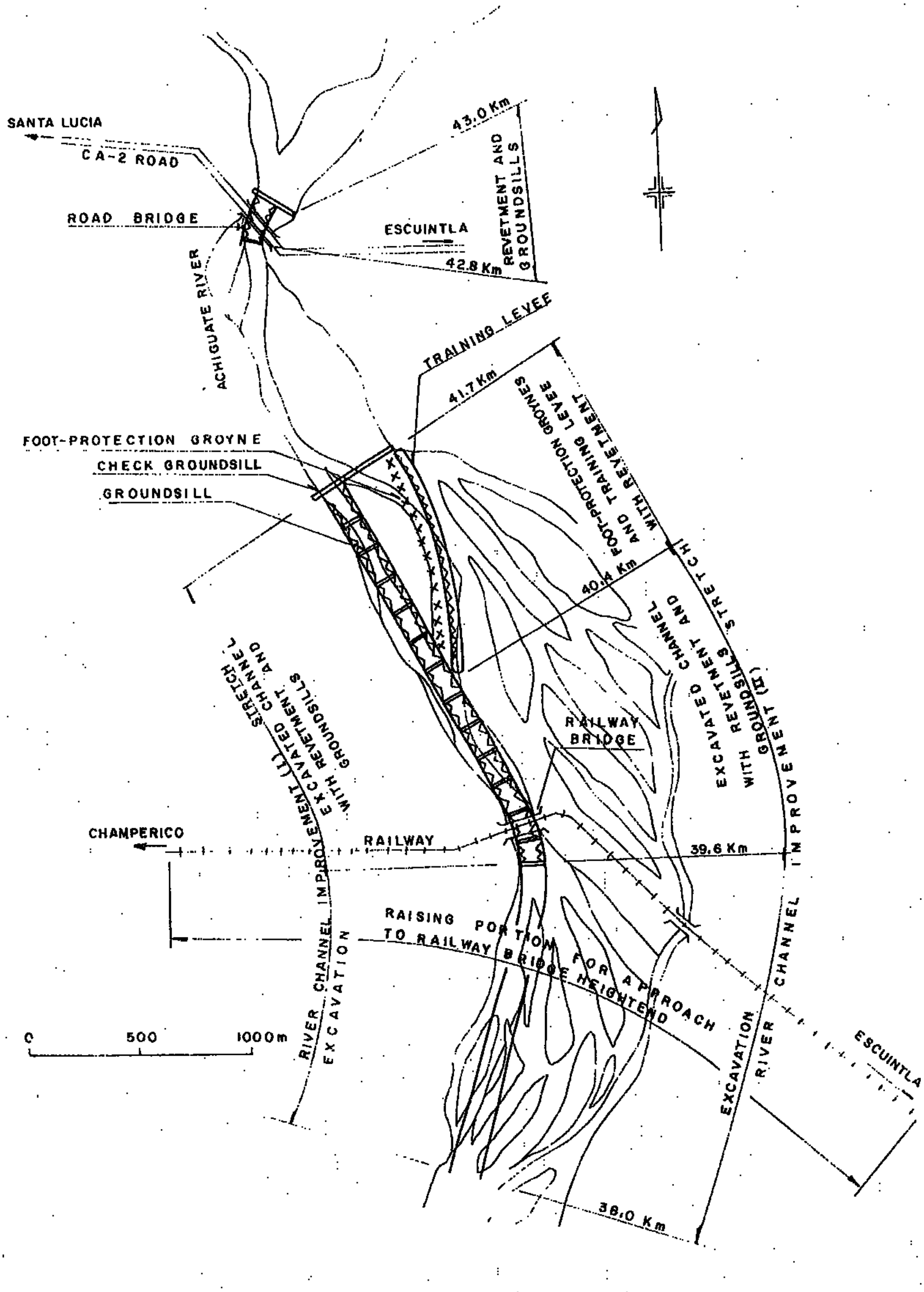


Fig. 4-18 (1/4) LOCATION OF ALTERNATIVE WORKS (ACHIGUATE RIVER, PROTECTION OF THE BRIDGE)

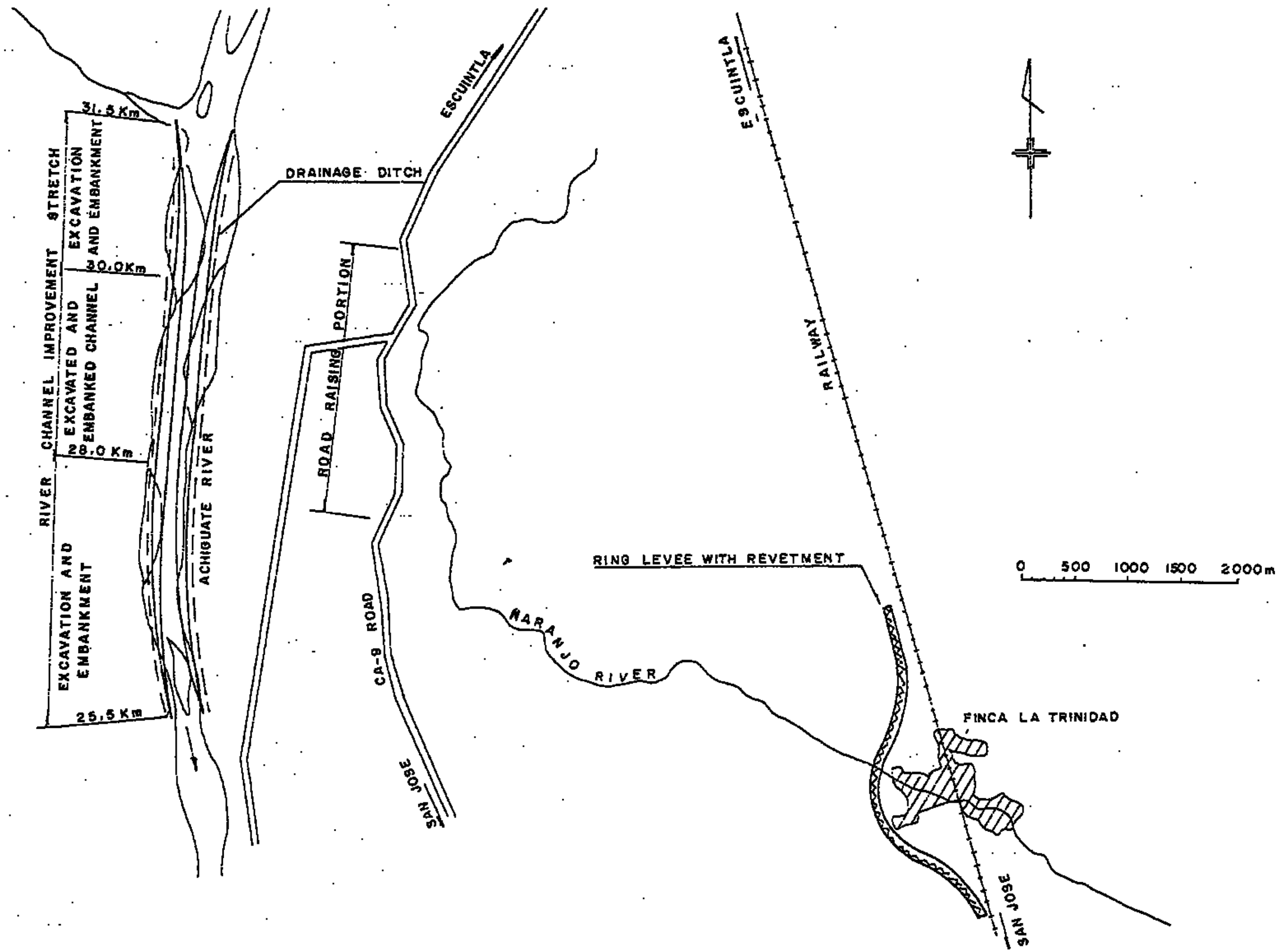


Fig. 4-18 (2/4) LOCATION OF ALTERNATIVE WORKS
(ACHIGUATE RIVER, PROTECTION OF FINCA LA TRINIDAD)

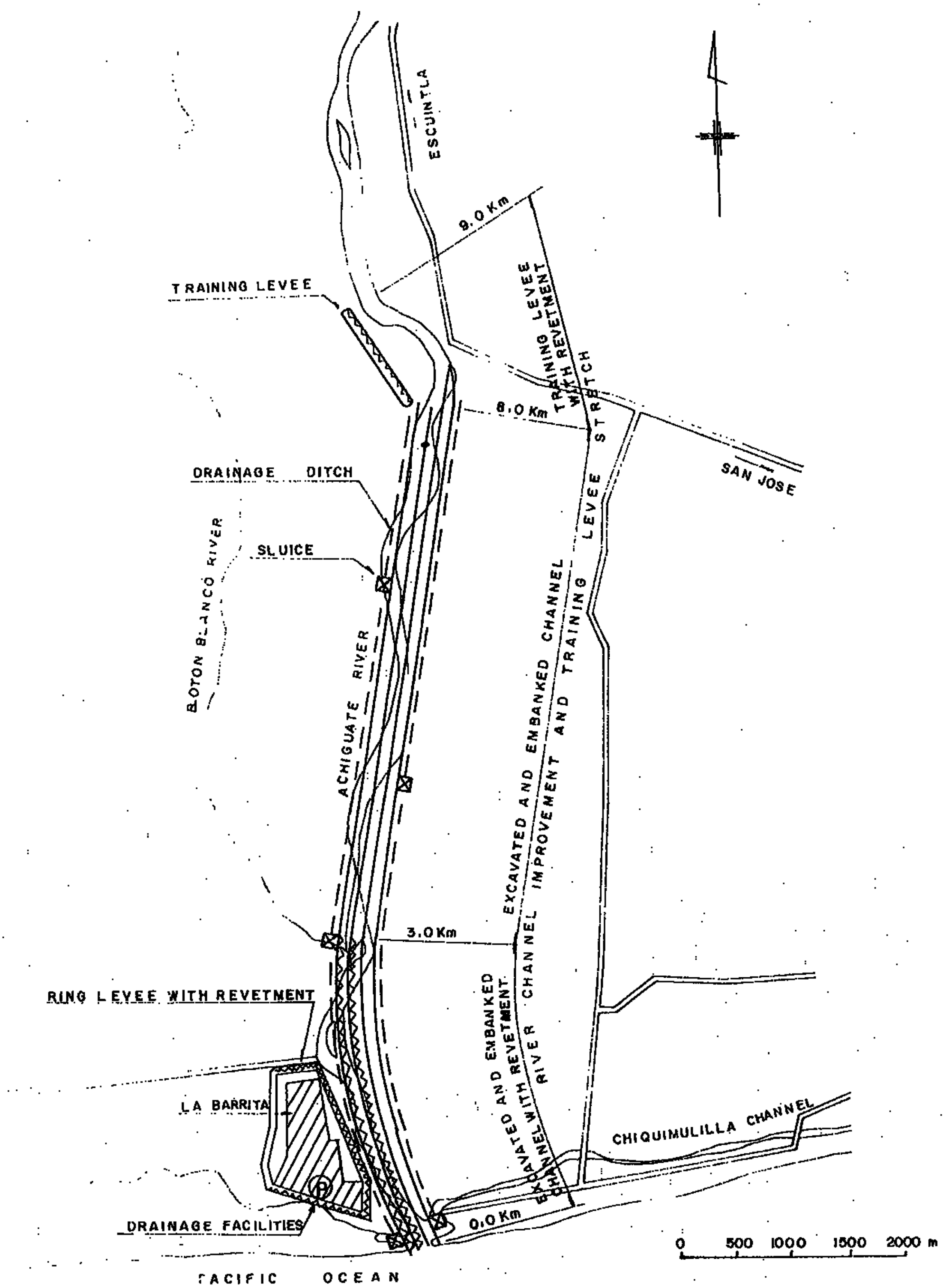


Fig. 4-18 (3/4) LOCATION OF ALTERNATIVE WORKS (ACHIGUATE RIVER, PROTECTION OF LA BARRITA)

