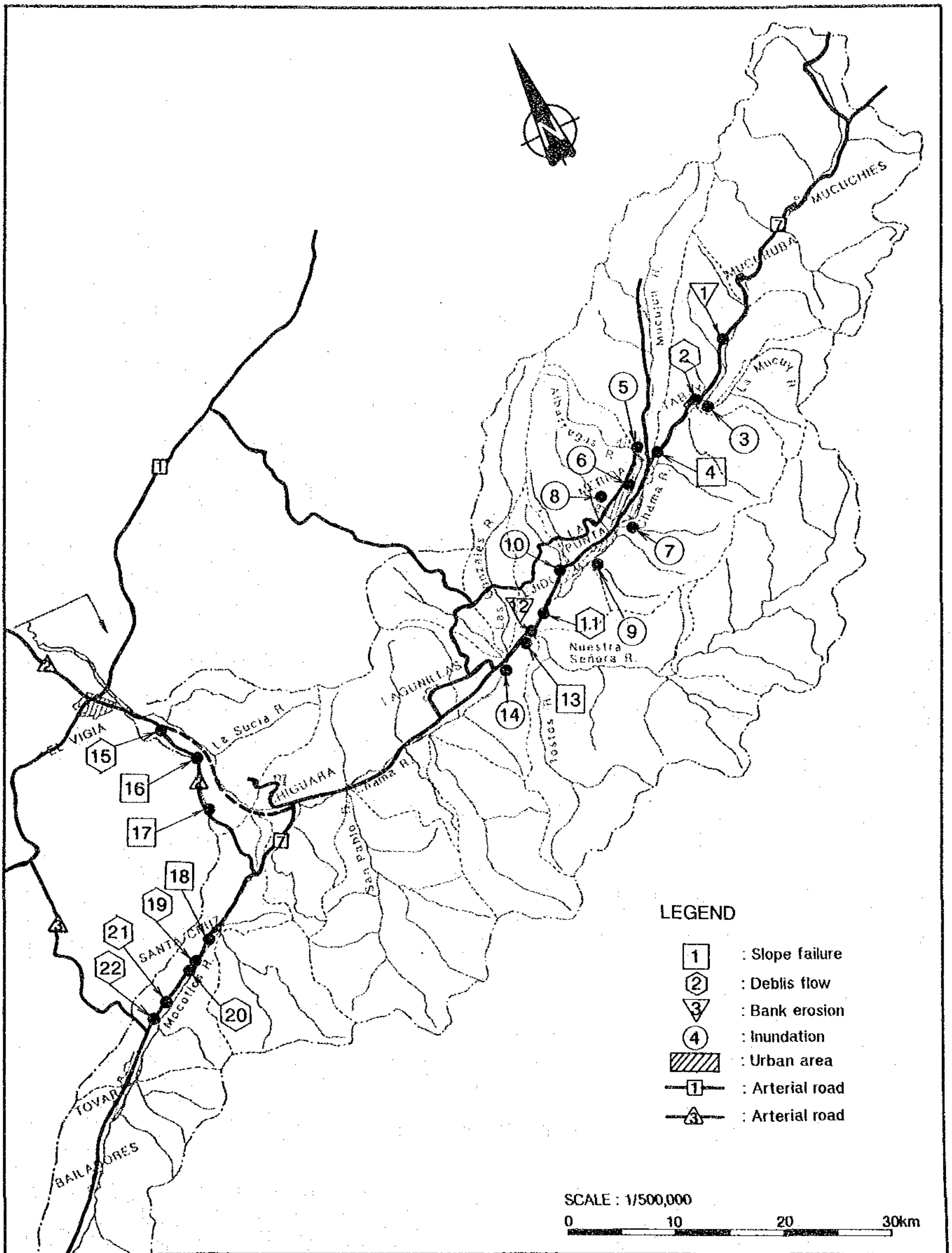
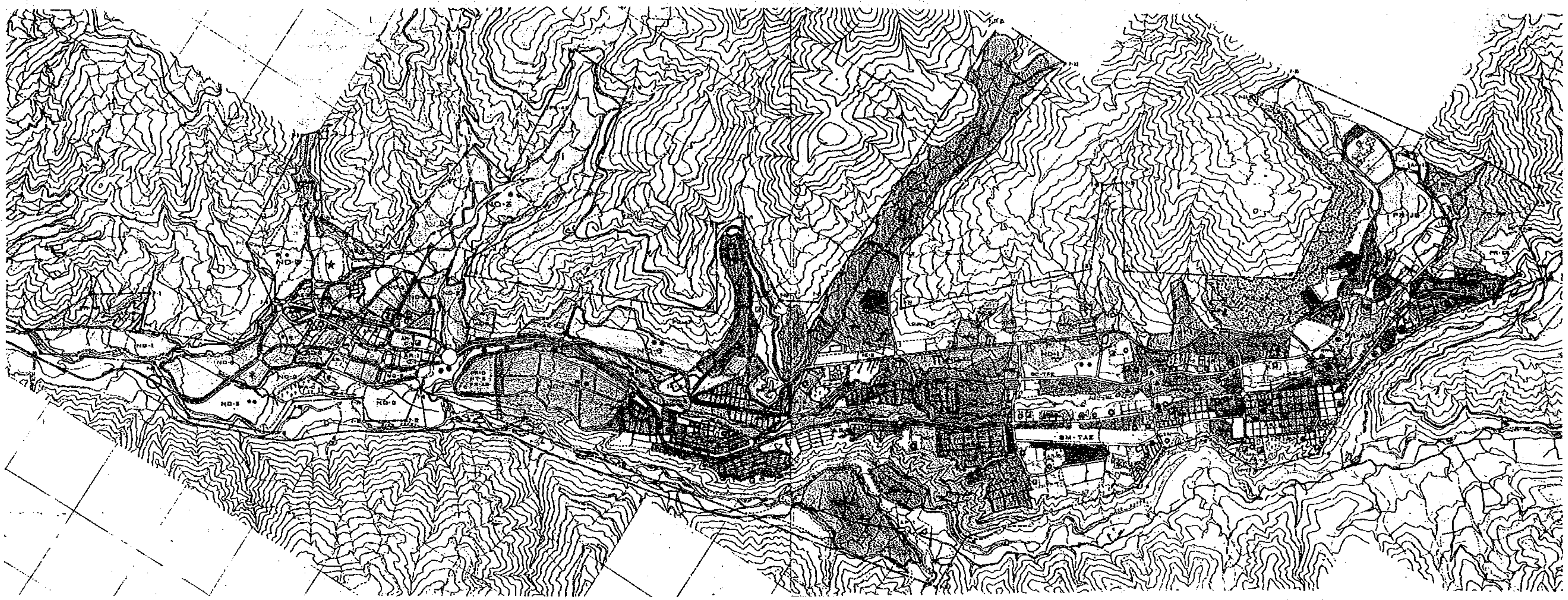


LOCATION MAP FOR PAST DISASTERS

Fig. V-5

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY



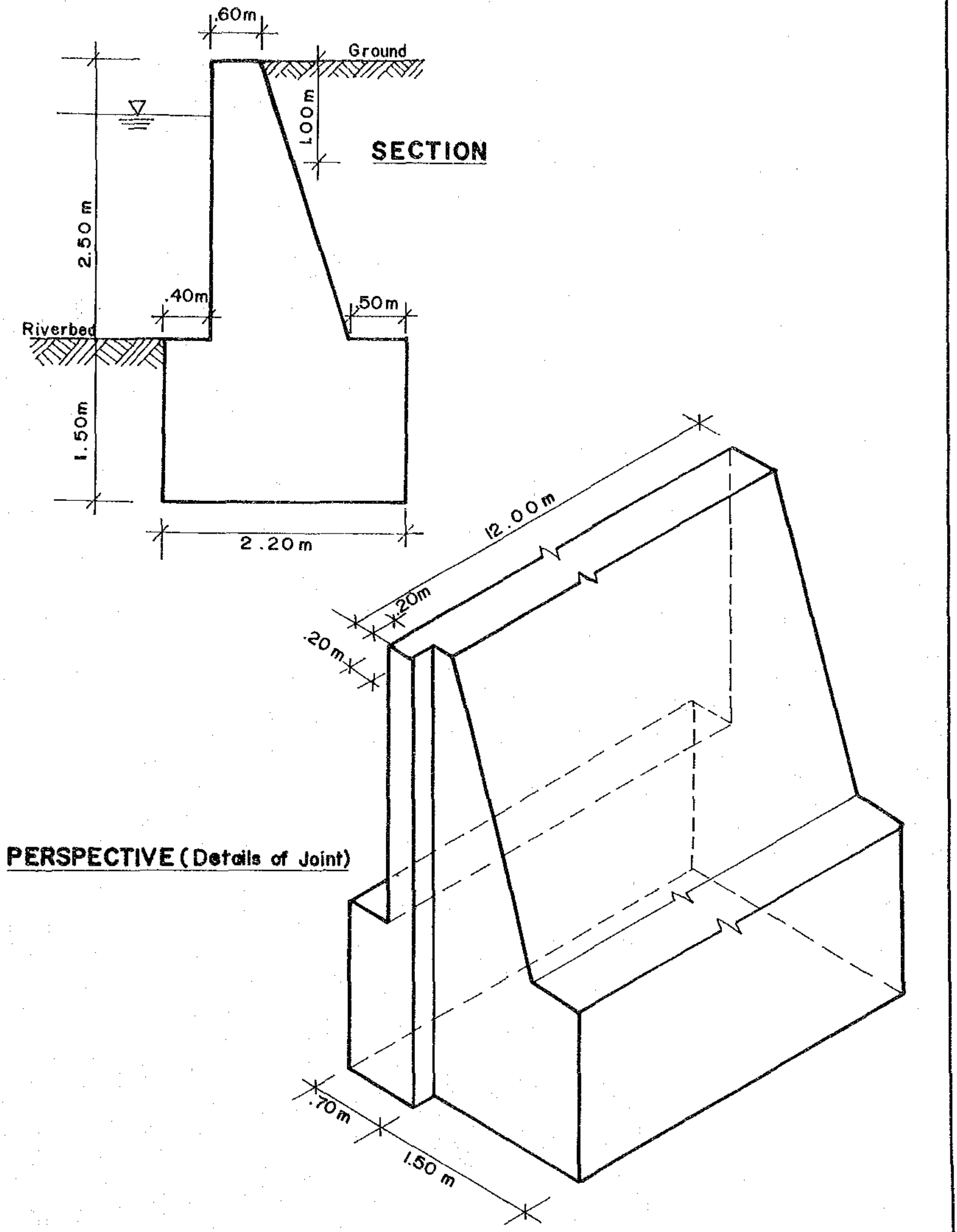
LEGEND

:	AE-2	CONSERVACION URBANA
:	AE-4	CONSORIDACION URBANA
:	AE-5	REUBICACION
:	AR-1	DENSIDAD ENTRE 180Y 500Hab/Ha.
:	AR-2	DENSIDAD ENTRE 300Y 700Hab/Ha.
	MS-1	
:	AR-3	DENSIDAD ENTRE 110Y 1000Hab/Ha.
:	ND-2	DENSIDAD BRUTA ENTRE 150Y 250Hab/Ha.
:	ND-4	DIFERIDO DENSIDAD BRUTA 75Hab/Ha.
:	ND-5	DEFERIDO DENSIDAD BRUTA ENTRE 100Y 200Hab/Ha.
	IE-2	
:	ND-6	PARA PROGRAMAS ESPECIALES
:	PR-AP	AREAS DE PROYECCION
:	PR-E2	INSTALACIONES DEPORTIVAS METROPOLITANAS

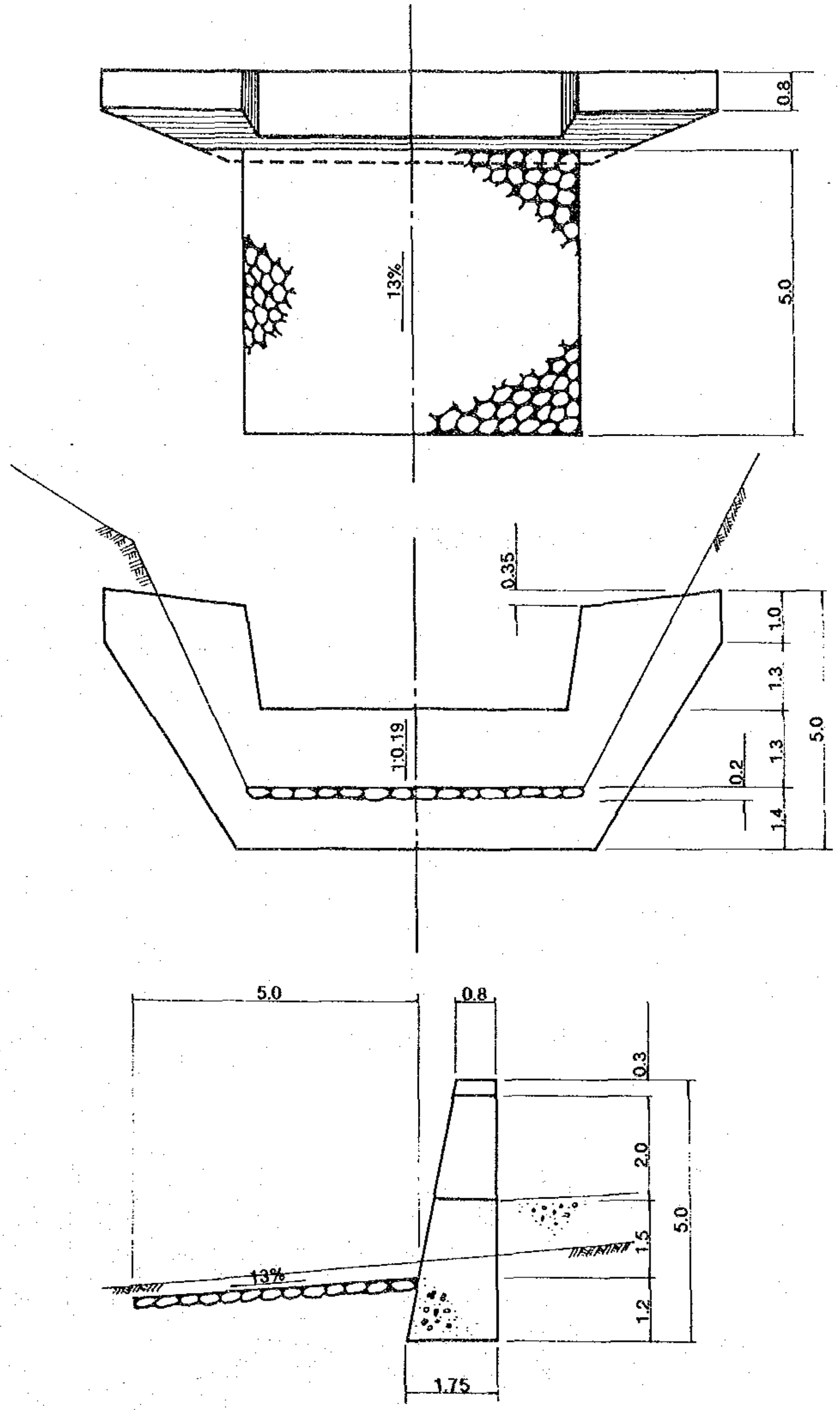
SCALE : 1/56,000

0 1 2 3 km

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT	URBAN DEVELOPMENT PLAN FOR MÉRIDA AND EJIDO CITIES
JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. V-6



