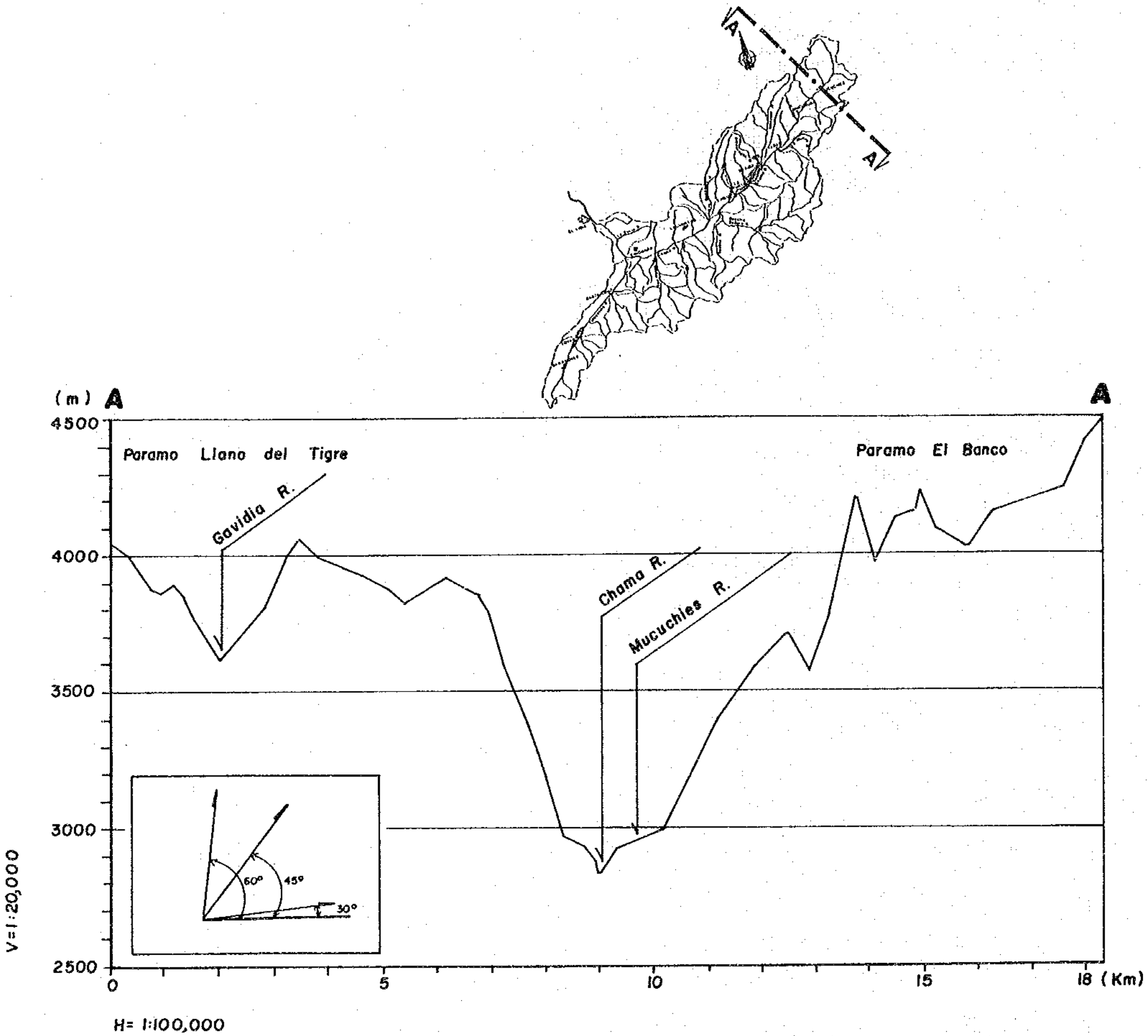
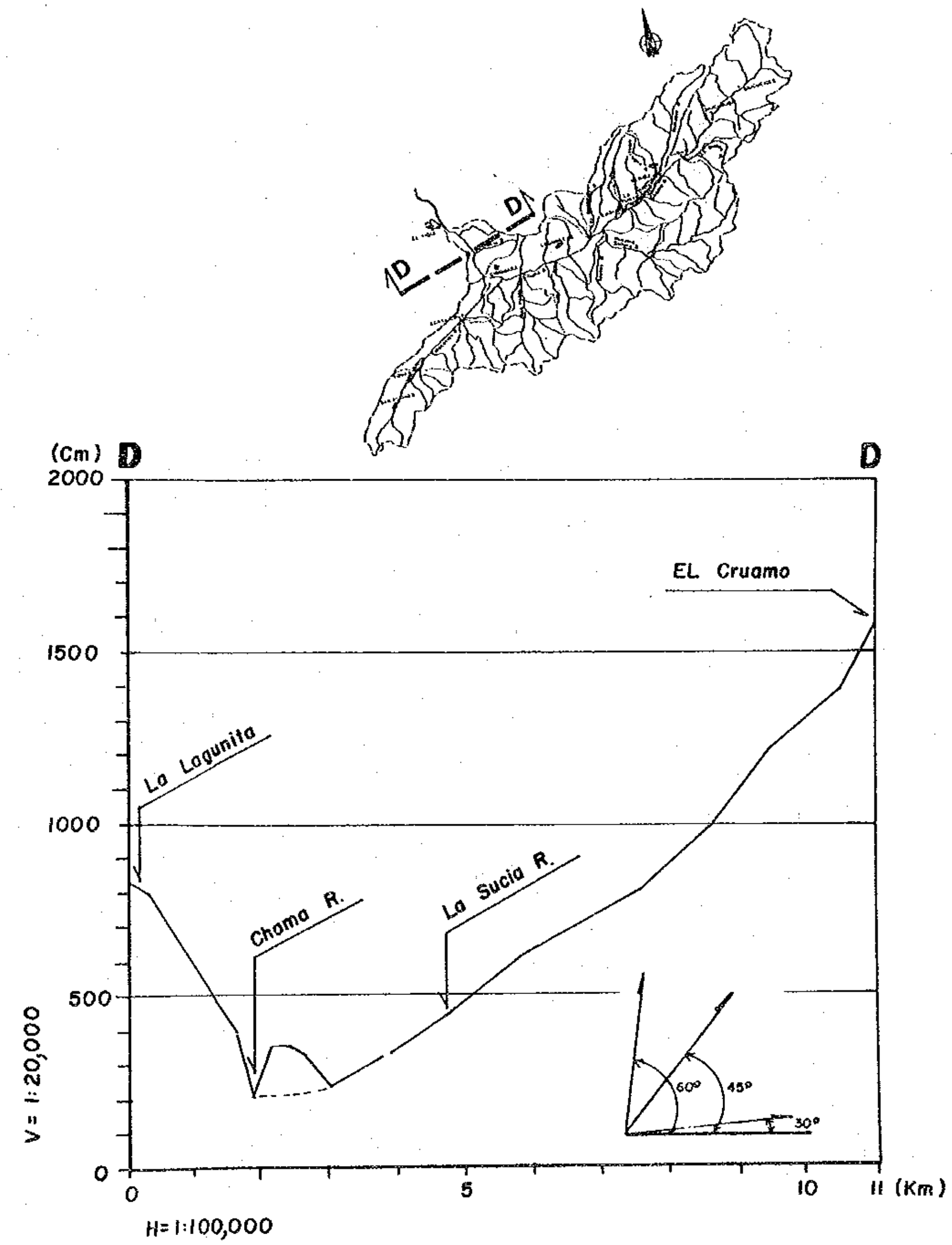
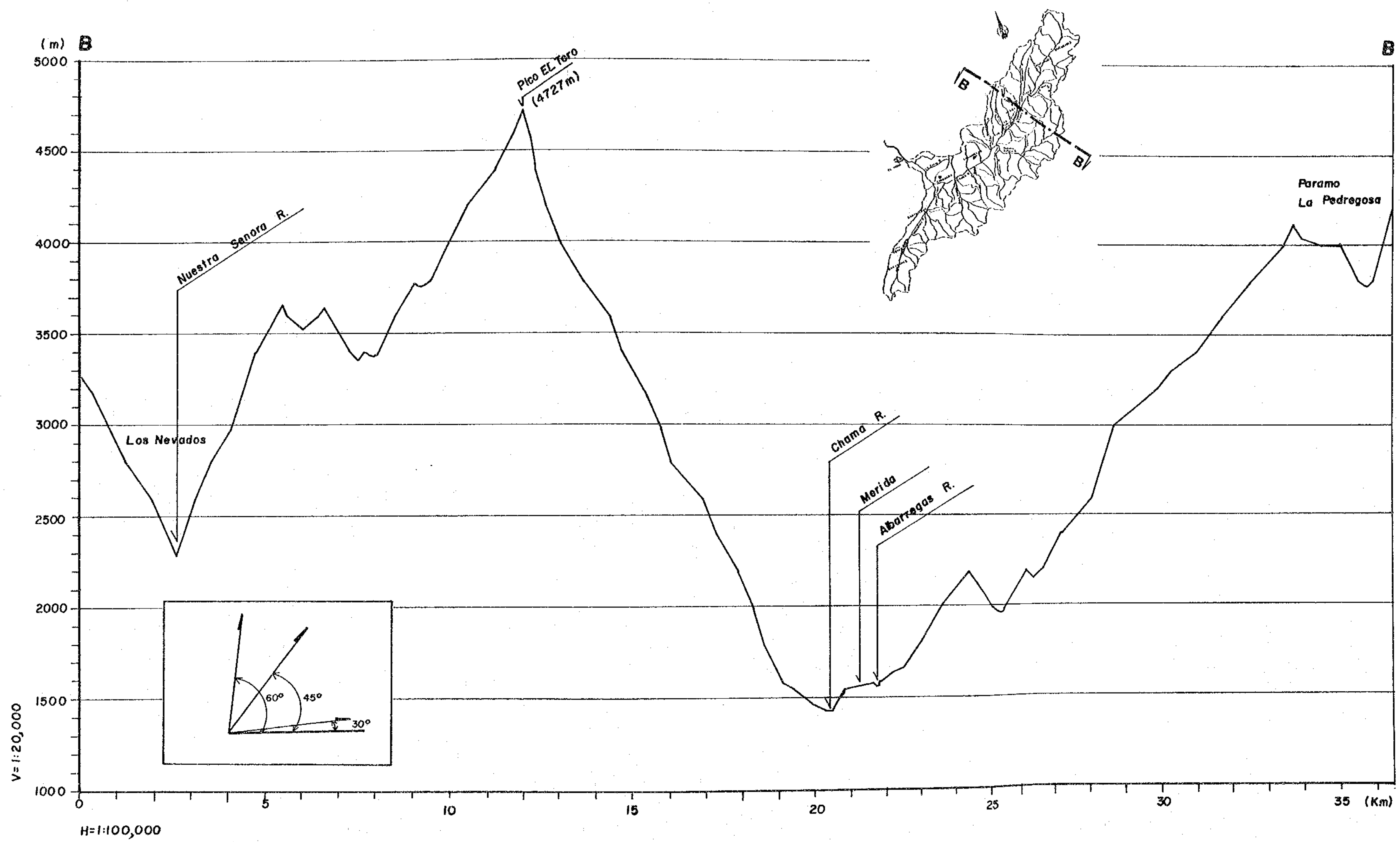


170 KM FROM THE RIVER MOUTH



80 KM FROM THE RIVER MOUTH

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT	TOPOGRAPHICAL CROSS SECTIONS OF THE CHAMA RIVER BASIN
JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. II-4 (1/4)



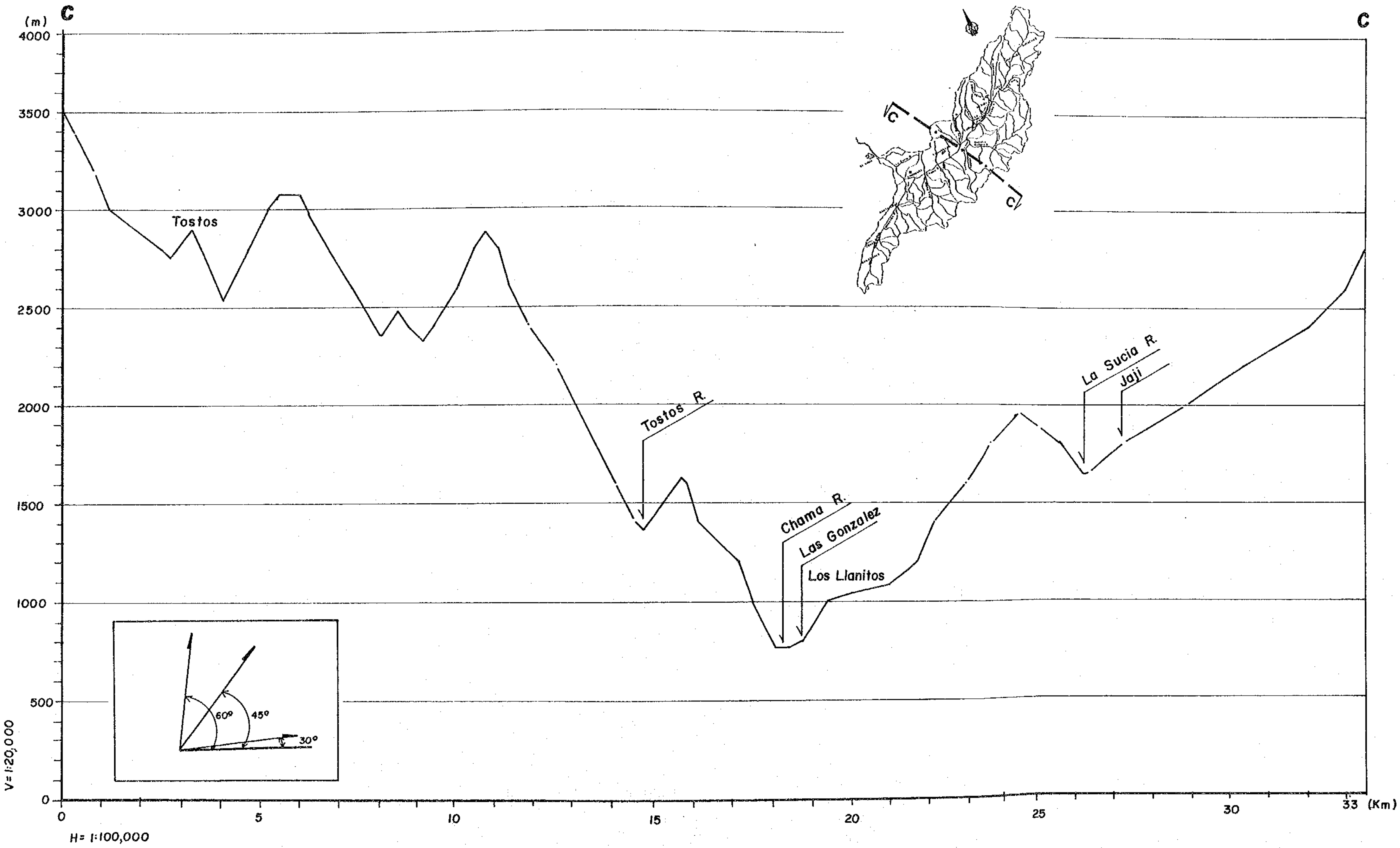
140 KM FROM THE RIVER MOUTH

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

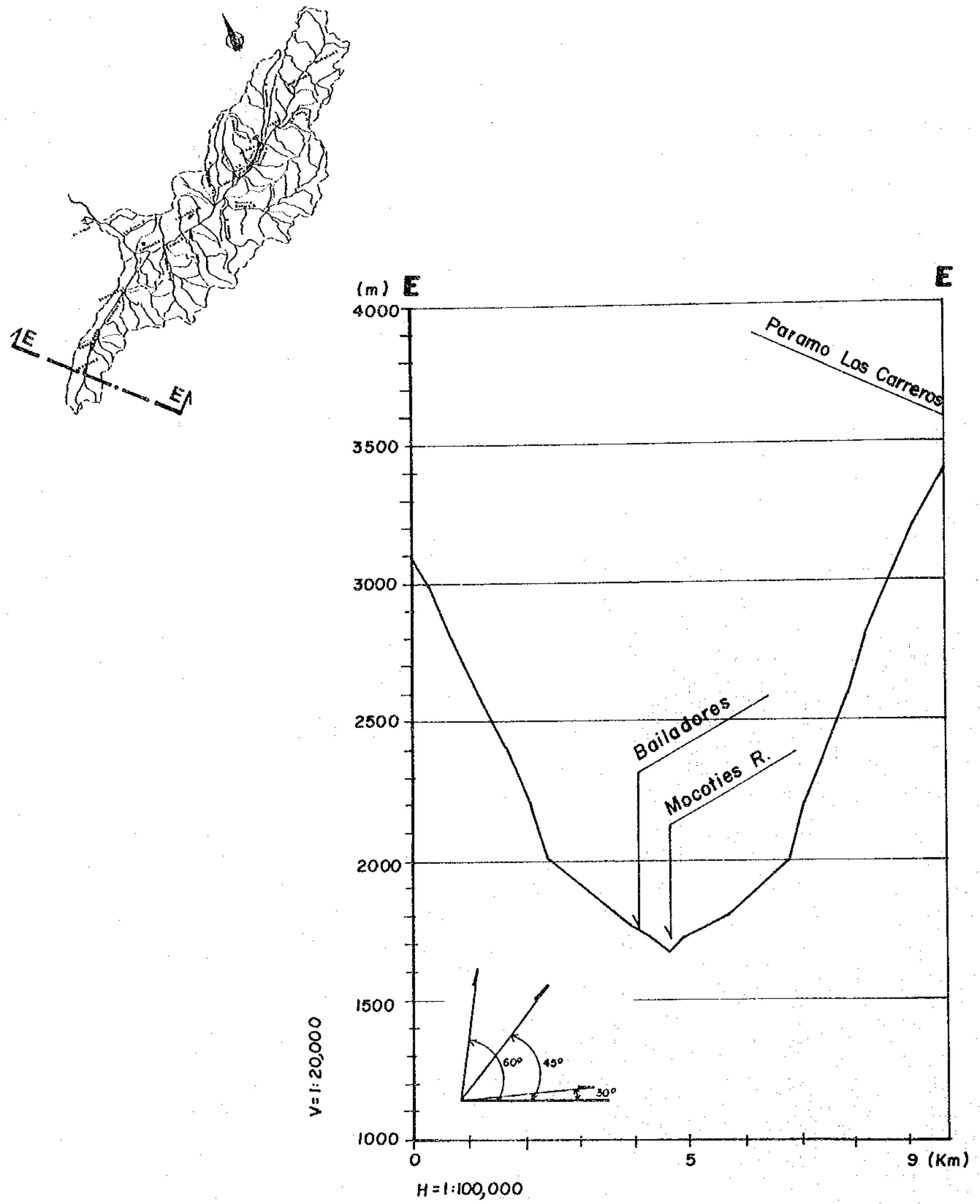
TOPOGRAPHICAL CROSS SECTIONS OF THE CHAMA RIVER BASIN

Fig. II-4 (2/4)

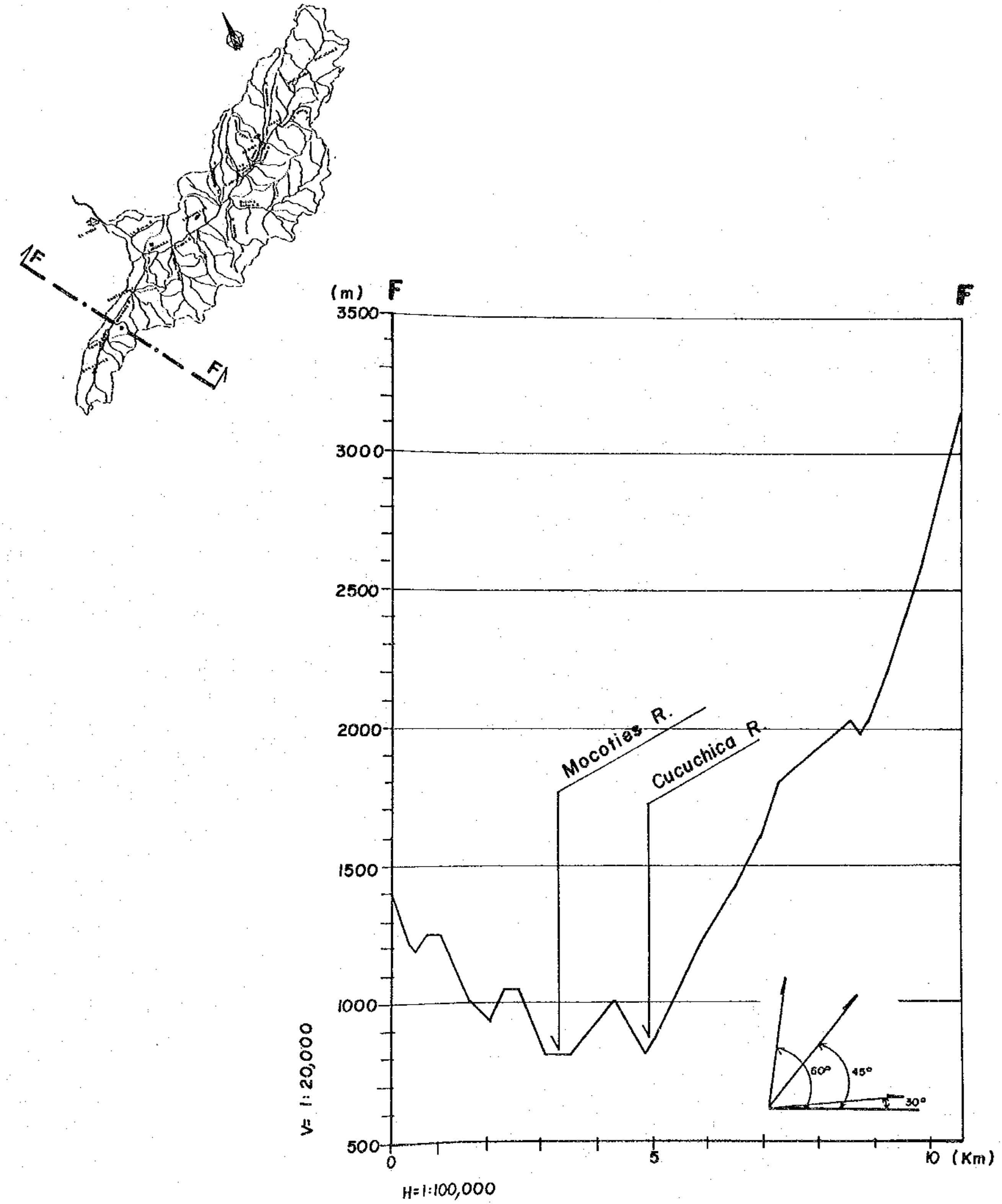


115 KM FROM THE RIVER MOUTH

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT	TOPOGRAPHICAL CROSS SECTIONS OF THE CHAMA RIVER BASIN
JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. II-4 (3/4)