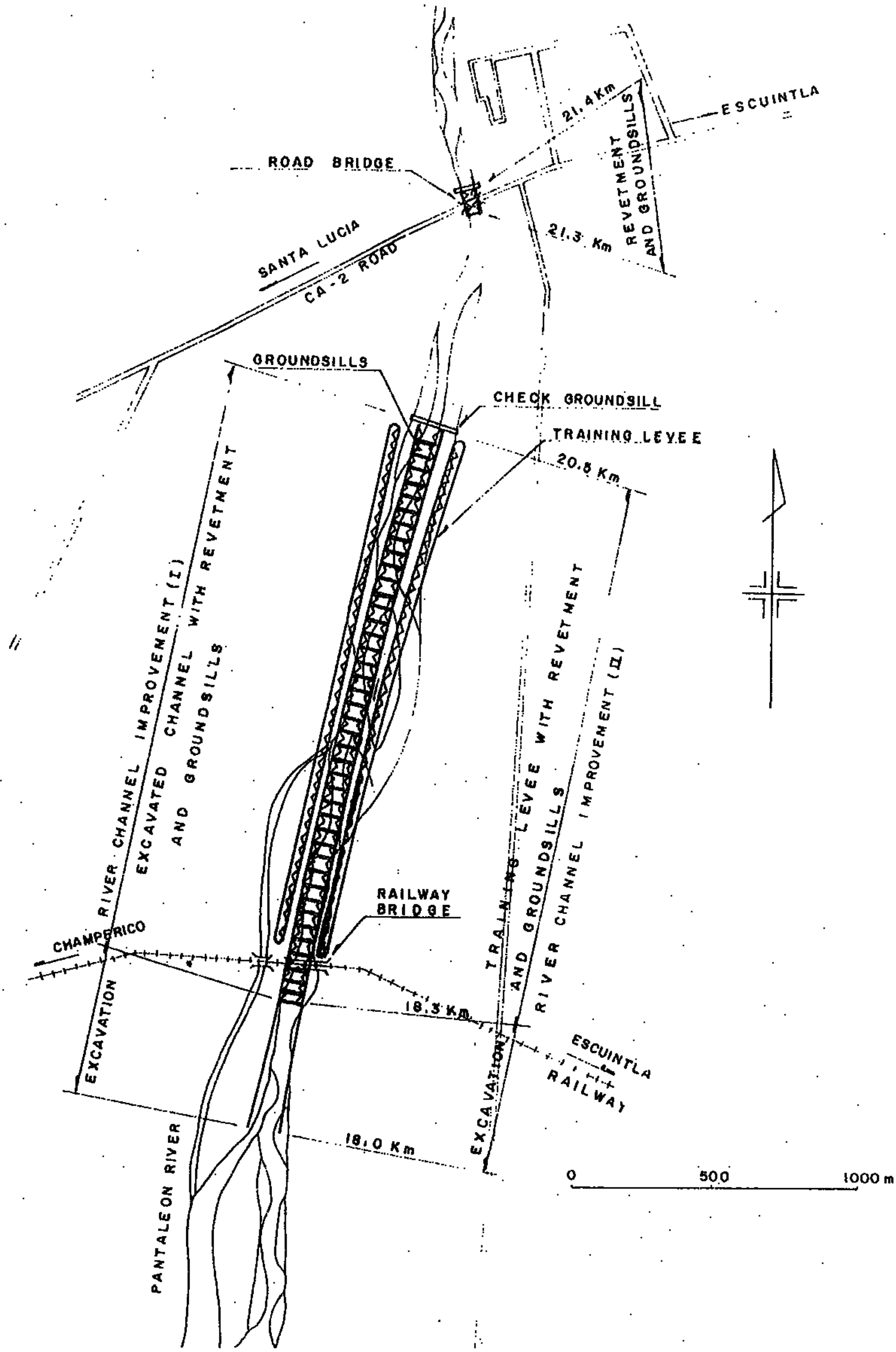
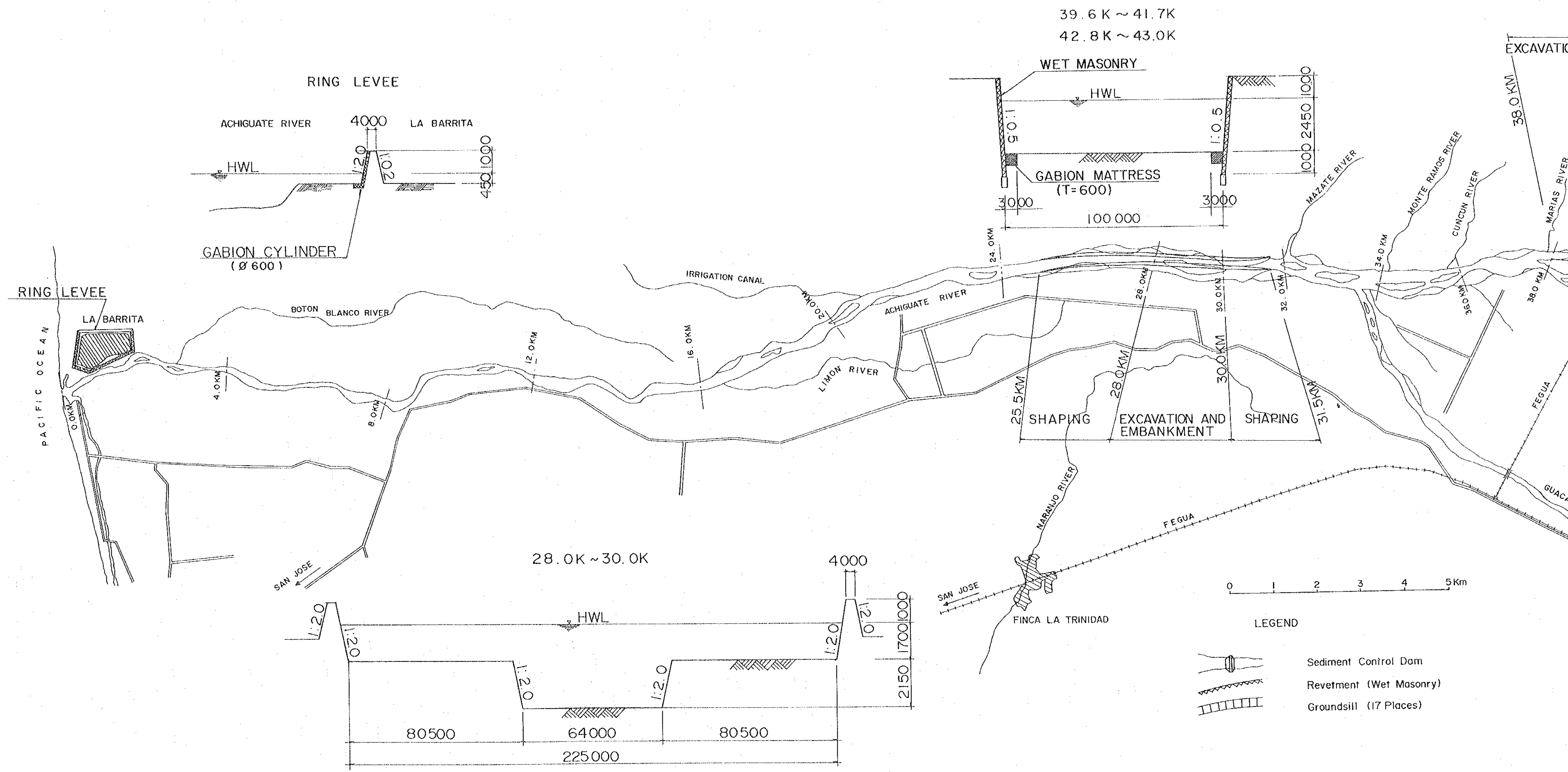
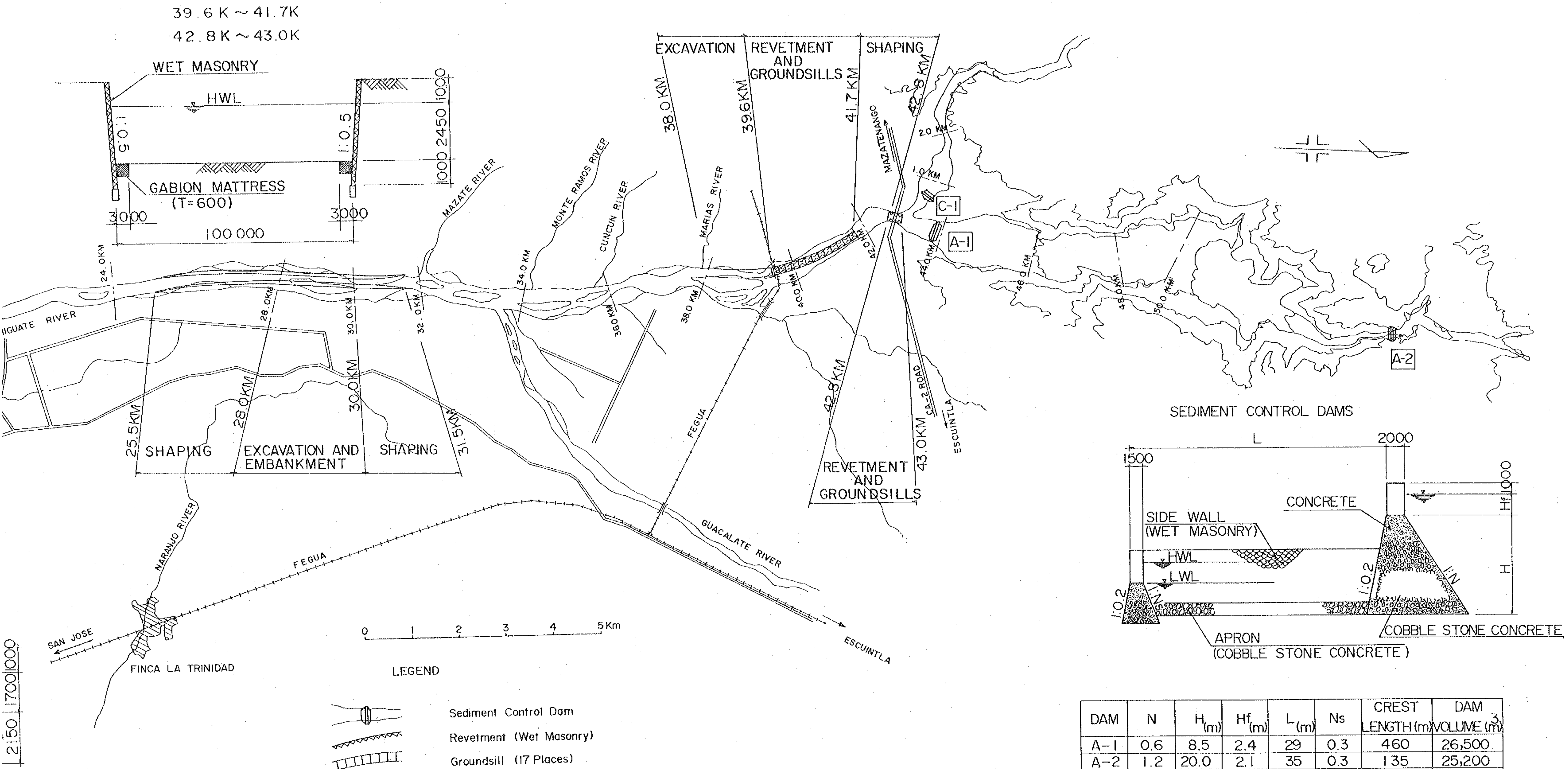


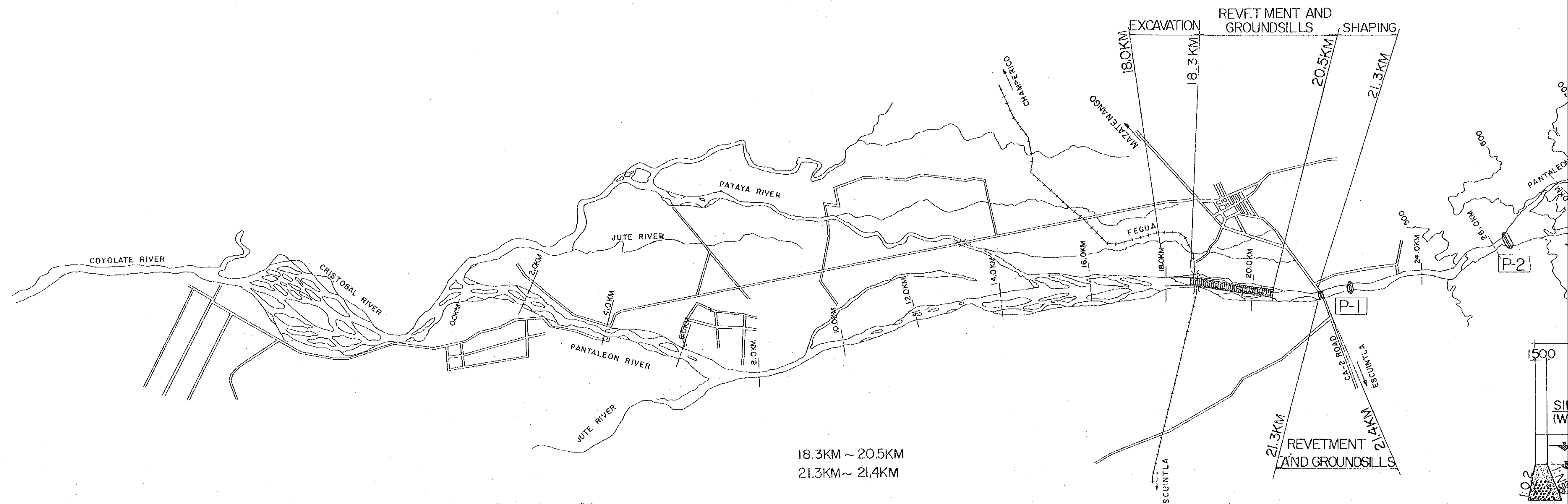
Fig. 4-18 (4/4) LOCATION OF ALTERNATIVE WORKS
(PANTALEON RIVER, PROTECTION OF THE BRIDGE)


39.6K ~ 41.7K
42.8K ~ 43.0K
WET MASONRY
HWL
1:0.5
1:0.5
GABION MATTRESS
(T=600)
3000
3000
100 000
1000 2450 1000
EXCAVATIO
RING LEVEE
ACHIGUATE RIVER
4000
LA BARRITA
HWL
1:2.0
1:0.2
1000
450
GABION CYLINDER
(Ø 600)
RING LEVEE
LA BARRITA
PACIFIC OCEAN
0.0KM
4.0KM
8.0KM
12.0KM
16.0KM
20.0KM
24.0KM
28.0KM
30.0KM
32.0KM
34.0KM
36.0KM
38.0KM
38.0KM
BOTON BLANCO RIVER
IRRIGATION CANAL
ACHIGUATE RIVER
LIMON RIVER
MAZATE RIVER
MONTE RAMOS RIVER
CUNCUN RIVER
MARIAS RIVER
NARANJO RIVER
25.5KM
28.0KM
30.0KM
31.5KM
SHAPING
EXCAVATION AND EMBANKMENT
SHAPING
FEGUA
FEGUA
GUACA
SAN JOSE
SAN JOSE
FINCA LA TRINIDAD
0 1 2 3 4 5Km
LEGEND
Sediment Control Dam
Revetment (Wet Masonry)
Groundsill (17 Places)
28.0K ~ 30.0K
4000
HWL
1:2.0
1:2.0
1:2.0
1:2.0
1:2.0
1:2.0
1000
1700
2150
80500
64000
80500
225000