TYPICAL STRUCTURE OF RETAINING WALL	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT
Fig. V-7	JAPAN INTERNATIONAL COOPERATION AGENCY

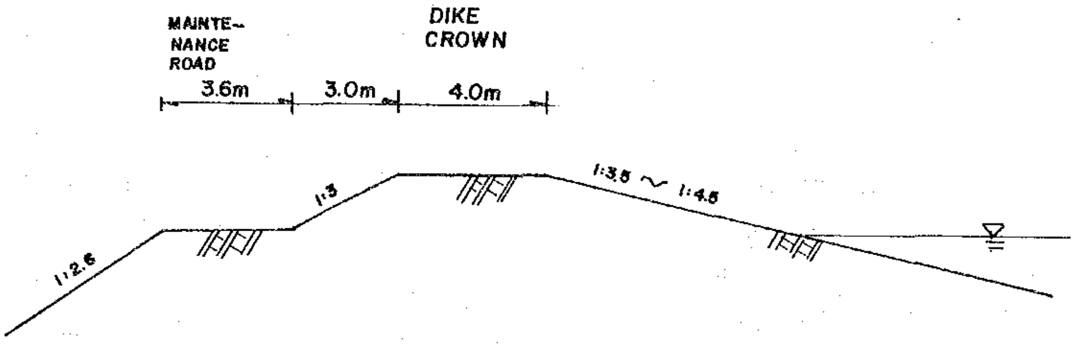


TYPICAL STRUCTURE OF CHECK DAM

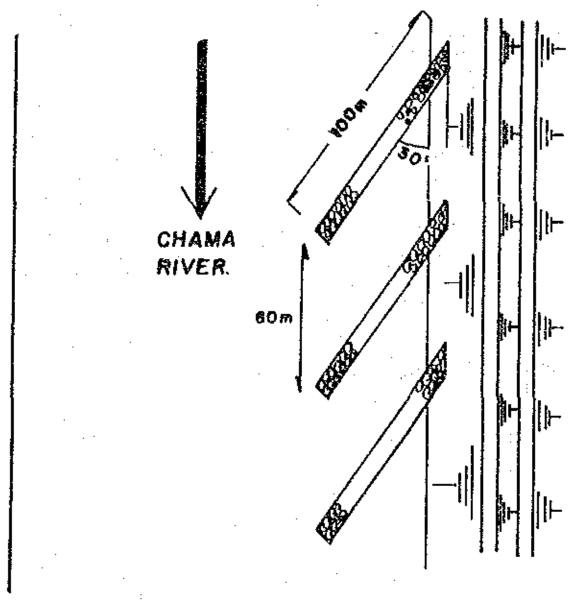
Fig. V-8

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

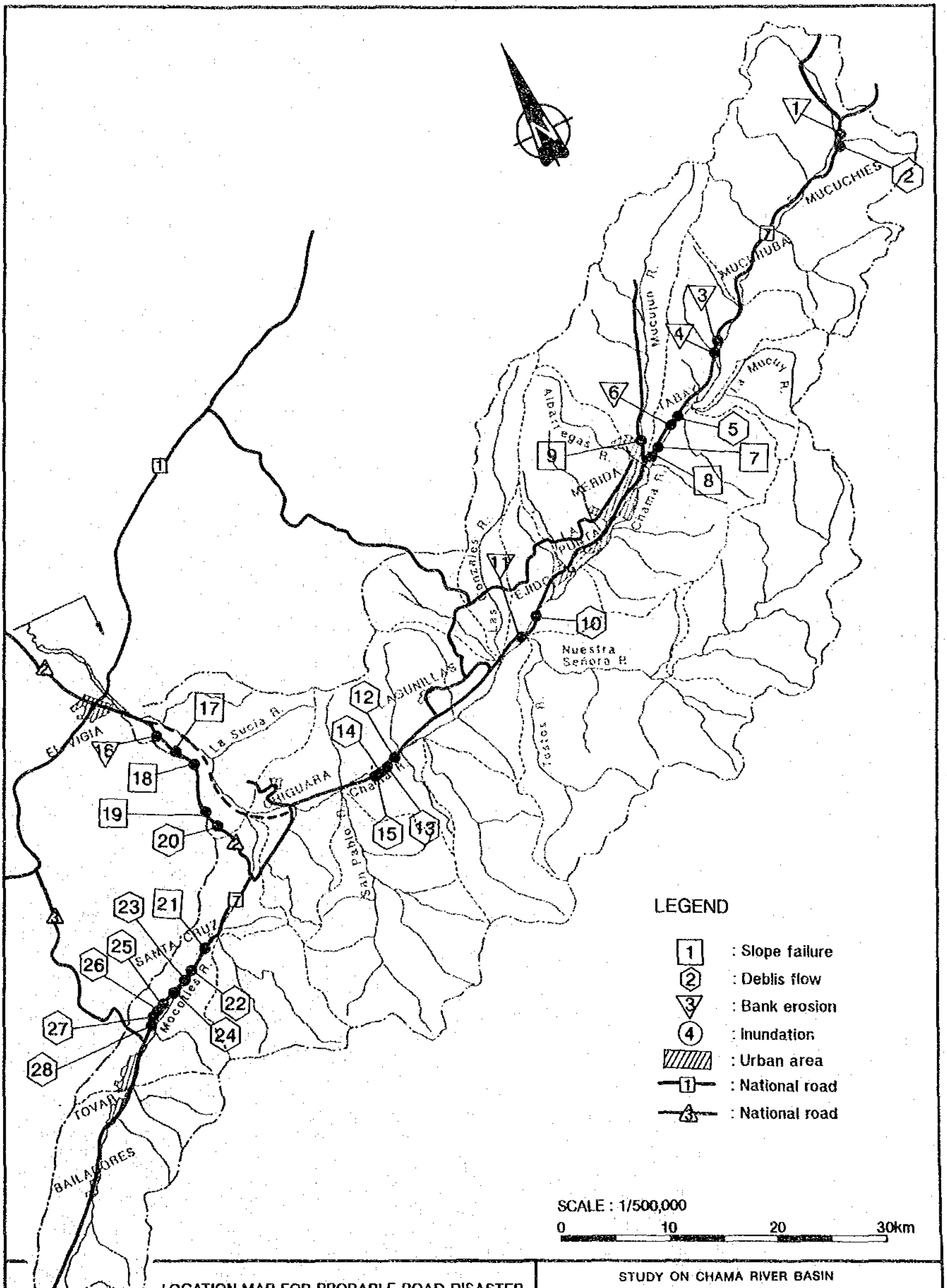


STANDARD BANK CROSS SECTION



TYPICAL ARRANGEMENT OF GROYNE

ARRENGEMENT OF GROYNE AND CROSS-SECTION OF DIKE OF EXISTING LEFT BANK DIKE OF THE CHAMA RIVER Fig. V-9	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT JAPAN INTERNATIONAL COOPERATION AGENCY



LOCATION MAP FOR PROBABLE ROAD DISASTER

Fig. V-10

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

VI. SEDIMENT CONTROL

SUPPORTING REPORT

VI. SEDIMENT CONTROL

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1. PRESENT SEDIMENT CONDITION

1.1 General Condition of the Basin

The Mérida mountain range extends between the Maracaibo Lake and the Orinoco Plains at an average elevation of 4,000 m. This mountain range is generally divided by an active fault, called the Bocono Fault, into the northern mountains called Sierra de la Culata and the southern ones called Sierra Nevada.

The Chama River runs between these two mountains, originating at an elevation of around 4,400 m in Piedras Blancas near El Aguila Pass. It flows in the U-shaped valley formed by glaciers 10 km from the river source to Apartaderos; thence, 80 km to Estánquez in the valley plain which contains many river terraces.

At Estánquez, the Chama River recieves the Mocotíes River and turns northward for 20 km to El Vigía forming a V-shaped valley in the tertiary mountains. At El Vigía, the river flows out of the Mérida Mountains to the Maracaibo lowlands and after running 10 km forming the fan and the delta, it flows into the Maracaibo Lake. El Vigía is situated at the top of the fan. The catchment areas and riverbed gradients are presented as follows:

Basin	Catchment Area	Riverbed Gradient
Upper Reaches (El Aguila Pass to Tabay)	491 km^2	1/17 - 1/70
Middle Reaches (Tabay to El Vigía)	3,026 km^2	1/110 - 1/70
Lower Reaches (El Vigía City to Maracaibo Lake)	268 km^2	1/1,400 - 1/110

The valley of the Upper Reaches is formed by Pleistocene glacier and the gentle land is formed by the action of periglacier. The bedrock is covered with moraines and its sediment. The valley in the Middle Reaches is wide at about 2 to 3 km, and large scale river terraces are formed along the Chama River. These terraces are about 200 m high around Mérida City. In the Lower Reaches, the Chama River forms an alluvial fan and a delta, and finally empties into the Maracaibo Lake after a heavily meandered river channel.

The annual average rainfall of the Chama River Basin was estimated at 1,168.6 mm from the data of 21 years from 1967 to 1987. According to rainfall, the basin is divided into two areas; namely, the semi-arid zone stretching from the confluence of the Chama and La Vizcaína rivers to the Nuestra Señora River with an annual rainfall of 650 mm, and the area with approx. 1,200 mm of annual rainfall. The basin has two heavy rainfall periods in May to July and October to December, but the upstream area from Mucurubá has one rainy season from April to October.

Owing to the areal and seasonal distribution of rainfall and the topographic condition, there are three types of vegetation in the Chama River Basin. The first type consists of scarce low trees and grass on the steep slopes in the semi-arid zone, the second is of tropical forest covering most of the basin up to the elevation of 2,000 m, and the third type has low trees and grass occupying the area above 2,000 m in elevation.

The tropical forest in the Lower Reaches has been converted into a plantain plantation and pasture land, and the highland area is mainly used for pastures. The slopes in the semi-arid zone, especially the southern slopes, have been continuously devastated by gully erosions.

1.2 Sediment Survey and Sampling

1.2.1 Source of Sediment

A sampling survey of erosion was made on torrents and rivers where abundant sediment supply to the Chama River is expected. The survey on mass wasting was conducted in areas formed by mass flow, slide and glide.

Rockfall zones were also studied, together with the rockfall materials, as the major source of sediment supply. Sampling of rockfall materials together with sieving analyses were carried out to grasp the characteristics of sediment production.

Survey on Torrent Erosion

The survey on torrents including stream channels was made at 11 sites on five major tributaries; namely, the Mucujún, La Mucuy, the Nuestra Señora, La González and the Mocotíes rivers. Data sampling was carried out with the items of river topography, geologic conditions, vegetation and sediment characteristics. Measuring additional topographic data on the map with a scale of 1:25,000, sediment volume which is expressed in square meter per section was computed as those of eroded, residual and their summation. The results of the survey are summarized in Table VI-1 and the survey locations are as shown in Fig. VI-1. The condition of sediment movement such as erosion and deposition of each river was observed as follows.

(1) Mucujún

The Mucujún River Basin is generally covered by thick and high forest and its stream channels are steady. Gullies are rare and no slide nor glide was observed. At the site of sampling, the channel bed is covered with boulders and gravels measuring 200 cm at the maximum and 30 cm on an average. The channel bank is formed with old debris deposits.

(2) La Mucuy

The sampling was conducted at two sites. The first site is 1 km from the confluence with the Chama River and the second is on a tributary, the Desbarrancadero River, at 1 km downstream of the slope gliding area. Both sites were formed by debris flow in the olden times and small scale secondary erosions have frequently occurred. Gully erosions on the debris flow lobes are rare.

(3) Nuestra Señora

A total of four sites were selected for the sampling survey. Two sites are located on the main stream of the Nuestra Señora River and the other two are on the tributary, the Mucusurú River, which joins the Nuestra Señora at 14.5 km from the confluence of the Chama and the Nuestra Señora rivers.

The Nuestra Señora River Basin is covered with a sparse forest and grass; sometimes with farmlands. Gullies are developing and hence gully erosions play a significant role in the production of sediment.

On the other hand, the Mucusurú River was found to be heavily loaded with sediment deposits which were mainly produced by gully erosions along the river channel. Around the sampling sites, many gullies and gliding slopes which may have brought a large volume of sediment to the channel were observed.

(4) La González

La González River Basin has two distinct vegetation covers in its downstream and upstream areas. The upstream area is provided with thick and high forests, while the downstream area, particularly around the confluence with the Chama River, has only a sparse forest, grass and cactuses.