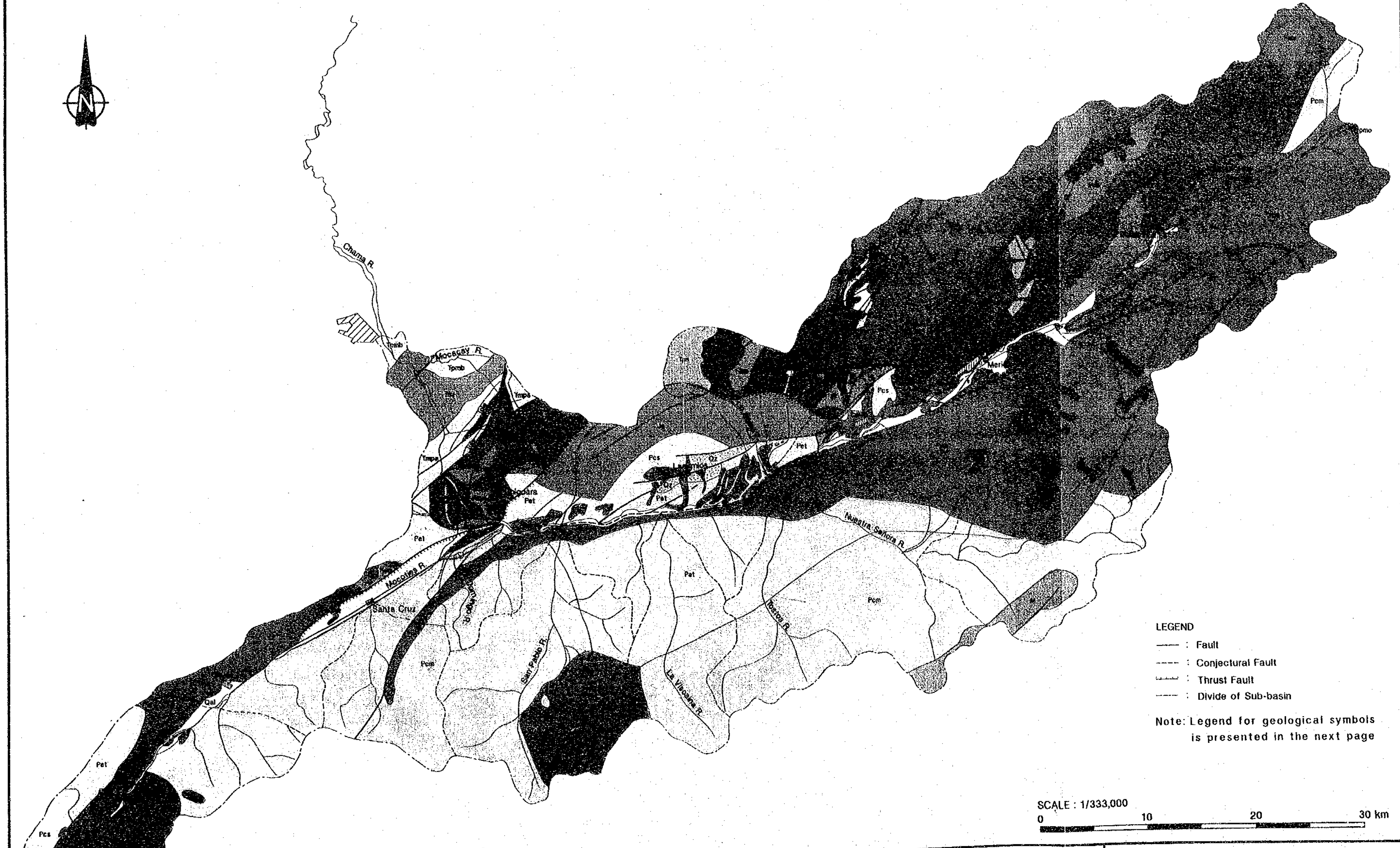


50 KM FROM CHAMA RIVER



24 KM FROM CHAMA RIVER

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT	TOPOGRAPHICAL CROSS SECTIONS OF THE CHAMA RIVER BASIN
JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. II-4 (4/4)



STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT	GEOLOGICAL MAP OF THE CHAMA RIVER BASIN
JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. II-5(1/2)

Chart	Symbol	Formation	Facies	Epoch	Era
	Qal	Alluvium Deposits	Gravel, Sand, Silt, Clay	Holocene	
	Qpmo	Moraine Deposits	Gravel, Sand, Silt, Clay, Peat	Holocene	Cenozoic Quaternary
	Qpt	Terrace Deposits	Gravel, Sand	Pleistocene	
	Qz	Tectonicted Quaternary Deposits	Conglomerate	Pleistocene	
	Tpmb	Betijoque Formation	Mudstone, Conglomerate	Pliocene	
	Tmi	Isnotu Formation	Mudstone, Sandstone	Miocene	
	Tmm	Mucujún Formation	Sandstone, Calcareous Shale	Miocene	
	Tepa	Palmar Formation	Sandstone, Mudstone, Shale	Miocene	Cenozoic Tertiary
	Tole	León Formation	Shale	Oligocene	
	Teca	Carbonera Formation	Sandy Shale, Coal	Eocene	
	Tpev	El Valle Formation	Mudstone, Sandstone	Paleocene-Eocene	
	Tpe	Unidentified Tertiary	Mudstone, Sandstone	Paleocene-Eocene	
	Kc	Colon Formation	Shale	Upper Cretaceous	
	Kl	La Luna Formation	Limestone	Upper Cretaceous	
	Kcp	Capacho Formation	Shale, Siltstone, Limestone	Middle Cretaceous	
	Kag	Aguardiente Formation	Sandstone, Limestone, Shale	Middle Cretaceous	
	Ka	Apon Formation	Limestone, Calcareous Shale	Lower Cretaceous	Mesozoic
	Karn	Apon Formation and Rio Negro Formation	Limestone, Shale, Sandstone	Lower Cretaceous	
	Krn	Rio Negro Formation	Sandstone, Arkose, Conglomerate, Shale	Lower Cretaceous	
	Jq	La Quinta Formation	Red Sandstone, Siltstone, Conglomerate	Jurassic	
	M	Unidentified Mesozoic			
	Ppp	Palmarito Formation	Shale, Marlstone, Limestone	Permian	
	Pcs	Sabaneta Formation	Siltstone, Sandstone	Carboniferous	Paleozoic
	Pcm	Mucuchachi Formation	Slate, Metasandstone, Green Schist	Carboniferous	
	Pet	Tostos Formation	Phyllite, Slate, Green Schist, Gneiss		
	Peis	Sierra Nevada Formation	Schist, Gneiss, Migmatite		Pre-Cambrian
	Gr	Granite of El Carmen, Monzonite of La Carlota, Others	Granodirite, Quartz Monzonite		Paleozoic

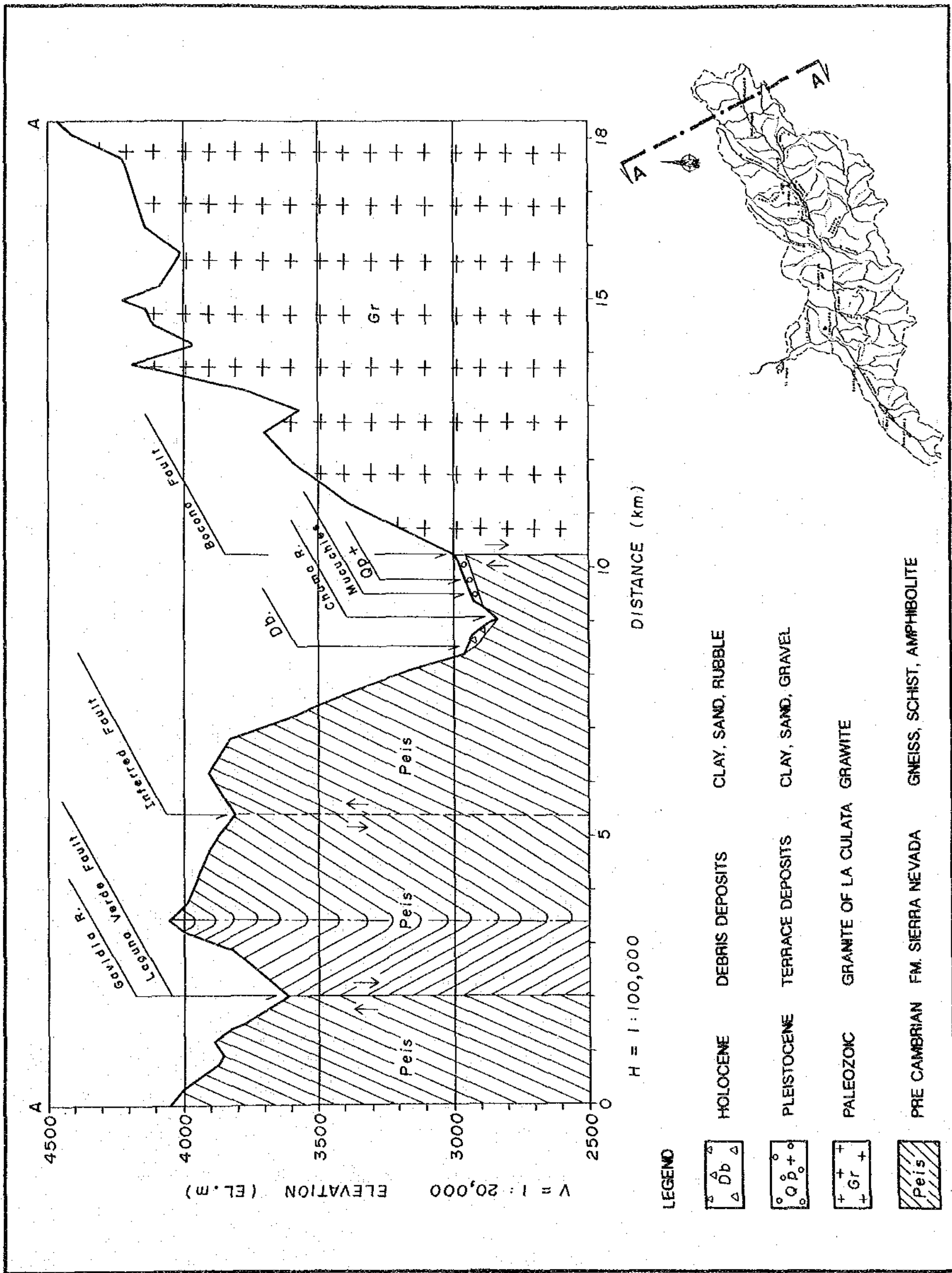
GEOLOGY OF CHAMA RIVER BASIN

GEOLOGICAL MAP OF THE CHAMA RIVER BASIN

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

Fig. II-5(2/2)

JAPAN INTERNATIONAL COOPERATION AGENCY

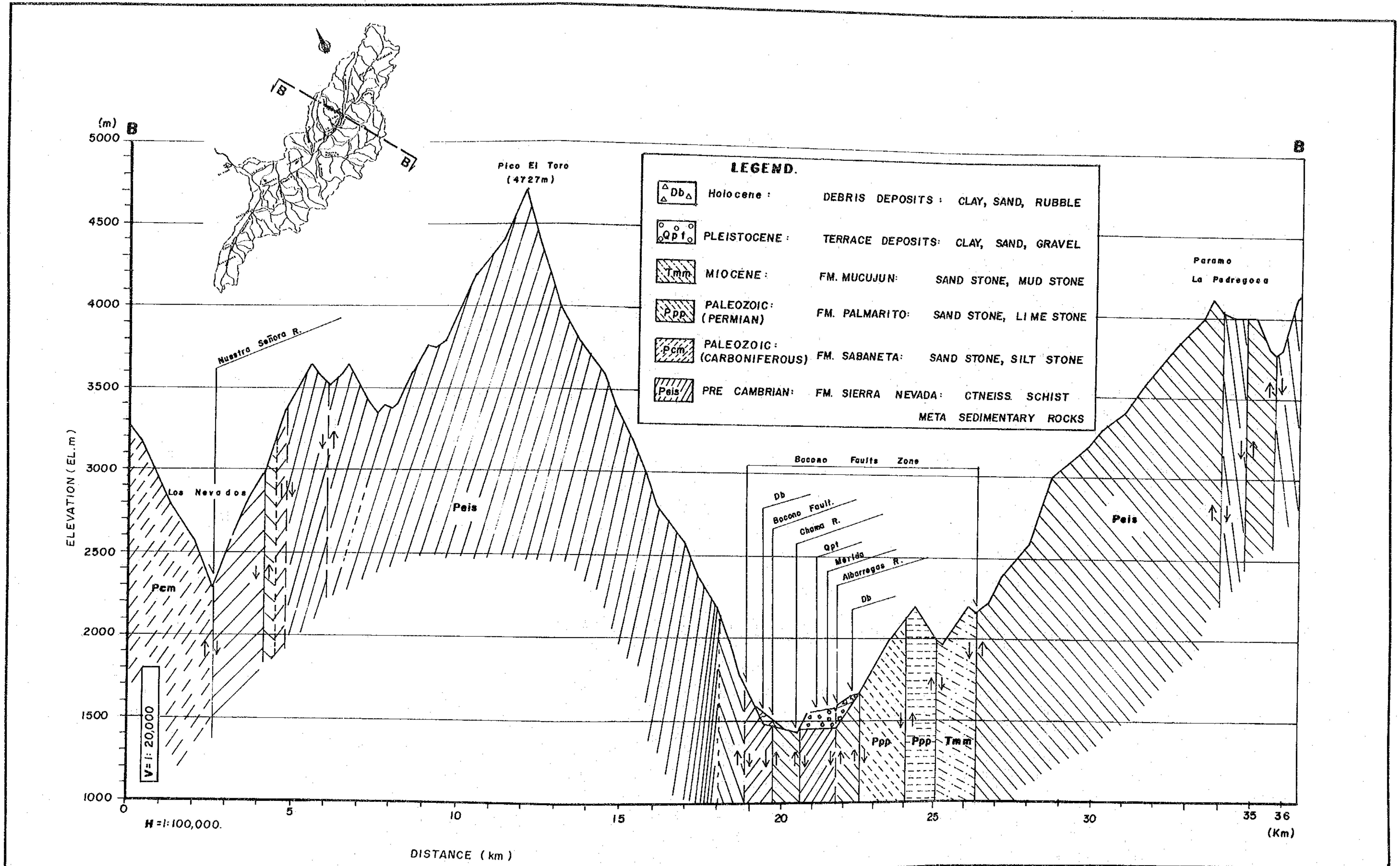


GEOLOGICAL CROSS SECTIONS OF THE CHAMA RIVER BASIN

Fig. II-6 (1/4)

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

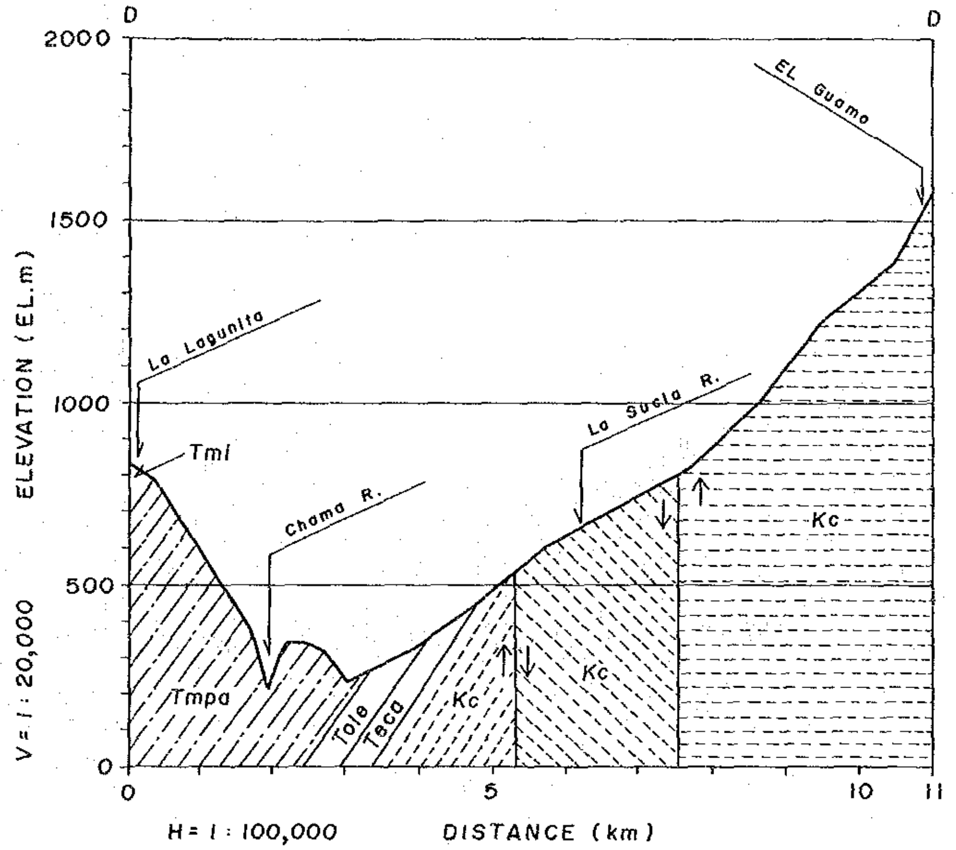


STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

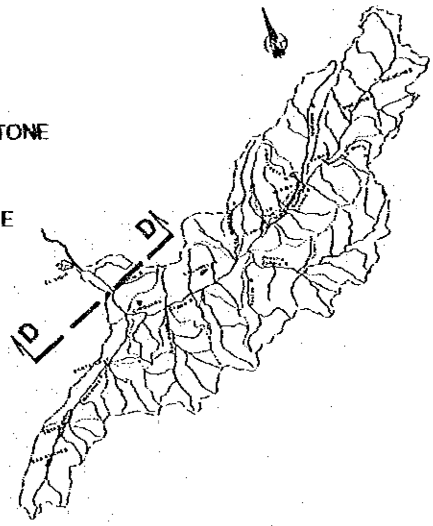
GEOLOGICAL CROSS SECTIONS OF THE CHAMA RIVER BASIN

Fig. II-6(2/4)



LEGEND

Tmi	MIOCENE	FM. ISNOTU	SAND STONE, MUD STONE
Tmpa	MIOCENE	FM. PALMER	SAND STONE, MUD STONE, SHALE
Tole	OLIGOCENE	FM. LEON	SHALE
Teca	EOCENE	FM. CARBONERA	SAND STONE, MUD STONE
Kc	CRETACEOUS	FM. COLON	SHALE, SANDY SHALE

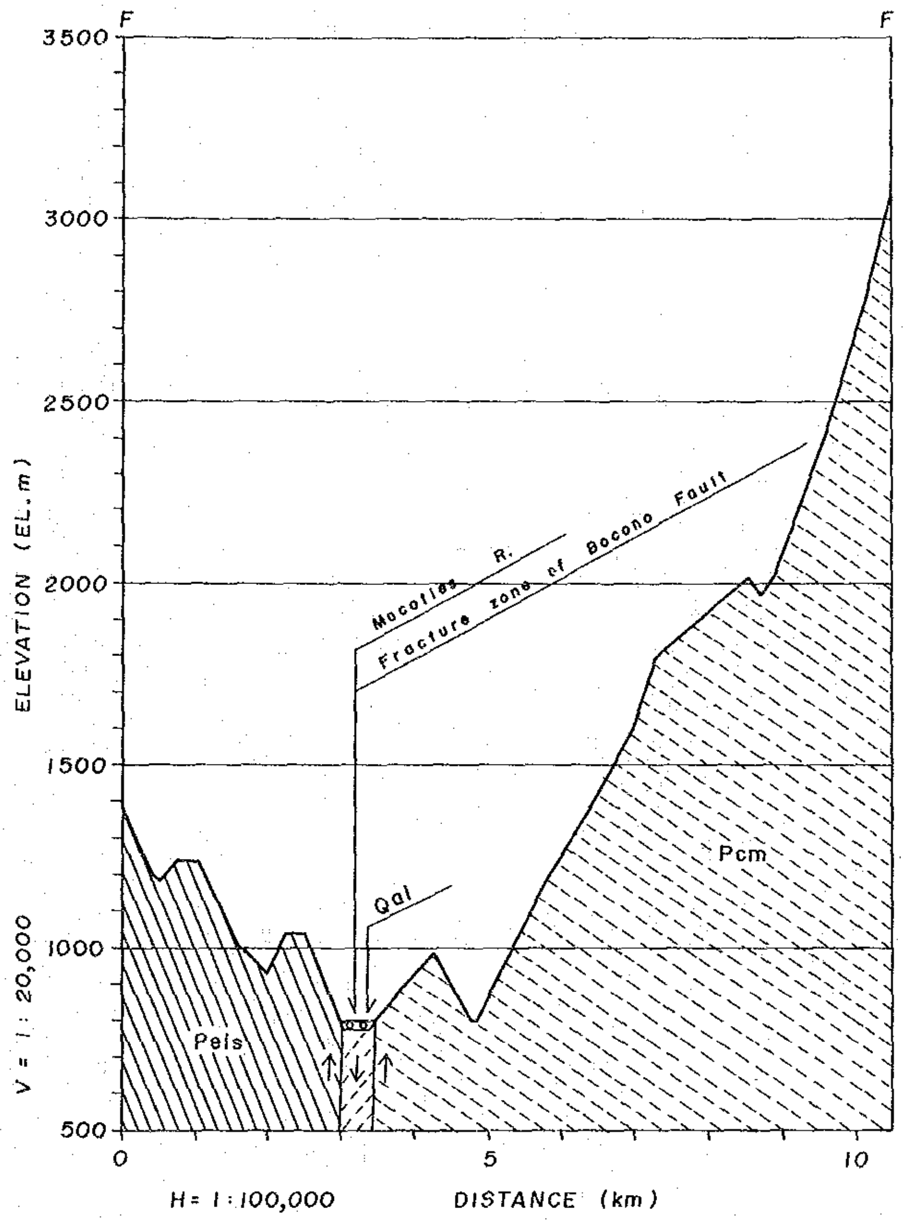


GEOLOGICAL CROSS SECTIONS OF THE CHAMA RIVER BASIN

Fig. II-6 (3/4)

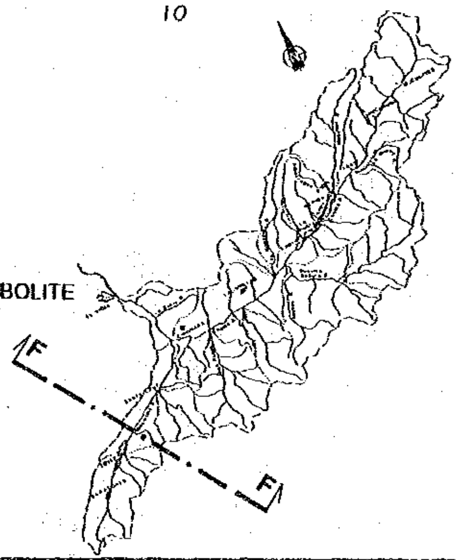
STUDY ON CHAMA RIVER BASIN
CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY



LEGEND

Qal	HOLOCENE	RIVER DEPOSITS	CLAY, SAND, GRAVEL
Pcm	PALEOZOIC	FM. MUCUCHACHI	GREEN SCHIST, AMPHIBOLITE
Pels	PRE CAMBRIAN	FM. SIERRA NEVADA	GNEISS, SCHIST