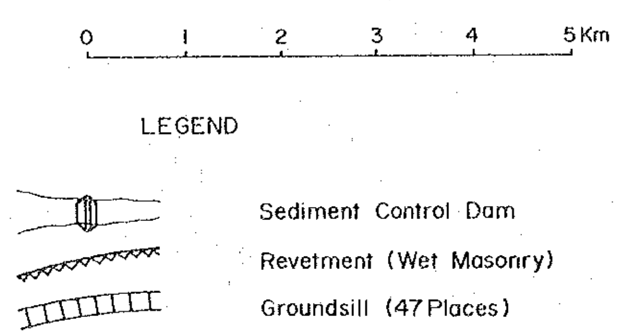


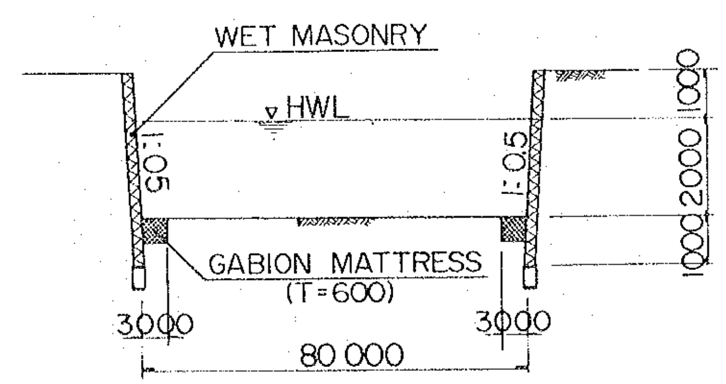
DAM	N	H(m)	Hf(m)	L(m)	Ns	CREST LENGTH (m)	DAM VOLUME (m^3)
A-1	0.6	8.5	2.4	29	0.3	460	26,500
A-2	1.2	20.0	2.1	35	0.3	135	25,200
C-1	0.6	8.5	2.1	29	0.2	455	23,200

Fig. 4-19 (1/2) PROPOSED PLAN (ACHIGUATE RIVER)

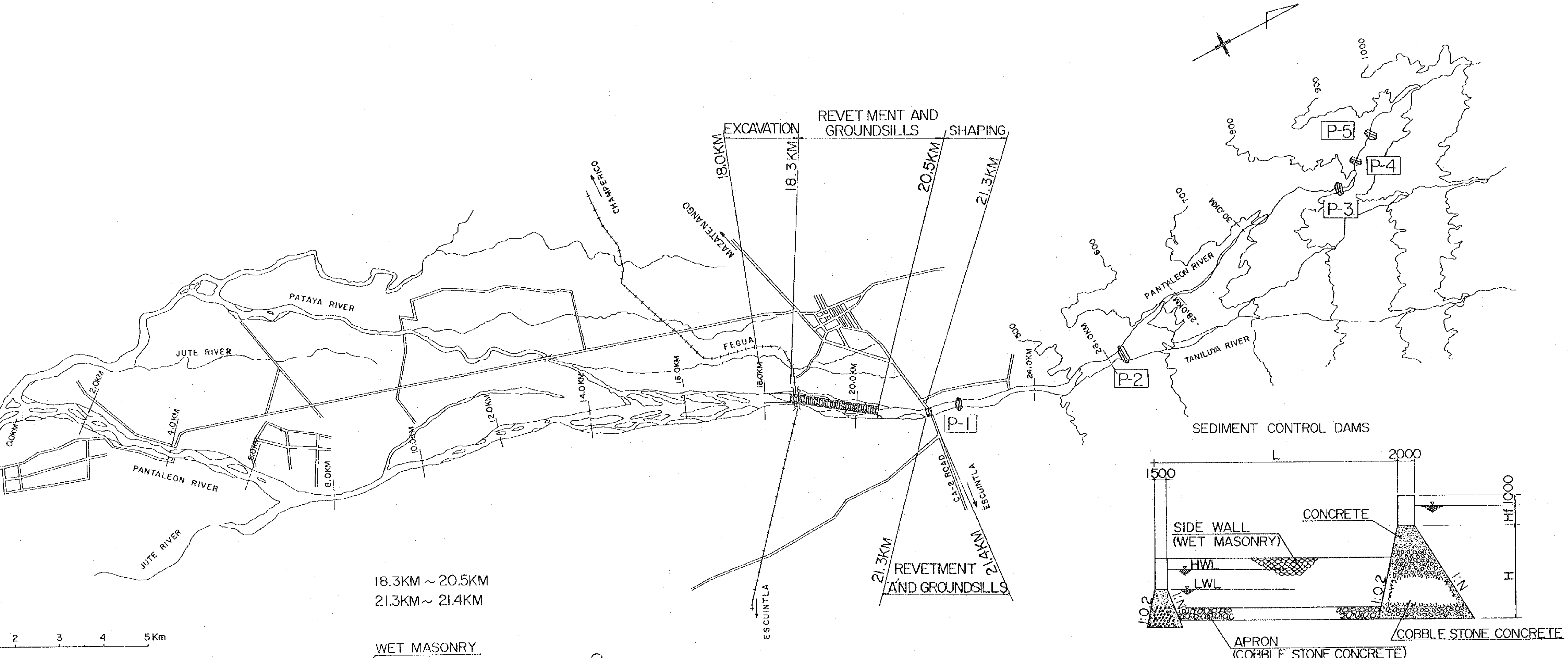


18.3KM ~ 20.5KM
21.3KM ~ 21.4KM





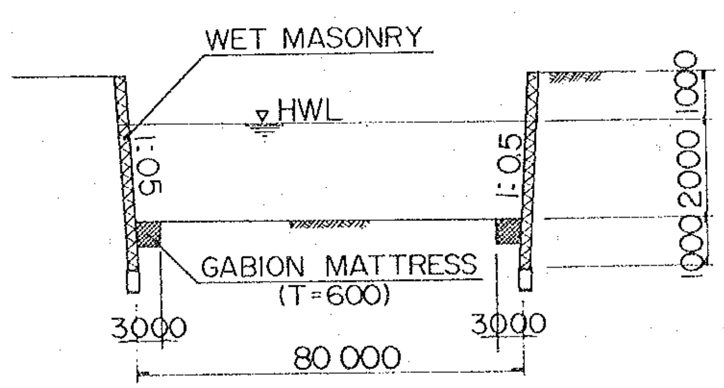
DAM	N
P-1	0.5
P-2	0.65
P-3	0.90
P-4	0.65
P-5	1.30



Sediment Control Dam

Revetment (Wet Masonry)

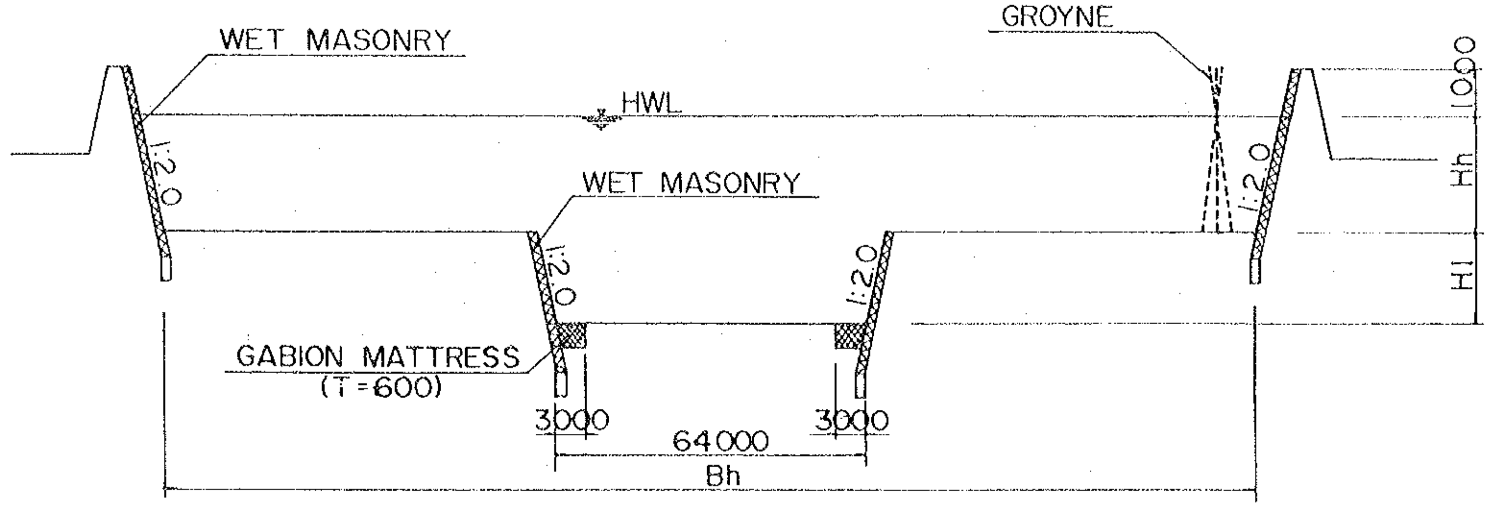
Groundsill (47 Places)



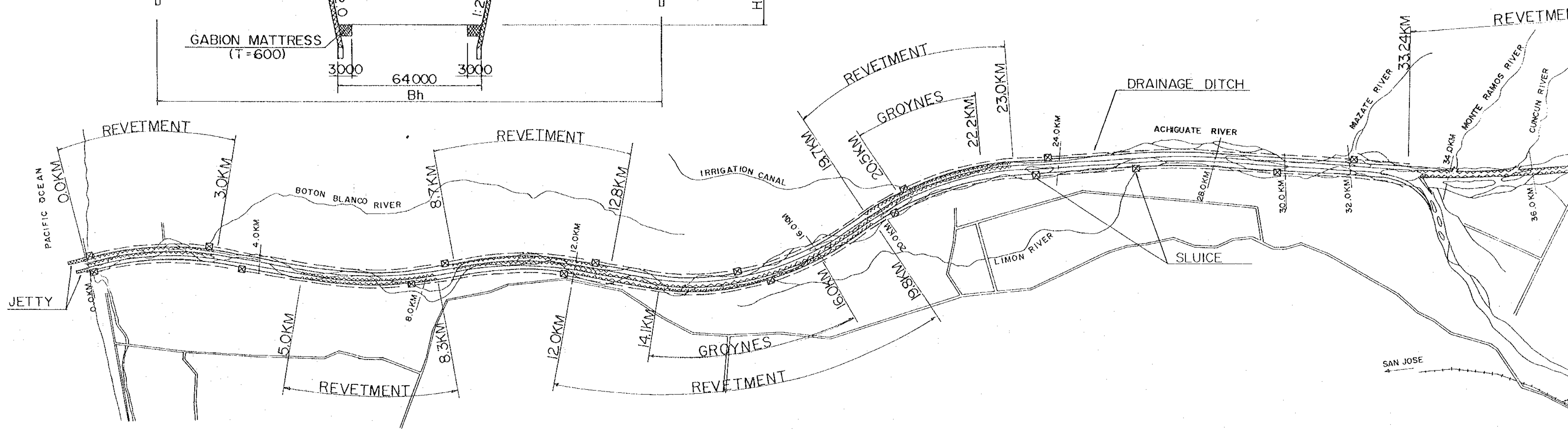
DAM	N	$H_{(m)}$	$Hf_{(m)}$	$L_{(m)}$	$Ns_{(m)}$	CREST LENGTH (m)	DAM VOLUME (m^3)
P-1	0.5	6.5	2.6	20	0.4	210	4,400
P-2	0.65	11.0	2.6	29	0.4	392	20,600
P-3	0.90	13.0	2.8	30	0.4	155	19,600
P-4	0.65	10.5	2.8	29	0.4	190	15,400
P-5	1.30	20.0	2.8	35	0.4	230	47,400

Fig. 4-19 (2/2) PROPOSED PLAN (PANTALEON RIVER)