Comparing the grain size of bed materials in the lower stream to that in the upper stream, it was recognized that sediment is produced more from the bank slopes of the downstream channel than the mountains in the upstream area. Although some small-scale slope slides were identified along the channel, the upstream area has suffered less from gully erosions due to the thick vegetation cover.

(5) Mocotíes

The Mocotíes River Basin is covered by a very dense and high forests. Except the artificial causes of erosion such as cultivation practices, housing and road construction, only small erosions have taken place in this river basin.

The sampling survey was conducted at the sites of two rivers; namely, the Tabacal and the Casiguito. Channel erosions mainly occur because of the down-cutting and side erosion by flood flows. Although sediment deposit was observed at every heavy rainfall, the volume was rather small.

Survey on Mass Wasting

The sampling sites were chosen, as shown in Fig. VI-1, among the locations where mass wasting was actually observed within a year before the survey. Eleven sites were selected from the upstream areas of La Sucia River (Chiguara), La Portuguesa River and La González River and the middle reaches of the Chama River. The collected data are slope type and gradient, depth of surface soil, vegetation cover, dimension of mass wasting and sediment volume. Sediment volume was classified into three categories; namely, total wasted volume, residual volume in the slope and expanding volume to be produced by another wasting. The results of the survey are summarized in Table VI-2.

(1) La Sucia (Chiguara)

Two large-scale landslides were identified in the upstream area of La Sucia River, in the vicinity of El Guamo. These two landslides are around 300 m apart. The area surrounding the landslides is covered by a dense and high forests and geologically formed up with meta-black shale. The two landslides consecutively took place because of the downpours in December 1988, and the rural road at the top seemed to have contributed to the slides.

The total volume of sliding debris of the two areas is estimated at approx. 900,000 m^3, and there still remains in the slope the residual debris of approx. 500,000 m^3 which could be gradually conveyed to La Sucia River and to the Chama mainstream.

(2) La González and La Portuguesu

There are two landslides along the trunk road from Mérida to Jají in the upstream area of La González and La Portuguesa rivers. The area is also covered by a dense and high forests and its bedrock is mainly composed of granitic sandstone. Although topography around the area shows many traces of landslides in the olden times, most of them are now rather stable covered by forests and grasses.

The volumes of debris produced by the landslides are estimated at approx. 4,500 m^3 and 20,500 m^3 for La González River and La

Portuguesa River, respectively. The remaining and expanding debris volumes are approximately 900 m^3 and 2,500 m^3 for La González River, and 10,000 m^3 and 2,500 m^3 for La Portuguesa River.

(3) Chama

There are totally seven sites identified to have large-scale mass wastings which supply sediment to the Chama River. All sites are located inside the semi-arid area which is covered only by sparse grass, low trees and cactuses. Three sites among the seven are classified into debris flow lobe and levee, while the other four are slope-gliding.

Three of the latter slope glides were observed in the vicinities of Pte. Real, Chama Bridge No. 3 and the confluence with the Nuestra Señora River along either new or old arterial roads. As their locations indicate, the slope glides were triggered by road construction.

The total volume produced by these slope glides was estimated at approx. 570,000 m^3, but the untreated volume remaining at the foot of the slope was estimated at approx. 6,000 m^3 only owing to some protection works made by the MTC. The debris volume expanding due to instability of the slope was also estimated at approx. 40,000 m^3.

With regard to the debris flow lobes which are located at González, S. Onofre, Higuerones and Pte. Viejo, three debris flows (except at Pte. Viejo) occurred due to the heavy rain in September 1988. The debris flow at Pte. Viejo occurred in the late 1970's, and it is presently stable without secondary erosion. The total volume of debris flow is estimated at approx. 420,000 m^3 and the remaining volume is approx. 90,000 m^3.

Although a large volume of debris estimated at approx. 400,000 m^3 may be caused by another heavy rainfall, most of it can be stabilized by ground leveling works undertaken immediately after the disaster. Little debris will then be supplied to the Chama River.

Rockfall Materials

Many rockfall zones are distributed in the middle reaches of the Chama River Basin. Sampling of rockfall materials was carried out along the Nuestra Señora, the San Pablo and La Vizcaína rivers and the mainstream of the Chama River, where sediment production due to slope erosion was predominantly observed through the field investigation.

The sampling sites were selected as shown in Table VI-3 and their locations are given in sequence named R-1 to R-5 from upstream site in Fig. VI-2. Sampled rockfall materials were analyzed by sieving for grain size distribution, and the results are compiled in Table VI-4. Grain size accumulation curves for comparison are also given in Fig. VI-3.

The mean diameter of grain size at R-1 site in the Nuestra Señora River is estimated at 13.1 mm, while those at the San Pablo and La Vizcaína rivers decrease to 9.1 mm at R-3 site and 6.2 mm at R-2 site, respectively. Rockfall materials are mainly composed of sand and gravels, with the sand component occupying more than 60% of the rockfall materials in the San Pablo and La Vizcaína rivers.

1.2.2 Riverbed Sediment

Bed material load is defined as sediment moving on or near the bed, so that the load occupies a major part of the bed sediment that is transported or deposited in the river channel. Materials to be transported in suspension and saltation may also contribute to the sediment deposition in the river and riparian area.

To grasp the characteristics of bed sediment, the bed material in the river and sediment deposit in the alluvial fan were sampled and analysed as follows.

Bed Materials

The sampling sites for riverbed materials were selected along the course of the Chama River and major tributaries. As shown in Table VI-5, the sampling was made at a total of 18 sites located in sequence as B-1 to B-18 from the upstream site in Fig. VI-4.

Sampled materials were analyzed by sieving for grain size distribution and the results are shown in Table VI-6. Typical grain size accumulation curves for the Chama and the Nuestra Señora rivers are given in Figs. VI-5 and VI-6, respectively. The average grain size components at the sampling sites were classified on the basis of sand, gravel and cobble as shown in Table VI-7.

River materials in the upstream channels of the Chama River and major tributaries, e.g. B-1, B-3, B-4 and B-10, are mainly composed of cobbles and gravels. The sand component gradually increases towards the downstream sites. In the downstream channel of the Chama River from El Vigía, all the riverbed materials are composed of sand and silt. The variation of grain size components of riverbed materials in the Chama River is illustrated in Fig. VI-7.

The mean diameter of grain size at the B-1 site is estimated at 116 mm. Those at the middle and downstream decrease to 41 mm at the B-9 site and 9 mm at the B-12 site. In the channel of the Chama River between Estánquez and El Vigía, however, the mean diameter at the B-14 site is larger than that at the upper-located site of B-12. This implies that some sediments are supplied to the Chama River, either from tributaries or of man-induced production due to the construction of the Pan-American Highway.

An armor coat usually covers the riverbed of the Chama River. The grain size of the armor coat materials are generally bigger than those of the riverbed materials. The armor coat is usually composed of cobbles and gravels, because fine sediment is transported to the downstream and the coarse materials remain.

The armor coat materials were sampled at three sites, B-1, B-11 and B-14, and analyzed by sieving for grain size distribution. The analyzed results are shown in Table VI-8. The grain sizes of riverbed materials and armor coat materials were compared at the B-1 and B-14 sites as given in Figs. VI-8 and VI-9, respectively.

The mean diameters of grain size of the armor coat at the B-1 and B-11 sites were estimated at 210 mm and 84 mm, which are about two to four times of those of the riverbed materials at the respective sites.

At the B-14 site in the downstream channel, however, the mean diameters are almost the same.

Sediment in the Alluvial Fan

The area of the alluvial fan in the Chama River downstream of El Vigía was determined from the field investigation and the sampling of alluvial fan materials.

The alluvial fan materials were sampled at the two sites shown in Fig. VI-2. As shown in Fig. VI-10 where the grain size accumulation curves are given, together with the curves of riverbed materials at Los Naranjos, Aroa and El Vigía along the river in the alluvial fan, the sand component increases towards the downstream sites. Near Los Naranjos and Vera de Agua, more than 90% of the riverbed and the alluvial fan materials are composed of sand.

The field investigation was conducted together with the sampling in the downstream area of El Vigía. The following were observed through the investigation.

- Coarse sand and fine gravels of about 10 mm in grain size are readily observed from El Vigía to Los Naranjos.

- The river bank is higher than the riverbed by about 2 to 3 m from El Vigía to Los Naranjos, while it is about 1 m downstream of Los Naranjos.

- Materials are composed of fine sand and silt from Los Naranjos to the rivermouth.

Based on the above, the alluvial fan is assumed to be formed from El Vigía to Los Naranjos which is located at about 20 km downstream of El Vigía.

1.2.3 Suspended Load and Reservoir Deposit

Suspended Load Materials

The sampling of suspended load materials was made in order to measure the concentration of suspended sediment at the Mucurubá Hydrological Station and the Puerto Chama Bridge, where the measurement of suspended load has been periodically conducted by the MARNR. Measurement records are available from 1973 at the Mucurubá Hydrological Station and from 1977 at the Puerto Chama Bridge.

The records at these two stations, together with the data obtained through this sampling survey, are tabulated in Tables VI-9 and VI-10 and plotted as given in Figs. VI-11 and VI-12. Through correlation analysis, the suspended load rating curves which express the relationship between sediment discharge and water discharge were constructed as expressed by the following equation.

$Qs = 0.18Q^{2.62}$ (Puerto Chama Bridge)

$Qs = 2.4Q^{1.16}$ (Mucurubá Hydrological Station)

where, Qs : sediment discharge of suspended load (tons/day)

Q : water discharge (m^3/sec)

By using the above rating curves, the annual sediment discharges were calculated for 9 years from 1967 to 1975 when the daily discharge data are available, as presented in Table VI-11. The annual average sediment discharges were estimated at 21,550,000 tons and 10.5 tons at the Puerto Chama Bridge and the Mucurubá station, respectively.

Reservoir Deposit

The Onia Dam for flood and sediment control purposes was constructed on the Onia River in 1973 and has been in operation under the MARNR. This dam with a catchment area of about 302 km^2 is located near El Vigía in the western side of the Chama River Basin.

Through the field investigation, it was recognized that the design sediment capacity of the reservoir for 50 years has been filled up with sediment in about 10 years, and that the surface level of the deposited sediment is now over the design water level. The annual sediment yield of the reservoir was estimated on the basis of the following conditions of the reservoir.

Deposited Sediment Volume	:	10×10^6 m^3
Period for Deposition	:	10 years
Trap Efficiency	:	100%
Catchment Area	:	302 km^2

Based on the above, the average annual sediment yield was estimated at about 1.0×10^6 m^3 and the average specific annual sediment yield was estimated at about 3,300 m^3/km^2/year.

1.3 Sedimentation in the Basin

1.3.1 Sediment Transport

The characteristics of sedimentation in the Chama River Basin were generally identified through the field reconnaissance and survey for riverbed materials and suspended load materials. The main course of the Chama River is broadly divided into the sediment transportation section, the sediment semi-deposition section and the sediment deposition section as discussed hereinafter.

Sediment Transportation Section

This section is located in the main channel of the Chama River upstream of the confluence with the Mucujún River. The river channel of major tributaries such as the Mucujún, La Mucuy, the Mocoties, the Albarregas, La González and the Nuestra Señora are also categorized in the sediment transportation section. These river sections have steep bed gradients of more than 1:50, and the maximum river widths are around 10 m.

An armor coat usually covers the riverbed in these sections. The riverbed materials are mainly composed of stable coarse materials with large particle sizes such as gravel, cobble and boulder, where large boulders with the diameter of more than 1 m are readily observed.

Sediment Semi-deposition Section

This section is located at the middle reaches of the Chama mainstream between the confluence with the Mucujûn River to the entering point of the alluvial fan at El Vigía.

A considerable amount of sediment produced in the mountainous upstream area is temporarily deposited or stored in this section before being transported to the deposition area in the alluvial fan. Consequently, this section is playing the role of a temporary sediment storage basin.

Sediment is not uniformly deposited in this section. The deposited area is topographically divided by the bottle-neck portion of the river channel, where five new bridges of the arterial road Route No. 7 were constructed. The deposited depth seems to be more than 10 m and in particular, the river stretches between Bridge No. 2 near the town of S. Onofre and Bridge No. 3 near the town of Pte. Viejo are heavily deposited.

The temporary deposited sediment in the river channel become a source of secondary sediment production to be re-eroded. In addition, it was observed that bank erosion has taken place at many places resulting in a new sediment production.

Sediment Deposition Section

This section is located in the lower reaches of the Chama River from El Vigía. Sediment transported from the upstream area as well as the sediment semi-deposition section is deposited over the widely spreading alluvial fan.

The riverbed materials consist of fine gravel and sand. Since the sediment transport capacity is presumed to be poor, the riverbed tends to aggradate when the sediment conveyed from the upper reaches during floods exceeds the transport capacity.

1.3.2 Sediment Deposition

Alluvial Fan

The alluvial fan formed by deposits of predominantly coarse sediment ranging from gravel to sand is located in the lower reaches of the Chama River downstream of El Vigía. The deposited volume in the alluvial fan was estimated using the following two river cross-section data:

- Cross-section survey conducted in 1976 by MOP
- Cross-section survey conducted in 1988 by JICA

River cross-sections were plotted and compared at 22 sites (Fig. VI-13) in about 12 km of the river course between El Vigía and Los Naranjos. As shown in the illustrations, the sediment conveyed from the upper reaches are mainly deposited in the right side of the river section. The typical cross sections are shown in Fig. VI-14.

The riverbed elevations at river sections from S-2 to S-22 were estimated based on the cross-section data. As shown in Table VI-12, the riverbed elevation in the alluvial fan increases by 0.8 m on an average. The longitudinal profiles of the riverbed in 1976 and 1988 are given in Fig. VI-15.

Assuming that the alluvial fan extends from 50 to 90 km^2, the total sediment volume deposited over the fan is estimated at 40 to 72 x 10^6 m^3. Therefore, the annual sediment deposit is estimated at 3.3 to 6 x 10^6 m^3 during 1976 to 1988.