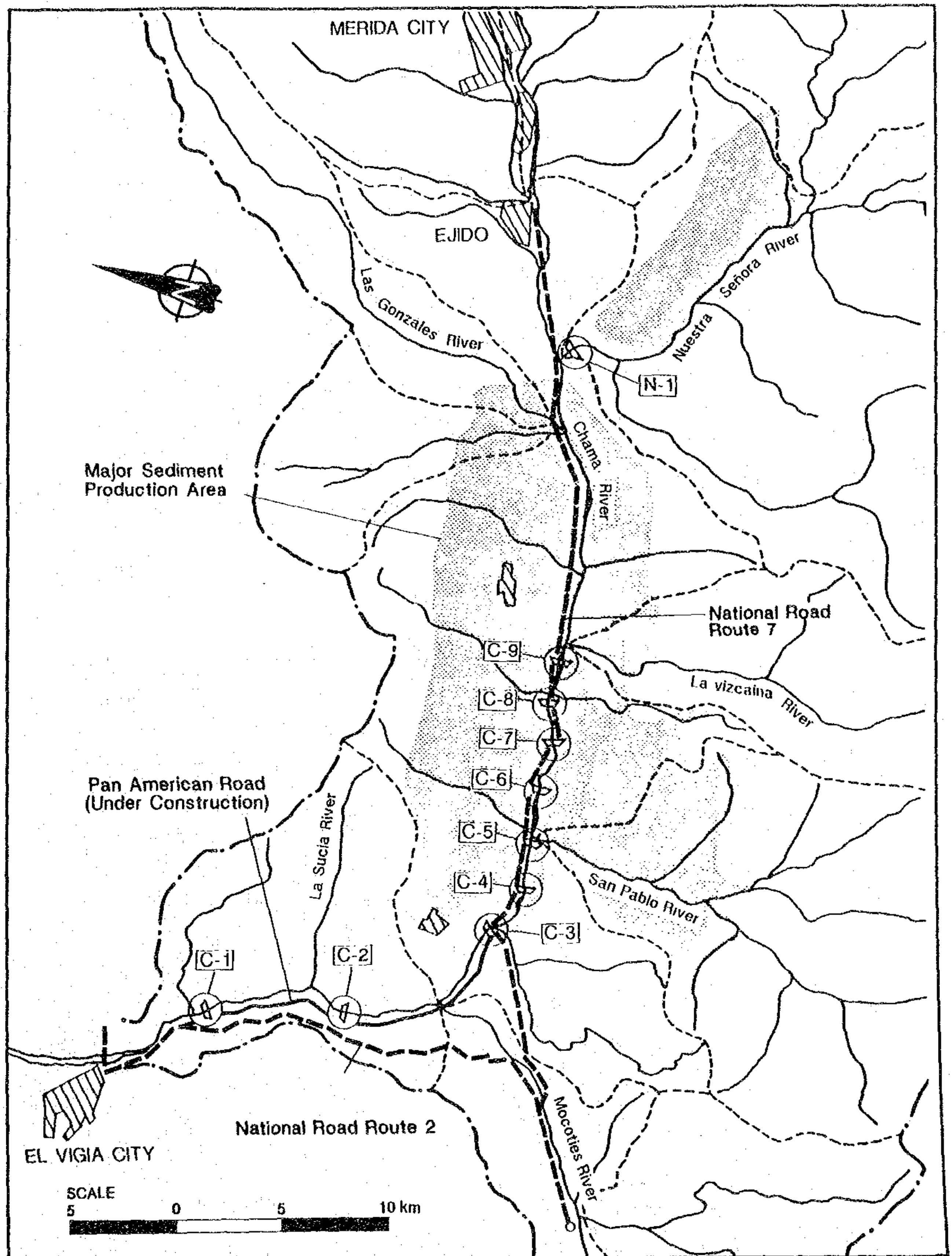


GEOLOGICAL CROSS SECTIONS OF THE CHAMA RIVER BASIN

Fig. II-6 (4/4)

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

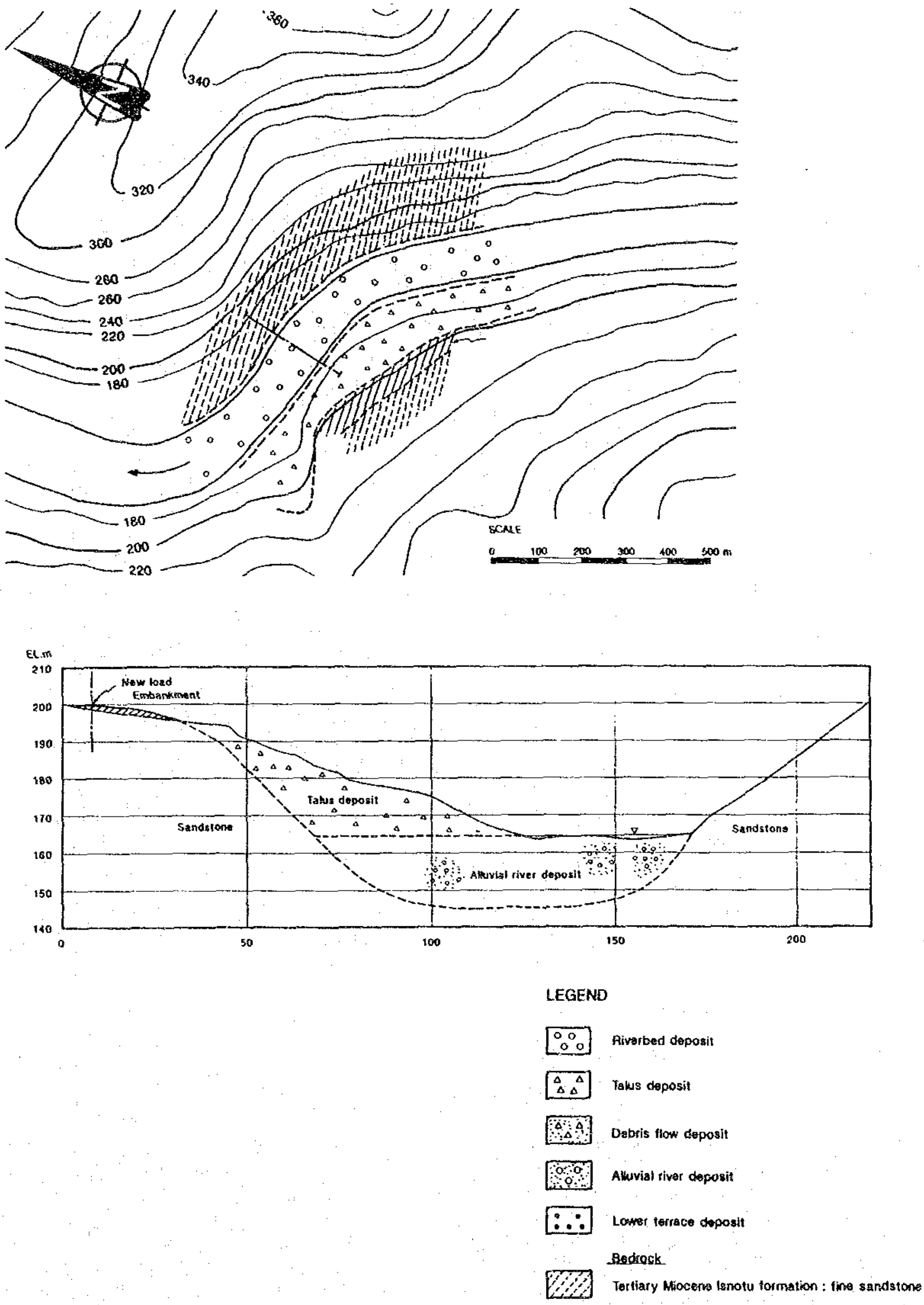


LOCATION MAP OF PROPOSED DAMSITES

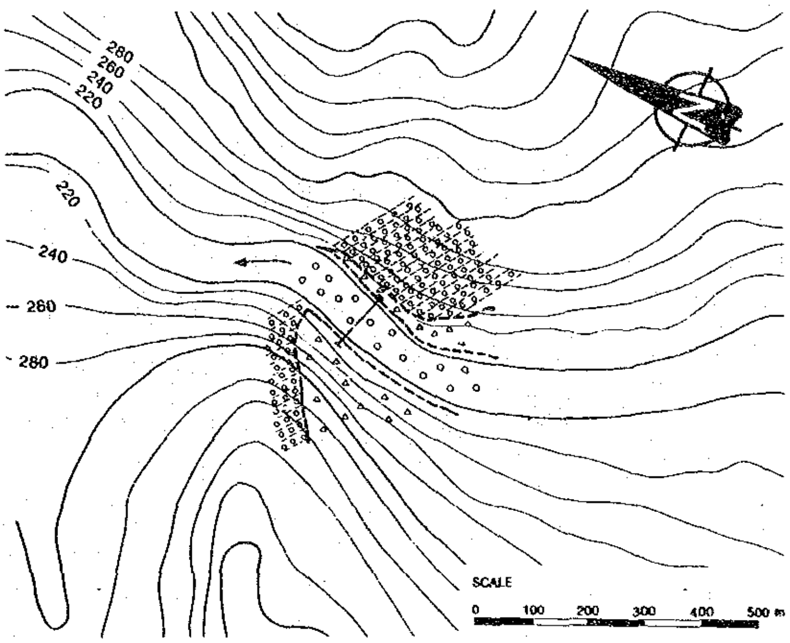
Fig. II-7

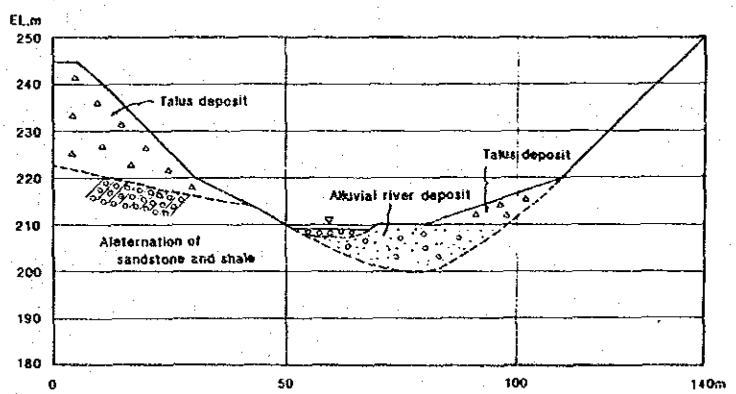
STUDY ON CHAMA RIVER BASIN
CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY



GEOLOGICAL MAP AND CROSS SECTION AT DAMSITE C-1	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT
Fig. II-8	JAPAN INTERNATIONAL COOPERATION AGENCY





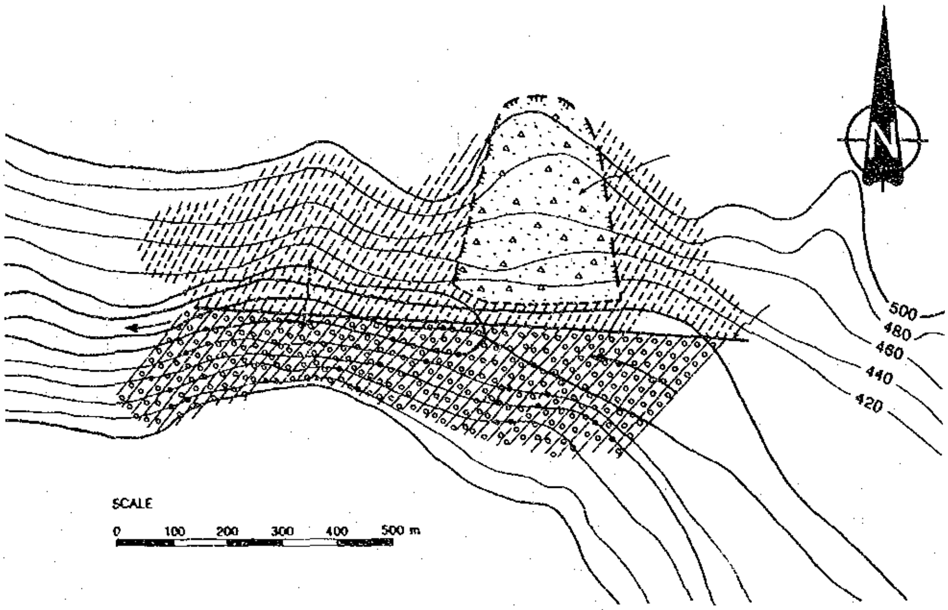
LEGEND

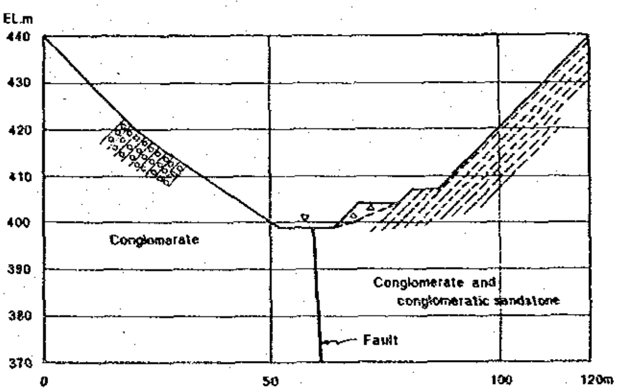
- Riverbed deposit
- Talus deposit
- Debris flow deposit
- Alluvial river deposit
- Lower terrace deposit

Bedrock

- Alternation of sandstone and shale : Tertiary Miocene Palmar formation

GEOLOGICAL MAP AND CROSS SECTION AT DAMSITE C-2	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT
Fig. II-9	JAPAN INTERNATIONAL COOPERATION AGENCY





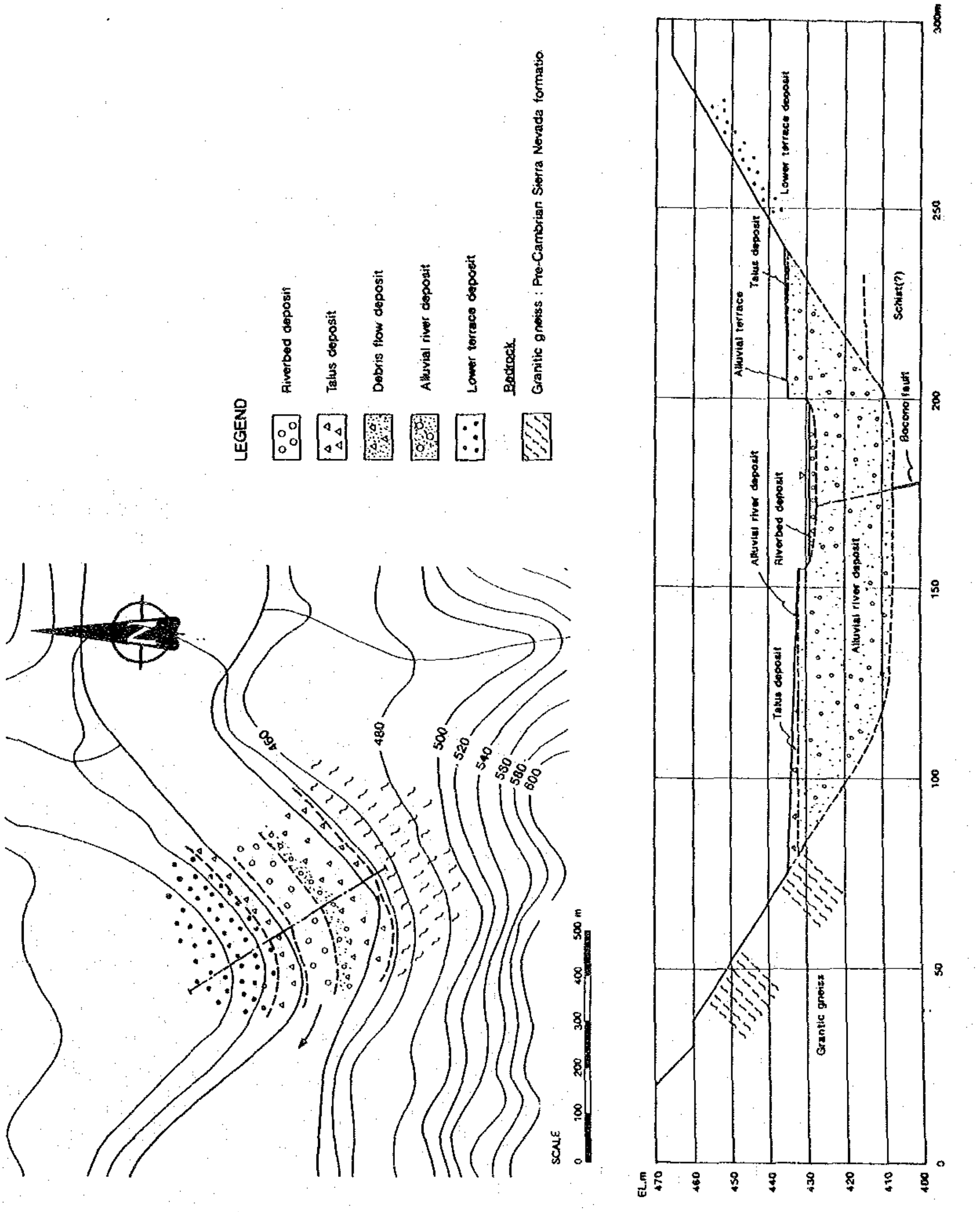
LEGEND

- Riverbed deposit
- Talus deposit
- Debris flow deposit
- Alluvial river deposit
- Lower terrace deposit

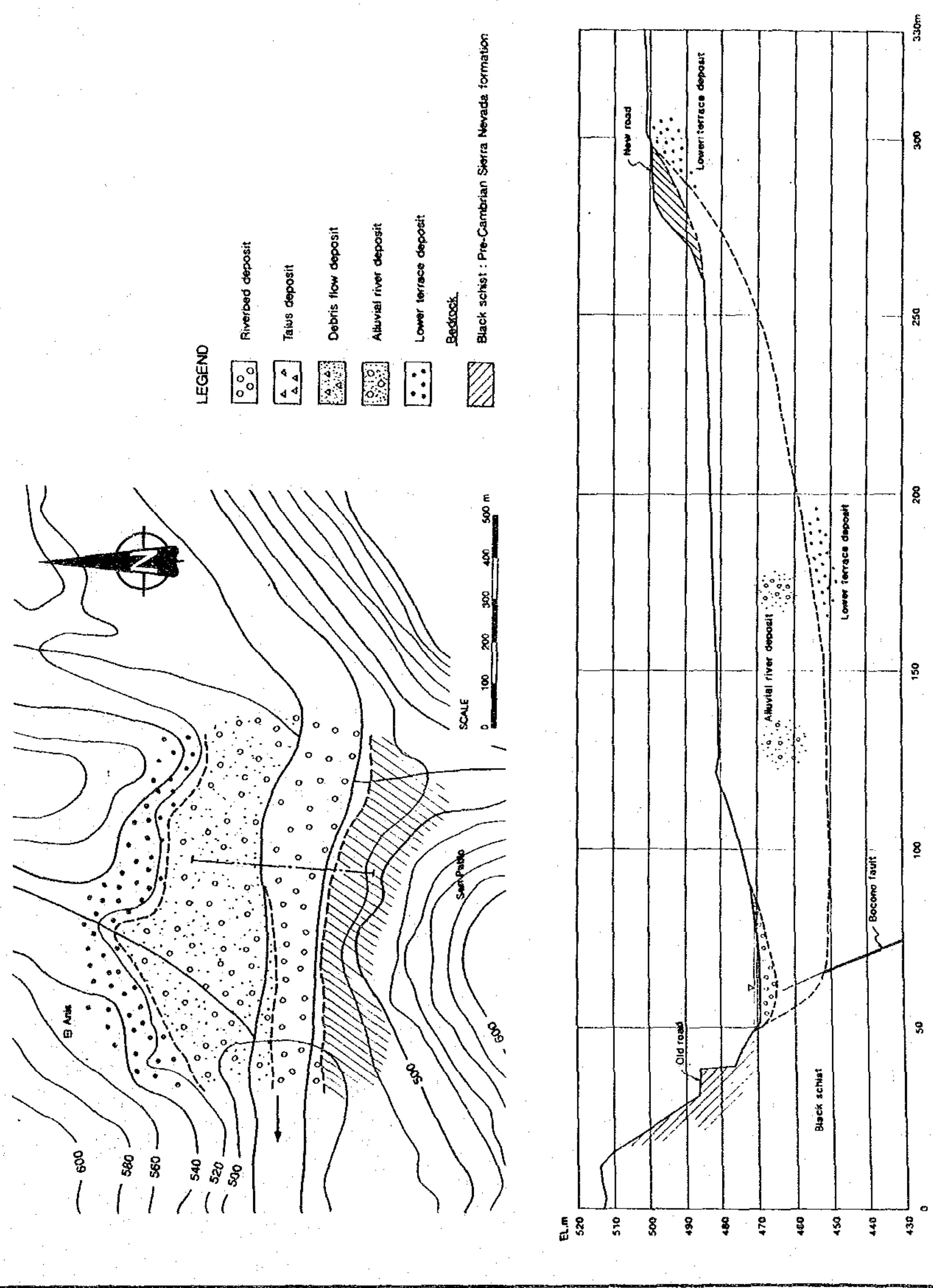
Bedrock

- Conglomeratic sandstone } Mesozoic Jurassic La Quinta formation
- Conglomerate } Mesozoic Jurassic La Quinta formation

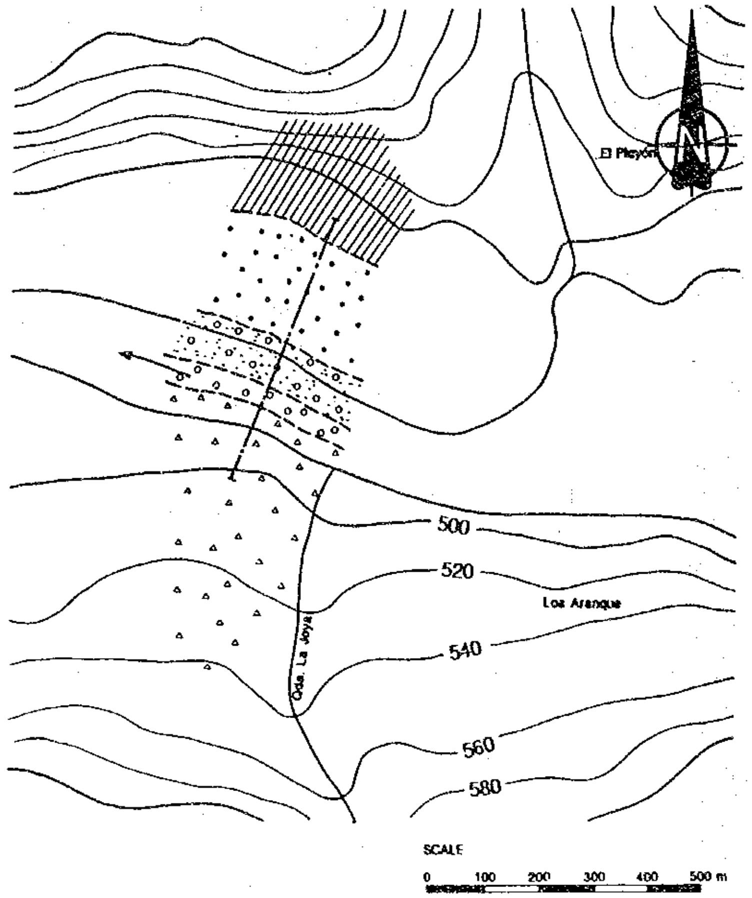
GEOLOGICAL MAP AND CROSS SECTION AT DAMSITE C-3	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT
Fig. II-10	JAPAN INTERNATIONAL COOPERATION AGENCY