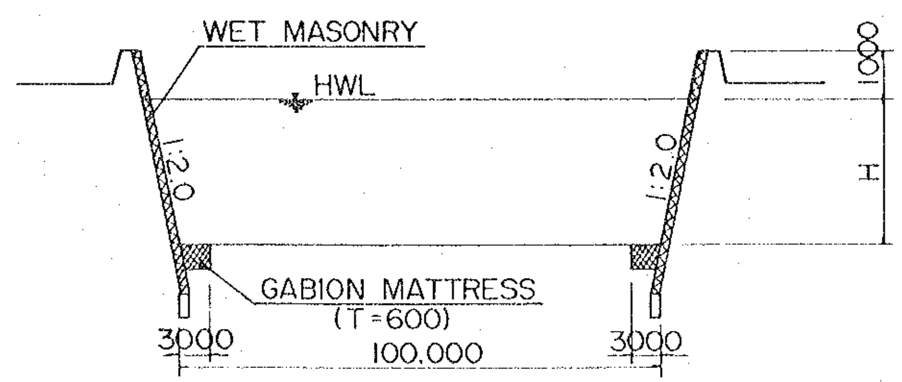
0.0KM ~ 33.24KM



STRECH	Hl	Hh	Bh
0.0KM~16.0 KM	2500	2000	226000
16.0KM~27.0 KM	2350	1850	225400
27.0KM~33.24KM	2150	1700	225000

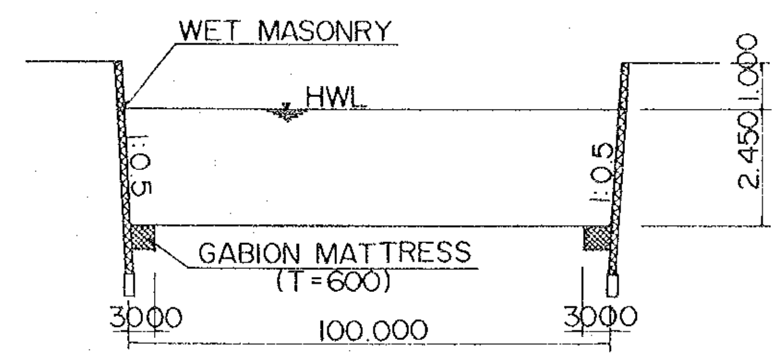


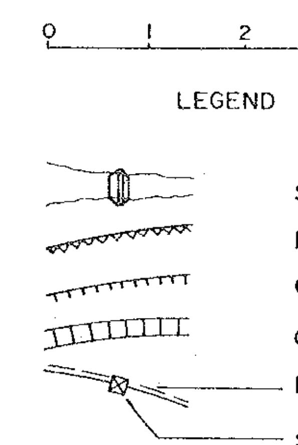
33.24KM ~ 39.6KM



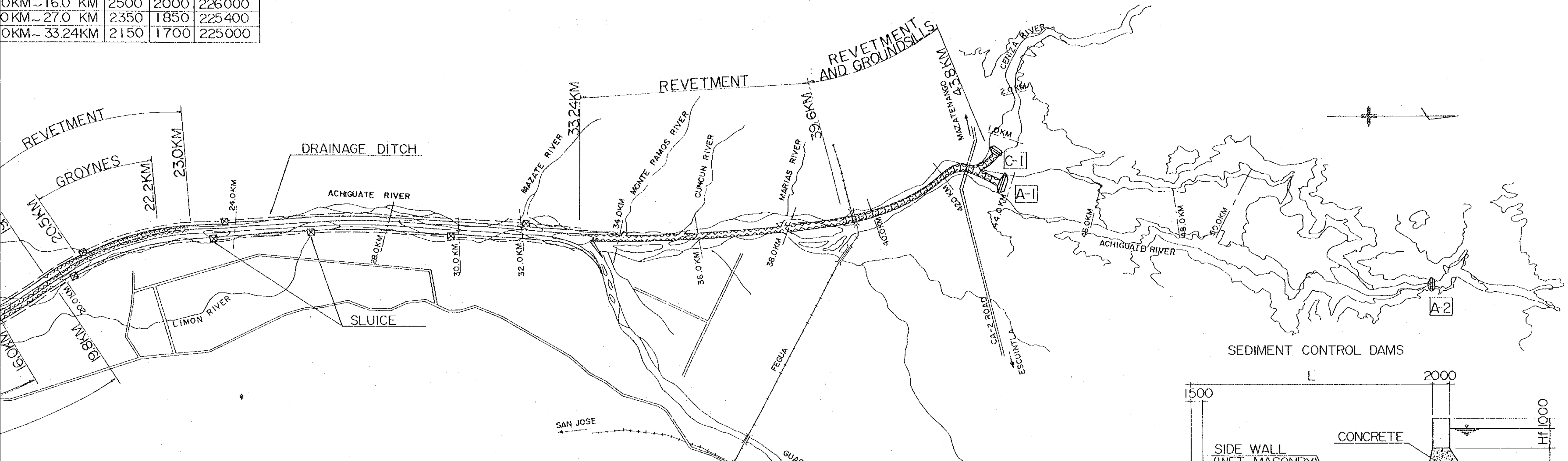
STRECH	H
33.24KM~38.0KM	3250
38.0 KM~39.6KM	2750

39.6KM ~ 43.8KM



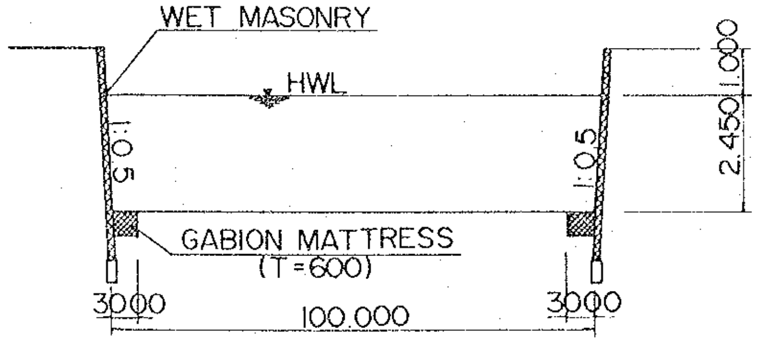


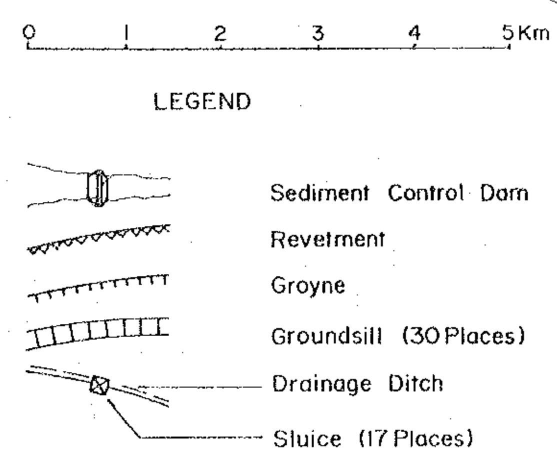
STRECH	Hl	Hh	Bh
0KM~16.0 KM	2500	2000	226000
0KM~27.0 KM	2350	1850	225400
0KM~33.24KM	2150	1700	225000

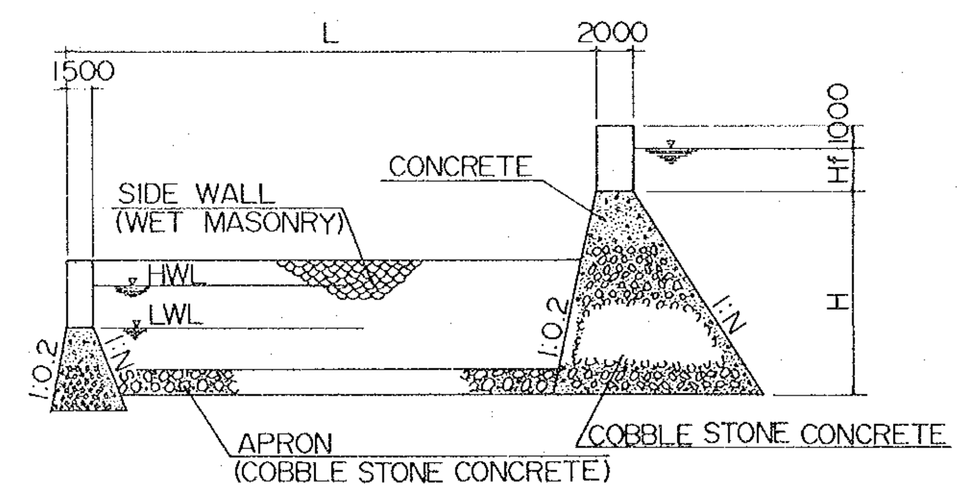


39.6KM ~ 43.8KM

STRECH	H
33.24KM~38.0KM	3250
38.0 KM~39.6KM	2750

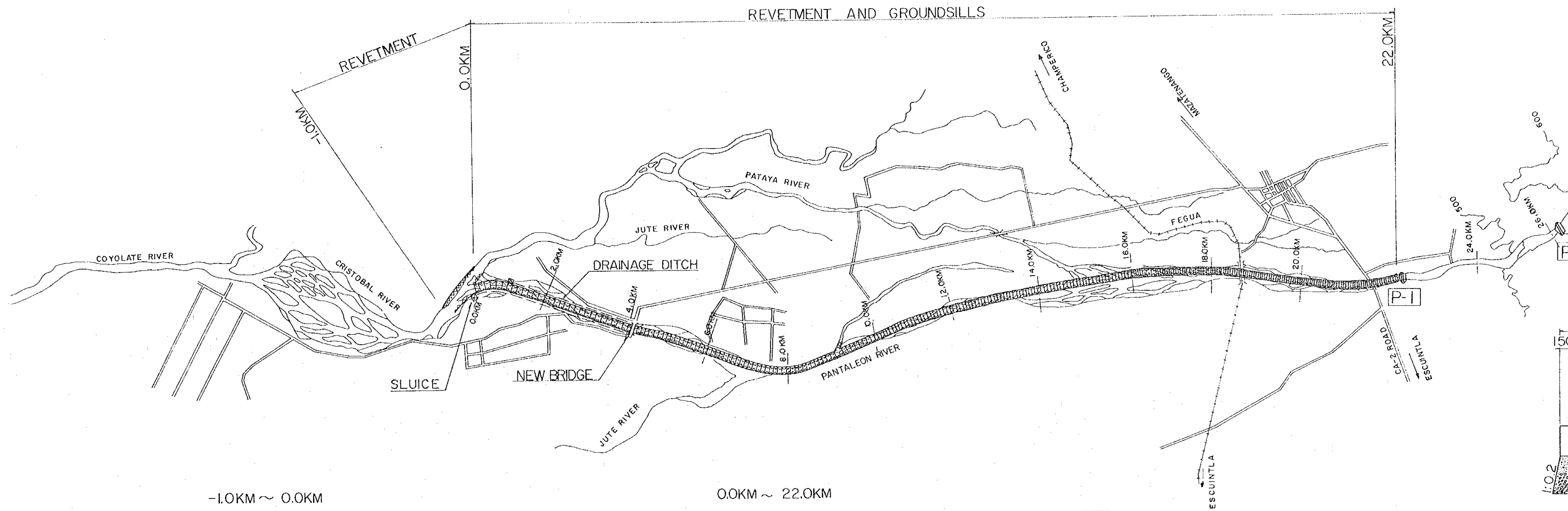


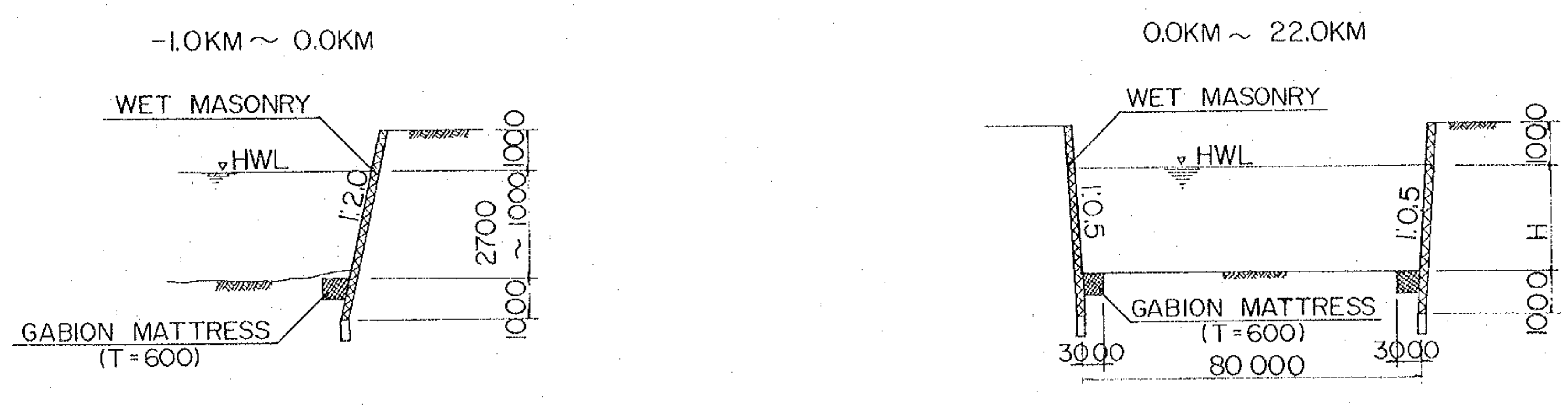




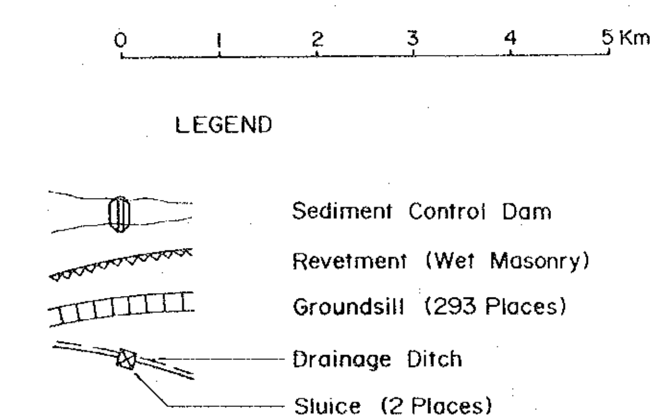
DAM	N	$H_{(m)}$	$Hf_{(m)}$	$L_{(m)}$	Ns	CREST LENGTH (m)	DAM VOLUME (m^3)
A-1	0.6	8.5	2.4	29	0.3	460	26,500
A-2	1.2	20.0	2.1	35	0.3	135	25,200
C-1	0.6	8.5	2.1	29	0.2	455	23,200

Fig. 4-20 (1/2) COMPREHENSIVE PALN (ACHIGUATE RIVER)