Rivermouth

Most of the suspended load flowing down through El Vigía have accumulated at the estuary of the Chama River in the Maracaibo Lake. In three years, from 1986 to 1989, the sand bar had expanded at 2 km long and 1.5 km wide (refer to Fig. VI-16). Taking account of the larger submerged portion of the sand bar under the lakewater stage, the expanded sand bar has a sediment volume of approx. 38 x 10^6 m^3. The annual sediment volume deposited at the estuary is estimated at 12 x 10^6 m^3.

On the other hand, the volume of suspended load calculated by the sediment rating curve at Puerto Chama Bridge was estimated for the three years from 1985 to 1987. The total suspended load ranges from 29 to 36 x 10^6 m^3. Consequently, the total suspended load including a part of wash load is estimated at 15 to 18 x 10^6 m^3 a year.

2. SEDIMENT STUDY

2.1 General

The Chama River Basin is classified as "active" in terms of sedimentation, i.e., sediment production, transportation and deposition is continuous throughout the year, unlike in "non-active" basins which have only a big sediment discharge when an extraordinary flood occurs. Therefore, sediment discharge has to be calculated on the yearly basis for the formulation of the sediment control plan.

Sediment discharges were estimated for the formulation of the sediment control plan. The study was carried out, firstly, to estimate the sediment production volume and sediment discharge in a river channel by applying the most suitable formula, and secondly, to prepare the sediment balance model of the basin for the computation of design sediment discharge at the reference point, namely El Vigía.

2.2 Production

<u>Production Type</u>

In view of the results of field investigation on topography, geology, soil and meteorology, sediment production in the Chama River Basin is believed to be brought from three causes; namely, (1) slope erosion in denuded areas, (2) slope failure at mountain slopes, and (3) torrent erosion in steep streams.

Denuded slopes are mainly observed in the semi-arid area in the middle reaches of the Chama River and the Nuestra Señora River Basin where rainfall is only around 600 mm per annum. Due to the scarce rainfall, slope erosions appear as gully erosions rather than sheet erosions.

Slope failures are mainly observed in hilly areas formed with weathered rocks of the Tertiary, Mesozoic and Paleozoic layers. Failures are estimated at approximately 2,000 m^2 in area and 20,000 m^3 in volume, except the landslide in the upstream of the Desbarrancadero River, a tributary of La Mucuy River, which is estimated at 2,240 m^2 in area, 15 m in depth and 3,360,000 m^3 in volume.

Torrent erosion is predominantly observed along the Nuestra Señora River, the San Pablo River, La Vizcaína River, and their tributaries. Streams of more than second-order have been the sources of eroded sediment which is deposited in the stream bed. Major streams of more than fourth-order have bank side erosions. Rivers and streams in other basins are rather free from torrent erosion owing to the encroaching vegetation cover and armor coat formed on the riverbed.

Production Volume

In accordance with the above classification of sediment production, production volume was calculated by employing the most suitable equation in consideration of the following conditions:

- Volume of production, discharge and transportation of sediment shall be estimated for daily rainfall and flow discharge in terms of cubic meter per annum (m^3/year).

- Volume at each reference point and at each sub-basin shall both be calculated; topographical and geological conditions of each sub-basin shall be reflected in calculations.

In view of the above considerations, the following formulas were adopted for the calculation of sediment production volume:

(1) Slope Erosion

The following formula developed by S. Kohmura for large river basins has been adopted:

$$E_V = \frac{476\ C_a C_e}{d} q^{15/8} \cdot L^{3/8} \cdot So^{3/2}$$

where, the inflow discharge on a slope, q is expressed as follows:

$$q = 2.778 \times 10^{-7} \cdot f \cdot i$$

E_V : eroded sediment volume ($m^3/s/m^2$)

C_a : areal ratio of denuded land

C_e	:	erodability coefficient
f	:	runoff coefficient
i	:	rainfall intensity (mm/hr)
L	:	slope length (m)
d	:	mean size of sediment particle (mm)
So	:	slope gradient

Furthermore, the erodability coefficient Ce is expressed by the following equation:

$$Ce = 0.17Cm \frac{(1 + 3.67Rd)}{(Cr/Dr)} \; : Cr/Dr > 0.0425$$

$$Ce = 4Cm\ (1 + 3.67Rd) \; : Cr/Dr \leqq 0.0425$$

where,

Cm	:	compaction efficiency of soil
		cultivated area Cm = 1.5
		compacted soil Cm = 1.0
		cut slope soil Cm = 0.5
Cr	=	Clay(%) / [Sand(%) + Silt(%)]
Dr	=	Suspension(%)/[Silt(%) + Clay(%)]
Rd	=	nBr/B : density of gully

where,

B	:	slope width
Br	:	width of gully
n	:	number of gullies in the slope width of B

The parameters and variables which were used in the computation for each sub-basin are given in Table VI-13.

(2) Slope Failure

The following formula was developed by Uchiogi through the continuous observation of slope failures in Japan. The volume of slope failure C_v is expressed as follows:

$$C_v = D \cdot K \cdot A\ (\sum r - r_n)^2$$

where,

C_v : volume of slope failure (m^3)
D : average failure depth (m)
K : coefficient
r_n : failure non-effective rainfall (mm)
A : basin area (m^2)
$\sum r$: cumulative rainfall (mm)

Density, length, width and depth of the existing slope failures were extracted from the aerophoto taken in 1989 and presented in Table VI-14.

The slope failure depth D was determined at 2 m at minimum as well as 10 m for La Mucuy River Basin and 5 m for the devastated tributary basins on the basis of the data obtained from the sampling survey and aerophotos. The coefficient K was derived from the study results conducted in Japan, which was set at 4.0×10^{-6}.

(3) Torrent Erosion

Torrent erosion is caused by tractive force of water flow. Brown's formula as given below has been applied for calculation of the volume of bed load in torrents.

$$q_b / U^*d = 10[U^{*2} / (\sigma/\rho)gd]^2$$

where,

q_b : bed load ($cm^3/s/cm$)
U^* : critical tractive force
d : mean diameter of bed load particle (cm)
σ : unit weight of sediment (g/cm^3)
ρ : unit weight of flowing water (g/cm^3)
g : gravity acceleration (cm/s^2)

Converting the formula for a torrent with a width of B, torrent erosion volume is expressed as below:

$$Q_b = \frac{1.925 \times 10^3}{d} \left[\frac{nQ}{B}\right]^{3/2} \cdot i^{7/4} \cdot B$$

where,

Q_b	:	torrent erosion volume (m^3/s)
B	:	torrent width (m)
i	:	gradient of torrent bed
n	:	Manning's roughness coefficient
Q	:	flow discharge (m^3/s)

In this formula, the torrent width (B) was computed by using the Regime Theory as expressed below:

$$B = \alpha Q^{1/2}$$

where,

B	:	torrent width (m)
Q	:	flow discharge (m^3/s)
α	:	constant (= 2.0)

The other parameters used for the calculation are given in Table VI-15.

By using the data in the said tables as parameters of the equations, annual sediment production were estimated for 21 years from 1967 to 1987 as shown in Table VI-16. The average annual sediment production volume was estimated at 25,560,000 m^3, consisting of 5,240,000 m^3 coarse material load and 20,320,000 m^3 fine material load. The coarse sediment produced by slope erosion, slope failure and torrent were estimated at 2,775,000 m^3, 55,000 m^3 and 2,410,000 m^3, respectively.

2.3 Transport and Balance

Sediment discharge is defined as the quantity of sediment per unit time carried across any cross section of a stream, therefore, it is mostly considered to be similar to water discharge in movement. However, the sediment is very different from water from the following aspects.

- Sediment cannot flow by itself without any external force such as liquid or gas.
- Such an external force must be of a certain strength to move sediment, which is called the critical force that vary according to the size of sediment.
- Due to the above characteristics, sediment show a discontinuous motion; flowing down or staying in a stream or a slope.

In the Chama River Basin, the sediment produced in the upstream area is carried down finally to the Maracaibo Lake. This is the principal movement of all sediment in the basin. However, as discussed in Subsection 2.3, the sediment from sub-basins is sometimes deposited in the middle reaches of the Chama River and transported to the downstream area with floods.

In the alluvial fan or the floodplain, the sediment may spread out and be deposited with a big flood, and the deposited sediment will not reach the lake for a long time. Therefore, it is necessary to conduct a study on sediment transport and balance along the Chama mainstream and major tributaries to understand the sediment movement in the basin.

A model sediment transport and balance was constructed to estimate sediment transport at the major points and balance among the said points. In the model, all the sediment discharge, transport and balance were measured in a unit of m^3/year. The general procedure used in the study is shown in Fig. VI-17.

Sediment Transport Model

The base points for the calculation of sediment volume were selected along the Chama River and major tributaries, taking into account the requirement of the formulation of the sediment control plan. In the selection of base points, the following locations were considered. As done for the flood runoff analysis, 33 sites were selected as presented in Table VI-17.

- Confluence point of major tributaries to the Chama River;
- Downstream point of mainstream section between the confluence points of tributaries; and
- Promising site of sediment control facilities in the Chama River.

The Chama River Basin was divided into 21 sub-basins and 12 channel sections, as shown in Fig. VI-18. The area of sub-basins are given in Table VI-18, and the lengths and widths of the divided channel sections are shown in Table VI-19. From this basin division, the model diagram of sediment transport and balance in the Chama River Basin was constructed as presented in Fig. VI-19.

Sediment Discharge

Sediment rating curves showing the relationship between river discharge and volume of riverbed materials to be transported in the river channel were constructed at the base points on the basis of the grain size distribution given by the riverbed materials survey. As a sediment transport formula to estimate the bed load under the present river condition, the Ashida, Takahashi and Mizuyama's Formula was employed. This formula is widely applied for the estimation of bed load in mountain rivers with steep riverbed slope and wide distribution of riverbed materials, and it is expressed by the following equation:

$$\frac{Qb}{\sqrt{(\sigma/\rho - 1)\ gdm^3}}$$

$$= \frac{12 - 24 \bullet \sqrt{\tan\theta}}{\cos} \bullet \gamma^{2/3} \sqrt{\tan\theta} \bullet (1 - \gamma^2 \frac{Uc^{*2}}{U^{*2}}) \bullet (1 - \gamma^2 \frac{Uc^*}{U^*})$$

where,

Qb	:	sediment discharge per river width ($cm^3/s/cm$)
U*	:	friction velocity (cm/s)
Uc*	:	critical friction velocity (cm/s)
γ*	:	non-dimensional tractive force
θ	:	riverbed gradient
dm	:	mean diameter of bed materials (cm)
σ	:	specific weight of bed materials (= 2.65 g/cm^3)
ρ	:	water densityof water (= 1.0 g/cm^3)
g	:	acceleration of gravity (= 980 cm/s^2)

$$\alpha = \left[\frac{2 \{ \mu f - (\sigma/\rho) / (\sigma/\rho - 1) \bullet \tan\theta \}}{1 - (\sigma/\rho / (\sigma/\rho - 1) \bullet \tan\theta} \right]^{1/2}$$

μf : friction coefficient of sediment (= 0.425)

The transport volumes of riverbed materials at base points were calculated by the above formula under the present river condition. Manning's roughness coefficient and the riverbed gradient are given in Table VI-20.

In this calculation, the grain size distribution of riverbed materials are divided into eight ranges as given in Table VI-21. Sediment discharge is estimated for each range of grain size and the total transport volume of riverbed materials at base points is estimated by summing up the respective volumes of grain sizes.

The obtained rating curves at several base points are presented in Fig. VI-20. In addition, the determined constants of rating curves by base point are shown in Table VI-22.

Critical Discharge

As described in Subsection 2.2.2, an armor coat has been formed over the riverbed of the Chama River and major tributaries. The riverbed materials covered by the armor coat are not transported unless the armor coat is removed and washed out by a big flood.

In general, a force of flowing water known as the tractive force is developed and acts on the riverbed in the flow direction. This tractive force becomes stronger as the river discharge increases; thus, the armor coat is forced to moved when the tractive force becomes higher than the friction force of the armor coat materials. At this condition, the tractive force is known as the critical tractive force.

The discharge that will cause the armor coat materials to move is called the critical discharge. The critical discharges were estimated at the respective base points by the following procedures.

(1) Estimation of Critical Tractive Force

Critical tractive force is expressed by the following equation:

$$\gamma c^* = \frac{Uc^{*2}}{(\sigma/\rho - 1) \cdot g \cdot dm}$$

where,

γ^*c : critical tractive force (non-dimensional)
Uc^* : critical friction velocity (cm/s)
σ : specific weight of bed materials (= 2.65 g/cm^3)
ρ : water density of water (= 1.0 g/cm^3)
g : acceleration of gravity (= 980 cm/s^2)
dm : mean diameter of materials in the armor coat (cm)

For the estimation of critical friction velocity, the Iwagaki's Formula was employed. This empirical formula is expressed as follows:

$0.303\ cm < d$: $U^*c^2 = 80.9\ d$
$0.118\ cm < d < 0.303\ cm$: $U^*c^2 = 134.6\ d^{31/22}$

$0.0565\ cm < d < 0.118\ cm$: $U_{*c}^2 = 55.0\ d$
$0.0065\ cm < d < 0.0565\ cm$: $U_{*c}^2 = 8.41\ d^{11/32}$
$d < 0.0065\ cm$: $U_{*c}^2 = 226\ d$

where, U_{*c} is the critical friction velocity (cm/s)

The relation between the critical tractive force and the particle size of materials is shown in Fig. VI-21.