GEOLOGICAL MAP AND CROSS SECTION AT DAMSITE C-4	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT
Fig. II-11	JAPAN INTERNATIONAL COOPERATION AGENCY



GEOLOGICAL MAP AND CROSS SECTION AT DAMSITE C-5	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT
Fig. II-12	JAPAN INTERNATIONAL COOPERATION AGENCY

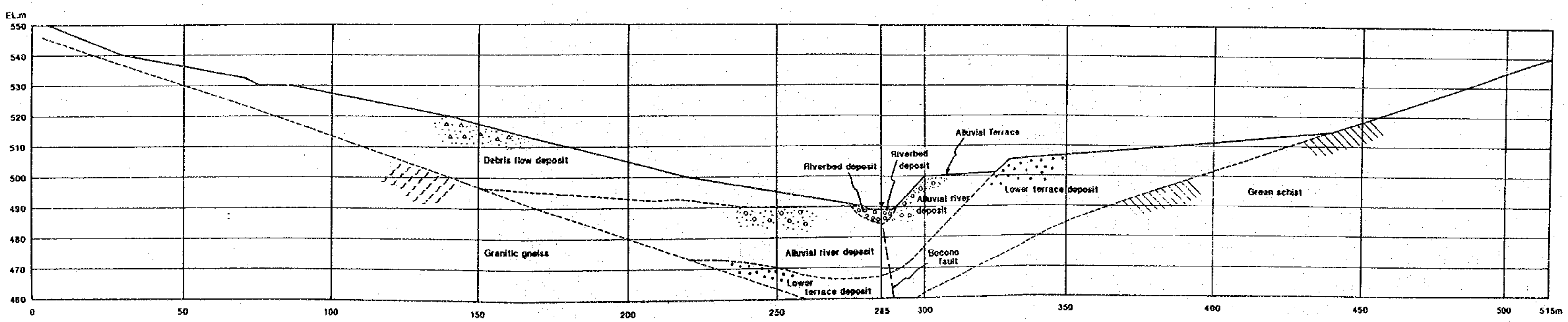


LEGEND

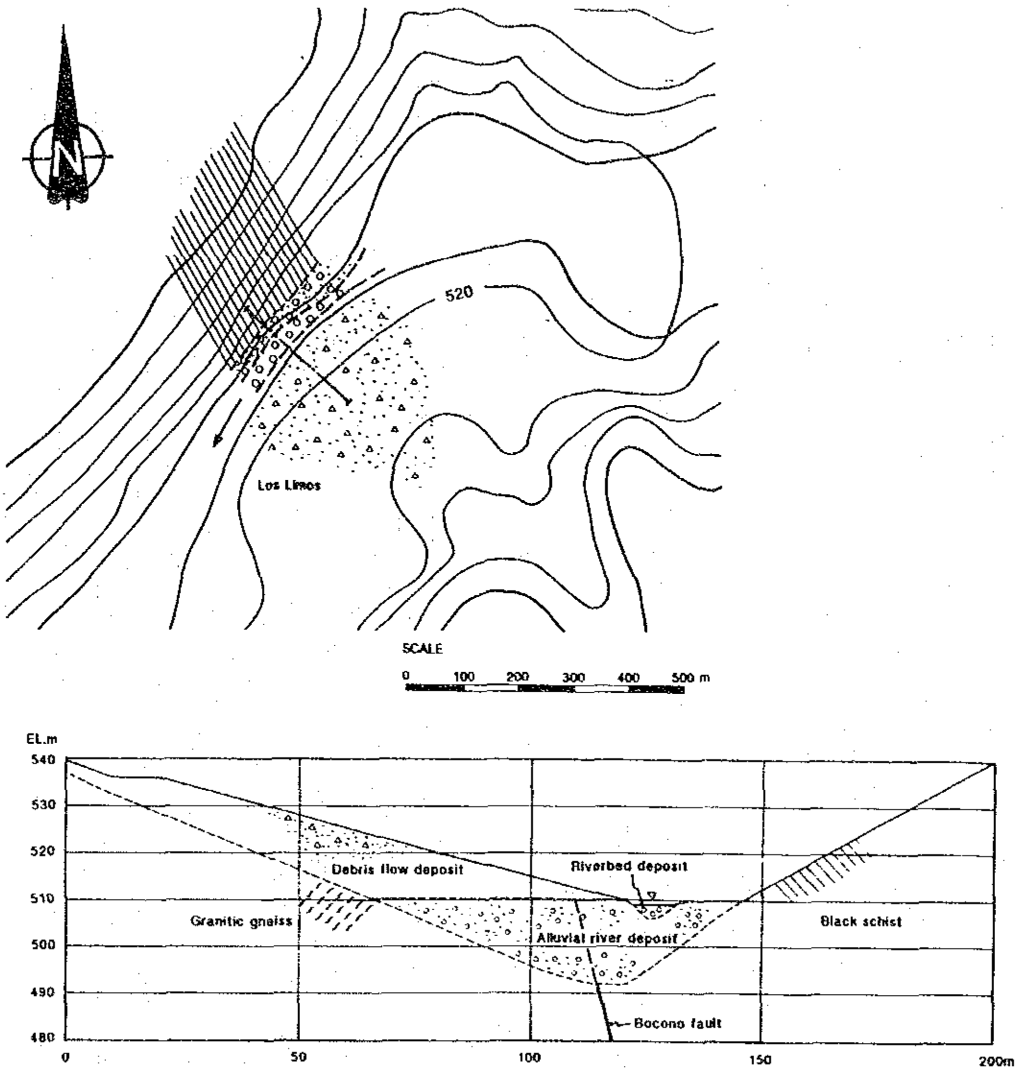
- Riverbed deposit
- Talus deposit
- Debris flow deposit
- Alluvial river deposit
- Lower terrace deposit

Bedrock :

- Green schist : Pre-Cambrian Tostos formation



STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT	GEOLOGICAL MAP AND CROSS SECTION AT DAMSITE C-6
JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. II-13



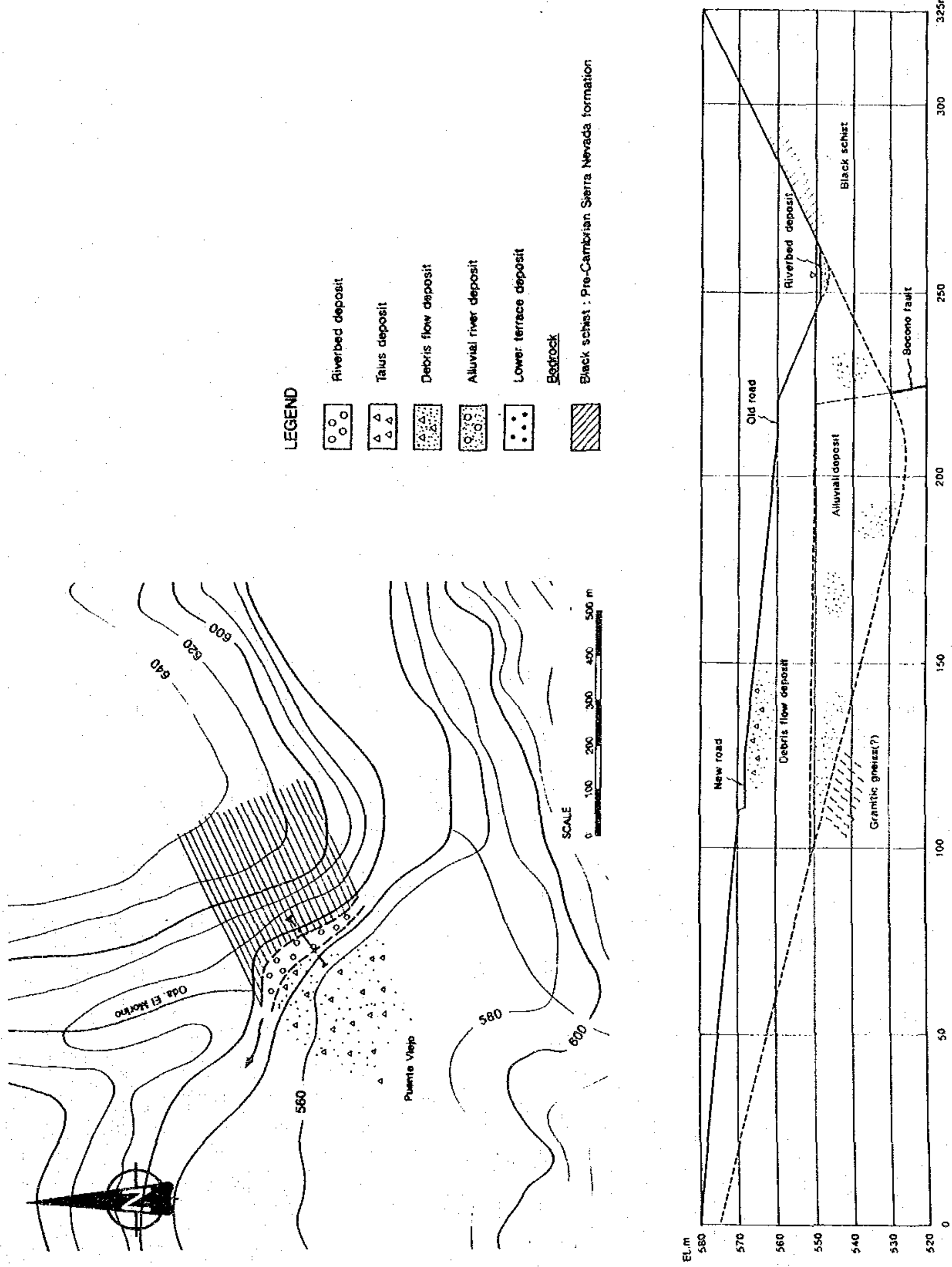
LEGEND

- Riverbed deposit
- Talus deposit
- Debris flow deposit
- Alluvial river deposit
- Lower terrace deposit

Bedrock

- Black schist : Pre-Cambrian Sierra Nevada formation

GEOLOGICAL MAP AND CROSS SECTION AT DAMSITE C-7	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT
Fig. II-14	JAPAN INTERNATIONAL COOPERATION AGENCY

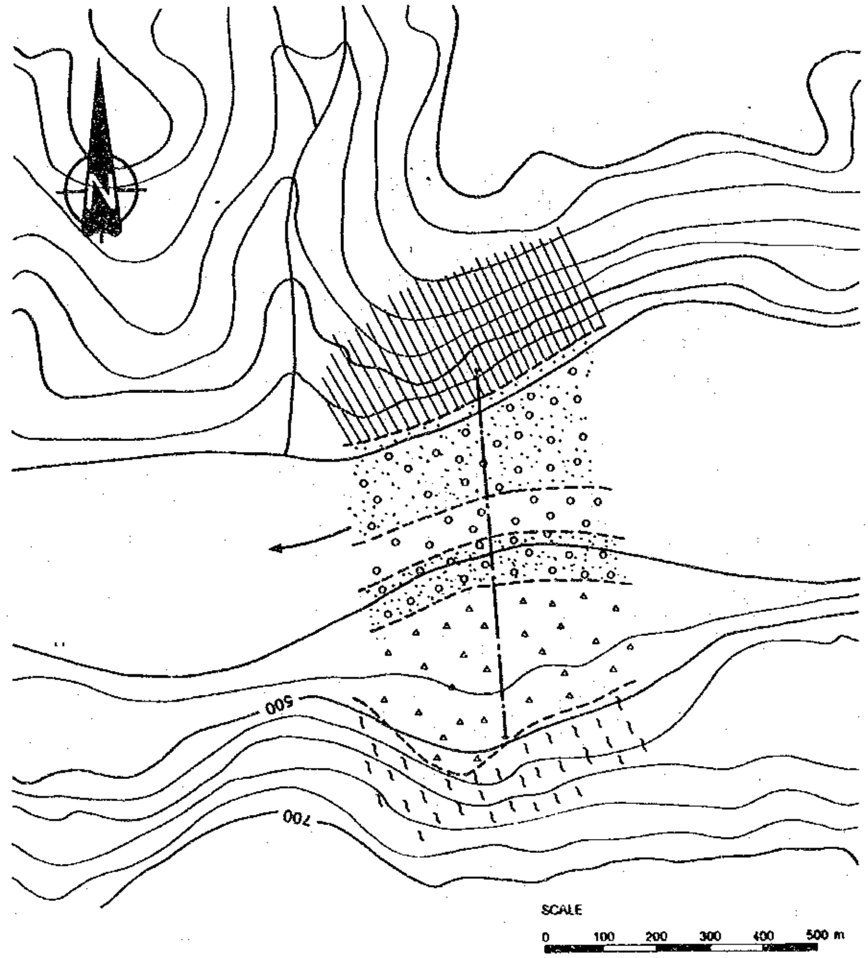


GEOLOGICAL MAP AND CROSS SECTION AT DAMSITE C-8

Fig. II-15

STUDY ON CHAMA RIVER BASIN
CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

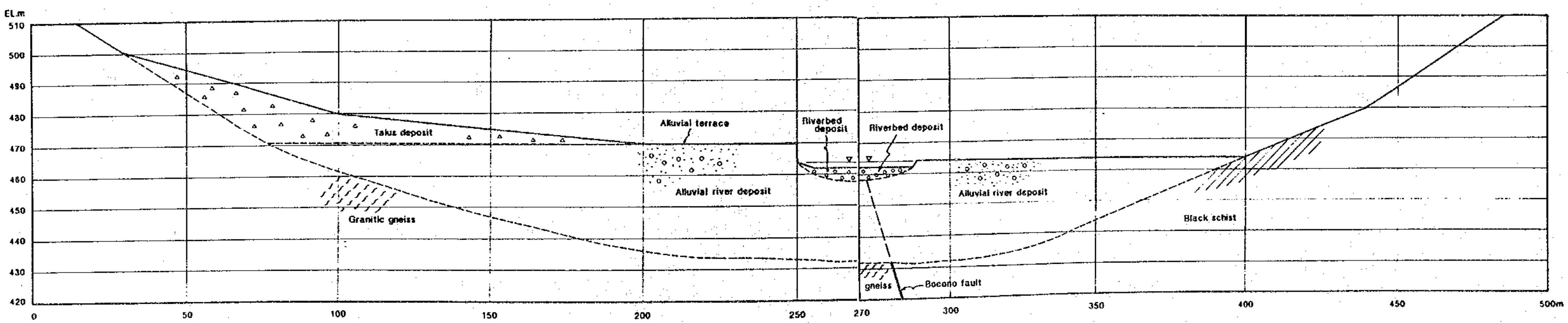


LEGEND

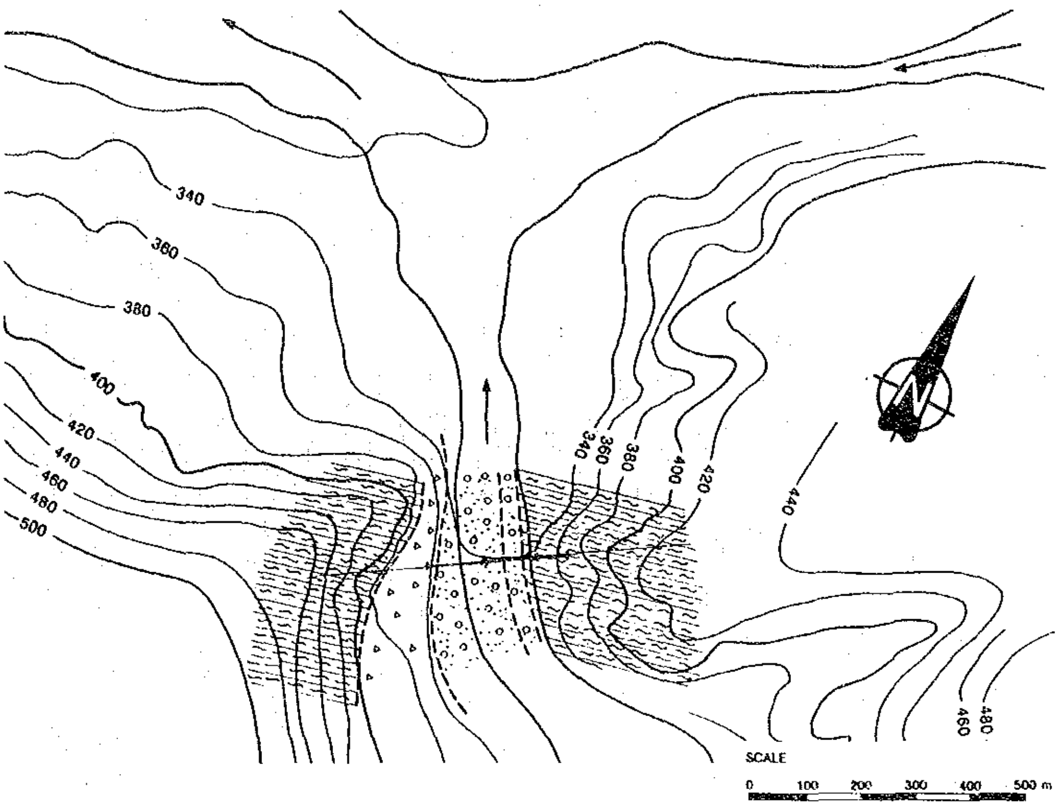
- Riverbed deposit
- Talus deposit
- Debris flow deposit
- Alluvial river deposit
- Lower terrace deposit

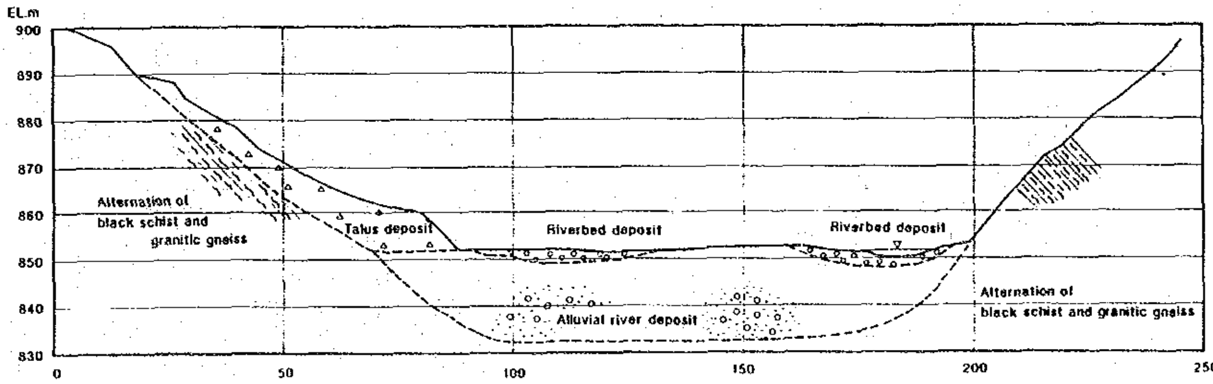
Bedrock

- Black schist : Pre-Cambrian Tostos formation
- Granitic gneiss : Pre-Cambrian Sierra Nevada formation



STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT	GEOLOGICAL MAP AND CROSS SECTION AT DAMSITE C-9
JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. II-16





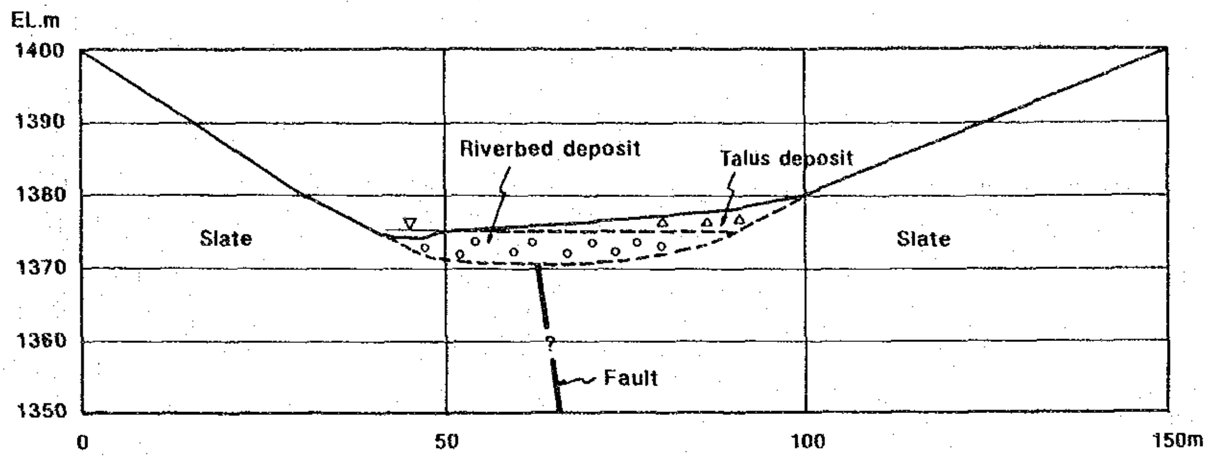
LEGEND

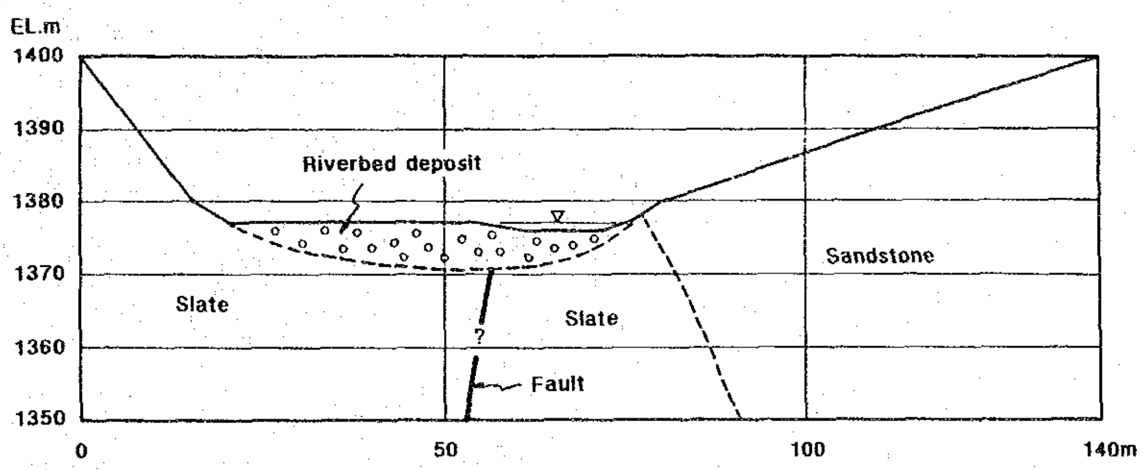
- Riverbed deposit
- Talus deposit
- Debris flow deposit
- Alluvial river deposit
- Lower terrace deposit

Bedrock

- Alternation of black schist and granitic gneiss : Pre-Cambrian Sierra Nevada formation

GEOLOGICAL MAP AND CROSS SECTION AT DAMSITE N-1	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT
Fig. II-17	JAPAN INTERNATIONAL COOPERATION AGENCY





GEOLOGICAL CROSS SECTIONS AT CONTINUOUS DAMSITES	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT
Fig. II-18	JAPAN INTERNATIONAL COOPERATION AGENCY

III. VEGETATION

SUPPORTING REPORT

III. VEGETATION

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ANNEX III-1 Data for Reduction of Sediment Discharge by Afforestation in Japan

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1. PRESENT CONDITION

Vegetation of the Chama River Basin is much influenced by its topography and climate which varies from tropical at less than 1,000 m in elevation to frigid at 5,000 m above. The distribution of vegetation was then studied through field reconnaissance and the collected reference materials, as explained hereinafter.