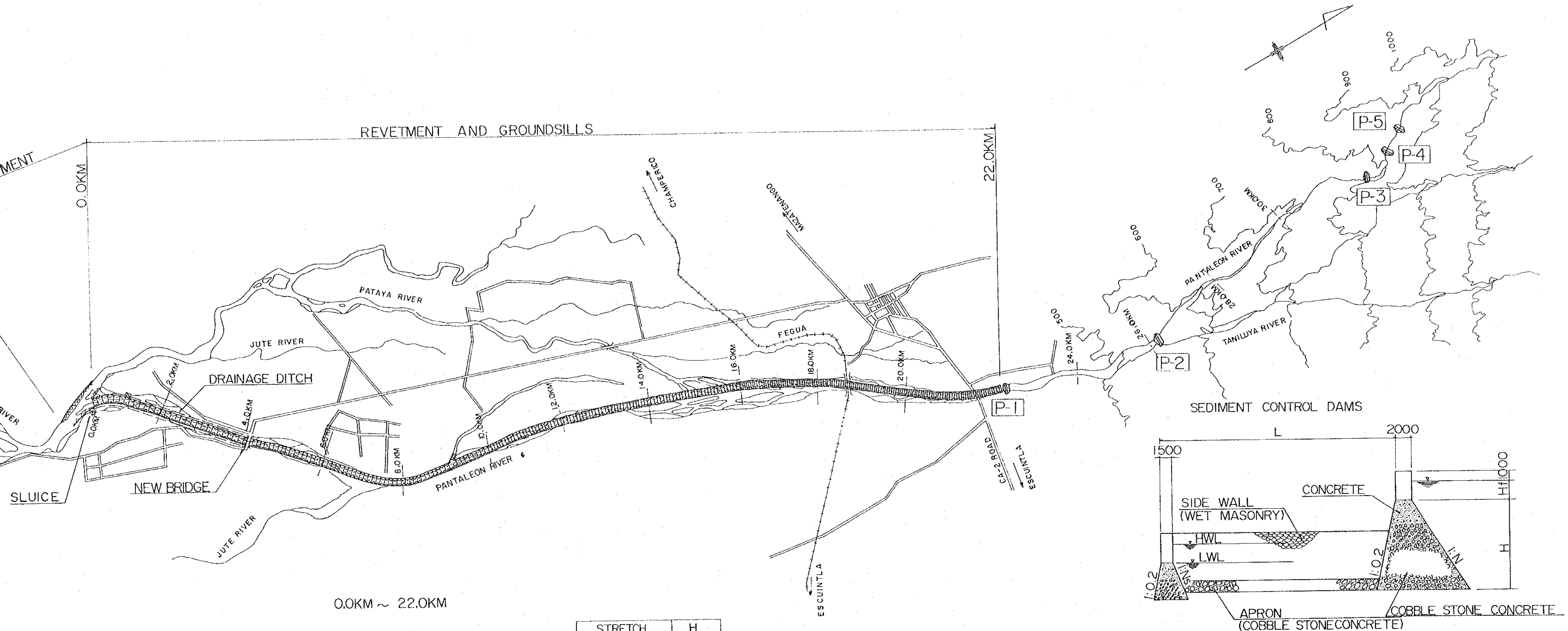


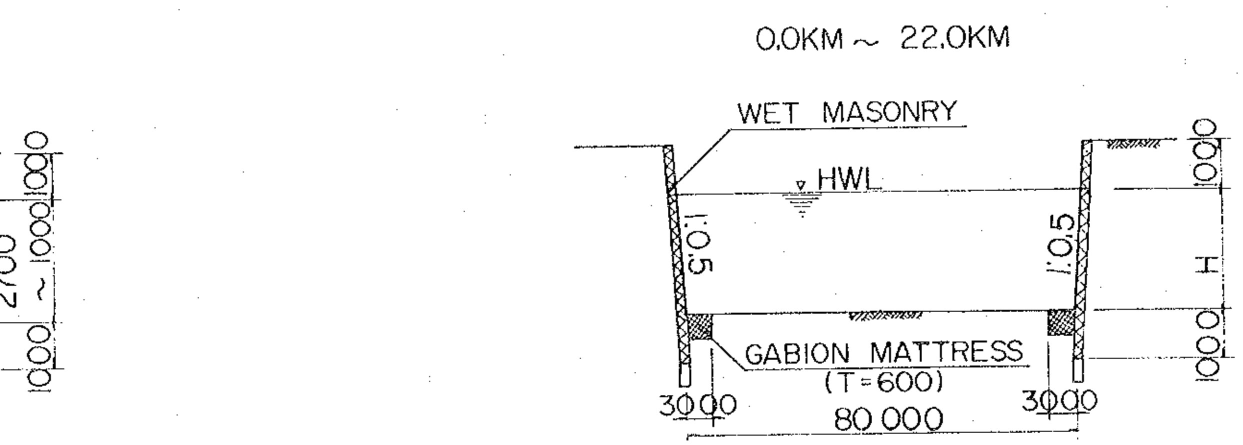


STRETCH	H
0.0KM~4.0KM	2700
4.0KM~6.0KM	2600
6.0KM~10.0KM	2500
10.0KM~12.0KM	2350
12.0KM~14.0KM	2250
14.0KM~16.0KM	2200
16.0KM~18.3KM	2050
18.3KM~22.0KM	2000

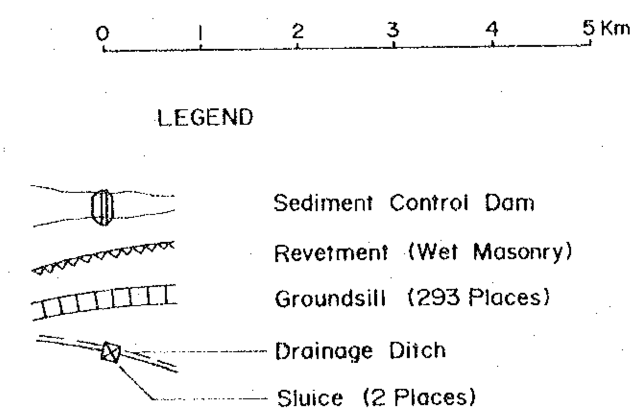


DAM
P-1
P-2
P-3
P-4
P-5





STRETCH	H
0.0KM~4.0KM	2700
4.0KM~6.0KM	2600
6.0KM~10.0KM	2500
10.0KM~12.0KM	2350
12.0KM~14.0KM	2250
14.0KM~16.0KM	2200
16.0KM~18.3KM	2050
18.3KM~22.0KM	2000



DAM	N	H (m)	Hf (m)	L (m)	Ns	CREST LENGTH(m)	DAM VOLUME(m^3)
P-1	0.5	6.5	2.6	20	0.4	210	4,400
P-2	0.65	11.0	2.6	29	0.4	392	20,600
P-3	0.90	13.0	2.8	30	0.4	155	19,600
P-4	0.65	10.5	2.8	29	0.4	190	15,400
P-5	1.30	20.0	2.8	35	0.4	230	47,400

Fig. 4-20 (2/2) COMPREHENSIVE PLAN (PANTALEON RIVER)

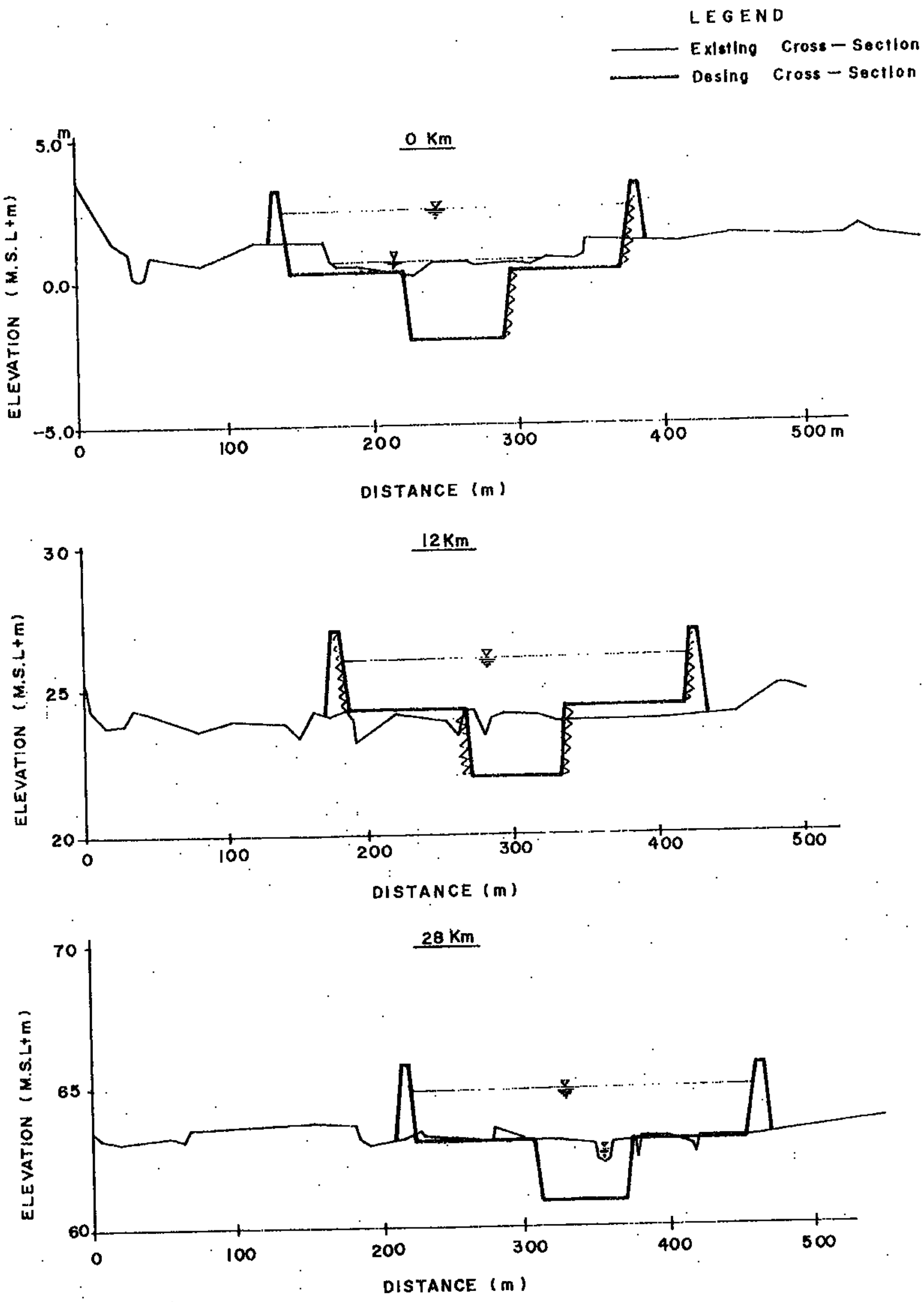


Fig. 4-21 (1/4) TYPICAL CROSS SECTION (ACHIGUATE RIVER)

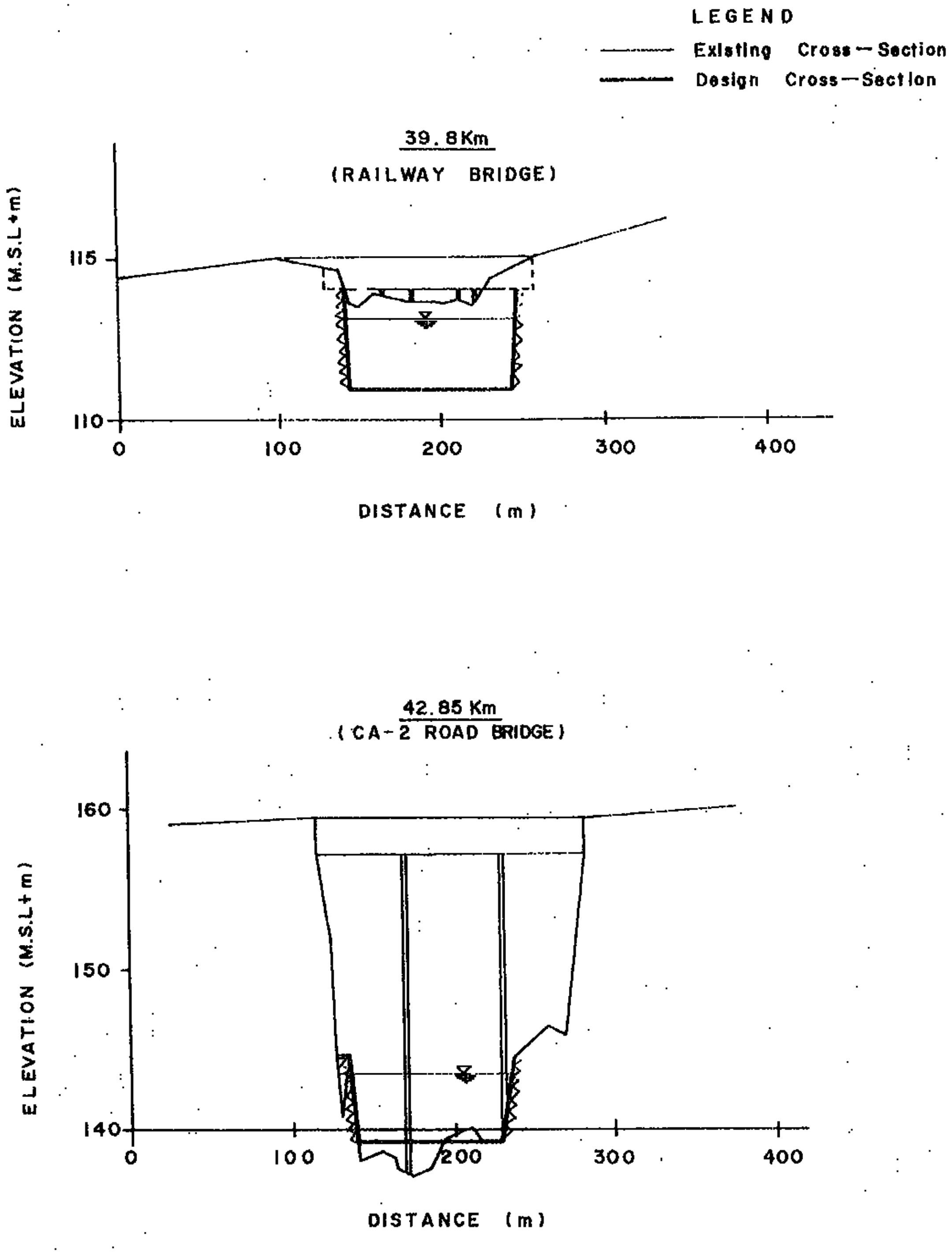


Fig. 4-21 (2/4) TYPICAL CROSS SECTION (ACHIGUATE RIVER)