(2) Calculation of Critical Water Depth

The critical water depth of the river channel is estimated in terms of friction velocity, riverbed slope and acceleration of gravity as given below:

$$U_{c*} = \sqrt{g \cdot hc \cdot I}$$

where,

- U_{c*} : critical friction velocity (cm/s)
- g : acceleration of gravity (= 980 cm/s^2)
- hc : water depth (cm)
- I : riverbed slope

With the above equation, the water depth for the critical discharge is estimated as shown below:

$$hc = \frac{U_{c*}^2}{g \cdot I}$$

(3) Calculation of Hydraulic Values

The Chama River has steep riverbed gradients of more than 1/100 at all the base points. The hydraulic calculation was therefore made by applying the uniform flow condition.

The following Manning's uniform flow formula is applied:

$$V = \frac{1}{n} \cdot R^{2/3} \cdot I^{1/2}$$

where,

V	:	mean velocity (m/s)
n	:	roughness coefficient
R	:	hydraulic radius (m)
I	:	riverbed slope

The empirical Regime Theory representing the relation between the river discharge and flow width is applied at the base points where no river cross section data is available. The said relation is expressed as follows:

$$B = 2\ Q^{1/2}$$

where,

B	:	flow width (m)
Q	:	river discharge (m^3/s)

(4) Estimation of Critical Discharge

By using the two equations introduced in (2) above, the critical discharge is calculated as follows:

$$Qc = A \bullet V$$

$$= \frac{1}{n} \bullet B \bullet hc^{5/3} \bullet I^{1/2}$$

where, A : flow area; $A = B \bullet hc$

In combination with flow depth (hc) introduced by the Regime Theory mentioned above, the critical discharge is finally calculated as presented below:

$$Qc = \left(\frac{5}{n} \bullet I^{1/2} \bullet hc^{5/3} \right)^2$$

where,

Qc : critical discharge (m^3/s)
n : roughness coefficient
I : riverbed slope
hc : water depth (m)

Consequently the estimated critical discharges at the base points are summarized in Table VI-23.

Sediment Balance

Sediment balance calculation was carried out at 33 base points composed of 21 sub-basins and 12 channel sections to examine the movement of sediment under the existing river condition. With the daily discharges, sediment volumes of inflow, outflow and balance in both sub-basins and channel sections were calculated. The procedure for sediment balance calculation for each river channel is explained hereinafter.

(1) Sediment Inflow

For sub-basins, sediment inflow is estimated based on the sediment production yield from the catchment as computed in Subsection 2.2. On the other hand, sediment inflows for channel sections, e.g., the Chama River and the Mocoties River, were calculated by the summation of the following:

- Sediment outflow from the upper river channel
- Sediment outflow from the tributary channel(s), if any.

(2) Sediment Outlow

Sediment outflows from sub-basins and channel sections are dominated by the sediment transport capacities characterized by the hydraulic conditions of the respective river channels such as river cross section, riverbed gradient and roughness coefficient, and grain size distribution of riverbed materials.

Sediment outflow was estimated by using the sediment rating curve and flood discharge distribution to be prepared at each base point.

(3) Sediment Balance

Sediment balance is expressed as follows:

$Sb = Si - So$

where, Sb : sediment balance volume (m^3)
Si : sediment inflow volume (m^3)
So : sediment outflow volume (m^3)

If the sediment balance volume (Sb) is positive, the sediment is deposited in a sub-basin or a river channel, and if negative, erosion occurs.

(4) Condition of Balance Calculation

For the sediment balance calculation, two riverbed conditions, i.e., the fixed bed and the movable bed, are applied. In the case of the fixed bed channel, erosion does not occur. The river channels of No. 1, 2, 3, 9 and 10 and all sub-basins are assumed to be the fixed bed channel. The other river channels, e.g., No. 4, 5, 6, 7, 8, 9, 11 and 12 are considered to be of movable bed condition, where both erosion and deposition will take place.

Results of Calculation

The sediment discharges were estimated with the daily water discharge for the period of 9 years from 1967 to 1975. The average inflow sediment discharge was estimated at 6,260,000 m^3/year, and the average sediment discharge at the reference point is 9,600,000 m^3/year as presented in Table VI-24. Consequently, the sediment balance was estimated at -3,340,000 m^3/year, and that the said volume is produced from the main stream by bed and bank erosions. Compared with the water discharge of 2×10^9 m^3/year on an average, the rate of sediment discharge to water discharge was calculated at approx. 0.5%.

2.4 Design Sediment Discharge

Sediment production and transport vary according to the amount of rainfall and geographical conditions. As described in Subsection 2.3, the total sediment discharge at El Vigía was estimated from approx. 15 to 20 x 10^6 m^3. Fine materials are transported up to the Maracaibo Lake, while coarse materials are deposited in the alluvial fan. The fine materials include all suspended load and a small part of wash load.

For the formulation of the basin-wide sediment control plan, the design sediment discharge was estimated at the reference point of El Vigía. Sediment discharges are defined as follows.

- Project Sediment Discharge is the discharge carried to the reference point by water flow of annual mean regime.

- Allowable Sediment Discharge (Sediment Transport Capacity) is the discharge which may be transported through the existing or proposed river channel downstream of the reference point without giving any damage and adverse effect on the channel and its area.

- Design Sediment Discharge is the remainder of the project sediment discharge after the allowable sediment discharge.

In the sediment discharge, only coarse material load which may be deposited in the river channel shall be counted in the estimation.

Project Sediment Discharge

The project sediment discharge was determined at 9,600,000 m^3/year which is the average sediment discharge for 9 years from 1967 to 1975. To obtain the sediment discharges of inflow, outflow and balance at all base points, an analysis on the transport and balance model was carried out under the following conditions:

- Sediment inflow discharge is estimated at 5,850,000 m^3/year, produced from slope erosion of 3,100,000 m^3/year, torrent erosion of 2,690,000 m^3/year and slope failure of 60,000 m^3/year which are projected to increase by 11.7% in 2020 using the US Soil Conservation's formula expressing an annual gully head advance.

- The daily discharge hydrograph of 1971 is adopted as a model hydrograph to compute sediment transport and balance in the basin.

The result of analysis is schematically presented in Fig. VI-22. Major sediment sources concentrate in the middle reaches of semi-arid area, especially Nuestra Señora, La Vizcaína and San Pablo river basins. Aside from the sediment production in the mountain slopes, another sediment production of 3,750,000 m^3/year also contributes to the sediment discharge at El Vigía.

Allowable Sediment Discharge

On the premise that the river channel downstream of El Vigía will be improved so as to carry the design flood of a 100-year return period, the allowable sediment discharge was evaluated for the proposed river improvement. The allowable sediment discharge is considered to be conveyed to the Maracaibo Lake without aggrading nor degrading the riverbed.

As mentioned in the Supporting Report on Flood Control, the proposed river improvement of the master plan has the following features.

Improvement Length	:	53.4 km
Standard Cross-Section	:	single with a width of 600 m
Dike	:	earth with a slope of 1:2.0

The sediment discharge which will pass the improved river channel is evaluated on the presumption that the sediment of rockfall materials shall mainly be transported through the river. Therefore, the grain size distribution of rockfall materials was applied to calculate the transport discharge.

The same formula of Ashida, Takahashi and Mizuyama was employed for the calculation. A representative cross-section where the sediment transport capacity is considered to be minimum was selected at the end of alluvial fan.

The sediment discharge computed using the model hydrograph of 1971 was 2,120,000 m^3/year at the representative section; hence, this discharge was determined to be the allowable sediment discharge.

Design Sediment Discharge

The design sediment discharge which is a part of the project sediment discharge exceeding the allowable sediment discharge was consequently estimated at 7,480,000 m^3/year. This sediment discharge shall be controlled to avoid aggradation of riverbed downstream of El Vigía.

3. SEDIMENT CONTROL WORKS

3.1 General

As clarified in the Supporting Report on Sediment and Flood Disaster, the sediment disasters in the Chama River Basin are classified into two types with their affected areas. One type takes place in the downstream area and causes flood inundation over the plantain plantation and the populated area. The sediment conveyed from the upstream mountainous area is deposited in the river resulting in riverbed aggradation and the flow capacity becomes insufficient to confine floods in the river channel. The other occurs in the upper and middle reaches, especially along the arterial road routes No. 2 and No. 7. The disaster sites are scattered and their magnitude is rather small compared with the former type. Debris or sediment flow, slope failure and bank erosion are the major disasters inflicting damage on the roads.

3.2 Existing Control Works

Works in Lower Reaches

No specific sediment control works has been carried out in the downstream area, although some projects were proposed not only to control sediment but also to mitigate flood damage. The Mucujepe Diversion Channel has been proposed to divert most of the flood discharge of the Chama River towards the Mucujepe River, but no particular plan of sediment control was involved. The Mocacay Dam Project was once proposed for both sediment and flood control, but it was not realized due to technical and economic difficulties. Aside from these projects, some river training works were executed to provide sufficient flow capacity to the river. However, excavation and dredging were not effective to avoid riverbed aggradation.

Works in Upper/Middle Reaches

Sediment control works in the upstream area which covers almost all of the Chama River Basin can be categorized into two; namely, soil conservation and torrent control.

(1) Soil Conservation

Soil conservation has been initiated by the MAC as one of the important components of a rural development project. This rural development project consisted also of electrification, road construction, housing, potable water supply and irrigation aimed at the betterment of living standards in the rural area.

The MAC prepared a program for soil conservation in 1960 and implemented the works in an area of 450 ha in the upstream of the Chama River Basin around Mucuchíes from 1962 to 1966. The works, costing Bs. 159,500, were mainly composed of water tanks, small ponds and diversion canals to convey stream water to farmlands. Secondary and tertiary channels with either contour trench or stone/concrete walls were also constructed with the cooperation of the rural communities.

Operation and maintenance of the structures were undertaken by the MAC for ten years from 1967 to 1977. Upon the foundation of the MARNR in 1978, the operation and maintenance of the soil conservation works in the area was taken over by the MARNR.

(2) Torrent Control

Torrent control works in the Chama River Basin are mainly composed of check dams, retaining walls and groudsills. In the last five years from 1984 to 1988, the MARNR had invested 21,763,384 bolivares for the works which have been concentrically undertaken for the rivers that may affect urban or populated areas (refer to Table VI-25). The works were then provided mainly to protect specific areas from sediment disaster, rather than a basin-wide sediment control. The standard designs of typical torrent works are presented in Figs. VI-23 and VI-24.

In addition to the works by the MARNR, some sediment control works in the upstream of the Chama River Basin were done by the MTC and the ULA. The MTC constructed the channel works on the Limos River in 1982 to protect the arterial road Route No. 7 from debris flow. The ULA implemented the sediment control works consisting of a series of check dams on La Virgén River as a pilot project.

Other Sediment Control Plans

For sediment control in the future, Zone Office No. 16 of the MARNR had prepared the "Plan de Inversiones desde 1989 hasta 1993, Grupo de Infrastructura, Zona No. 16, MARNR" which spells out the 5-year plan for sediment control covering not only the Chama River Basin but also the Sto. Domingo River Basin. The plan of the works in the Chama River Basin is summarized in Table VI-26, and the types and locations of works are presented in Fig. VI-25.

The total cost of all the works was tentatively projected at 31,691,788 bolivares. More than 30% of the cost will be allocated to the construction of check dams on stream channels. Comparing this investment allocation to that of the past five years (1984-88), it is recognized that land treatment measures such as reforestation, soil conservation and tree nursery have been emphasized more than the structural measures. However, the plan is still aimed at protecting only limited areas but formulated from the viewpoint of basin-wide sediment control.

3.3 Sediment Control Method

As described, sediment problems are classified into two problems. One is the instability and aggradation of the downstream river channel leading to overbank flow to the flood prone area, and the other is debris/sediment flow, slope failure or bank erosion inflicting damage to arterial roads and residential buildings. The aim of the applicable method for the former is to control the sediment discharge and that for the latter is to stop the occurrence of debris/sediment flow, slope failure and bank erosion.

The methods are of different types in accordance with the project area where the structures are to be constructed. In the sedimentation process of production, transport and deposition, the methods of alleviating sediment damage was selected in consideration of not only the required effects such as control of erosion, increase of transport capacity and reduction of sediment discharge, but also the project site conditions such as mountain slope, gullies/streams, and rivers. In accordance with the concept of project formulation mentioned before, the effective sediment control methods are discussed hereinafter.

Basin-Wide Sediment Control

The target area of the project has been defined as the lower reaches, especially in the alluvial fan where the channel aggradation has been accelerated due to the big volume of sediment deposition. To solve the problem, the following methods may be applied.

(1) Sediment Production Area

Since sediment production, erosion and mass wasting are considered to be the main sources of sediment, the applicable methods are as follows:

- Erosion : afforestation, hillside works, groundsill, retaining wall, continuous low dam

- Mass Wasting : drainage works, grouting/piling works, diking works, retaining wall, check/step dam

(2) Sediment Transport Area

To control the sediment flowing into the main channel of the tributary and the main stream of the Chama River, some structures to store and regulate the sediment discharge, as well as prevent bank erosion, shall be applied.

- Tributaries : check dam, groundsill, channel works
- Main Stream : sabo dam, groundsill

(3) Sediment Deposition Area

The deposition area is the lower reaches in the alluvial fan downstream of El Vigía. To avoid channel aggradation, some methods to increase the sediment transport capacity, to store and to divert the sediment discharge are considered to be effective. The applicable methods are:

- Increasing Capacity : diking works, channeling works
- Storing Sediment : debris basins
- Diverting : diversion channel

Local Sediment Control

The target areas are localized and scattered in the river basin. Moreover, the sediment problems are limited to the damage on the arterial road and some residential buildings. The causes are specified to be debris/sediment flow from the torrents, and slope failure and bank erosion along the roads. The applicable methods are as follows:

(1) Debris/Sediment Flows

For the prevention of debris/sediment flows, the effective methods are classified into the following, depending on their functions:

- Occurrence Control : check/step dam, groundsill, hillside works

- Flow Diversion : channeling works

- Flow Trapping : sabo dam, debris basin

(2) Slope Failure

To protect roads and residential buildings, the particular methods to prevent slope failure are classified according to the scale of slope failure, as follows:

- Large Scale : retaining wall, piling/anchoring works, grouting works

- Small Scale : sodding, shotcreting, wire sheeting

(3) Bank Erosion

To avoid bank erosion by flood flow, there are two methods; one is to protect bank from erosion and the other is to dissipate the flow velocity of flood.