1.1 Vertical Distribution of Vegetation

The relationship between the elevation of land and the annual mean temperature in the Chama River Basin is shown in Fig. III-1, where the basin is classified into five zones by annual mean temperature; namely, tropical zone, temperate zone, arctic zone, páramo zone as a characteristic of the Andes Mountains, and frigid zone. The natural forest limit is bounded on the páramo zone, which is covered with weeds of the Poaceae such as Calamagrostis, Festuca, Agrostis, etc.

The relationship between annual rainfall and vegetation form is shown in Fig. III-2. Land in the tropical zone of less than 1,000 m in elevation with annual rainfall of more than 2,000 mm has tropical rain forest of 30 to 50 m high. Thornscrub low forest of 2 m high covers the semi-arid area.

There is a cloud forest in the high land of more than 1,500 m in elevation. This extends to the higher place according to the volume of rainfall; however, the forest does not exist in the area of more than 3,300 m despite of the volume of rainfall. This area is covered with the grassland of the páramo zone.

1.2 Areal Distribution and Characteristics of Vegetation

The vegetation map of the Chama River Basin is shown in Fig. III-3, where vegetation is classified into high forest, low forest and grassland. Trees of 20 to 40 m high with big trunks comprise the high forest. On the other hand, low trees of 2 to 3 m high and branched off at the root dominate the low forest.

The distribution ratio of high forest, low forest and grassland is different in the five sub-basins (Fig. III-3) of the Chama River Basin. Table III-1 presents the ratio of area of vegetation form in the sub-basins derived from the distribution of vegetation shown in Fig. III-3.

The characteristics of vegetation in the five sub-basins are discussed hereinafter, based on the conditions of climate and vertical distribution of vegetation.

Upper Reaches

The river course in the upper reaches runs through the alpine land area of from 4,400 m to 2,000 m in elevation. The climate belongs to the arctic, frigid and páramo zones, and the former two zones are composed of low forest of 15% and high forests of 5% of the whole area of the Upper Reaches.

The páramo zone located higher than the other two zones is composed of grassland which shares 76% of the Upper Reaches. The zone includes a wide semi-arid area with annual rainfall of 600 to 800 mm. The effect of aridity extends to the growth of vegetation of agricultural products or afforestation land, but not to the change of vegetation form or the decrease of grassland.

Most of the grassland in the upper reaches is uncultivated, and some areas along the Chama River are utilized as agricultural and pasture land. Soil erosion occurs on the mountainside of more than 30 degrees, in particular on the steep slope. Erosion control works have been conducted by local farmers under the assistance of MAC for the purpose of conservation of the agricultural or pasture land.

Middle Reaches I

The river course in Middle Reaches I flows down from 2,000 to 1,000 m in elevation and the climate is classified into the temperate zone, except the mountains of 3,000 to 4,000 m located around the watershed which belong to the temperate or the páramo zone.

Most of this Middle Reaches I have the annual rainfall of 1,200 to 1,600 mm. The forest is relatively well developed and high forest shares 54% of the area. The páramo zone at the watershed is covered by grassland as in the Upper Reaches.

Grasslands and the low trees are widely distributed in the forestal area of this reaches because the high trees were cut and the area is utilized for pastures. This pasture land grows well due to the fertile soil and the abundant rainfall, and soil erosion has advanced in a few places.

<u>Middle Reaches II</u>

The river course in Middle Reaches II flows down from 1,000 m to 110 m in elevation. Its climate falls under the tropical zone. The mountains of 2,000 to 3,000 m around the watershed has the annual rainfall of 1,000 mm to 1,200 mm, and climate is of the arctic or the páramo zone. A wide semi-arid area with the annual rainfall of 600 to 800 mm lies along the Chama River. The vegetation therein is only thornscrub low forest; high trees do not grow.

Vegetation in this area is composed of low trees of 45%, high trees of 47% and grassland of 8%. There are many steeply sloped areas of more than 40 degrees, especially at the mountain slope area along the river course where soil erosion has advanced with the progress of devastation. The surface soil had washed out of the steep slope of more than 45 degrees and no vegetation exists.

Vegetation at the mountain slope facing south or southwest is generally poorer than that facing east or north and devastation is also more advanced. The geology at the semi-arid area is mainly composed of metamorphic rocks, e.g., slate, phyllite, schist and gneiss. Soil thereat has a high very-fine-sand content and is in general easy to dry up. Therefore, it is necessary to select trees and plants that are durable to the arid climate or barren land for revegetation at the slope area.

Vegetation at the semi-arid area from Ejido to Estánquez along the Chama River was investigated in 1976. There were 19 families and 108 sorts including the high trees of 9 sorts, the low trees of 29 sorts and weeds of 58 sorts as shown in Table III-2. Among the 19 families, the leguminosae has many high and low trees of which conservation effect is higher among all trees and plants. The principal features of the leguminosae are shown in Table III-3.

Trees of leguminosae keep rhizobiumfia which fix nitrogen in the atmosphere. They then make the surface soil fertile, and are durable to the arid climate. The leguminosae is, therefore, set at a high value in the world as the sort of tree for reforestation in barren land.

Melinis minutiflora of the poaceae family was found, through the reconnaissance, to grow wild and dominate at the waste land, the mountain slope of more than 40 degrees or the crack of rocks, with the plants of cactaceae or trees of leguminosae. This weed also grows wild in the tropical areas of Brazil, South Africa or New Guinea and breeds by a tiller of sort and stump. This is also utilized effectively for the conservation of mountain slopes or side slopes.

Middle Reaches III

The river course in Middle Reaches III flows down from EL 3,400 m at the origin of the Mocoties River to EL 600 m at the confluence of the same with the Chama River. Climate falls under the tropical, temperate and arctic zones. This reaches has much rainfall of from 1,000 to 1,600 mm.

Forests cover the whole area of this reaches. High trees dominate 78% of the area and low trees mostly grow on the high mountain area at the east side. This reaches has the most stable vegetation area and the least volume of sediment production in the whole Chama River Basin.

Lower Reaches

The river course flows down from EL 110 m at the confluence of the Chama and the Mocoties rivers to the Maracaibo Lake. Annual rainfall varies from 2,200 mm to 1,600 mm. The annual mean temperature is more than 24°C and the whole area belongs to the tropical zone.

The vegetation in the reaches is shared by the agricultural land of 56% and the high forest of 44%, but pastureland or plantain plantation is increasing in the area facing the river mouth. Therefore, flood control is necessary for the lower reaches instead of the conservation of vegetation.

2. CONDITION OF SOIL CONSERVATION WORKS

Soil loss is attributable to natural erosion and to accelerated erosion induced by tree-cutting. The soil conservation works performed were identified through the field reconnaissance and collected reference materials as discussed in the following paragraphs.

2.1 Afforestation Works

To reduce sediment production, soil conservation works by afforestation to expand the forest area was performed for the period from 1955 to 1981. The location of the afforestation project is presented in Fig. III-4, and the list of afforested trees and their respective areas are given in Table III-4. After that period, supplemental afforestation works on 115 ha at Lagunillas in 1982 to 1988 and 147 ha at Mérida City in 1988 were carried out.

Pinus sp, is mainly utilized for afforestation because species or saplings are easy to obtain, the strike root is easy after afforestation, natural renewal is easy after the growth, and so on.

Through the field reconnaissance in the afforestation area in the upper reaches near the town of Mucuchíes, it was observed that planted trees belonging to the Eucalyptus sp. with heights of 6 to 10 m have weathered in their upper portions. This is believed to be due to cold climate or the infertile soil condition. More careful consideration should be given to the selection of site and trees in the execution of afforestation programmes.

2.2 Protection Works on Mountain Slope

Around the mountainside areas near the town of Mucuchíes in the upper reaches of the Chama River, trenching works were carried out at a certain interval along the contour line. These trenches collect and keep moisture, protect soil erosion, and prevent drought damage. Such works were performed by the MAC and Mérida State from around 1960.

This method was also applied for the afforestation area near Mucuchíes with some improvements. It was found to be useful for the conservation of steep slope areas, except for cases in extreme waste land or of unsuitable selection of seed for afforestation.

Concerning the application of this method for semi-arid area in Middle Reaches II, the following conditions are necessary from the economical point of view: (1) there is a head of stream, (2) this work is useful for the improvement of residential area, and (3) this is useful for the improvement of agricultural production.

2.3 Slope Protection Works for Road

Slope protection works were successfully performed at Route No. 7 of the arterial highway running in the semi-arid area in the middle reaches of the Chama River. This works was conducted by direct seeding of the tree of the leguminosae family and melinis minutiflora of the poaceae family.

3. AFFORESTATION AND REVEGETATION

The permanent measures to control the sediment discharge in the watershed of the Chama River are to scheme a vegetation recovery of the sediment discharge sources such as the collapsed sites and the bare lands, and to develop them to the most stable forest vegetation. From this point of view, the objectives of forest land conservation were presented and the importance of vegetation in the watershed as well as the methods of revegetation was investigated.

3.1 Upper Reaches

The Mucuruba area in the upstream watershed of the Chama River is a low rainfall area with an annual amount of 800 to 600 mm where the production of crops and grass are decreasing due to frequent water shortage. The natural vegetation area is occupied by the grassland of the páramo zone extending above the timber line, and large scale landslide area and bare land are rare.

In a part of the central area of Mucuchíes, a bare land exists in an intense arid zone with annual rainfall under 600 mm. Vegetation has remained at the bottom of gullies, however, and sediment been scarcely discharged into the main stream of the Chama River. Accordingly, the revegetation scheme for sediment discharge control is not directly required in the planning of disaster prevention of the Chama River.

The Ministry of Agriculture and Breeding Activities and the State of Mérida have successfully implemented a major project for the conservation of arable land and grazing land at Mucurubá (in the upstream of the Chama River) including the extensive agricultural land with steep slope. This project has been implemented since around 1960.

The design of the project is partly indicated in Fig. III-5. The contour trench with horizontal distance of 20 meters contributes greatly to the prevention of top soil erosion as well as water conservation. This project is desirable to be developed further for land conservation of the upstream watershed.

3.2 Middle Reaches I

The vegetation in the whole watershed is in a satisfactory state due to comparatively high precipitation ranging from 1,500 mm to 1,800 mm per annum and the denudation is scarcely observed. Therefore, large scale revegetation is not required.

A large scale collapse occurred in 1973 at Tabay, the confluence of La Mucuy River, and rehabilitation works have not been executed yet.

3.3 Middle Reaches II

The semi-arid areas with an annual rainfall of 600 to 800 mm are situated mainly along the Chama River and extend over the area of 500 to 600 km^2. The vegetation in this zone is low forest as shown in Fig. III-3 and the ratio of vegetation coverage is mostly 40 to 60%.

Erosion of topsoil and denudation are active in this area. The largest sediment discharge has also been observed. Therefore, it is necessary to reinforce the vegetation in this area by employing the method to revegetate the extensive land and selecting the effective plant species. The following schemes are required to achieve the above objectives.

3.3.1 Selection of Plant Species for Revegetation

In the revegetation works of the barren and landslide areas, the primary requirement for the plant species is to grow persistently in barren land and satisfy the land conservation. In this respect, an investigation was made for the present vegetation condition at the central area of the semi-arid zone as shown in Table III-2. The result indicate that 20 species of the Compositae family and 18 species of the Leguminosae family constitute the largest plant group within the same family which belongs to the same group in plant taxonomy occupying 35% of the total 108 species of the plant.

This is therefore considered advantageous to utilize mainly the plants of the families mentioned above in the semi-arid zone. Among those plants required for the afforestation, only two species of shrub are available in the Compositae family while six species of tree and four species of shrub are available in the nitrogen fixation plants family, Trees of the Leguminosae family have to be utilized mainly for the afforestation to be executed in the future. Further, the leguminosa plants are considered indispensable in the barren land because they fix nitrogen which fertilizes the land.

The scientific names of the leguminosa plants growing spontaneously in the semi-arid zone are presented in Table III-3. The Forest Resource Department of Los Andes University has made a study on the tree species for afforestation in arid zones and Leucaene trichodes has been selected in the first rank and Pithecellobium saman in the second rank. In the semi-arid zones Cassia siamea have been widely planted for the roadside tree and green belt along the arterial highway No. 7 since about ten years ago.

All of the three plants mentioned above belong to the Leguminosae family and this fact indicates that in the semi-arid zone no potential tree is existing except the leguminous tree. The weed of the leguminosa plant is also required to be utilized for land cover.

Most of the plants are annual grass and there is only one species of a perennial plant which can retain the effect of land cover. On the other hand, there are five species of perenial plants of the Compositae family to be utilizied for land cover.

As a result of the field survey, Melinis minutiflora of the Gramineae family is found to be growing spontaneously all over the semi-arid zone even in the crack of rocks and on the steep slopes. This is fast growing species and contibutes greatly to the hillside slope protection.

There is the Eragrostis curvula of South African origin which is very similar in nature to the weed mentioned above. This weed has been widely used for the conservation of slope land in the United States since 1948. In Japan, this has been used for the revegetation of bare mountain and road cuts on highways since 1952 and it has widely prevailed because it grows anywhere even on sandy land and is extremely resistant to heat and dryness.

The seed of this weed is fine-grained and 3,300 seeds can be contained in one gram. Since they are easily retained in the cracks of rocks, this weed has a high potential for utilization in the arid zones together with the conventional Melinis minutiflora.

The scientific names of plants selected for the semi-arid zone revegetation in the present watershed are shown in Table III-5 in the order of priority. In case these plants are employed, it is recommended to select the tree, shrub and grass preferentially from the first to the third rank.

3.3.2 Hillside Revegetation Method

The main areas for revegetation in the present watershed is the semi-arid zone along the Chama River with annual rainfall under 800 mm. The objective area is estimated to be about 500 km^2.

Large scale works will be required to accomplish the revegetation in the whole area. An efficient work schedule and work method is necessary, dividing the zone into two, i.e., a zone for the immediate works and another zone for long ranged works.

In the objective area where sedimentation is presently active, immediate works are required against soil erosion and landslide. Most of the objective areas are denuded and are distributed in the level of 40% in terms of vegetation coverage.

The objective areas where long ranged works are required are those having the vegetation coverage of more than 40% The restoration of vegetation is expected by planting leguminous trees, watering and fertilization.

The hillside revegetation works are largely categorized by elementary hillside works to stabilize the deposited sediment. The hillside revegetation works are as shown in Table III-6.

For the soil erosion and landslide areas where immediate works are required, elementary hillside works and subsequent hillside revegetation works have to be executed. For the objective area where vegetation has remained for a long time, elementary hillside works should be limited to the minimum level and hillside revegetation works should be emphasized. In the following subsections, the methods are described in accordance with the type of work indicated in Table III-6.

3.3.3 Works in Eroded Area and Landslide Area

Order of Work

The following works are to be conducted in the presented order on eroded bare land: gully control works, soil retaining works, road cutting works, contour trench works, slope covering works, and revegetation works. For landslide areas, the order of works is gully control works, soil retaining works, hillside drainage works, terracing works, slope covering works, and revegetation works.

Explanation of Works

(1) Gully Control Works

Works are executed in accordance with works for erosion control dam.

(2) Soil Retaining Works

Stone masonry, retaining wall, etc., and other useful materials are used depending on local conditions.

(3) Road Cutting Works

Stability can often be obtained if the road cut is graded gentler than 1:1. Generally, the upper part is finished in high gradient and the lower part in low gradient.

(4) Hillside Drainage Works

The necessary trenches are provided depending on the local condition such as waterways to deal with the surface water and underground water.

(5) Terracing Works

Grasses and stones are applied to the terrace. Road cutting works are executed from the lower part to the upper part, while terracing on hillsides is made from the upper to the lower part to minimize the quantity of soil to be transported.

(6) Works for Trenches Along Contour Line

Ditches are excavated instead of hillside drainage works to retain rainwater and sediment and to conserve soil moisture needed to facilitate the growth of plants. This method, developed by the steep land agriculture in Utah State, U.S.A., is considered similar to the work method executed from the year 1960 for the low rainfall areas of Mucuchíes in the upper stream of the Chama River. The excavation method of the ditches is indicated in Fig. III-5 and to be described later.

(7) Slope Covering Works

Road cuts on terraces are totally covered to prevent soil erosion. The dead grass of the gramineous weed growing in the fields and the branchor growing abundantly in the forests can be used as cover materials.

In Japan, vegetation mat, vegetation bag, paper mat and mesh mat have been developed and widely used where grass seeds, fertilizer and humus soil are mixed. They are also used in the direct seeding mentioned below.

(8) Direct Seeding

The grass seeds are sown for early revegetation. The suitable plants are indicated in Table III-5.

(9) Revegetation Works

The seedlings are planted for early vegetation. The suitable tree species are indicated in Table III-5. As a general rule, the pot planting in sizes of 15 to 30 cm is used. Fertilizers should be applied.

Outline of Revegetation Works

(1) Selection of Plant Material

Among the plants indicated in Table III-5, more than three species of each tree, bush, and grass are selected and mixed. As for the tree, pot planting is executed. For the early covering of top soil, seeds of grasses are mainly sown.

(2) Planting Period

The first part of the rainy season from May to June is the appropriate period for direct seeding and pot planting.

(3) Number of Planted Trees

Planting holes are made the terraces and trees and shrubs are planted in the proportion of 1:2. Planting interval is 50 cm and the number of plants per hectare is 4,000 to 6,000 as a general standard.

(4) Direct Seeding

Direct seeding is carried out on road cuts of terraces with slope covering works. Direct seeding is also conducted on terraces after pot planting. The quantity of direct seeding is determined from the number of seeds reduced to weight. The expected number of germinating seeds is 7,500/m^2 if grass seeds only are used, and more than 3,000 tree/m^2 if grass seeds and tree seeds are mixed.

The average number per one gram of seeds is estimated at 1,000. The adequate weight per square meter is considered to be 10 to 20 grams and at least 5 to 8 grams taking account of the germination rate, failure rate and risk.

(5) Fertilizer

Fertilizer is applied into the planting hole on the terrace and after the soil covering of pot planting is made. In the direct seeding on cuts of terraces, seeds and fertilizer are simultaneously applied. Refertilization is made a year after planting and continued every year. Fertilizers with much organic component and fertilizers with slow effect are used because side effects will likely appear in the arid zones. The standard quantity of the fertilizers is presented in Table III-7. In case of pot planting, 30 grams of fertilizer per one seedling is considered adequate.

3.3.4 Works for Area to be Vegetated

Procedure of Work

(1) Revegetation Works

Revegetation works include gully control works, contour trench works, vegetation works, and direct seeding.

(2) Air Seeding Works

This work includes gully control works, work for trenches along contour line, and direct seeding works.

Explanation of Works

(1) Gully Control Works

Gully control works shall be at the minimum level for the sake of safety, because denudation progresses even with the vegetation. Since the sediment discharge is rather small compared with the area of soil erosion and landslide, a more simple specification can be applied than the case of an erosion control dam.

(2) Works for Trenches Along Contour Line

This work is executed instead of terracing works to carry the sediment and rainwater of the hillside slope. The excavation method is mentioned later.

(3) Direct Seeding and Vegetation Works

The objective of these works is to achieve early revegetation similar to the objective to remedy land erosion and collapsed land with more emphasis on short term recovery works. Direct seeding and vegetation works are effectively executed in combination for the revegetation works and direct seeding is exclusively executed for air seeding works.

Outline of Revegetation Works

(1) Excavation Method of Trenches Along Contour Line

Attention is paid to retain the topsoil of the hillside slope and rainwater. The size of the trench is of great concern because the water will overflow if the trench is small, even by the small rainfall, and the costs of the works will increase if the size is large and soil quantity is increased. The standard sizes are: upper width of 1.30 m, bottom width of 0.30 m and depth of 0.40 m with horizontal distance of about 10 m between trenches along the contour line as shown in Fig. III-5.

Partition banks 0.1 m lower than the trench banks are provided at 6 to 12 m interval in the trenches. These banks are provided to minimize the damage by allowing only partitioned water to flow down to the lower levels when the trenches are incidentally broken by flood. After the trenches are constructed, easily grown grass are planted on both sides. The design criteria for the trenches along contour is indicated in Table III-8.

(2) Selection of Plant Species

After the construction of trenches, seedlings are planted in addition to the direct seeding of the grass. The mixed planting of tree and bush is executed in the proportion of 2:1, because bushes are comparatively numerous and trees are less in number in the existing vegetation. Then, direct seeding is carried out. The species of the plant are shown in Table III-5, and three species in the upper rank are selected from the species listed in the table and mixed when applied.

(3) Planting Method of Seedling

Planting is to be made according to the afforestation method applied in the watershed of the Chama River. Planing holes each 20 cm in width and 30 cm in depth are excavated and fertilizer is applied into each hole and covered by soil, and then the seedling is planted. The length of pot is of 15 to 30 cm.

The planting distance follows an equilateral triangle with sides of 3.5 m and 943 seedlings are planted per one hectare. The planting density is accorded with a soil covering ratio of the existing vegetation of about 40%. The vegetation is lost at the location where trenches are excavated, therefore, planting should be made at one meter interval to achieve early revegetation by the same manner where road cuts and terracing works are executed. The appropriate planting period in all cases is from May to June, the first part of the rainy season.

(4) Direct Seeding

After the direct seeding of tree species, direct grass seeding is executed. The direct seeding of tree species can also be made, but the weed of Graminae family is grown more easily in the cracks of rocks and on land with shallow topsoil and they can facilitate early revegetation.

The use of Melinis Minutiflora and Eragrostis curvula belonging to Poaceae which is indicated in Table III-5 as the weed to be used for early revegetation, is strongly recommended. Further, 2 or 3 species of grass plants abundant in the object area shall be seledted and mixed for direct seeding. The seeding quantity should be accorded with the working standard for eroded and landslide areas. The expected number of germinating seeds should be 7,500 per hectare, and 10 to 20 grams per hectare which is based upon the average seed number of 1,000 per one gram.

(5) Fertilizer

Fertilizer is necessary for both pot planting and direct seeding. The quantity of fertilizer and fertilizer application method are accorded with the works for eroded and landslide areas. The standard for the quantity of fertilizer is indicated in Table III-7.