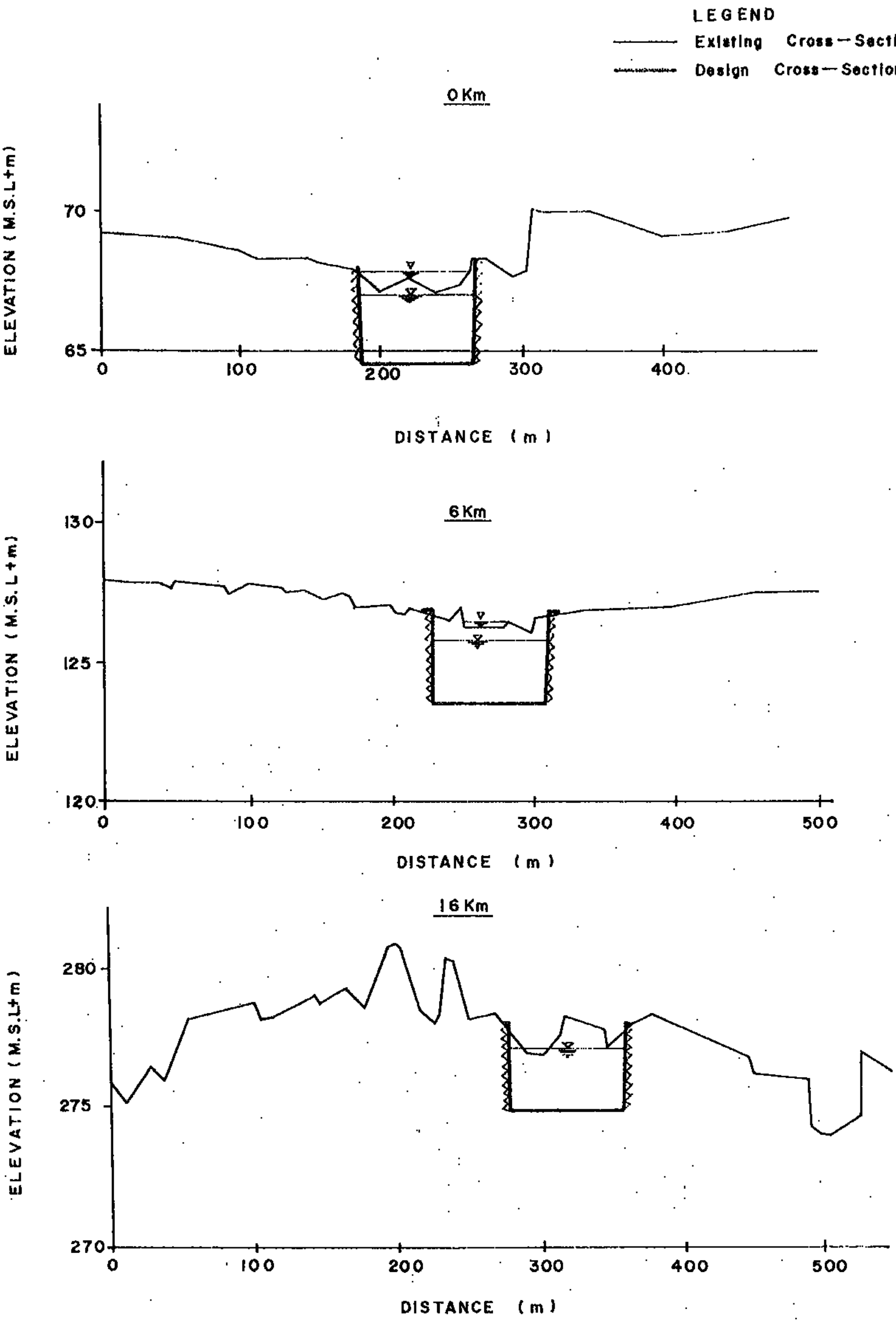


Fig. 4-21 (3/4) TYPICAL CROSS SECTION (PANTALEON RIVER)

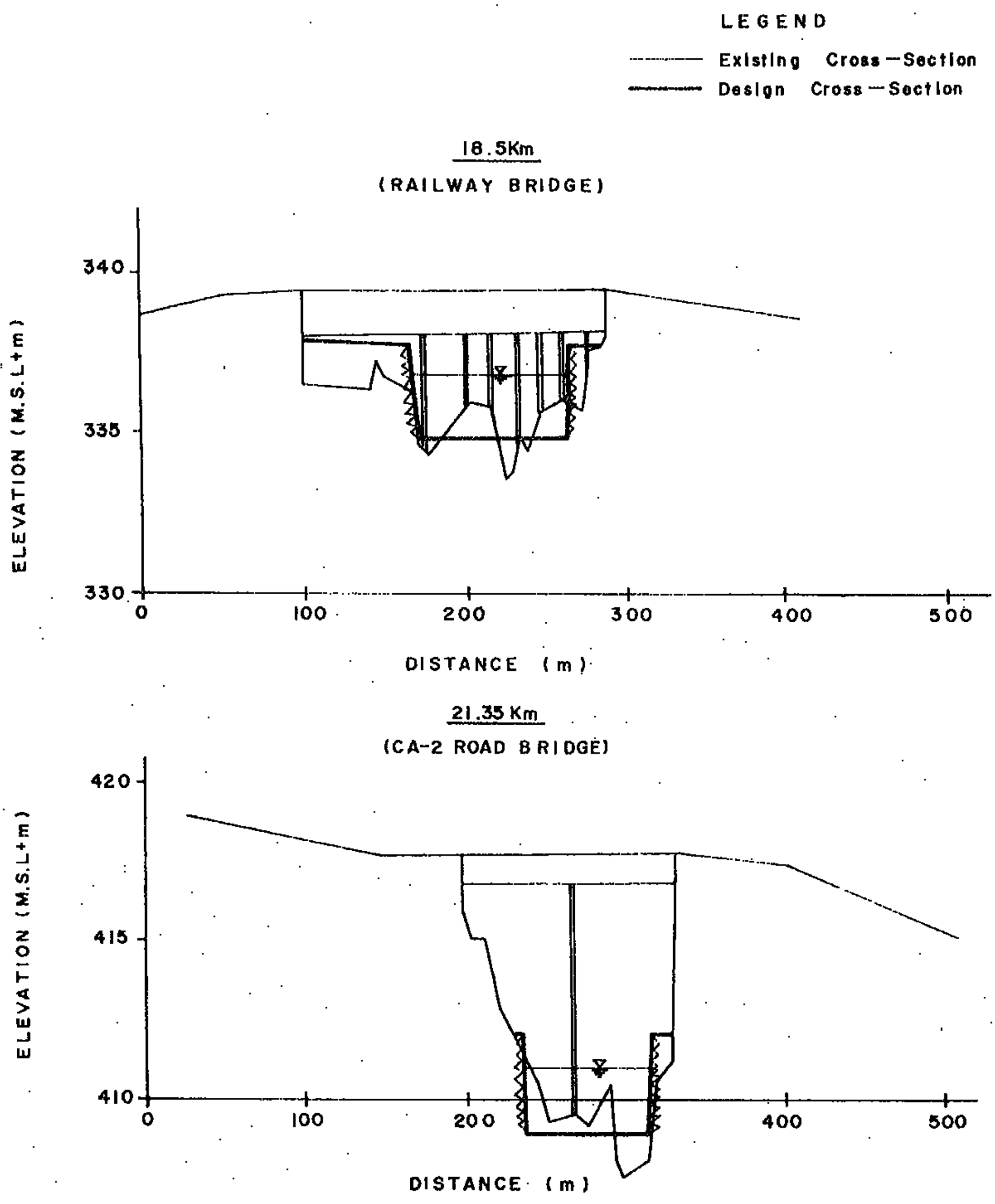


Fig. 4-21 (4/4) TYPICAL CROSS SECTION (PANTALEON RIVER)

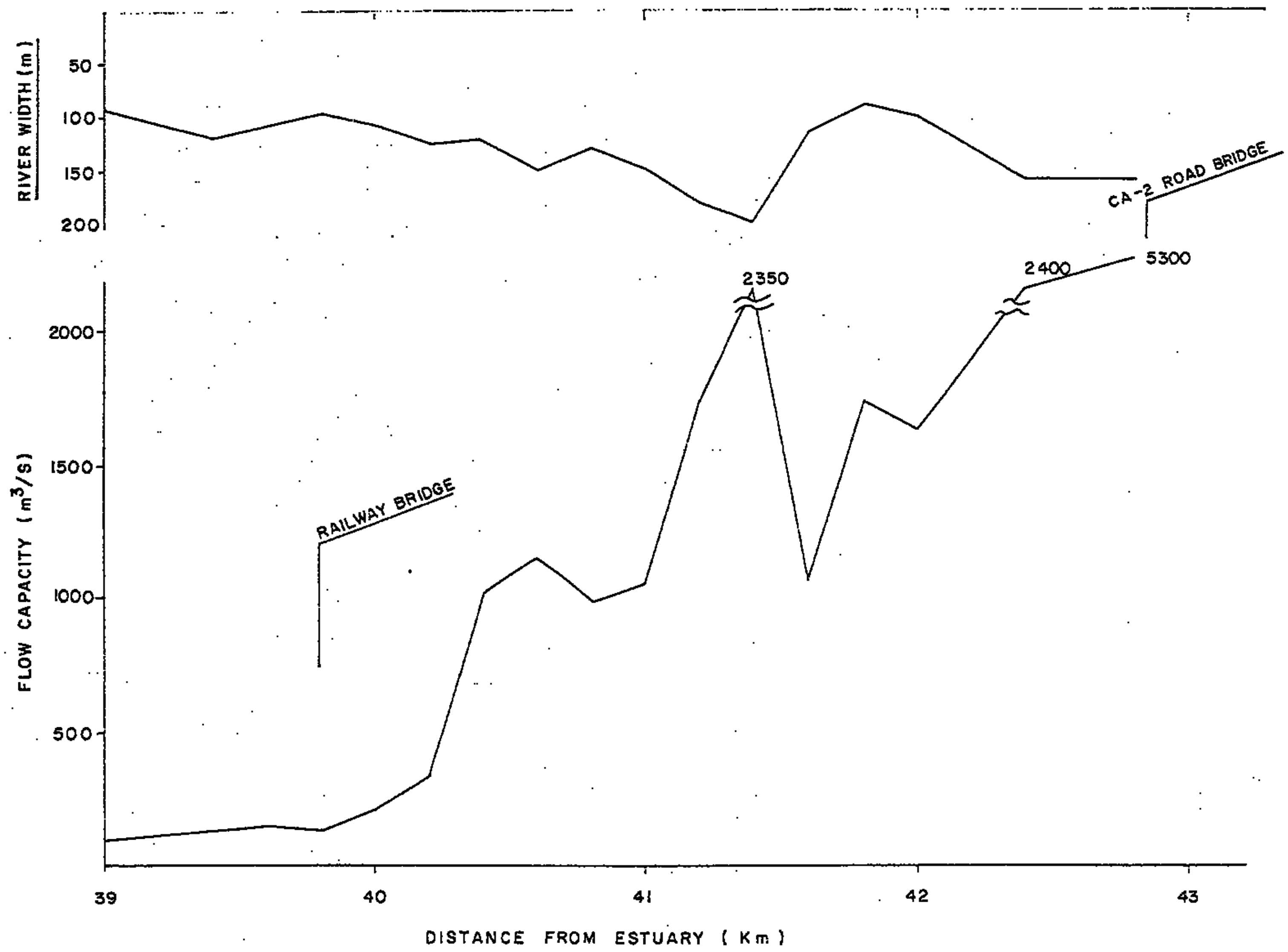


Fig. 4-22 (1/2) FLOW CAPACITY (ACHIGUATE RIVER)

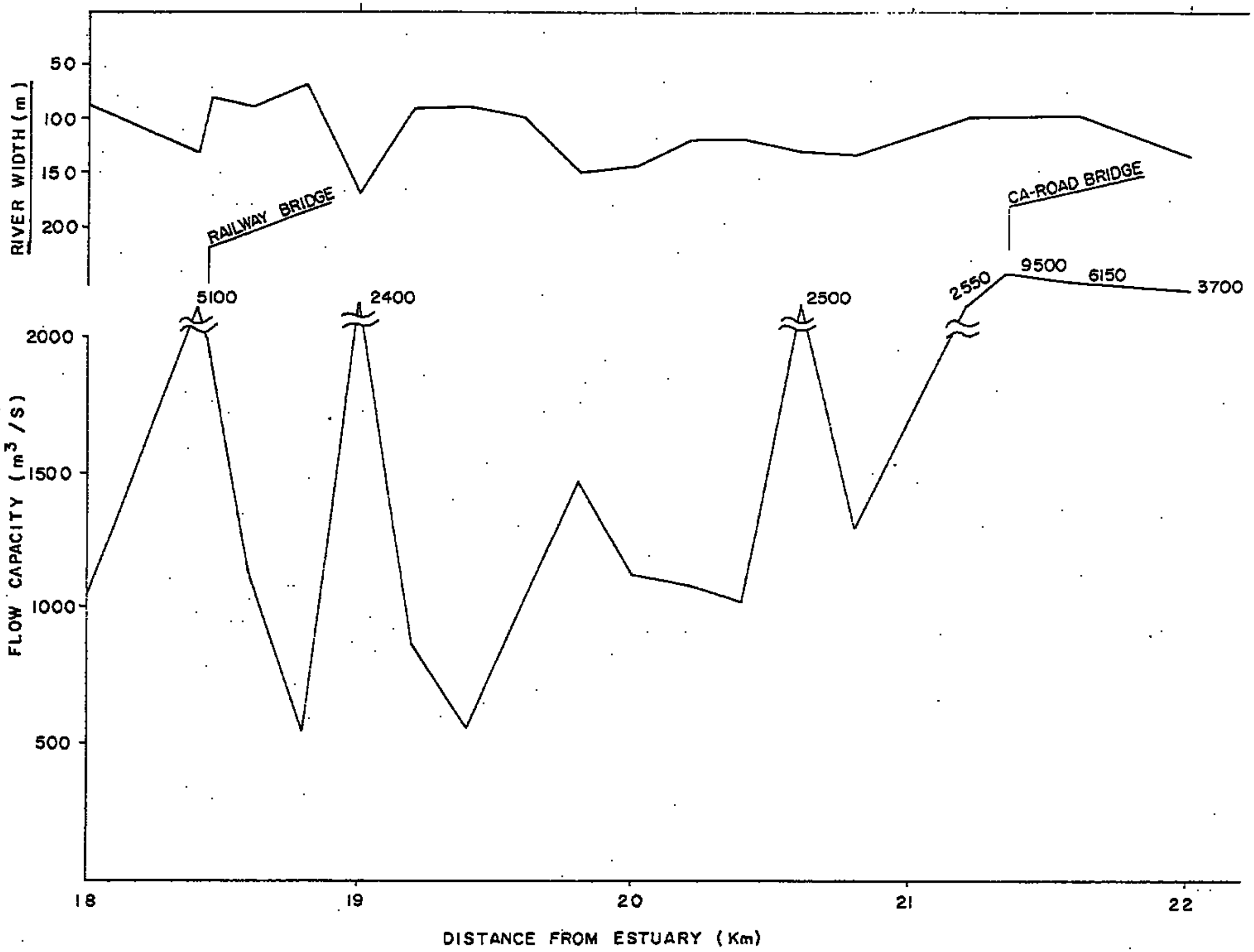


Fig. 4-22 (2/2) FLOW CAPACITY (PANTALEON RIVER)