- Protection : retaining wall, revetment
- Velocity Dissipation : spurdike, groin

4. SEDIMENT CONTROL PLAN

4.1 Master Plan

4.1.1 Basin-wide Project

Evaluation on Control Methods

To mitigate the sediment disaster in the downstream area by reducing the harmful sediment discharge, several methods may be adopted in the process of sediment movement of production, discharge/transport and deposition. Generally, the methods can be classified into three categories; namely, (1) control in production, (2) regulation in discharge/transportation, and (3) reduction in deposition. The optimum method shall be selected either singly or in combination with each other on the basis of technical soundness and economic feasibility.

Comparison among the following methods in the three categories was made as follows:

(1) Production Control

Production control includes afforestation, hillside works and torrent works. Afforestation shall be done in two steps; first, to change the denuded land to grassland by seeding before the rainy season, and second, to plant young trees of the pulse family. For seeding, 10 kg/ha of seeds are required, while for planting, 10,000 young plants per hectare are needed.

Taking account that Eragrostis (weeping lovegrass) is employed for the first stage of afforestation and that Acacia Tortuose (pulse family) will be planted, the unit cost of afforestation is estimated at about 325,350 Bs/ha. Thus, the investment rate in controlling sediment production by afforestation, since it is effective for slope erosion, torrent erosion and slope failure, is computed at approx. 820 Bs/m^3.

Hillside works shall be the retaining wall of wet masonry and torrent works are of continous low dams. These works are economical because of the abundant boulders and gravels around the project sites.

With respect to the hillside works, when five retaining walls are applied to a gully with an average length of 325 m, the investment rate of this works is computed at approx. 120 Bs/m^3. Moverover, the torrent works which is assumed to be constructed at every 120 m interval will have the investment rate of approx. 117 Bs/m^3. Therefore, the total investment rate of both hillside and torrent works for sediment production control is estimated at 237 Bs/m^3.

(2) Discharge Regulation

Discharge regulation may be in the form of sabo dam and groundsill. A high and large-capacity sabo dam is effective for regulating the sediment discharge and it is further efficient with a sieving function to allow sediment transport without deposition in the river channel. Such regulation effect shall be approximately 10% of the sabo dam's storage capacity.

The efficiency of a sabo dam was evaluated on the assumption that the dam will be constructed only at suitable sites on the Chama main stream and major tributaries. The type of sabo dam will be of rubble concrete and 10 sabo dams with the regulation capacity of a 2,580,000 m^3/year is feasible for construction as described later. The investment rate was estimated at approx. 355 Bs/m^3.

On the other-hand, the sabo dam may have a function of erosion control of the channel where the dam is to be constructed. Therefore, the investment rate including the function of erosion control decreases to about 145 Bs/m^3.

(3) Deposition Reduction

Channeling works is employed to reduce sediment deposition in the downstream area. This works is usually made with a concrete lining to increase the sediment transport capacity of rivers and a continuous groundsill to stabilize the riverbed. The downstream section of the Chama main stream from El Vigía to the river mouth shall have a concrete-lined 100 m wide channel and continuous groundsills with intervals of approx. 50 m, which may be able to transport all the sediment discharge from the upstream area.

The unit cost of the said channeling works was calculated at approx. 120,000 Bs/m, and thus the total cost of the works was estimated at about 6.41 x 10^9 bolivares. Therefore, the investment rate of the channeling works was estimated at approx. 668 Bs/m^3.

The required rates of investment for the respective methods were estimated as shown in the following table. Some other methods are to be applied in combination with these methods depending on the extent of controllable sediment discharge.

	Control Method	Feature of Method	Investment Rate
1.	Afforestation /1	Seeding of Eragrostis: 10 kg/ha	820 Bs/m^3
		Planting of Acacia: 10,000 trees/ha	
2.	Hillside/Torrent /1 Works	Retaining Wall of Dry Masonry: 5 site/gully	237 Bs/m^3
		Continuous Low Dam: 1 site/120 m	
3.	Sabo Dam /2	Cobblestone Concrete	145 Bs/m^3
4.	Channeling Works /3	Concrete Lining: 100 m wide single section	669 Bs/m^3
		Groundsill: 50 m interval	

Note: /1 : Afforestation or hillside/torrent works may control only the sediment production, so that sabo dams or groundsills are additionally required to control channel erosion.

/2 : With 10 sabo dams, only 2,580,000 m^3/year out of the surplus sediment inflow of a 3,730,000 m^3/year and 3,750,000 m^3/year of channel erosion will be controlled, so that some additional methods to control the remaining volume of 1,150,000 m^3/year shall be employed.

/3 : With the channeling works, the whole project sediment discharge of a 9,600,000 m^3/year will be conveyed to the Maracaibo Lake.

The cost of afforestation was estimated to be the highest when applied to the entire denuded land in the Chama River Basin; besides, approximately 2.4 million man-days will be required to execute planting. Since channeling works with concrete lining and groundsill will also require an additional cost of 3.8×10^9 bolivares to the proposed river improvement plan, both afforestation and channeling works are not employed in the sediment control plan. The method which is feasible and sound for the Chama River sediment control plan is composed of sabo dams for sediment discharge regulation and hillside/torrent works for sediment production control.

Selection of Optimum Method

Out of the harmful sediment discharge of 7,480,000 m^3/year, channel erosion of 3,750,000 m^3/year will be primarily controlled by erosion control works, e.g., sabo dam or groundsill. The remaining 3,730,000 m^3/year will be treated by either sabo dam or hillside/torrent works, or a combination of both methods. To meet there requirements, the sediment control plan mentioned before consisting of a combination of sediment discharge regulation and production control by means of sabo dams and hillside/torrent works has three alternatives, as follows:

Alternative A : Groundsill + Hillside/Torrent Control Works
Alternative B : Sabo Dam
Alternative C : Sabo Dam + Hillside/Torrent Control Works

Erosion control works shall be constructed on the eroded portions of two river stretches; namely, from El Vigía to the confluence with the Mocotíes River and from Estánquez to the confluence with the Nuestra Señora River. A comparative study on the unit costs of a sabo dam and a groundsill to control erosion on a river stretch of 2,000 m long shows that the sabo dam is cheaper than the groundsill by 79% as shown in the following table. Moreover, the sabo dam has the additional function of regulating sediment discharge.

Particulars	Sabo Dam		Groundsill
Height	10 m		2 m
Number	1 site		5 sites
Length	200 m	(1)	200 m
		(2)	300 m
		(3)	400 m
		(4)	400 m
		(5)	400 m
Concrete Volume	24,500 m^3		42,000 m^3
Construction Cost	Bs 56,350,000		Bs 100,800,000

In view of the above considerations, Alternative A is dropped from the plan. As for Alternative B, the effective sites for sabo dam construction are limited by the topographic condition and the suitable sites are limited in the Chama mainstream and major tributaries which have a wide river width, making it impossible to construct a sabo dam in all the sediment-discharging rivers.

To fulfill both functions of discharge regulation and erosion control, the most effective sites for sabo dams have been selected. Correspondingly, Alternative C is selected as the optimum sediment control plan. A total of ten sabo dam sites were selected, and the heights and lengths were correspondingly determined as presented in Table VI-27 and their locations are indicated in Fig. VI-26.

With ten sabo dams, the annual sediment discharge of 2,580,000 m^3 will be regulated and sieved for safe transportation through the downstream channel. The remaining 1,150,000 m^3 will be controlled by hillside works and torrent works. A schematic diagram of the sediment control plan and the sediment discharge to be treated by the preventive works are presented in Fig. VI-27.

Considering the ratio of sediment production volume between torrent erosion and slope erosion that was estimated at 8:9, the design sediment volumes for torrent and hillside works were evaluated at 530,000 m^3/year and 620,000 m^3/year, respectively. All torrent and hillside works are to be employed for the area where sediment production is dominant; namely, sub-basins 8, 9, 12, 13, 14, 15 and 16 as presented in Table VI-28.

(1) Sabo Dam

The dam sites and their affected areas are presented in Fig. VI-28. Additional field survey, topographic survey and geological reconnaissance were carried out to determine the most suitable dam sites. Structural dimensions of the sabo dams were determined and their functional efficiencies were expressed by the ratio of sediment capacity to dam volume, as presented in Table VI-27.

(2) Torrent Works

For torrents, continuous low dams will be employed for the denuded area on a length of 12,600 m. A total of 110 sites are required because the effective distance of a 4-m high low dam was calculated at only 90 to 120 m.

Among the sub-basins, the San Pablo River Basin brings the largest sediment discharge of 1,456,000 m^3/year and the Nuestra Señora River Basin does the second of 1,328,000 m^3/year. Sub-basin 15 (La Joya and others), Sub-basin 12 (Arbolote and others), Sub-basin 14 (Maruchi, El Molino, El Anís and others), and Sub-basin 13 (La Vizcaín) follow the first two sub-basins (refer to Table VI-29).

The required number of low dam sites was estimated in proportion to the sediment production volumes of sub-basins. Among the major sub-basins of sediment production, Sub-basin 16 (San Pablo) should have the largest number of low dams at 30 sites, as shown in the following table. The locations of all dam sites are indicated in Fig. VI-29.

Sub-basin Number	Name of Tributaries	Number of Low Dam Sites
8	Upper Nuestra Señora	18
9	Lower Nuestra Señora	9
12	Arbolote, etc.	15
13	La Vizcaína	6
14	Maruchi, El Molino, El Anís	14
15	La Joya, etc.	18
16	San Pablo	30
Total		110

(3) Hillside Works

Hillside works are employed only for the sediment productive sub-basins with a total area of 1,345.8 km^2, specifically, for gullies in the denuded area of 147.0 km^2. A retaining wall of wet masonry is adopted for the works in consideration of the availability of materials around the job sites, construction efficiency and cost. Provided that five retaining walls are constructed for a gully of 5 m wide and 325 m long on an average, 1,400 sites of retaining walls will be required for 280 gullies to control the sediment volume of 620,000 m^3/year from the slope erosion.

The required number of retaining walls was estimated in proportion to the sediment production volumes of sub-basins as made for the torrent works. The number of retaining walls for each sub-basin is shown in the following table and their locations are indicated in Fig. VI-29.

Sub-basin Number	Name of Tributaries	Number of Low Dam Sites
8	Upper Nuestra Señora	230
9	Lower Nuestra Señora	110
12	Arbolote, etc.	190
13	La Vizcaína	80
14	Maruchi, El Molino, El Anís	180
15	La Joya, etc.	230
16	San Pablo	380
Total		1,400

Selection of Area for Action Plan

The action plan focusses on some components of the master plan which shall be urgently implemented in the first 10-year period. Therefore, the required work volume was generally determined to be one-third of the master plan, and the works were selected from the viewpoint of economic superiority.

On the other hand, the sediment control works in the basin-wide project is to prevent river channel aggradation downstream of El Vigía, so that the lower Chama River will not bring any flood inundation over the lower reaches. Therefore, the work volume of sediment control in the action plan was determined with consideration on how the downstream channel will be improved in the action plan of flood control.

From the above, the required volume of sediment control works shall be determined to minimize the channel aggradation based on the following conditions.

- The channel section to be improved is about 28 km, with one-side embankment that corresponds to 25% of the total embankment length.

- It is assumed that a quarter of the sediment discharge to be deposited on the flood-plain will be confined in the river channel. Therefore, the confined sediment will bring about riverbed aggradation.

In accordance with the above conditions, more than a quarter of the sediment discharge are to be controlled by the sediment control works in the action plan. From this assumption, the required volume of sediment control works in the action plan was determined to be one-third of that of the master plan.

(1) Sabo Dam

With reference to the efficiency of 10 sabo dams as discussed in the foregoing (refer to Table VI-27), the C-1 dam is the most efficient and the C-5 comes second. To assure one-third of the total function of the 10 sabo dams such as sediment regulation and erosion control, the capacity of both the C-1 and the C-5 shall have to cover the required capacity. However, the N-1 shall be included in the action plan since this sabo dam will be effective for not only regulation and control but also retention of sediment from the Nuestra Señora River.

(2) Torrent Works

Among 7 sub-basins, Sub-basin 16 (San Pablo) has the heaviest sediment production and Sub-basin 8 (Upper Nuestra Señora) has the second heaviest, although the latter is more devastated than the former. This is due to rainfall which is heavier in Sub-basin 16.

Since Sabo Dam C-5 will play a role in retaining the sediment discharge from Sub-basin 16, Sub-basin 8 is the priority area for the torrent works in the action plan. Continuous low dams will be constructed at 18 sites along three torrents; namely, Mucusás with 10 sites, Mucusurú with 5 sites, and Mucusós with 3 sites. The locations of the proposed construction sites of continuous low dams are indicated in Fig. VI-30.

(3) Hillside Works

As discussed in torrent works, priority shall be given to Sub-basin 8 (Upper Nuestra Señora), together with Sub-basin 9 (Lower Nuestra Señora). Therefore, retaining walls on 340 sites, i.e., 230 sites in Sub-basin 8 and 110 sites in Sub-basin 9, will be constructed in the action plan. Areas of gullies where the rataining walls are to be constructed are also shown in Fig. VI-30.

4.1.2 Local Project

The object of local project for sediment control is to protect roads and houses from debris/sediment flow, slope failure and bank erosion. The project area has been specified as routes No. 2 and No. 7 of the arterial road. The potential sediment disaster sites have been identified at 170 locations through the field investigation, the 1/25,000 scale map and the aerophotographs.

Sites and Degree of Danger

Among the 171 potential sites indicated in Fig. VI-31 and Table VI-30, the risk was ranked on the basis of the natural conditions such as catchment area, channel length, channel/slope gradient, geology and vegetation cover, while the 27 sites which have been identified as the most dangerous by the field investigation are ranked as the highest. The degree of danger and number of corresponding sites are as shown in the following table.