Outline of Air Seeding Works

(1) Application of Air Seeding Works

This works is executed using an airplane and the objective area shall principally have a stable soil condition with a land gradient under 35 degrees retaining some vegetation. Terracing or excavation works for trenches are executed on land with unstable soil condition, if needed.

(2) Characteristic of Air Seeding Works

The simplicity of this works cannot be avoided because seeding is made from the air. The works can be easily applied, however, to hinterlands having no work road or to vast land. The working period can also be shortened.

(3) Necessity of Excavation of Trenches Along Contour Line

Erosion of topsoil easily occurs on collapsed land with vegetation coverage under 40% and steep slopes of more than 35 degrees. As a rule, trenches along contours are constructed at horizontal interval of 10 m before air seeding is executed. The excavation method of trenches is exactly the same with as the revegetation works.

(4) Choice of Plant Species

In accordance with the revegetation works, seeds of each highly ranked three species of tree, shrub, and grass are selected from the plants indicated in Table III-5. The seeds are mixed with fertilizer, soil improvement material, adhesive material, mixing material and water, stirred by a mixer, and then applied by the use of a helicopter. The quantity of material to be applied is indicated in Table III-9 and III-10.

(5) Adequate Quantity of Seed Application

In case of grass revegetation, standard application quantity is generally 10 to 20 grams. This quantity is estimated expecting the number of grass of 3,000 to 5,000 per square meter which will prevent the erosion when the grass is about 1 cm tall. Generally, the germination of seeds and the growth of grass plants are fast; those of tree plants are slow. Tree plants enable afforestation if two or three plants are grown per square meter.

(6) Application Method

The materials including mixing and adhesive materials as indicated in the Table are loaded on a helicopter with more than a 260 horsepower engine, and applied all over the objective area for revegetation. The hanging bucket tank is selected as the application apparatus. The loadage of application materials is 150 kg for land under 2,000 m above sea level and 140 kg for land over 2,000 m above sea level.

(7) Application Period

Adequate moisture and temperature are necessary for the germination of seeds, therefore, the first part of the rainy season from May to June is appropriate for the application to enable early vegetation in the same year the application is made. If the germination of seeds is not observed after one month of air seeding, additional seeding should be immediately executed.

(8) Application of Fertilizer

The quantity of fertilizer application is determined according to standards as indicated in Table III-7. The fertilizer applied before planting is mixed with other materials, but after planting only fertilizer is applied by the use of a helicopter.

The growth of the existing vegetation is also facilitated by the application of fertilizer, and vegetation coverage is increased. Therefore, fertilizer application after planting should be executed without fail.

3.4 Middle Reaches III

This area is blessed with much rainfall and most of it is developed to the forest zone. Therefore, afforestation works for the prevention of sediment discharge is not necessary. It is most appropriate to execute man-made forestation in the grass land presently used for stock farming, increasing the forest land area for land conservation purposes.

3.5 Lower Reaches

This area is mostly occupied by agricultural and flood control to protect farmlands is considered important. Afforestation is not considered immediately necessary. Only pot planting, together with the construction of trenches, is necessary.

3.6 Development of Man-made Forest

A man-made forest in the watershed of the Chama River has been implemented since 1955 under the national budget, covering about 1,239 hectares as of 1988. This man-made forest land has been extended from the upstream to the downstream area, except the arid zone of Middle Reaches II.

There are 18 forest tree species and among them, the main species is Pinus which has various advantages. For instance, the seeds of this species are easily obtained, they take roots easily, and natural regeneration after the maturation of the forest occurs easily.

Man-made forests are mainly developed in grasslands, because the potential of grasslands for land conservation is inferior to that of forest lands. It is desirable to develop the man-made forest to increase the area of the forest land and stabilize the sediment production at the watershed. In this respect, several reminders for future man-made forest are presented as follows.

Selection of Forest Tree Species

It is considered safe and sound to select the trees from good tree species grown spontaneously in the objective area to develop the man-made forest. It has been found, however, that such kind of trees are scarcely available. Therefore, Pinus species is widely used because it can be obtained from other countries.

It is necessary to investigate the growth of forests of the Pinus species starting from the year 1955 to select the suitable species for the predetermined sites of the man-made forest. The locations with suitable altitude for man-made forest were identified by the Forest Resource Department of Los Andes University as shown by Table III-11.

Most of the Pinus species are suited to the locations with altitude of 1,500 to 2,300 m. They are presently planted in the grassland by the páramo zone with altitude over 3,000 m upstream of the Chama River, but afforestation seems to be difficult in this area. The forestation by Pinus species in the area with altitude under 1,000 m seems inadequate because of high temperature.

Mix Planting of Nitrogen Fixing Tree

The topsoil of the grassland is generally thin and the Pinus species grow slowly in these areas although they easily grow spontaneously in the collapsed land. If nitrogen fixing trees, including Leguminous, Alnus species and Casuavina species, are mixed in the planting of the grassland, the lands are fertilized by nitrogen fixing bacteria in root nodules and the growth of Pinus species is facilitated. Accordingly, nitrogen fixing trees should be mixed, as a rule, when the man-made forest is developed on the barren land. The forest with mixed tree species of broad-leaf trees and coniferous trees is more effective for land conservation than the forest of single species of Pinus. It is more systematic to mix the tree species indicated in Table III-11 for effective planting.

Shade Trees for Grassland of Páramo Zone

The grassland of the páramo zone in the upstream of the river is high land located above the timber line, therefore, the natural forest is difficult to be developed even if the man-made forest is established. Most of the grasslands are therefore utilized for pastures. If the nitrogen fixing trees such as Leguminous and Alnus species are mixed and planted sporadically, they will contribute to the land conservation and increase of pastures, and they will further provide a resting place for livestocks.

Development of Forest Resources

The man-made forest is presently provided in the grassland, not for timber production but for land conservation as a disaster preventive measure, and its effect is highly evaluated. Any plan on the use of timber from the man-made forest should be given strict consideration in future long-range programs.

Table III-1 AREAL RATIO OF VEGETATION FORM IN THE CHAMA RIVER BASIN

Objective Aera	Area (km2)	Areal Ratio (%)			
		High Forest	Low Forest	Grassland	Agricultural Land
Upper Reaches	491	5	19	76	-
Middle Reaches I	696	54	22	24	-
Middle Reaches II	1,795	47	45	8	-
Middle Reaches III	535	78	22	-	-
Lower Reaches	268	44	-	-	56
Total	3,785	-	-	-	-

Table III-2 VEGETATION AT THE SEMI-AREA IN MIDDLE REACHES II

Family	High Tree	Low Tree	Herbage	Liane	Epiphyte
Apocynaceae	0	4	0	2	0
Asclepiadaceae	0	0	4	1	0
Boraginaceae	0	2	6	1	0
Burseraceae	2	0	0	0	0
Bromeliaceae	0	0	2	0	6
Cactaceae	0	8	3	0	0
Compositae	0	2	18	0	0
Hydrophyllaceae	0	0	1	0	0
Labiatae	0	0	2	0	0
Leguminosae	6	4	7	1	0
Menispermaceae	0	1	0	0	0
Papaveraceae	0	0	1	0	0
Scrophulariaceae	0	0	2	0	0
stervuliaceae	1	0	2	0	0
Tilaceae	0	0	1	0	0
Turneraceae	0	0	1	0	0
Verbenaceae	0	6	6	0	0
Vitaceae	0	0	1	1	0
Zygophyllaceae	0	0	1	0	0
Total	9	29	58	6	6

Source: Florua de la Zona Xerofila Ejido - Estanquez del Estado
Merida, Universidad de los andes, 1976

Table III-3 LEGUMINOSAE AT THE SEMI-ARID AREA IN MIDDLE REACHES II

	Family	Height (m)
1.	High Tree	
	(a) Bauhinia emarginata	5
	(b) Cassia grandis	8 - 20
	(c) Parkinsonia aculeate	10 - 25
	(d) Pithecellobium saman	30
	(e) Erythrina poeppigiana	20
	(f) Gloricidia sepium	7
2.	Low Tree	
	(a) Acacia tortuose	1.5 - 5
	(b) Calliandra graciles	divergence & expansion
	(c) Calliandra magdalonae	6
	(d) Prosopis juliflora	4.5
3.	Herbage	
	(a) Benthamantha mollis	1
	(b) Crotolaria incana	0.5 - 1.2
	(c) Indigofera suffructicosa	1.5
4.	Liane	
	(a) Mimosa velloziana	0.05 - 0.06
	(b) Crotolaria retusa	0.20 - 0.60
	(c) Stylosanthes viscosa	0.15
	(d) Stylosanthes sericeiceps	0.02
5.	Epiphyte	
	(a) Rhynchosia minima	2 mm diameter

Source: Florula de la Zona Xerofila Ejido - Estanquez del Estado
Merida, Universidad de los Andes, 1976

Table III-4 AFFORESTATION PROJECTS IN CHAMA RIVER BASIN

Administrative District	Municipality	Area (ha)	Species	Period
Rangel	San Rafael	76.5	Pinus pseudostrobus, P. patula, P. radiata, P. michoacana	1955-1976
	Mucuchies	140.7	P. radiata, P. pseudostrobus, P. oocarpa, P.patula, P. montezuma, P. gregui, Eucalyptus sp., Copressus sp.	1955-1976
Libertador	Stos, Marquina	20.9	P. oocarpa, P. patula p. rradiata, Cupressus sp.	1975-1978
	Milla	115.6	P. patula, P. radiata, P. pseudostrobus, Fraxinus sp.	1950-1977
	La Punta	69.0	P. oocarpa, P. radiata, P. pseudostrobus	1976-1978
	El Morro	3.0	P. radiata	1977
Campo Elias	Jaji	81.2	P. patula, P. radiata, P. pseudostrobus, P. oocapa, P. elliotti	1975-1976
	Montalban	98.2	P. oocarpa, P. radiata, P. pseudostrobus	1976-1978
Tovar	Tovar	96.3	P. radiata, P. rudi p. patula, Fraxinus sp., Cupressus sp., Acacia sp.	1973-1978
	Mora	117.9	P.patula, P. oocarpa, P.elliotti, P. radiata, P. michoacana, Fraxinus sp.	
Andres Bello	La Azulita	40.0	Falta informacion	1968
Rivas Davila	Bailadores	157.7	P. elliotti, P. patula, P. radiata, P. pseudostrobus, P. oocarpa, Fraxinus sp., Eucalyptus sp., Cupressus sempervirens	1940-1977
Total		1017.0	18 species	

Source: Zona Adiminstrativa no. 7 (Edos. Trujillo-Merida)

Table III-5 PLANT SPECIES USED FOR REVEGETATION OF SEMI-ARID ZONE IN MIDSTREAM OF CHAMA RIVER

Principal groups	Species	Tree height (m)	Family
Hight forest	1) Leucaena trichodes	6 - 15	Leguminosae
	2) Pithecellobium saman	20 - 30	Leguminosae
	3) Cassia siamea	6 - 15	Leguminosae
	4) Parkinsonia aculeate	10 - 25	Leguminosae
	5) Cassia grandis	8 - 20	Leguminosae
	6) Erythrina poeppigiana	10 - 20	Leguminosae
	7) Gloricidia sepium	5 - 10	Leguminosae
	8) Bauhinia emarginata	4 - 10	Leguminosae
Low forest	1) Acasia macracantha	2 - 5	Leguminosae
	2) Acasia tortuose	2 - 5	Leguminosae
	3) Prosopis juliflora	3 - 5	Leguminosae
	4) Calliandra graciles	2 - 5	Leguminosae
	5) Calliandra magdalonae	2 - 5	Leguminosae
	6) Benthamantha mollis	1 - 2	Leguminosae
	7) Crotolaria incana	1 - 2	Leguminosae
	8) Baccharis nitida	1 - 2	Compositae
	9) Trixis frutoscens	1 - 2	Compositae
Grass	1) Melinis minutiflora	0.3 - 1	Poaceae
	2) Eragrostis curvula	0.5 - 1	Poaceae
	3) Mimosa velloziana	0.5 - 1	Leguminosae
	4) Psila trinervis	0.5 - 1	Compositae
	5) Wedelia caracasana	0.5 - 1	Compositae
	6) Calea berteriana	0.3 - 1	Compositae
	7) Ageratum conyzoides	0.3 - 1	Compositae
	8) Vernonia cotoneaster	0.3 - 1	Compositae

Table III-6 SPECIFICATION OF HILLSIDE REVEGETATION WORKS

Category	Countermesure	Specification
Basic hillside works:		
	Gully control works	In every valley, preventive measures are taken against sediment discharge resulting from erosion. Erosion control dams (Sabo dams) are constructed.
	Soil retaining works	Sediments deposited on hillslopes are stabalized. These will form the foundation for structures which will be built on the hillsides.
	Hillside stabilization works	Very steep slopes and irregular relief are smoothened and stabalized.
	Hillside channel works	To prevent destruction of hillside structures by rain water or underground water, the runoff water is immediately removed.
Hillside seeding and planting works:	Terracing works	Terraces are constructed along contour lines for soil erosion control, water conservation and tree planting.
	Contour trenching works	A ditch is dug along contour line for collecting rain water and sediment. This will help prevent sediment dischage and contribute to the growth of plants.
	Slope covering works	The whole slope surface is covered to prevent erosion of surface soil.
	Direct seeding works	Seeds of grasses are sown to achieve the establishment of a vegetation cover quickly.
	Vegetation works	Seeding are planted in denuded mountains for forest establishment.

Source : Yoshioka Yoshio, Shintaikei doboku, Gihodo, 1980.

Table III-7 STANDARDS FOR FERTILIZER APPLICATION

Classification	Soil condition and plant growth condition	Plant introduction condition	N:P:K(g/m2)
Fertilizer given at sowing	In places such as collapse scars, slope cuts etc. where there is little surface soil	Only grass Mixed grass tree	8:4:4 4:12:7
	In places such as fill areas, colluvial deposits etc. where there is a lot of surface soil	Only grass Mixed grass tree	6:3:3 4:10:7
Additional fertilizer	When surface soil is thin and the plant growth is poor	Only grass Mixed grass tree	4:1:1 4:7:6
	When there is a lot of surface soil but plant growth is poor	Only grass Mixed grass tree	3:1:1 3:6:5

Source : Rinyacho kokuryokkako no keikaku, sekkei, seko-shishin to sono kaisetsu, 1980.

Table III-8 STANDARDS FOR THE DESIGN OF CONTOUR TRENCH

	Item	Inclination (%)			
		20	30	40	45
Design condition	Runoff ratio	0.60	0.65	0.70	0.75
	Rate of infiltration in trench (%)	10	10	10	10
	Horizontal distance between trenches (m)	10	10	10	10
	Stored rainfall (mm)	50	50	50	50
	Maximum water storage capacity of a trench (m3)	0.27	0.29	0.28	0.27
Standard cross section	Upper width of trench (m)	2.8	3.6	5.0	6.0
	Horizontal interval (m)	7.5	7.5	7.5	9.0
	Vertical interval (m)	1.5	2.1	3.0	4.0

Source : Yoshioka Yoshio, shintaikei doboku kogaku, Gihodo, 1980.

Table III-9 COMPOSITION OF MATERIAL USED IN AIR SEEDING

Name of material	Amount (kg/ha)	Commercial name
Seed	160	
Granular fertilizer	1,000	N:P:K =15:15:15
Soil improving material	2,000	
Adhesive material	1,000	
Mixing material	1,000	coloring, dispersing, mouse repellent and neutralizing materials
Water	13,740	

Source : Rinyacho kokuryokka no keikaku,
sekkei, seko-shishin to sono kaisetsu, 1980

Table III-10 KIND AND AMOUNT OF SEEDS USED IN AIR SEEDING

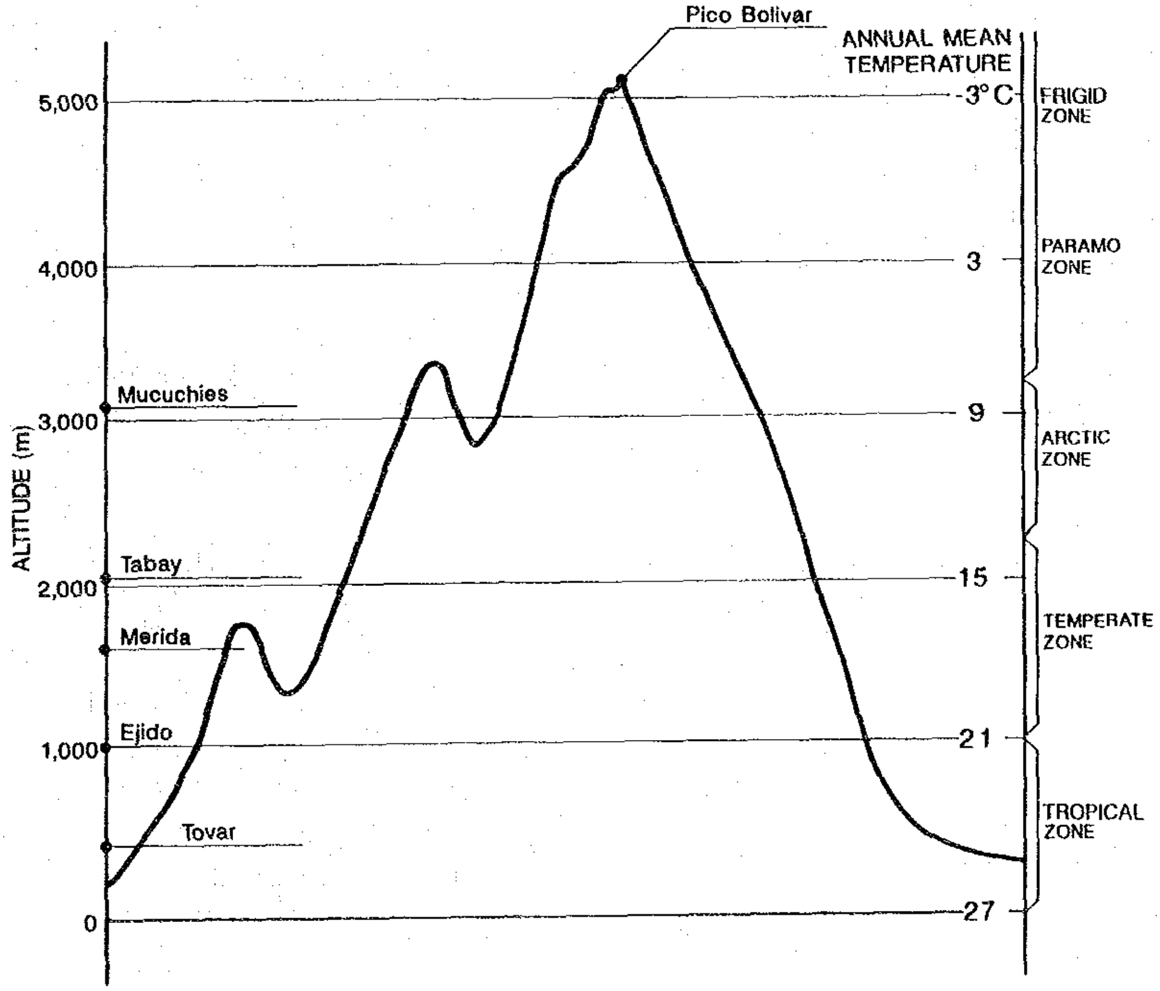
Principal groups	Species	Amount (Kg/ha)
High forest	Leucaena trichodes	10
	Pithecellobium saman	10
	Cassia siamea	5
Low forest	Acasia macracantha	10
	Acasia tortuose	5
	Prosopis juliflora	5
Grass	Melinis minutiflora	50
	Eragrostis curvula	50
	Mimosa velloziana	15
Total		160

Source : Rinyacho kokuryokkako no keikaku, sekkei, seko-shishin to sono kaisetsu, 1980

Table III-11 SUITABLE ALTITUDES FOR TREE SPECIES FOR MAN-MADE PLANTATIONS IN THE CHAMA BASIN

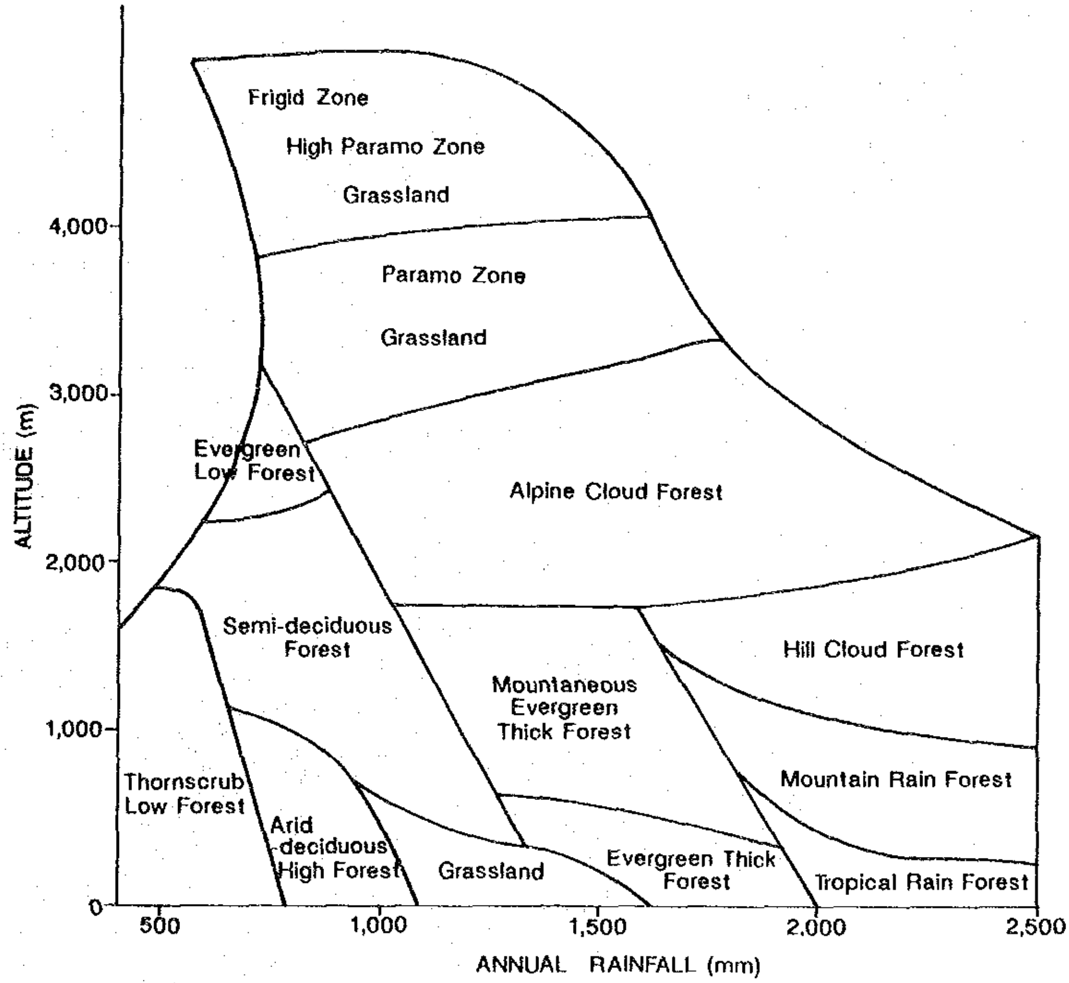
Species	Altitude (m)
Pinus radiata	over 700
Pinus oocarpa	1500-2300
Pinus elliotti	1500-2300
Pinus pseudostrobus	1500-2300
Pinus sanaueusis	1500-2300
Cupressus lusitanica	1000-3000
Fraxinus aunacana	1500-3400
Alnus awninata	1700-3200
Myrica arguta	1600-3180

Source : Universidad de Los Andes 1989.