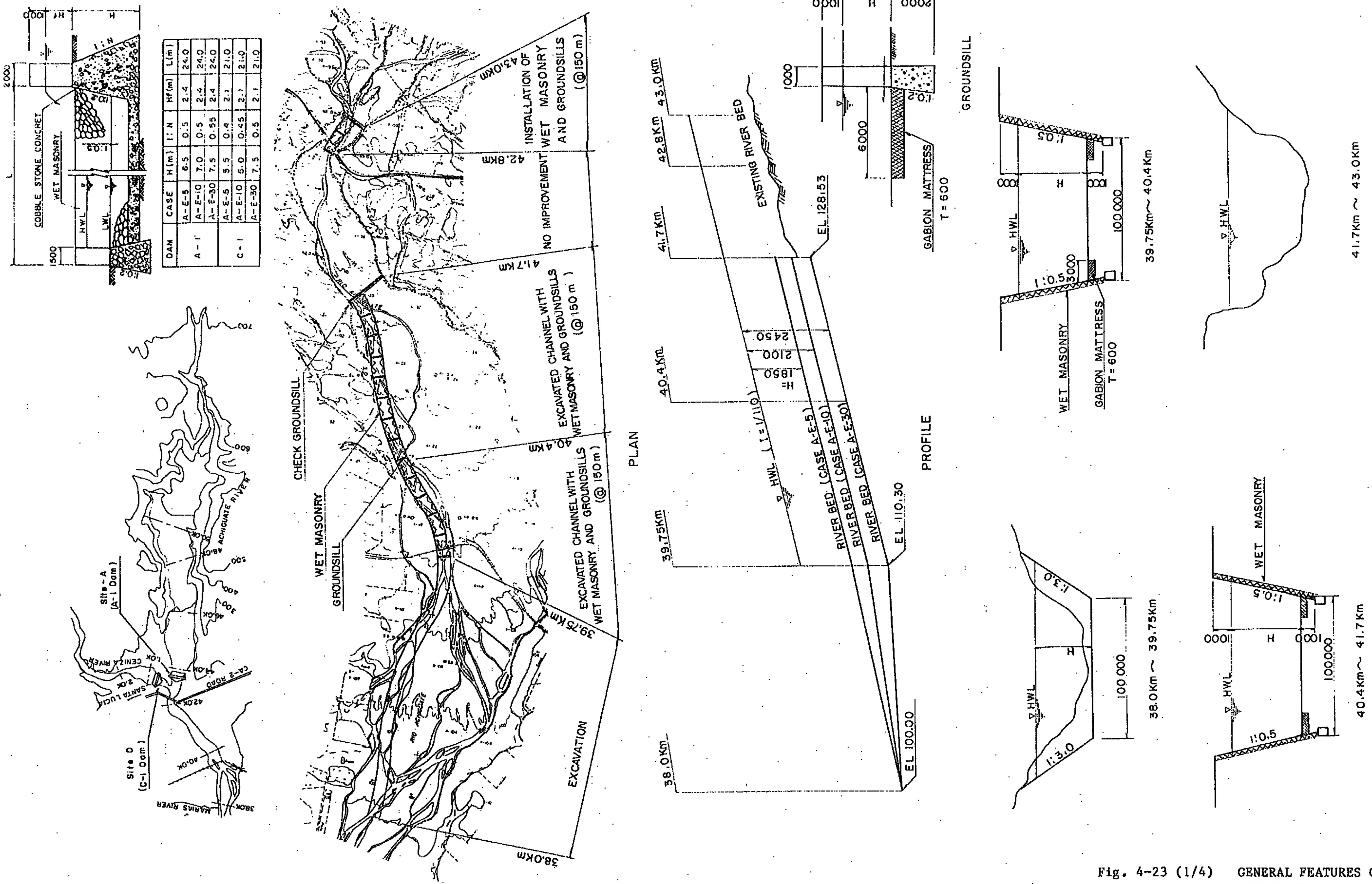
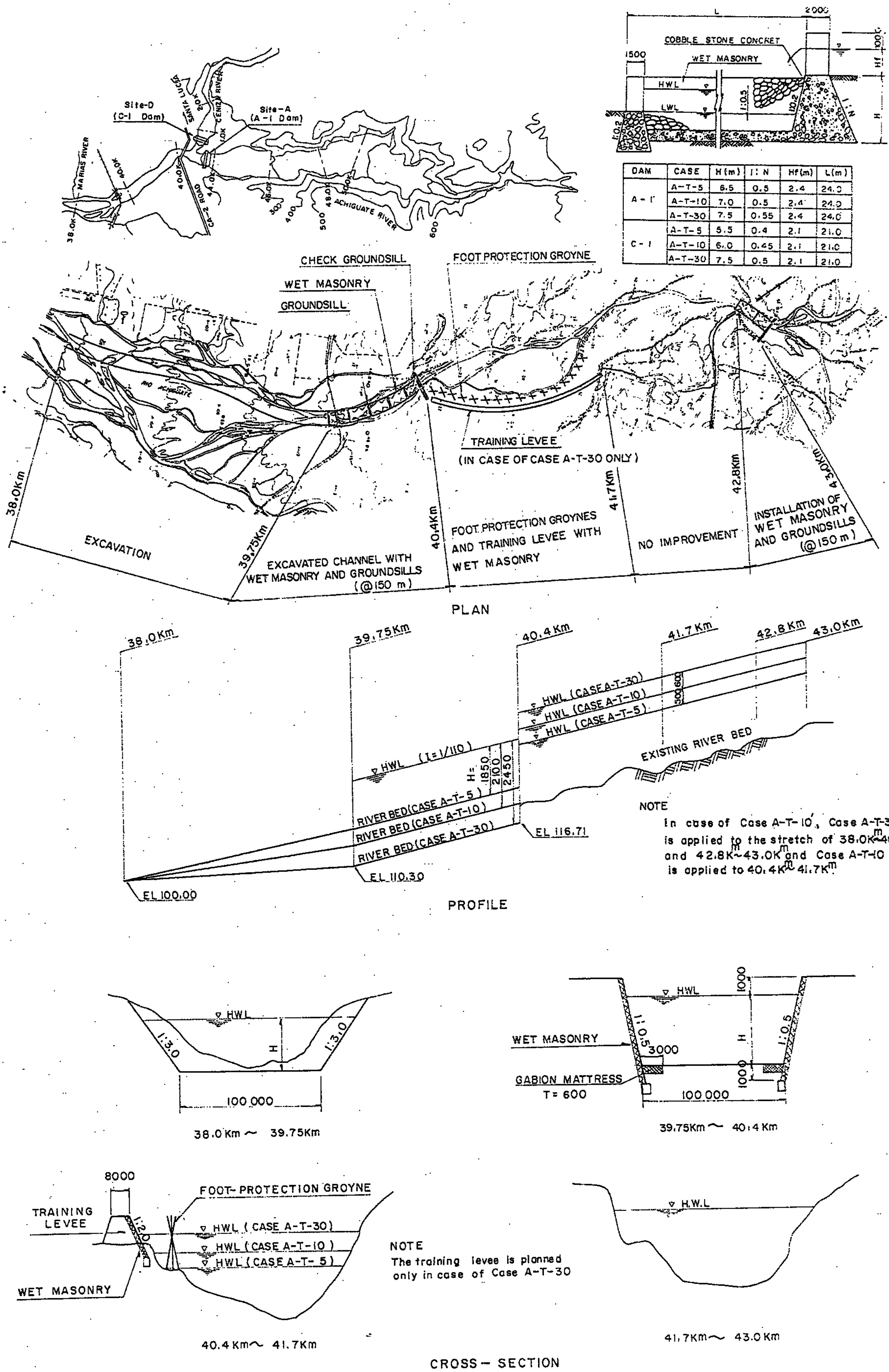


Fig. 4-23 (1/4) GENERAL FEATURES OF COMPARATIVE PLANS (A-E)



DAM	CASE	H(m)	1:N	Hf(m)	L(m)
A-1	A-T-5	6.5	0.5	2.4	24.0
	A-T-10	7.0	0.5	2.4	24.0
	A-T-30	7.5	0.55	2.4	24.0
C-1	A-T-5	5.5	0.4	2.1	21.0
	A-T-10	6.0	0.45	2.1	21.0
	A-T-30	7.5	0.5	2.1	21.0

Fig. 4-23 (2/4) GENERAL FEATURES OF COMPARATIVE PLANS (A-T)

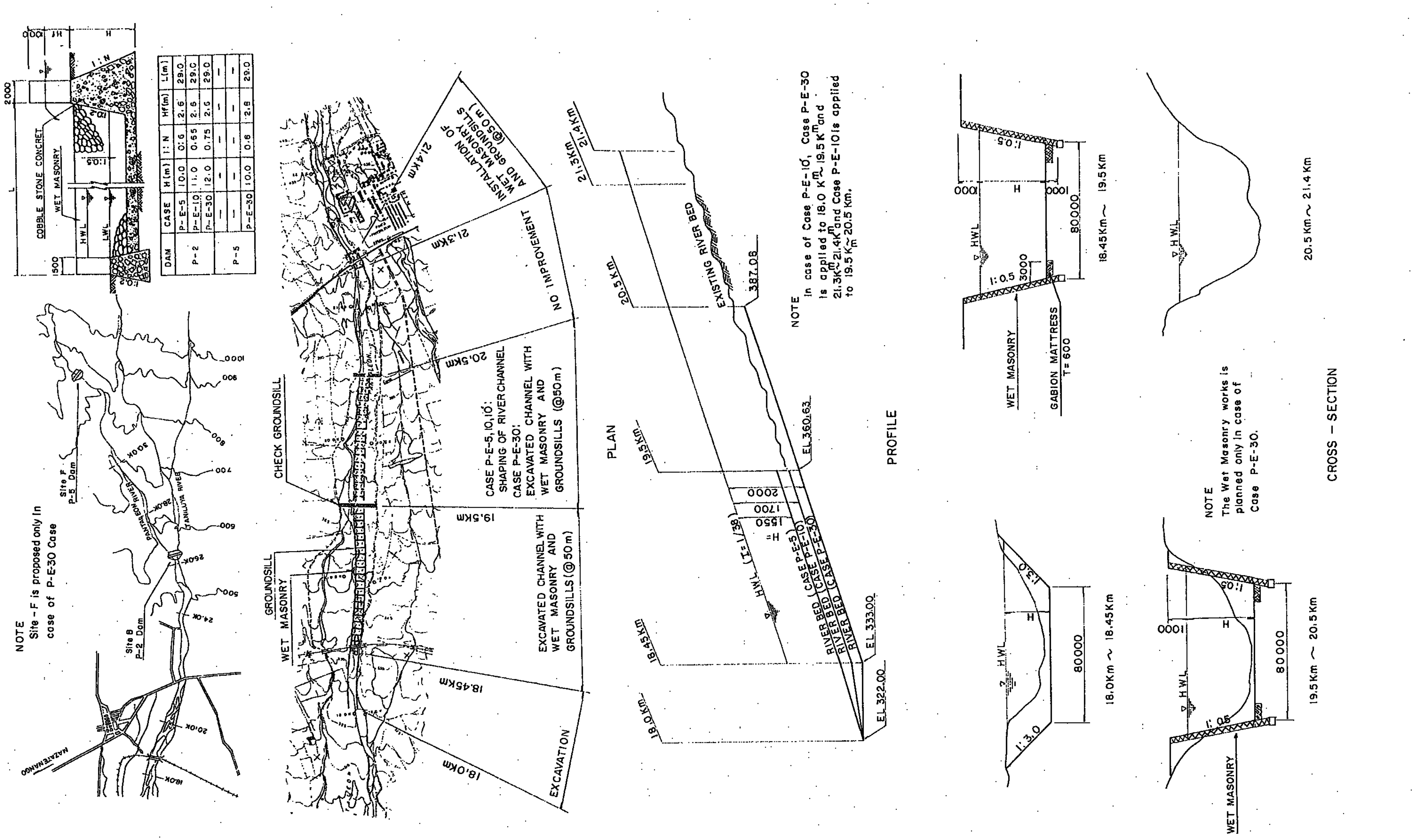


Fig. 4-23 (3/4) GENERAL FEATURES OF COMPARATIVE PLANS (P-E)