Danger Degree	Number of Sites	Cumulative Number
1	27	27
2	4	31
3	24	55
4	17	72
5	37	109
6	61	170

Probable Number of Disaster Sites

The number of sediment disaster sites were estimated from the probable daily rainfall to formulate a prevention plan. The highest ranked sites were recognized among the damaged sites for the past five (5) years.

The non-effective daily rainfall to the sediment disaster was evaluated from the past records at 15 mm/day corresponding to the basin average rainfall at El Vigía. The relationship between the basin average rainfall and the maximum point rainfall was established as shown in Fig. VI-32. Therefore, the daily rainfall of 15 mm/day corresponding to the basin average at El Vigía indicates that the maximum daily rainfall at a certain location is 60 mm/day in the basin.

Since the potential disaster sites are scattered all over the whole basin, the number of disaster sites were estimated on the basis of the basin average daily rainfall. Presuming that the number of disaster sites is in proportion to the square of difference between the probable daily rainfall and the non-effective rainfall, the occurrence probability and number of disaster sites including their types were estimated, as shown in the following table.

Return Period	Number of Sediment Disaster Sites			
	Debris/Sediment Flow	Slope Failure	Bank Erosion	Total
100 years	88	6	6	100
50	63	6	6	75
30	48	6	6	60
10	20	4	6	28
5	7	2	6	15
2	0	0	0	0

Prevention Methods

Depending on the types of sediment disaster, the prevention works were selected as follows:

(1) Debris/Sediment flow

All debris/sediment flows have taken place in small rivers running out to the arterial roads. Steep-sloped riverbeds accelerate the flow velocity resulting in the erosion of the riverbank and the bed. The prevention method is to be a check dam which may stabilize the riverbank and the bed, as well as control the sediment discharge.

(2) Slope failure

All the cut slopes along the arterial road Route No. 7 have been well treated with sodding, shotcreting or wire sheeting, but the natural slopes along Route No. 2 have been left without any protection works. Retaining walls are proposed to stabilize the slopes.

(3) Bank erosion

Some portions of the arterial road have been eroded by water flow. Serious ones were observed along the Chama mainstream at its meandering points. Since the eroded portions are located along the boundary of river terraces, the revetment is suitable as protection works.

With regard to the project scale for the master plan of the local project, a 100-year return period flood was adopted in consonance with that of the flood control plan of both the basin-wide and the local projects determined from the social and technical aspects. Therefore, check dams on 88 small streams, retaining walls on 6 unstable slopes and revetment on 6 eroded portions River were proposed for the master plan of the local sediment disaster prevention works.

Selection of Area for Action Plan

The action plan for local disaster prevention is to cover all of the required sediment control works for the master plan. The project scale of the action plan for local sediment control is a 100-year return period. The action plan is composed of check dams on 88 small streams, retaining walls on 6 unstable slopes, and retaining walls on 6 eroded river banks.

4.2 Action Plan

Before proceeding to the preliminary design, all the structures composing the action plan were studied as to basic design conditions and structural features.

4.2.1 Basin-wide Project

As selected in the preceding Section 4.1, the basin-wide sediment control works in the action plan consists of 3 sabo dams, 18 continuous low dams and 340 retaining walls.

Sabo Dam

(1) Dam Type

From the structural viewpoint, the five types of sabo dam that are applicable to the sediment control plan of the basin are the gravity dam, the fill dam, the arch dam, the steel-frame dam and the concrete block dam, where a gabion type is structurally categorized under the steel-frame dam. Their general features, topographic/ geologic conditions and materials were comparatively studied as presented in Table VI-31.

Generally, the fill dam and the arch dam are hardly applicable for the selected dam sites of C-1, C-5 and N-1 dams. The river widths at the dam sites are narrow and the design discharges are quite big, therefore, not enough space is expected for the construction of a spillway. Furthermore, it is technically difficult to divert floods by means of a diversion channel/tunnel, and the topographic and geologic conditions may not allow the construction of arch dam at the sites.

Based on the experiences in Japan, the steel-frame dam and the concrete block dam are only constructed with a height of less than 15 m. Therefore, the selection of optimum dam types for the three dams was made by focussing on the following alternatives. According to material, the gravity dam is further classified into three types; concrete, rubble and masonry.

C-1 and N-1 dams: gravity dam
C-5 dam : gravity, steel-frame or concrete block dam

(2) Selection of Optimum Type

The topographic and geologic conditions at the three dam sites, as shown in Table VI-32, may allow construction of the suitable type of sabo dam with a height of 10 to 20 m. The alluvial deposit of more than 10 m at the dam sites will be retained as the foundation, therefore, the dam type shall be able to prevent piping and sustain a small bearing capacity.

The middle stream of Chama River is located on the active Bocono Fault. The sites of C-1 and N-1 dams are away from the fault, but the C-5 dam site is on the fault. From these circumstances, the C-5 dam shall be of the steel-frame or the concrete block type, instead of the gravity type which is not suitable for the site with an active fault.

The riverbed of the three dam sites are mainly composed of gravel with diameters of 10-20 cm. According to the investigation, the gravel can be used for coarse aggregates and the boulders for rubble stone concrete. The construction costs of the three dams were estimated among the selected alternative types, as follows.

Sabo Dam	Dam Type	Construction Cost (million Bs)
C-1	Concrete	208.9
	Rubble	147.8
	Masonry	169.8
C-5	Steel-frame	54.3
	Concrete Block	98.8
N-1	Concrete	195.7
	Rubble	134.6
	Masonry	157.9

From the above comparison, the optimum types of sabo dam are as follows:

C-1 Dam : rubble (gravity) dam
C-5 Dam : steel-frame
N-1 Dam : rubble (gravity) dam

The features of the three sabo dams are presented in Table VI-33.

Torrent Works

A continuous low dam is proposed as the most effective method of torrent works. Although a continuous low dam is smaller than a sabo dam, its optimum dam type can be selected from among three types; namely, gravity dam, steel-frame dam and concrete block dam. Since the comparative study on the three types shows that the steel-frame dam and the concrete block dam have a construction cost higher than the gravity dam, the gravity dam was selected since no geological condition requiring a sustainable type against weak foundation was identified at the construction sites on the three torrents.

On the other hand, the riverbed materials in the three torrents of the Mucusás, Mucusós and Mucusurú were identified to compose mostly of slate. Since the slate is easy to weather and that it is thin and flat, the riverbed materials at the dam sites are not to be used for concrete aggregate nor gabion. The slate can be used only for aggregate inside of the dam body.

From the above conditions, the masonry dam with boulders/cobbles inside the dam body was selected as the optimum type for the continuous low dam. The number and basic dimensions of all continuous low dams are shown in Table VI-34.

Hillside Works

Since the hillside works is to control gully erosion, only the retaining wall is applicable due to the topographic condition of gullies. In consideration of the available materials at and around the structure sites, the retaining wall will be of wet or dry masonry type. Mountain slopes where gullies have developed have steep gradients, therefore, the wet masonry type is employed to sustain flash flow.

4.2.2 Local Project

As selected in the preceding Section 4.1, the local sediment control works in the action plan consists of 17 check dams, 4 portions of retaining walls and 6 stretches of revetments.

Check Dam

The type of check dam to control the debris/sediment flow from small streams was selected from among the types of gravity dam, i.e., concrete, rubble, masonry and gabion. Since the topographic and geologic conditions are similar among the construction sites and that there is no structural difficulty in distinguishing the dam type, the optimum type was selected from the viewpoint of easier construction and cost. From the comparative study on construction cost as summarized in the following table, the wet masonry is selected as the optimum type.

Dam Type	Unit Construction Cost (Bs/dam)
Concrete	112,000
Rubble	70,000
Wet Masonry	55,000
Gabion	57,000

Retaining Wall

The retaining wall is of a leaning-to-slope type made of concrete. This wall shall be extended longer than the contacting distance between the collapsing slope and the road. The leaning-to-slope type is more economical than the self-supporting type due to the required volume of concrete. The height of the retaining wall is set at 2 m above the road surface. The dimensions of the proposed retaining walls are shown in Table VI-35.

Revetment

As discussed in the Supporting Report on Flood Control, four types of revetment were selected as applicable for the protection of river banks from erosion caused by high velocity flow. They are of concrete, wet masonry, gabion and textile form concrete.

The gabion type of revetment, however, requires some stronger plastering or cover of concrete to protect the gabion itself from boulders and cobbles. In consideration of this additional protection works, the construction costs for the four types of revetment were compared as shown in the following table. As a result, the wet masonry type which shows the lowest cost is employed for the revetment works. The locations and dimensions of the works at 6 sites are shown in Table VI-36.

Revetment Type	Construction Cost (Bs/m)
Concrete	18,298.50
Wet Masonry	8,818.70
Gabion	9,330.20
Textile Form Concrete	11,820.00

5. PRELIMINARY DESIGN

5.1 Basin-wide Project

5.1.1 Sabo Dam

Seismic Condition

The construction sites of the proposed sabo dams are located at the most probable earthquake disaster zone in Venezuela, since the Chama River Valley was formed by the active Bocono Fault. In this connection, seismic force is essential to the dam design. Therefore, a bigger seismic coefficient of K = 0.18 was employed in the design with reference to "Propuesta de Normas para el Diseño Sismorresite de Puentes" (Proposal for Design Standards Against Seismic Force for Bridges), as well as the results of the analysis on seismic data from 1910 to 1970. The seismic coefficient was calculated from the design maximum acceleration as described hereinafter.

(1) Design Maximum Acceleration

The design maximum acceleration was determined at 350 gal on the basis of the two references as follows.

(a) Proposal for Design Standards against Seismic Force for Bridges

The design maximum acceleration for the design of bridges is shown in Fig. VI-33. The values in this figure is of a 65-year structural life and a 517-year return period. As shown, the proposed dam sites are located in the 350 gal zone which is the heaviest value in Venezuela.

(b) Seismic Data (1910-1970)

The seismic data from 1600 to 1970 were provided by the U.L.A. Of these, the data from 1910 to 1970 were employed for the frequency analysis, since the data from 1600 to 1910 are discrete and unreliable. As the results show (refer to Fig. VI-34), the magnitude of 76 was obtained as a 100-year return period value.

On the other hand, the relationship between the maximum acceleration and the magnitude is expressed by the following formula:

$$Ma = 2000\ e^{0.8M}\ R^{-2}$$

where;

Ma : maximum acceleration (gal)

M : magnitude

$R = X^2 + h^2 + \gamma^2$

X : distance from epicenters

h : profundity of epicenters

γ : constant (= 20 km)

e : constant (= 2.71818), base of natural logarithm

In this formula, X=15 and h=30 km were applied for the following reasons:

The distance from the epicenters which were employed for the frequency analysis on the proposed dam sites are more than 15 km as shown in Fig. VI-35. According to the information from the U.L.A., the mean profundity of epicenters along the Bocono Fault is 30 km. Therefore, the maximum acceleration was calculated as follows:

$$Ma = 2000\ e^{0.8x7}\ (15^2 + 30^2 + 20^2)^{-1}$$
$$= 354 \text{ gal} = 350 \text{ gal}$$

(2) Conversion from Maximum Acceleration to Seismic Coefficient

The relationship between the maximum acceleration and the seismic coefficient is presented by the following formula.

$$K = \alpha \bullet Ma/g$$

where;

K : seismic coefficient

Ma: maximum acceleration (= 350 gal)

α : reduction coefficient (0.5 is applied for dam)
g : gravity acceleration (= 980 cm/s^2)

The seismic coefficient was calculated as follows:

$$K = 0.5 \bullet 350 / 950 = 0.179 = 0.18$$

Overflow Section

The overflow section was provided at such position and direction that overflow water may easily concentrate to the center of the downstream to avoid any river bank erosion. The bottom width of the overflow section is the same as the river width to minimize the overflow water depth.

The overflow water depth can be obtained from the equation given below, on the condition that the inverse trapezoid overflow section is assumed.

$$Q = 1/5 \bullet C\,(3B_1 + 2B_2)h^{3/2}$$

where,

Q : design flood discharge (corresponding to a 100-year return period flood)
C : coefficient of overflow (= 1.8)
B_1: bottom width of overflow section (m)
B_2: water surface width on the overflow section (m)
h : overflow depth (m)

The overflow depth was estimated for each sabo dam site as follows:

Dam Site	Q	B_1	B_2	h
C-1	2,300	100	105.4	5.4
C-5	1,950	75	80.9	5.9
N-1	610	100	102.3	2.3

Main Dam

(1) Major Dimensions of Main Dam

For the crest width of the main dam, 3 m is employed from the viewpoint of stability of the dam crest and safety against erosion by sediment. For the downslope, the gradient of 1:0.2 is employed and not to be steeper than the napp of sediment flow from the overflow section so as not to be damaged by sediment. The gradient of the upslope is obtained by Stability Analysis. The dam body is to be embedded more than 2.0 m below the existing riverbed.

(2) Stability Analysis

- Load Condition

Load conditions for stability analysis vary according to the dam height of 15 m, more or less, as shown in the following table.