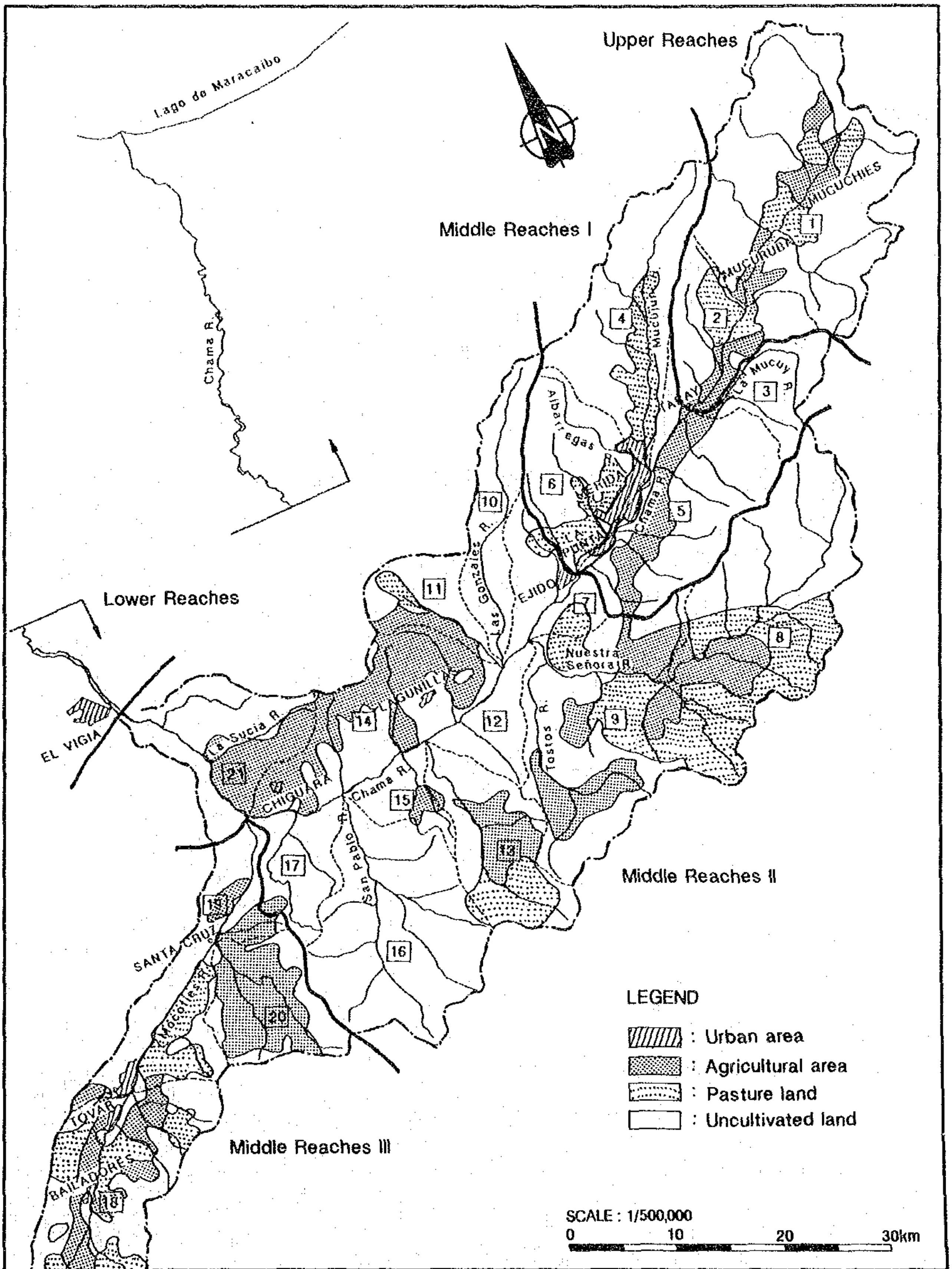
Source: ESTUDIOS ECOLOGICOS EN LOS PARAMOS ANDINOS 1980

VERTICAL DISTRIBUTION OF CLIMATE AT THE ANDES MOUNTAINS Fig. III-1	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT JAPAN INTERNATIONAL COOPERATION AGENCY



Source: ESTUDIOS ECOLOGICOS EN LOS PARAMOS ANDINOS 1980

VEGETATION-ALTITUDE-ANNUAL RAINFALL RELATIONSHIP AT THE ANDES MOUNTAINS Fig. III-2	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT JAPAN INTERNATIONAL COOPERATION AGENCY

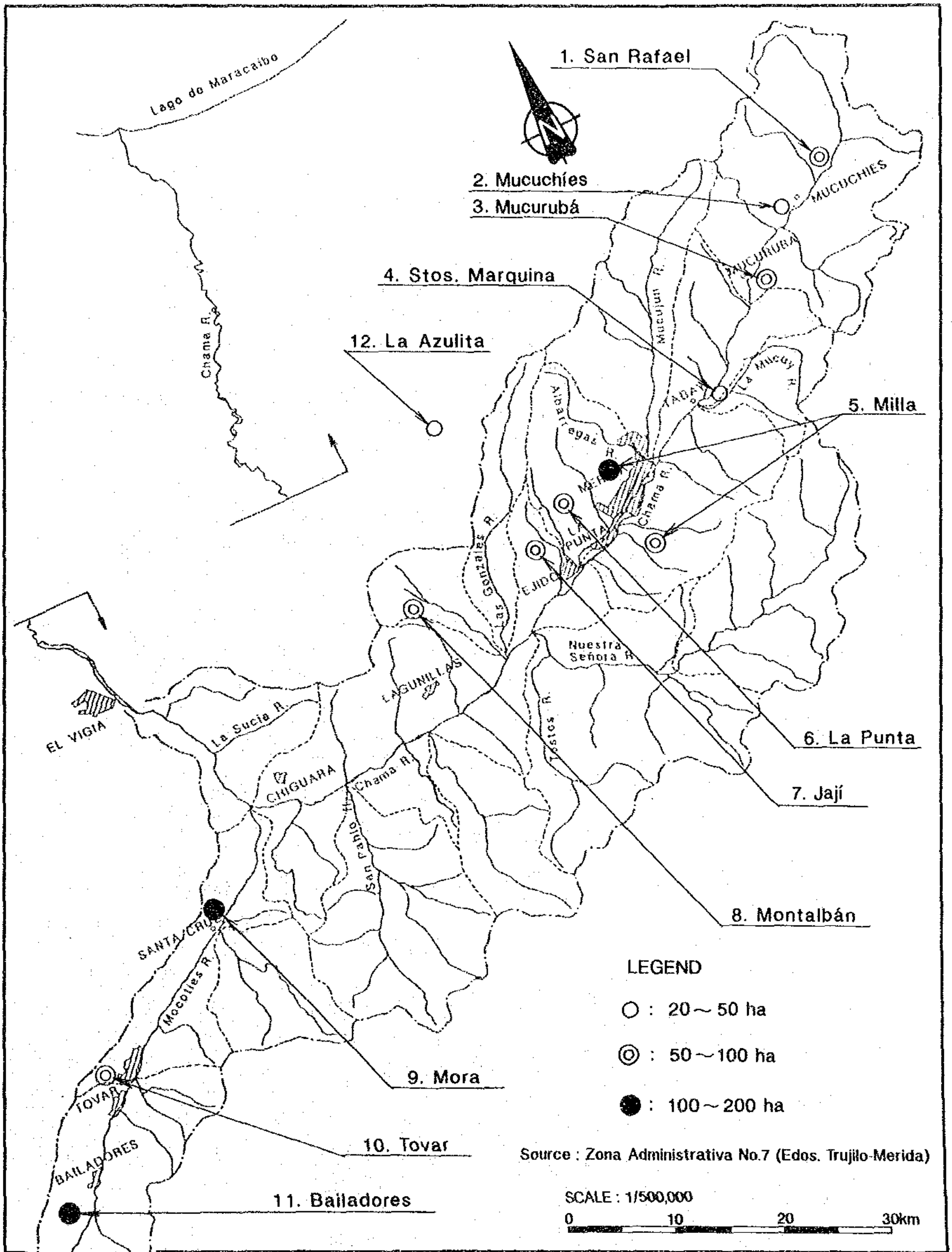


VEGETATION MAP OF THE CHAMA RIVER BASIN

Fig. III-3

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

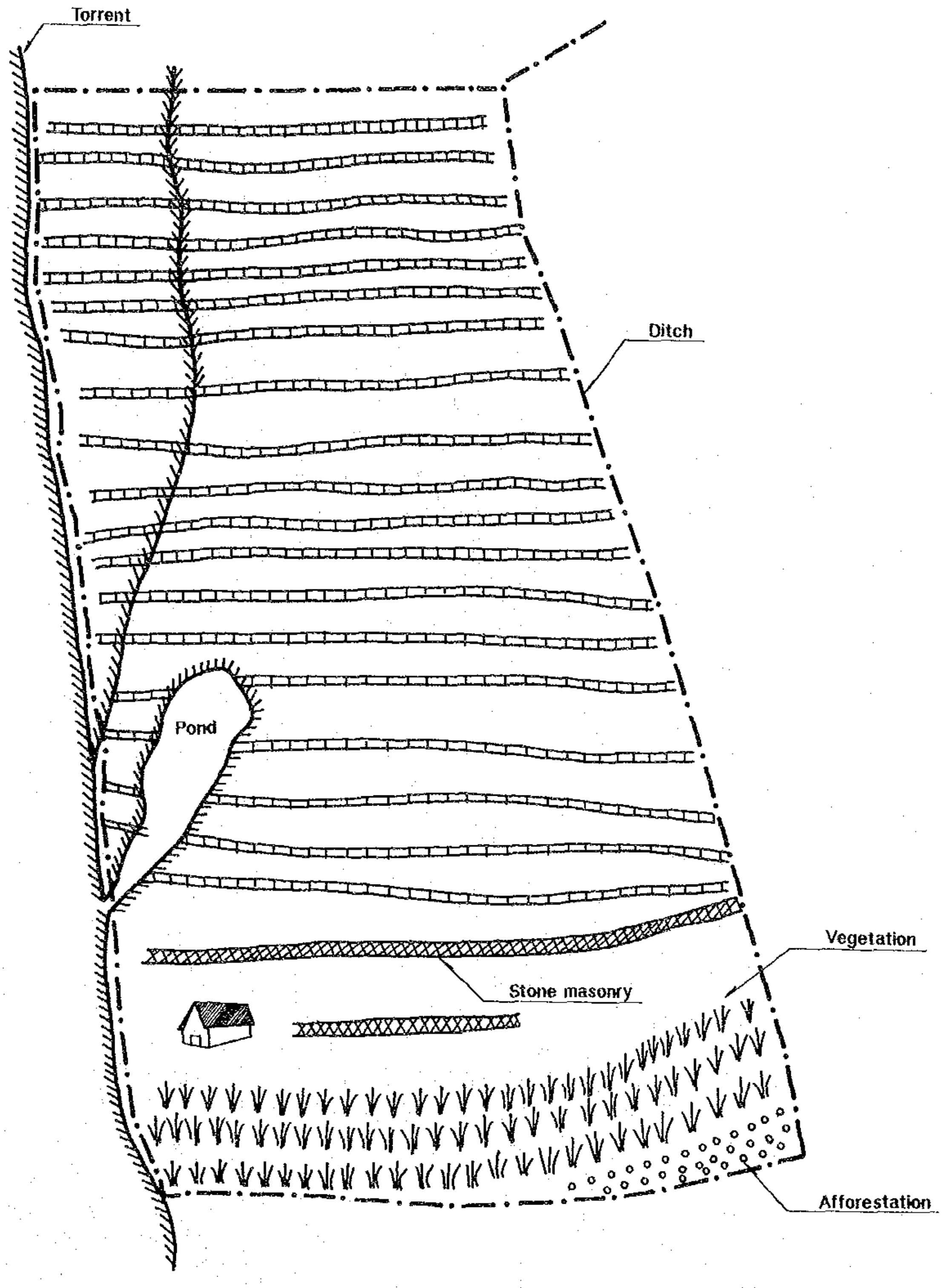


AFFORESTATION PROJECTS IN THE CHAMA RIVER BASIN

Fig. III-4

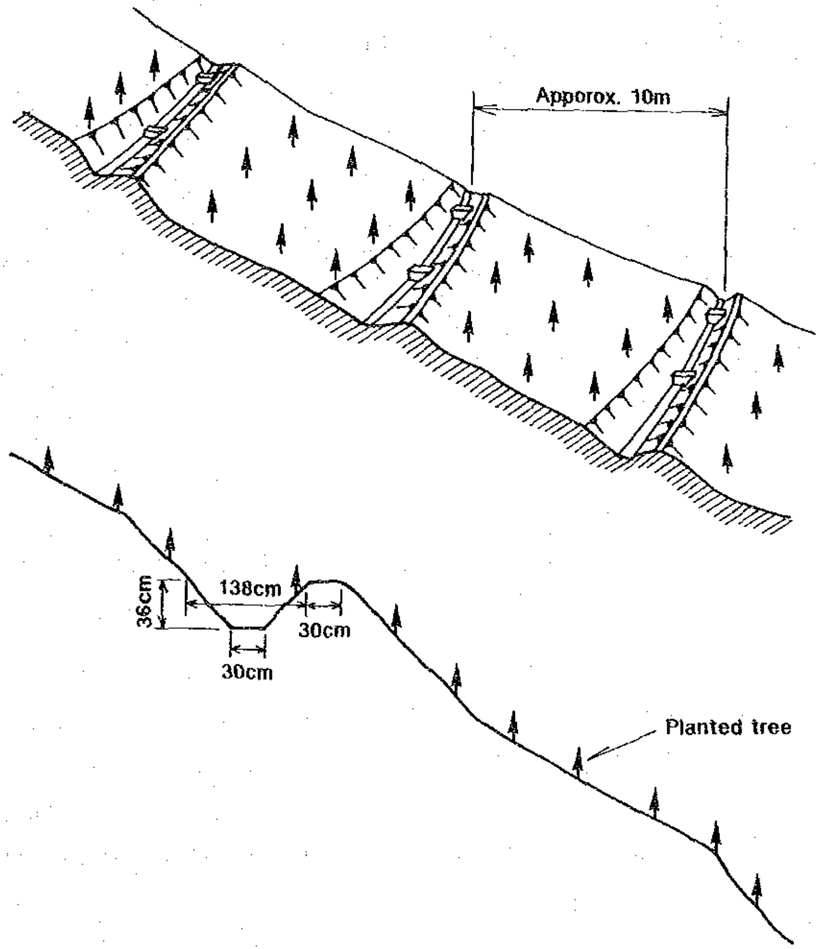
STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY



Source : Planification Conservacionista (Proyecto Mucurubá)

GENERAL DRAWING FOR CONTOUR TRENCHING WORKS	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT
Fig. III-5 (1/2)	JAPAN INTERNATIONAL COOPERATION AGENCY



Source : Yoshioka Yoshio, shintaikei doboku kogaku, gihodo, 1980.

GENERAL DRAWING FOR CONTOUR TRENCHING WORKS	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT
Fig. III-5 (2/2)	JAPAN INTERNATIONAL COOPERATION AGENCY

DATA FOR REDUCTION OF SEDIMENT DISCHARGE BY AFFORESTATION IN JAPAN

Forest vegetation is highly evaluated among nations for their significant effects on the prevention of erosion of topsoil. As a result of the investigation made on the various hilly districts throughout Japan, it has been recognized that the quantity of eroded soil material from forested land is extremely small equivalent to only 1 to 0.2% of land slide area and 10 to 2% of bare land as shown below.

Land Cover Condition	Erosion Depth (mm)	Eroded Sediment (m^2/ha)
Denuded Land	40 - 50	400 - 500
Bare Land	4 - 5	40 - 50
Degraded Forest Land	Approx. 0.5	4 - 5
Non-Degraded Forest Land	Under 0.1	Under 1.0

Source: Omasa Masataka, Shinringaku, Kyoritsu shuppan, Tokyo, 1987.

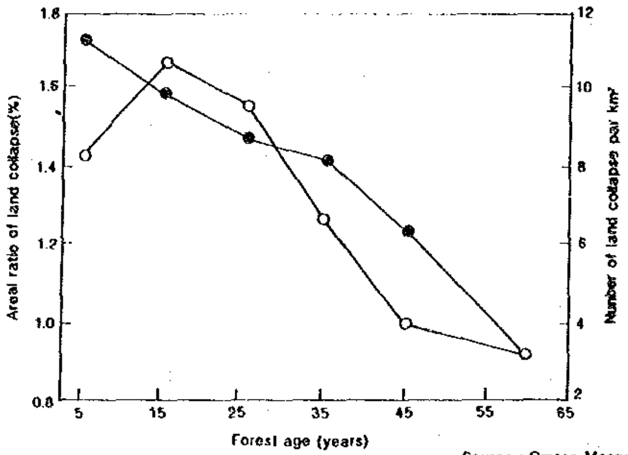
The forest is also recognized to be effective to prevent the collapse of land. The Conservation Division of Forestry Agency in Japan investigated the occurrence of slope collapse of the forest land and non-forest land (including grassland and cutover area) in approximately 50 districts where the collapses are frequently occurring. As a result of this investigation, the magnitude of collapse in the forest land was found to be smaller than those in non-forest land and the number of collapse per unit area and total area of collapse in forested land were found to be about 50 and 75% of those in the non-forest lands, respectively, according to an investigation as presented in the following table.

Classification	Area of Investigated Sites (km²)	Number of Land Collapse	Area of Land Collapse (ha)	Sediment from Collapsed Sites (m³)
Forested Land	1,270	8.1	1.23	22,800
Non-Forested Land	121	18.4	2.38	29,900

Note : Grassland or cut-over land

Source: Omasa Masataka, Shinringaku, Kyoritsu shuppan, Tokyo, 1987.

Further, the relation between the occurrence of slope collapse and the age of forest is shown below, which indicates that the rate of the occurrence of slope collapse decreases gradually 15 to 20 years after afforestation.



Source : Omasa Masaraka, Shinringaku, Kyoritsu Shuppan, Tokyo, 1987

In the hillside slope where soil erosion of landslide area and collapse area are rampant, the comprehensive rehabilitation works are executed including soil retaining works, hillside slope cutting works as well as hillside revegetation works representing terracing and vegetation works.

An investigation was made in the past for measuring the sediment discharge fifteen years after the completion of erosion control forest in the foremost granite zone in Japan and its results are manifested as follows:

Year	Annual Sediment Discharge (m^3/km^2)	
	Bare Land	Vegetated Land
1962	9,180	53.8
1963	4,501	13.91
1964	5,244	10.00
1966	10,474	3.05
1967	2,813	9.32
1968	2,494	10.27
1969	2,894	19.88
1970	6,015	10.36
1971	2,921	12.68
1972	4,123	10.01
1973	1,299	11.11
1974	842	11.24
1975	3,043	14.28
1976	7,109	17.09
Average	4,500	14.80

Source: Biwako Work Office, Ministry of Construction, Japan.

As shown in the above table, the yearly average sediment discharge in the bare land is 4,500 m^3/km^2, while in the same area the sediment discharge decreased after completion of hillside revegetation to 14.8 m^3/km^2 which is equal to about 1/300 of the discharge in the bare land. The revegetation in the forest land is more effective than those in the grassland. Therefore, when planning vegetation recovery the primary objective should be to complete the afforestation with trees as well as grasses.

IV.HYDROLOGY

SUPPORTING REPORT

IV. HYDROLOGY

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1. AVAILABLE DATA

1.1 Meteorological and Hydrological Stations

An inventory of meteorological and pluviometric stations in the Chama River Basin and its neighboring area is given in Table IV-1. The locations of these stations are indicated in Fig. IV-1.

As shown in the figure, five meteorological stations; namely, Mérida Aeropuerto, El Vigía, Mucuchíes, Tovar and San Juan de Lagunillas are located within the basin. Among them, the station at Mérida Aeropuerto has the longest data period, and the data are well recorded and compiled.

Pluviometric stations are generally well distributed in the basin, although the density seems to be relatively lower in the middle reaches, the semi-arid zone. Since most of the pluviometric stations were installed in 1960-70, many of them have more than 20 years of data which can be utilized in this Study.

The hydrometric stations in the basin are Ejido (1,130 km^2) and Mucurubá (365 km^2) on the Chama River, and Cabana on the Mucujún River. These stations are equipped with automatic water level gauges, and discharge measurements are carried out once a month.

Operation and maintenance are conducted by Zone Office No. 16 of the MARNR for the stations in the upstream area from the confluence of the Chama and Mocoties rivers, and Zone Office No. 5 for those in the downstream from the confluence. Some stations such as Mérida Aeropuerto and Mucuchíes are under the other ministries, but all the data including those of the stations under the other ministries are sent to the Dirección de Hidrología y Meteorología , MARNR Caracas, where they are stored in a computer data bank after the necessary processing which includes supplementation for lacking periods.

1.2 Available Data Period

The available data and period of these meteorological and hydrological stations are illustated in Fig. IV-2.

2. METEOROLOGICAL AND HYDROLOGICAL CONDITIONS

2.1 General Meteorology

The Chama River Basin lies between latitudes 8°10' and 9°02'N, and longitudes 70°48' and 71°54'W. Throughout the year, but to varying degrees, Venezuela is under the influence of the equatorial trough and the northern hemisphere trade winds. The equatorial trough dominates during the wet months (May-November) and the trade winds prevail during the dry part of the year (December-April).

In accordance with the month-to-month distribution of rainfall influenced by the aforesaid large-scale circulations, two generic precipitation patterns occur. These are (1) the Llanos Pattern which has a single maximum occurrence during the high-sun months distinct from low-sun dryness, and (2) the Semi-Annual Pattern which completes the two cycles of wet and dry seasons during the year. The Andes Ranges (Cordillera de los Andes) which created the Chama River Basin forms the boundary between the two patterns.

The Llanos Pattern is a characteristic of the entire central part of Venezuela, while the Semi-Annual Pattern is mostly prevalent over the coastal areas and also at elevations above 1,000 m where the mountain climate type is expected. The valley of the Chama River is mostly under the Semi-Annual Pattern, however, the uppermost basin, with Mucuchíes in the center, enjoys the Llanos Pattern with an influence from inland Venezuela. The rainfall producers are the westward propagating easterly winds for the semi-annual type of rainfall and cold fronts from the Southern Hemisphere mid-latitudes for the Llanos type.

Temperature, relative humidity and evaporation data of the stations in the basin are tabulated in Table IV-2. The annual mean temperature in the most upstream area at Mucuchíes is 11.3°C, while it is 19.0°C at Mérida Aeropuerto. The month-to-month variation at both stations is minimal.