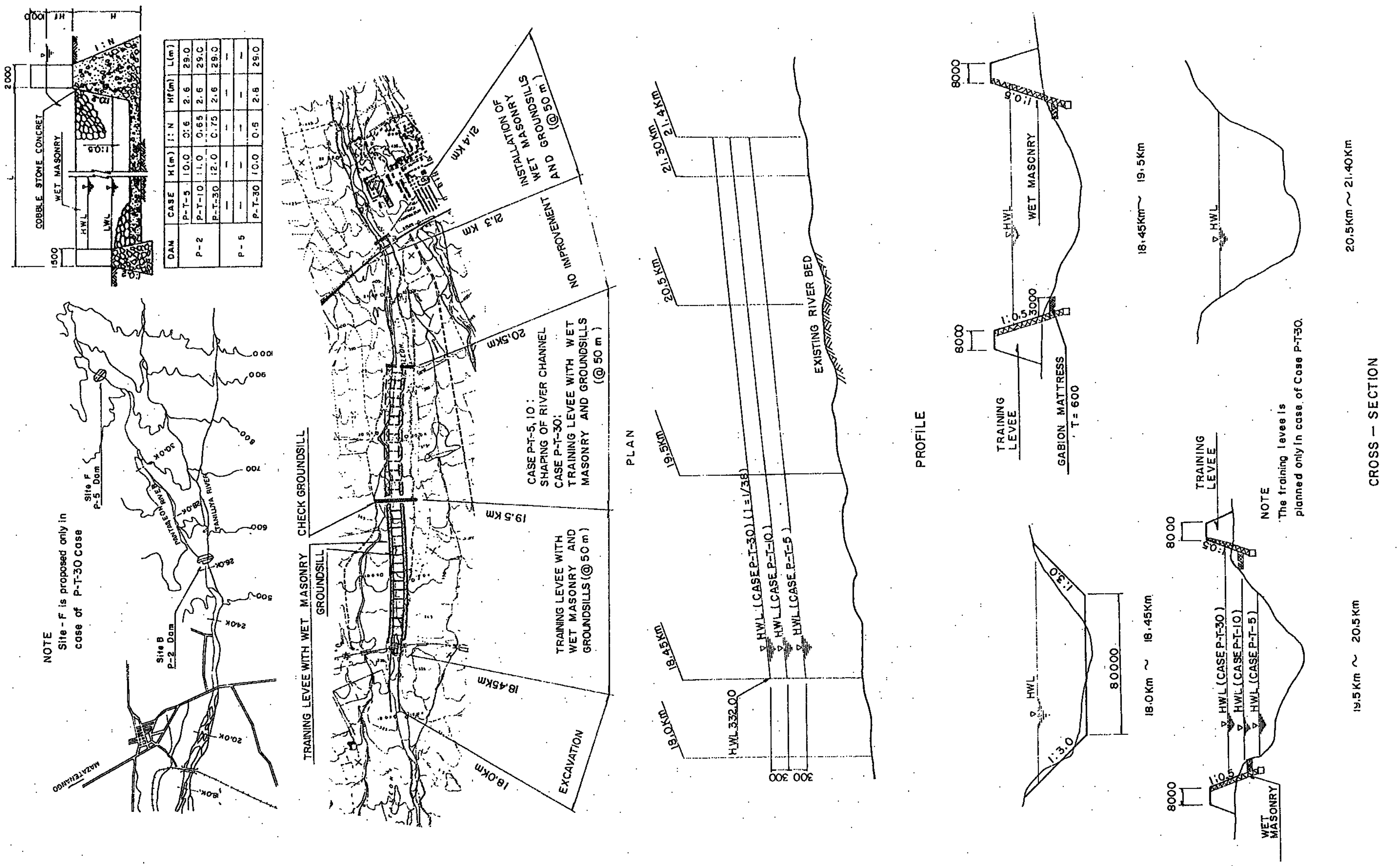


Fig. 4-23 (4/4) GENERAL FEATURES OF COMPARATIVE PLANS (P-T)

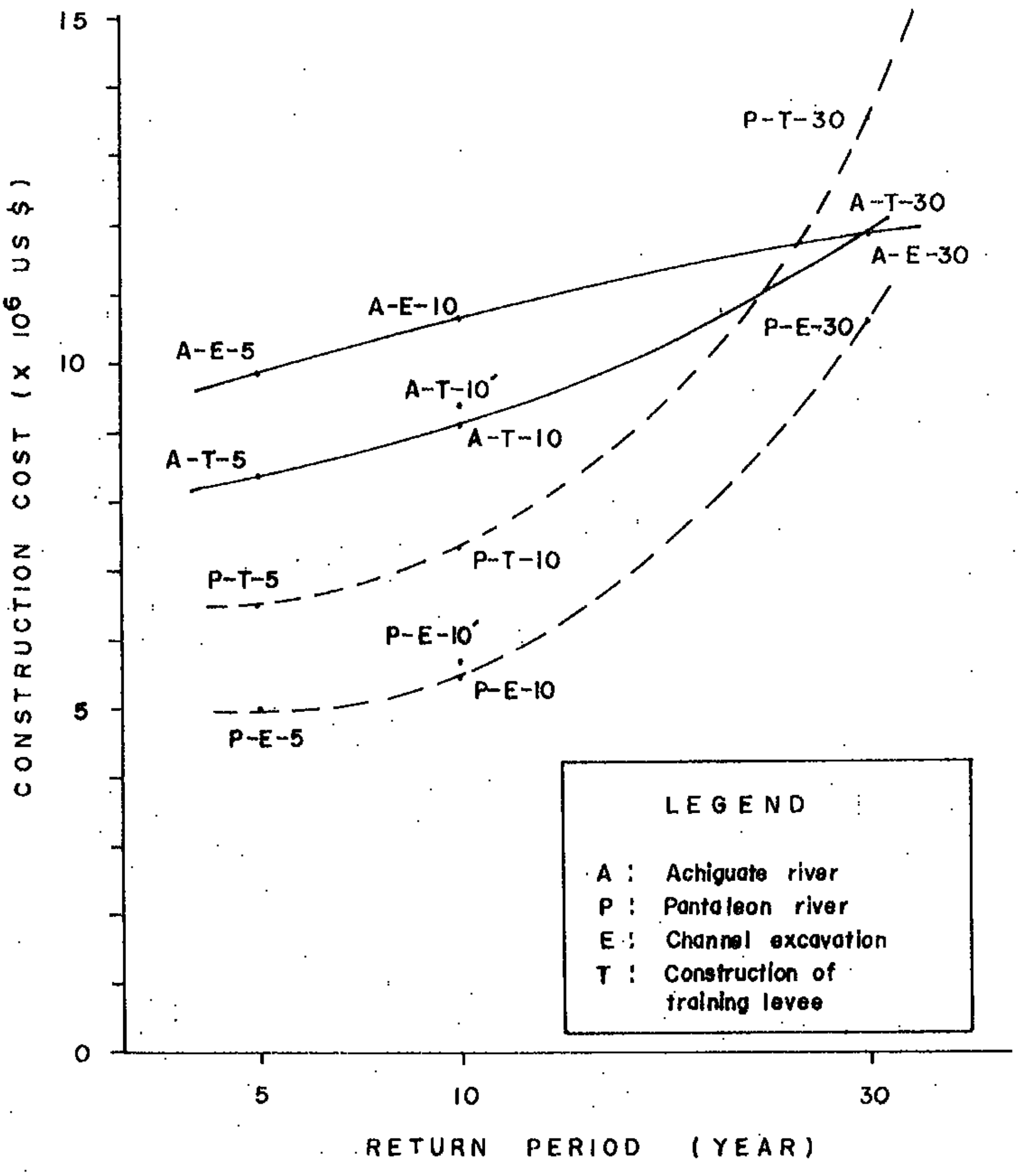


Fig. 4-24 COST COMPARISON FOR RIVER IMPROVEMENT METHODS

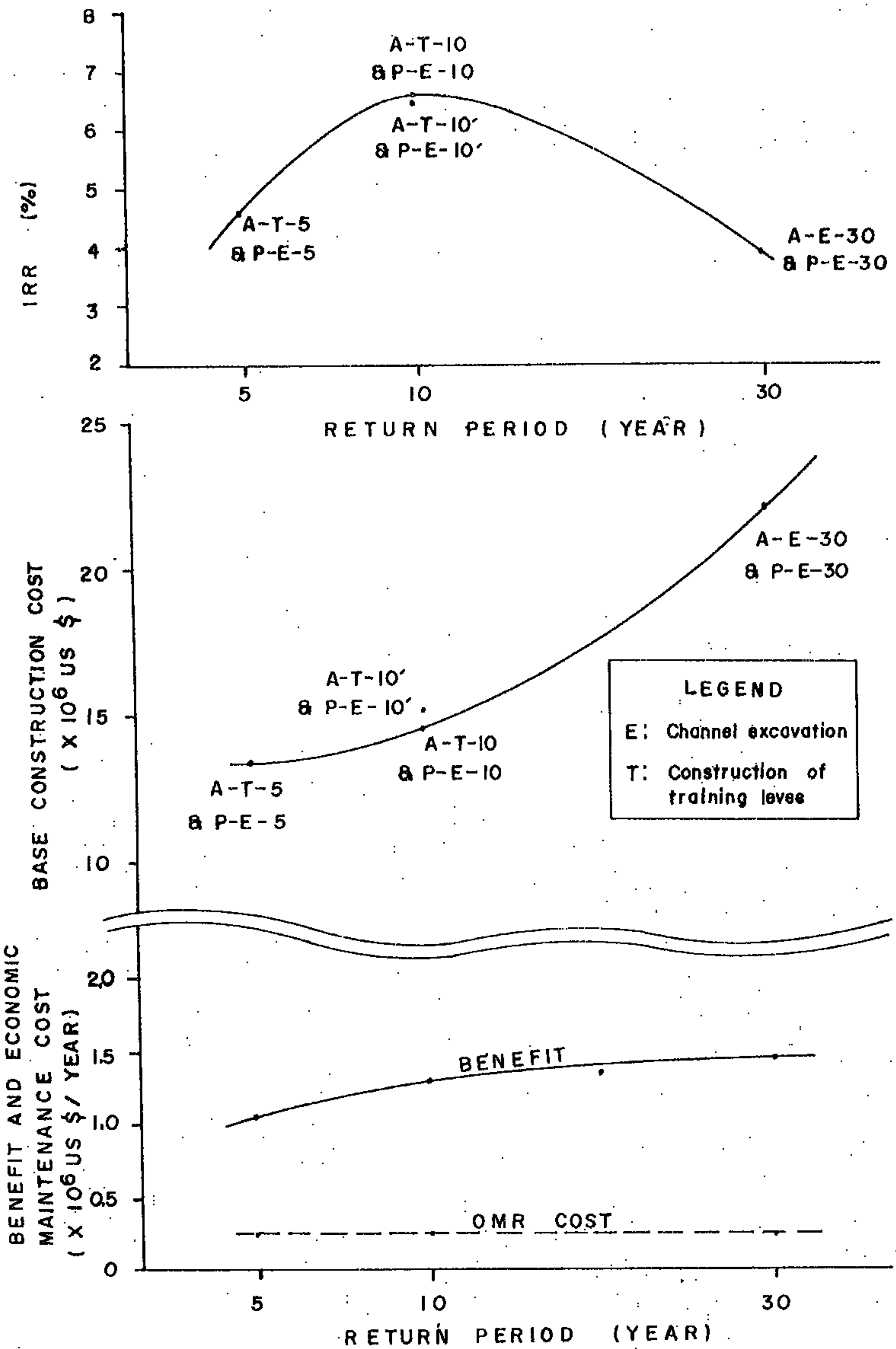


Fig. 4-25 ECONOMIC COMPARISON FOR PROJECT SCALES

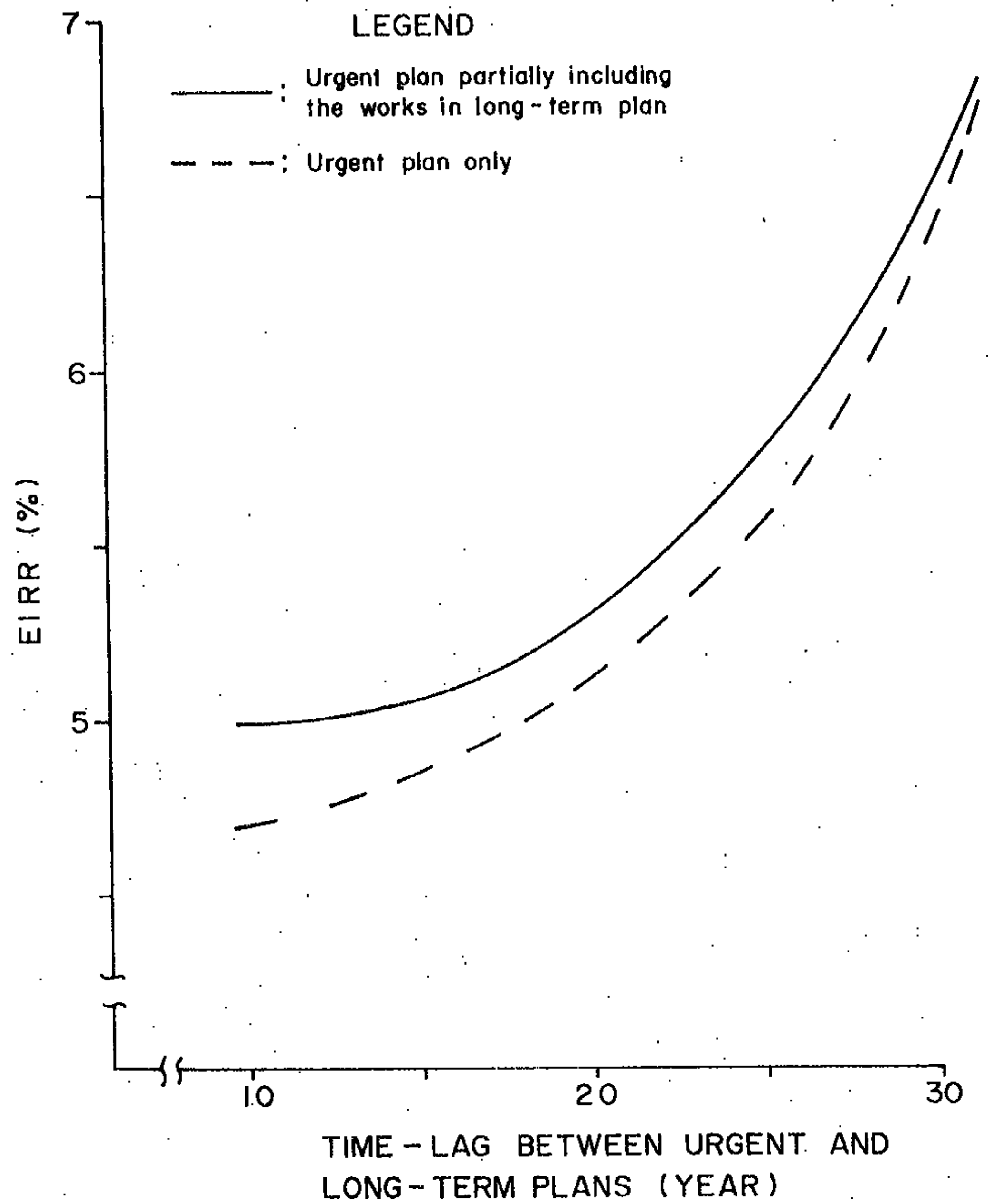


Fig. 4-26 ECONOMIC JUSTIFICATION FOR PARTIAL APPLICATION OF THE LONG-TERM PLAN