In the lower reaches, the annual mean temperature at El Vigía is relatively high at 27.9°C and the month-to-month variation is also comparatively small from 26.6°C in January to 28.9°C in June and August.

The difference between the daily maximum and minimum temperatures is large at about 10°C for all the stations. The annual evaporation rate at San Juan de Lagunillas in the semi-arid zone was recorded at 2,008 mm, while that at Tovar was only 1,248 mm.

2.2 Annual and Monthly Rainfall

The annual rainfall amount in the Chama River Basin is quite different among the various areas in the basin. As illustrated by the isohyetal map in Fig. IV-3, the semi-arid zone, an area with about 600 mm rainfall, stretches from the confluence between the Chama and La Vizcaína rivers to El Morro in the Nuestra Señora River Basin.

The middle reaches which is situated upstream of the semi-arid zone and the Mocoties River Basin enjoy higher annual rainfalls in the basin, reaching to 1,800 mm. The most upstream areas of the Chama River Basin have moderate rainfalls varying from 800 to 1,000 mm. The downstream of El Vigía receives much rainfall amounting to more than 2,100 mm.

Monthly rainfalls at major stations in the basin are tabulated in Table IV-3, while the annual rainfall patterns are presented in Fig. IV-4. Páramo de Mucuchíes, the most upstream area, presents a single maximum in July and August, while the other stations have two peaks, in May and October at Mérida and in April and November at El Vigía. At San Juan de Lagunillas, in the middle reaches, the monthly rainfalls are small at about 80 mm even in the rainy season in April, May, October and November.

2.3 River Discharge

Observed annual average discharges and peak discharges at Ejido (1,130 km^2) and Mucurubá (365 km^2) on the Chama River are listed in Table IV-4. The annual average flow of the Chama River is 24.0 m^3/s (2.1 $m^3/s/100\ km^2$, runoff height of 670 mm) at Ejido and 5.12 m^3/s (1.4 $m^3/s/100\ km^2$, runoff height of 440 mm) at Mucurubá.

With regard to the peak discharge, the observed highest value at Ejido is 419.7 m^3/s in April 1972, which corresponds to the specific discharge of 0.37 $m^3/s/km^2$. The peak discharges during the flood in September 1988 at Ejido and El Vigía are 360 m^3/s and 720 m^3/s, respectively.

The high discharges at Ejido occur twice in May and October, corresponding to the rainfall pattern in the catchments, and similarly, those at Mucurubá mainly occur in June and July.

3. RAINFALL ANALYSIS

3.1 Rainfall Producers

The bulk of rainfall in northern Venezuela is produced not by the very-large-scale features which seasonally translate or change intensely, but rather by the small, transient disturbances in the atmosphere (Riehl, 1973). Rainfalls in the Chama River Basin are also predominantly locally concentrated short-period showers.

Rainfalls in June and July, the peak of the Llanos pattern, are mainly of thunderstorms induced by cold fronts from the Southern Hemisphere. Such rainfalls are found in the most upstream area of the basin.

The disturbance of low latitude origin is the westward propagating easterly wave, and this wave brings rainfall in May-June and October-November. This period is the rainy season of the semi-annual type, the climate type prevailing widely in the Chama River Basin except in the most upstream areas. The easterly wave tends to manifest a repetition period of from 3 to 5 days.

Referring to the rainfall producing system as described above, as well as the analyses made in the next part, rainfall in the basin is not the type which extends widely, but locally concentrated showers.

Hurricanes can be expected to strike Venezuela not more frequently than once in a century and then only on the northeastern peninsula and islands (Goldbrunner, 1963). Hurricanes are accordingly not considered for establishing the flood hydrograph in this study.

3.2 Areal and Time Distribution of Rainfall

Isohyetal maps of daily rainfall (Table IV-5) for days when the annual maximum basin's average rainfall occurred for each year from 1967 to 1988 are shown in Fig. IV-5. These isohyetal maps reveal that areal distribution of rainfall which cause floods in the lower reaches tend to present relatively heavy rainfall areas; one in the middle reaches of the Chama with Mérida in the center, and the other near the basins' divide of the Chama and Mocotíes rivers.

The annual daily rainfall distribution observed at principal stations in the basin when a notable flood occurred in the lower reaches on April 27, 1972 are presented in Fig. IV-6. The same during the period when the notable floods occurred in 1972 and 1982 are presented in Fig. IV-7. From both illustrations, it can be said that the scale of the basin's average daily rainfall during floods is small at less than 30 mm.

The hourly rainfall records in the basin were compiled only after 1983. Fig. IV-8 shows the hourly distribution of rainfall at principal stations during the flood on September 6, 1988, together with the observed flood hydrograph of the Chama River at Ejido. The same during the flood in October 1988 is presented in Fig. IV-9. Table IV-6 shows the numeric value of these rainfalls. All data show that the rainfall which cause flood is in the scale of less than 30 mm/day with durations of about a few to several hours.

3.3 Annual Maximum Basin's Average Daily Rainfall

The annual maximum basin's average rainfalls from 1967 to 1988 were obtained from the isohyetal maps (Fig. IV-5) as listed in the following table.

Annual Maximum Basin's Average Rainfall

Year	Value	Year	Value
1967	17.1	1978	16.8
1968	21.4	1979	10.6
1969	31.6	1980	10.8
1970	8.7	1981	17.7
1971	22.5	1982	19.6
1972	19.4	1983	14.8
1973	19.2	1984	8.0
1974	16.2	1985	10.5
1975	11.1	1986	16.4
1976	24.3	1987	26.5
1977	22.7	1988	19.7

Probable values of basin's average rainfall for various return periods are calculated by Iwai's method based on the above value as presented in the following table.

Probable Values of Basin's Average Rainfall

Return Period (Year)	Value (mm/day)
100	35.2
50	32.5
30	30.5
10	25.8
5	22.4
2	16.9

3.4 Rainfall Intensity-Duration Curve

Table IV-7 gives the 100-year return period point rainfall intensity by duration at the stations in the basin. The curves at various stations can be grouped into four lines as illustrated in Fig. IV-10.

The duration curve with the highest intensity was derived from the stations at Tovar, El Meson, San Pedro Chiguara, La Palmita, El Vigía in the area from the Mocotíes basin, except those in the most upstream areas, to the lower reaches of the Chama River. The next highest curve is from those at Valle Grande, Mérida, Mesa de Ejido, Jají, San Juan de Lagunillas, Tostós, Páramo El Molino in the middle reaches of the Chama River.

El Morro, the station in the Nuestra Señora River Basin, presents a curve with smaller intensities. The lowest curve is of the stations at Páramo de Mucuchíes, Páramo Pico El Aguila and Mucubají in the most upstream area of the Chama River Basin.

Annual rainfalls at El Morro, Tostós and San Juan de Lagunillas in the semi-arid zone of the middle reaches of the Chama River are about 500 to 600 mm. Among them, Tostós and San Juan de Lagunillas present almost the same intensity with Mérida, Mesa de Ejido, Jají, etc., where the annual rainfall is 1,000 to 1,800 mm.

4. FLOOD RUNOFF MODEL

4.1 Runoff Model

Storage Function Model for River Basin

The storage function model which is most commonly used to simulate floods was employed to simulate the design floods in this study. This model is suitable in cases with a few data for verification, since various experimental values for constants have been developed for this model.

In the storage function model, the basin is divided into sub-basins with catchment areas of 10 to 1,000 km^2; usually, less than 300 km^2. In Japan, this model is applied either to a small catchment of about 10 km^2 or a large catchment of over 10,000 km^2.

The storage function model has been developed to express non-linear characteristics of runoff phenomena introducing the following function between the storage volume (S_1) of a basin or a river channel and the discharge (Q_1) from the same.

$$S_1 = K \cdot Q_1^p \text{ ....(1)}$$

where, K and p are constants.

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

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

$$\frac{dS_1}{dt} = \frac{1}{3.6} \cdot f \cdot r_{ave} \cdot A - Q_1 \text{ ......(2)}$$

where,

S_1 : apparent storage volume in the basin ($m^3/s/hr$)

f : inflow coefficient

r_{ave} : basin's average rainfall (mm/hr)

A : area of the basin (km^2)

$Q_1(t) = Q(t + T_1)$: direct runoff height with lag time (m^3/s)

T_1 : lag time (hr)

Runoff calculations for a basin are generally made by dividing the above two basic equations (1) and (2) by the area of the basin in order to express them by the storage height s (mm) and runoff height q (mm/hr). Accordingly, the basic equations are expressed as follows:

$$s_1 = k \bullet q_1^p \quad \text{.......................(3)}$$

$$\frac{ds_1}{dt} = f \bullet r_{ave} - q_1 \quad \text{................(4)}$$

The constant f in the above equation is to estimate the effective rainfall. In the storage function model, the coefficient f is not related to rainfall but to the drainage area A; namely, it is assumed that in the early stages of rainfall, f is f_1 (termed the primary runoff rate) and that runoff occurs only from the area f_1A (called the runoff area). When accumulated rainfall exceeds Rsa (saturation rainfall), then f = 1 (this is termed the saturated runoff rate), and the runoff occurs also from the remaining part $(1-f_1)A$ (infiltration area) due to the rainfall after Rsa.

In this model, runoff from both the runoff area and the infiltration area is calculated separately by equations (3) and (4) until the end of the flood. The total runoff from the whole basin is given by the sum of runoff from both areas plus the base flow, as shown in the following equation.

$$Q = \frac{1}{3.6} f_1A \bullet q_1 + \frac{1}{3.6} (1 - f_1)A \bullet q_{sat} + Q_1 \quad \text{......(5)}$$

where,

f_1 : primary runoff rate

q_1 : runoff height caused by total rainfall (mm/hr)

q_{sat} : runoff height caused by rainfall after saturation (mm/hr)

Q_i	:	base flow (m^3/s)
A	:	total drainage basin (km^2)

Storage Function Model for River Channel

The storage function of the river channel is expressed as follows:

$$S_1 = K \bullet Q_1^p - T_1' \bullet Q_1$$

where,

S_1	:	apparent storage volume in the river channel ($m^3/s/hr$)
Q_1	:	runoff (m^3/s)
K, p	:	constants
T_1'	:	lag time for river channel (hr)

Division of Basin and Channel

In the storage function model, division of the basin is made giving a sub-basin's size generally at about 300 km^2, so that topographical and geological conditions in the sub-basin can be considered homogeneous.

For the study, the Chama River Basin has been divided into 21 sub-basins as illustrated in Fig. IV-11. In addition, four river channels have been introduced in the model as presented in the model diagram shown in Fig. IV-12.

4.2 Storage Function

K, p and Te of Basin

The basin's storage function is expressed as

$$S_1 = K \cdot Q_1^p$$

as explained in the previous part. Constants K and p are determined as follows:

"p" was determined for each sub-basin by applying the following experimental formula:

$$p = 0.175 \, (I^{-1})^{0.235}$$

where, I is the average gradient of the catchment.

If the flow on slopes is considered as the laminar flow, p will be 1/3, and the value is usually about 0.3. Although the above experimental formula was developed for a mountainous basin in Japan, it is applicable to the Chama River Basin since the constant p is largely dependent on topographical condition because the average gradient of the basin is employed as a parameter.

K is assumed to be in the following relation with the average gradient of the basin (I).

$$K = \alpha \bullet (I^{-1})^{-0.3}$$

α in the above formula was determined by simulation on actual floods.

The hydrometric stations on the Chama River are Ejido (1,130 km^2) and Mucurubá (365 km^2). Simulation to determine α in the above formula was made for hydrographs observed at Ejido. Flood hydrographs at Ejido are available only for 1988 and 1989. From this record, eight hydrographs with peak discharges of more than 80 m^3/s were selected for simulation.

Hydrographs become sharp in both rising and descending stages if the constant α is small. On the contrary, if α takes a larger value, the hydrograph becomes blunt as shown in Fig. IV-13. α was finally determined at 25 after simulation.

Fig. IV-14 shows the simulated and observed hydrographs. Accordingly, K of $S = K \cdot Q^p$ is expressed as the following formula:

$$K = 25 \, (I^{-1})^{-0.3}$$

Lag time T_l, explained in the previous part, has been determined by the following formula:

$T_1 = 0.0470\,L - 0.56 \qquad (L \geq 11.9\text{ km})$

$T_1 = 0 \qquad (L < 11.9\text{ km})$

K, p and T_1 of River Channel

Four river channels were considered in the model as presented in the model diagram (Fig. IV-12). Only the time lag was considered for Channels No. 1, 2 and 4, since the river channel widths are small and storage effect is not expected from these channels. Storage effect was given to Channel No. 3 as follows.

K and p for Channel No. 3 were determined assuming the flow as Manning's uniform flow. Manning's formula is expressed as follows:

$$Q = \frac{1}{n} \cdot \left[\frac{A}{P}\right]^{2/3} \cdot I^{1/2} \cdot A$$

where,

Q : discharge (m^3/s)
n : Manning's roughness coefficient
A : flow area (m^2)
P : wetted perimeter (m)
I : gradient

If the subject river channel is considered as a wide channel, wetted perimeter P is expressed as:

$$P = B$$

where, B : river width

Accordingly, the Manning's formula can be converted as follows:

$$Q = \left[\frac{1}{n} \cdot \frac{I^{1/2}}{B^{2/3}}\right] \cdot A^{5/3}$$

$$A = \left[\frac{1}{n} \cdot \frac{I^{1/2}}{B^{2/3}}\right]^{-0.6} \cdot Q^{0.6}$$

Since the storage volume in the river channel S is A x L, the relation between S and Q for the period of 1 hour is expressed as follows:

$$S = \frac{L}{3600} \cdot \left[\frac{1}{n} \cdot \frac{I^{1/2}}{B^{2/3}} \right]^{5/3} \cdot Q^{0.6}$$

Channel No. 3 has a length of 30 km with an average width of 200 m along the Chama main river course from Ejido downstream to the confluence point with the Santo Domingo River. Storage function for this river channel was determined assuming the constants as follows:

Manning's Roughness Coefficient	:	$n = 0.04$
River Gradient	:	$I = 1/73$
Average River Width	:	$B = 200$ m
Channel length	:	$L = 30$ km

The storage function of River Channel No. 3 has thus been developed as follows:

$$S = 36.4\ Q^{0.6}$$

Lag time for River Channel No. 3, T_1' was determined from the experimental formula as follows:

$$T_1' = 7.36 \cdot 10^{-4} \cdot L \cdot I^{-0.5} = 0.19 \text{ hrs}$$

4.3 f1 and Rsa

f1 (Primary Runoff Rate) and Rsa (Saturation Rainfall Depth) were estimated on the basis of the observed and simulated cumulative runoff height curves. Accumulated runoff height of the simulated hydrograph assuming f1 = 1.0 and Rsa = 0 were plotted against the same of the observed flood hydrograph (Fig. IV-14) as illustrated in Fig. IV-15.

The primary runoff rates in Fig. IV-15 are in the range of from 0.4 to 0.6; Rsa is, however, not evident in the illustration. This means that the rainfall during those floods did not reach the saturation amount.

Saturation rainfall depths are generally more than 100 mm. Considering that the basin's average rainfall amount is relatively small at about 35 mm/day even for 100-year return period value, it is believed that even the design rainfall is within the saturation amount.

Accordingly, the runoff rate was assumed at a constant value, not relating to the rainfall amount. From Fig. IV-15, the runoff rate for estimation of design hydrograph was assumed at 0.6 for the catchment upstream of Ejido. Runoff rate was determined from the basin's condition, in this study. Vegetation cover was applied as a parameter. It was experimentally found that the runoff rate of bare land is approximately 0.2 more than that of vegetated land. The runoff rate of each sub-basin was thus determined, assuming the following rate for each vegetation condition.

Vegetation Cover	Runoff Rate
High and Low Forests	0.6
Grassland	0.6
Bare Land	0.8

4.4 Summary of Parameters

Various constants by each sub-basin and river channel for the storage function model were determined, as tabulated in Table IV-8.

4.5 Specific Peak Discharge Plot

Fig. IV-16 shows the specific peak design discharges of 100-year return period for rivers in the area south of the Maracaibo Lake. According to the illustration, those for the Chama River at El Vigía are 0.4 or less.

A group of specific discharges of 3-4 $m^3/s/km^2$ with catchment areas of 100 to 500 km^2 is of streams in the northern slope of the Cordillera de Mérida where rainfall is relatively strong.

5. DESIGN FLOOD HYDROGRAPHS

5.1 Design Flood Hydrograph at El Vigía

5.1.1 Design Rainfall

Duration and Amount

The duration of design rainfall has been determined at 1-day considering the following:

- Durations of rainfall which cause floods are generally few to several hours (approximately 2-10 hours), as discussed in the previous section.

- Daily rainfall is the rainfall amount from 9:00 a.m. to 9:00 a.m. in Venezuela. From the observed hourly rainfall distribution it can be said that rainfall which cause flood occurs in the afternoon until night and it seldom occurs in two hydrological days.

- Peak concentration time of the Chama River at El Vigía is about 6 hours.

- Daily rainfall data is available for a relatively long period of 22 years from 1967 to 1988.

The probable value for annual maximum basin's average 1-day rainfall was calculated on the basis of 22-year data from 1967 to 1988 as presented in 3.3, Annual Maximum Basin's Average Daily Rainfall.

Areal and Time Distribution

Areal and time distribution of design rainfall were determined on the basis of the observed rainfall pattern. Since sufficient data of observed hourly rainfall are available only for four years from 1985 to 1988, four rainfall patterns applying the observed hourly distribution of rainfall during the period when the annual maximum basin's average 1-day rainfall occurred in 1985 to 1988 (Table IV-9) were prepared as design rainfalls.

Limitation by Duration Curve

Design rainfalls were prepared by enlarging the actually observed rainfall as discussed above. However, the maximum amount by duration was given with reference to the duration of point rainfall. Aerial reduction factor by Fretcher's method (Fig. IV-17) was applied to obtain probable areal rainfall for each sub-basin from the probable point rainfall.

Design Rainfall

Four types of design rainfall were developed according to the conditions presented above. The design rainfalls based on the 1986 type of rainfall are shown in Table IV-10.

5.1.2 Design Flood Hydrograph

Design Flood Hydrograph

Flood hydrographs were prepared by applying the design rainfalls obtained above to the storage function model of the sub-basins and river channels. The calculated flood hydrographs at El Vigía are shown in Fig. IV-18, and the peak values are as follows:

Design Rainfall Type	100-year Return Period Peak Discharge at El Vigía (m^3/s)
1985	1,912
1986	2,239
1987	1,642
1988	1,947

From these results, the 100-year return period design discharge of the Chama River at El Vigía was determined at 2,300 m^3/s, and the 1986 type hydrograph was selected as the design flood hydrograph. The design discharges of the Chama River at El Vigía for various return periods were determined as follows:

Peak Discharges of the Chama River at El Vigía
for Various Return Periods

Return Period (year)	100	50	30	10	5	2
Design Peak Discharge (m^3/s)	2,300	2,100	1,850	1,450	1,200	750

Checking by Other Areal Distribution of Rainfall

Design rainfalls have been prepared on the basis of the rainfall from 1985 to 1986. Areal distribution of rainfall observed in 1967 to 1984 were also applied to check the peak discharge at El Vigía. From the areal distribution during the period when the annual maximum daily rainfall occurred in 1967 to 1984, those with enlarging ratio of less than 2.0 were selected.

After simulation, the 1981 type rainfall gave the highest peak value of 2,263 m^3/s at El Vigía. This value is, however, still less than the determined design discharge of 2,300 m^3/s.

Comparison of Design Discharge of Other Studies

Various design discharges for the Chama River have been established in different studies. The 100-year return period discharges are compared as follows.

No.	Peak Discharge (m^3/s)	Catchment Area (km^2)	Specific Discharge ($m^3/s/km^2$)	Source	Year
1	2,496	3,355	0.74	Estudio Preliminár del Control de Crecientes del Río Chama, Natalio J. Yunis	Jan. '67
2	1,300	3,400	0.38	Estudio Hidrologico Preliminár de la Cuenca del Río Chama en Puerto Chama, MARNR	May '72
3	1,500	3,338	0.45	Projecto Descación Río Chama al Río Mucujepe	'79
4	2,049	3,572	0.57	Actualizacion del Estudio Hidrologico de la Zona Sur del Lago de Maracaibo, Estado Zulia, MARNR	Nov. '87

Although the detailed information on the analysis made for the above data is not available, the basic rainfall data used for the analysis on the first three items are quite different from those of the present study. Item No. 4, however, used almost the same period of rainfall data as the present study. The 100-year return period basin's average rainfall, the basic value for design discharge estimation, was estimated at 46.1 mm which is relatively larger than the 35.2 mm in the present study.

Verification of floods in that study was made from the flood hydrograph recorded on May 18, 1979, while the present study used the hydrographs in 1988. Although it is difficult to compare the results of the two studies because the applied models are different, the obtained values are almost in the same magnitude and it seems that the results are appropriate.

5.2 Design Discharges Along the Chama River Course

The design flood hydrograph at El Vigía was determined as the 1986 type of hydrograph. Although this hydrograph gives the highest peak value among the four types at El Vigía, rainfall is rather concentrated in the lower reaches.

To determine the design discharges along the Chama River at the middle reaches, the 1988 type which has a relatively higher rainfall in the upstream area was selected. The design discharges at major points in the middle reaches were determined as follows.

River	Point	Peak Discharge (m^3/s)
Nuestra Señora River	Just upstream of the confluence with the Chama River	610
Chama River	Downstream of the confluence with the Nuestra Señora to the confluence with La González	1,800
Chama River	Downstream of the confluence with La González to the confluence with the Mocotíes River	1,950
Chama River	Downstream of the confluence with the Mocotíes River to the confluence with La Sucia River	2,250

5.3 Design Discharges at Upstream Tributaries

Subject Tributaries

The storage function model was also applied to estimate design discharges at upstream tributaries, i.e., Milla, Albarregas, Montalbán and Portuguesu rivers. The catchment area, river length, etc., of these tributaries are shown in the following table.

	Milla	Albarregas	Montalbán	Portuguesu
Catchment (km^2)	7.7	39.5	14.8	20.0
River Length (km)	5.5	16.0	6.0	9.8
Ave. Gradient (I)	1/4.5	1/6.3	1/2.5	1/4.7
Concentration Time (hr)	0.44	1.27	0.48	0.78
(Kraven, w = 3.5)				

Design Rainfall

A model hyetograph (center type) was adopted for design rainfall. Applying the duration curves at Valle Grande, Páramo La Culata, Mesa de Ejido and Mérida, the following rainfall intensities were prepared with areal reduction by Fretcher's method.

	Milla	Albarregas	Montalbán	Portuguesu
Catchment Area (km^2)	7.7	39.5	14.8	20.0
Areal Reduction Factor	0.95	0.83	0.93	0.91
Rainfall (mm)				
30 min	35.6	31.1	34.9	34.2
1 hr 30 min	54.2	47.4	53.1	52.0
3 hrs 30 min	75.5	66.0	73.9	72.3

Design Discharges

The peak discharges were determined as follows on the basis of calculations using the storage function model:

	Milla	Albarregas	Montalbán	Portuguesu
100-year Return Period				
Design Discharge (m^3/s)	65	180	110	130