Dam Height	Seismic	Flood
$H < 15$ m	-	Hydrostatic Pressure
$H \geq 15$ m	Hydrostatic Pressure	Hydrostatic Pressure
	Sediment Pressure	Sediment Pressure
	Uplift	Uplift
	Seismic Load	
	Dynamic Water Pressure	

- Stability Analysis

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

Tensile Stress:

$$d = \frac{Mx - My}{V} \geq B/3$$

Sliding:

$$S \leq f \cdot V/H$$

Bearing Strength of Bedrock:

$$\sigma = V/B \cdot (1 + 6e/B) < \text{bearing strength of bedrock} = 60 \text{ t/m}^2 \text{ (conglomerate)}$$

where,

- d : position along the dam base where the combined force of dam weight and external force act (m)
- f : coefficient of friction (0.6)
- V : vertical force per unit width (t/m)
- H : horizontal force per unit width (t/m)
- Mx : total moment of vertical forces per unit width at zero point (t·m/m)
- My : total moment of horizontal forces per unit width at zero point (t·m/m)
- B : bottom width of dam body (m)
- S : factor of safety (> 1.5)
- σ : vertical stress

(3) Piping

By Justin, the critical velocity of seepage to cause piping at the dam foundation is expressed by the folowing formula:

$$Us = ki/n$$

where,

- Us: critical velocity (cm/s)
- k : coefficient of permeability (cm/s)
- i : hydraulic gradient
- n : porosity

The relationship between grain size of riverbed materials and Justin's critical velocity is given Table VI-37. Likewise, the coefficient of permeability for various riverbed materials and the porosity depending on geologic stratum are given in Tables VI-38 and VI-39, respectively. Assuming that the riverbed materials are mainly composed of sand and gravels, the coefficient of permeability is set at 10^{-1} cm/s and the porosity stands at 15%.

The critical velocity was estimated for each sabo dam site as tabulated in the following table. The results show that no piping is anticipated at any dam site.

Dam Site	i	Critical Velocity (cm/s)	
		Computed	Justin
C-1	0.26	0.18	6.0
C-5	0.21	0.14	6.0
N-1	0.37	0.26	6.0

Subdam and Apron

Since the foundation of the dam is alluvial deposit, it is necessary to provide a subdam and apron at the downstream of the main dam, so that the base of the main dam will not be scoured by the impact of water dropped from the overflow section. From the following formula, apron length (L), sidewall height (hj), subdam height (D) and apron thickness (t) are obtained.

$$L \geq l + X$$

$$hj = h_1 / 2 \{(1 + qF^2)^{1/2} - 1\}$$

$$D = hj - h_2$$

$$t = 0.1 (0.6h_1 + 3h_3 - 1)$$

$$l = V_0 \{2 (h_1 + 0.5h_3) / g \}^{0.5}$$

$$V_0 = q_0 / h_3$$

$$X = 4.5hj$$

$$h_1 = q_1 / V_1$$

$$F = V_1 / \sqrt{gh_1}$$

where,

- l : distance between the dam axis and the point of water-drop (m)
- X : distance of hydraulic jump (m)
- hj: depth of hydraulic jump (m)
- h_1: super-critical flow depth before hydraulic jump (m)
- h_2: depth of overflow section of subdam (m)
- h_3: depth of overflow section of main dam (m)
- F : Froude number before hydraulic jump
- V_0: overflow velocity at main dam (m/s)
- V_1: flow velocity before hydraulic jump (m/s)
- q_0: discharge per unit width at main dam crest ($m^3/s \cdot m$)
- q_1: discharge per unit width before hydraulic jump ($m^3/s \cdot m$)
- D : subdam height (m)
- t : apron thickness (m)

The major dimensions of the subdam and apron were estimated for each sabo dam as shown in the following table. The preliminary design drawings for each dam are shown in Figs. VI-36 to VI-38.

Dam Site	Apron Length L (m)	Sidewall Height H (m)	Subdam Height D (m)	Apron Thickness t (m)
C-1	53	10	4.5	2.5
C-5	46	9	2.7	2.0
N-1	29	5	2.7	2.0

5.1.2 Continuous Low Dam

As in sabo dams, the continuous low dams are composed of main dam, overflow section, apron and subdam. These are designed in the same manner as the sabo dams.

All dam heights are 4 m and their overflow sections have a capacity corresponding to a 100-year return period flood. The body of the main dam is embedded 1 m below the existing riverbed.

Basically, the upper continuous low dam is placed at the end of the sediment trap area of the lower continuous low dam. However, in the Mucusás River, there is a gorge 400 m upstream of the junction with the Nuestra Señora River, therefore, one continuous low dam is placed at the downstream of the gorge and two are placed at the upstream. The layout of continuous low dam for each dam site is shown in Figs. VI-39 to VI-41.

5.1.3 Retaining Wall

A retaining wall of wet masonry is applied for gully erosion control. The major dimensions of the retaining wall are 2 m height, 50 cm of top width, downstream slope of 1:0.3, vertical upstream and 1 m of embedding. The features of the retaining wall are shown in Fig. VI-42.

5.2 Local Project

5.2.1 Check Dam

A rubble concrete check dam consisting of main dam, apron and subdam is basically designed in the same manner as the sabo dams described in Subsection 5.1.1. The typical structure of a check dam is shown in Fig. VI-43.

The height of the check dam is 3 m including the depth of embedment of 1.0 m. The major dimensions are 1.5 m of dam crest width, downstream slope of 1:0.2 and upstream slope of 1:0.3.

5.2.2 Retaining Wall

The leaning-to-slope type of concrete wall, 2 m in height, is proposed for the retaining wall. The design of the retaining wall was based on the Standard Structural Design prepared by the Ministry of Construction of Japan. The typical cross section is shown in Fig. VI-44.

5.2.3 Revetment

For the local project, wet masonry type of revetment is provided at the right bank of the confluence of the Chama River and the Nuestra Señora River and other eroded river banks. The height of 5.0 m was obtained by adding a 1 m freeboard to the design water depth and 1 m embedding. The front slope of 1:0.5, the steepest gradient of a 5 m high wet masonry, was employed taking into consideration surges from the Nuestra Señora River. The typical structure of a revetment is presented in Fig. VI-45. The design of the wet masonry type of revetment was based on the Standard Design prepared by the Ministry of Construction of Japan.

6. NON-STRUCTURAL MEASURES

6.1 Basin-wide Disaster Prevention

Non-structural measures for the basin-wide sediment disaster prevention, i.e., to control the sediment discharge towards the downstream area of El Vigía are only provided by means of the reduction of sediment production in the upstream area. Since it was clearly recognized that the road construction and the agricultural development have accelerated the slope erosion, a control or limit to the said activities will be effective for not aggravating the sediment problem. A useful measure is to have a land use regulation in areas which are expected to cause more sediment production.

As described in the Supporting Report on Socioeconomy, a watershed management study has been conducted on land use regulation at the upper reaches from Mérida City. It is recommended that the legislations shall cover other areas upstream of El Vigía.

6.2 Local Disaster Prevention

The local disaster prevention plan is, as described in the foregoing structural measures, mainly put on the sediment disaster along arterial road Route No. 2 and Route No. 7. Unless the prevention works is completed, the potential disaster sites at 170 locations will always be under the menace of damage by debris/sediment flow, slope failure and bank erosion, which may bring not only damage on the road itself but also loss of human life and injuries as experienced before.

From this situation, some non-structural measures shall be provided, firstly, to avoid dangers on human life which are exposed in the transportation along the road. Through the experience and accomplishment of such non-structural disaster prevention projects in Japan, there are two measures applicable to local disaster prevention along the arterial road. One is a warning system to disseminate information on traffic condition, and the other is to establish rules and regulations on structures of roads and houses.

(1) Warning System

The objective of a warning system is to provide information on impending sediment disasters along the arterial roads and to allow the agencies concerned to prepare the necessary actions such as temporary preventive works and traffic control. The system is to be installed as an integrated network consisting of weather observation system, data transmission system, dissemination system and a warning center.

The weather observation system is mainly composed of rainfall stations equipped with data transmission device. The stations transmit rainfall data of short interval such as hourly and 3-hourly.

The data transmission system includes the linkages between observation stations and the warning center, and between warning devices/stations and the warning center.

The dissemination system consists of devices or stations to disseminate warning/information directly to people and the agencies concerned with the road traffic.

The warning center which is to be located in the Chama River Basin shall collect data, analyze the danger degree and disseminate warning/information to people and the agencies concerned.

As the warning system shall be immediately installed to ensure safe traffic along the arterial road, as the first step, a rather simple and low cost system is proposed as follows (refer to Fig. VI-46):

- Warning Center : To be located in Zone Office No. 16 of MARNR.

- Observation System : 10 rainfall stations equipped with transmission devices.

- Transmission System : Simplex telemetering between the center and rainfall stations; existing telephone line between the center and warning station.

- Dissemination System : Four manned traffic control stations shall be installed under MTC.

(2) Rules and Regulations for Structure

Most of the damageable portions of the arterial road Route No. 2 crossing small rivers are not provided with culverts or bridges which are designed to allow passage of sediment flow. Sometimes, houses are constructed on or around steep and unstable slopes which have always been under the menace of failures and slides with strong rainfall.

Some rules and regulations shall be established for all the structures which will be constructed in the potential sediment disaster area, i.e., a certain structural code for road bridges and culverts to clear sediment damage shall be prepared, and zoning and public announcement regarding potential sediment disaster areas shall be carried out for achieving safe housing development.

Land use regulation shall also be applied to areas which have a high possiblity of sediment disasters. Particularly, houses in such areas will have to be relocated under this regulation.

Table VI-1 RESULTS OF SAMPLING SURVEY FOR TORRENTS

No. Name	River				Geology		Sediment Volume (m2/section)			Grain Size (cm)	
	C.A. (km2)	Slope (Deg.)	Width (m)	Length (m)	Rock	Condition	Ero-ded	Resi-dual	Sum	Max.	Mean
1. Mucujun	57.90	5.7	30	11,900	Gneiss	Debris Deposits	15	300	315	200	30
2. Mucuy	71.90	6.5	40	12,800	Gneiss	Debris-flow Deposits	32	316	348	200	30
3. Desbarran-cadero (Mucuy)	17.60	13.2	50	8,900	Quartz and Sand Schist	Debris-flow Deposits	1,270	500	1,770	300	30
4. N. Senora I	266.20	0.94	17	40,000	Meta-black Shale	Debris Deposits	14	20	34	150	40
5. Mucusuru I (N. Senora)	60.60	3.7	24	14,000	Meta-black Shale	Debris Deposits	8	40	48	100	30
6. Mucusuru II (N. Senora)	91.00	3.7	15	14,200	Meta-black Shale	Debris Deposits	11	19	30	200	40
7. N. Senora II	604.50	2.0	50	49,300	Sand Schist	Debris Deposits	4	56	60	100	30
8. Gonzalez II	90.30	7.0	15	24,500	Sandstone	Terrace Deposits	15	300	315	100	20
9. Gonzalez I	108.50	3.0	5	31,500	Sandstone Shale	Debris Deposits	25	450	475	300	50
10. Tabacal (Mocoties)	2.55	6.0	4	2,250	Sandstone	Debris-flow Deposits	12	8	20	30	10
11. Casiguito (Mocoties)	4.20	10.0	10	3,150	Sandstone	Debris-flow Deposits	10	10	20	50	10

Table VI-2 RESULTS OF SAMPLING SURVEY FOR MASS WASTING

No.	Location of Sampling Pt.	Slope (Deg.)	Depth of Top Soil (m)	Geology	Vegetation	Mass Wasting (m)			Sediment Volume (m3)		
						Type	Depth	Length	Total	Residual	Expanded
1.	Qd. Portuguesa	35	1.0	Granite sand stone	High forest Dense	Slide	38	300	28,500	10,000	25,000
2.	S. Onofre (Chama R.)	35	0.2	Debris deposits	Bare land	Debris flow	50	200	8,400	4,000	20,000
3.	Higuerones (Chama R.)	45	0.2	Debris deposits	Low forest Sparse	Debris flow	12	500	50,000	24,000	26,000
4.	Rio Negro (Chama R.)	50	0.2	Debris deposits	Glass land Sparse	Glide	40	200	400,000	4,000	25,000
5.	Gonzalez (Chama R.)	20	0.2	Debris deposits	Bare land	Debris flow	40	400	48,000	36,000	54,000
6.	Qd. Agua Caliente (Gonzalez R.)	25	1.0	Granite Sand stone	High forest Dense	Slide Glide	90	20	4,500	900	2,500
7.	Pte. Real (Chama R.)	40	0.2	Debris deposits	Glassland Sparse	Glide	40	50	20,000	5,000	5,000
8.	Pte. Viejo (Chama R.)	35	0.2	Debris deposits	Glassland Sparse	Debris flow	40	200	319,500	21,300	290,000
9.	Pte. Chama 3 (Chama R.)	50	0.2	Debris deposits	Glassland Sparse	Glide	5	300	150,000	1,500	10,000
10.	El Guamo (Sucia R.)	15	0.3	Meta-black shale	High forest Dense	Slide	8	300	144,000	100,000	100,000
11.	Qd. Delicious (Sucia R.)	20	0.2	Meta-black shale	High forest Dense	Slide	20	500	750,000	370,000	200,000

Table VI-3 SAMPLING SITES OF ROCKFALL AND ALLUVIAL FAN MATERIALS

Site No.	River Basin	Location
R-1	Nuestra Senora	Mucutan River,800 m upstream of the confluence with the Nuestra Senora River
R-2	La Vizcaina	Near the town of Pueblo Nuevo, 7.2km upstream of the confluence with the Chama River
R-3	San Pablo	6.5 km upstream of the confluence with the Chama River
R-4	Chama	Near the town of Puente Viejo, 3.0 km downstream of the confluence with the La Vizcaina River
R-5	Chama	Near the town of La Gonzalez, 4.5km downstream of the confluence with the Nuestra Senora River
F-1	Chama	Near the town of Vera de Agua
F-2	Chama	Near the town of Vera de Agua

Table VI-4 RESULTS OF SIEVE ANALYSIS FOR ROCKFALL MATERIALS

Site No.	d20 (mm)	d50 (mm)	d60 (mm)	dm (mm)
R-1	0.9	6.4	10.5	13.1
R-2	-	1.6	2.4	6.2
R-3	0.8	3.4	5.0	9.1
R-4	1.3	6.0	8.8	11.5
R-5	-	2.4	4.7	9.0

Remarks: d20 : Effective diameter corresponding to 20% of the grain size accumulation curve.

d50 : Median diameter corresponding to 50% of the grain size accumulation curve.

d60 : Diameter corresponding to 60% of the grain size accumulation curve.

dm : Mean diameter as given below:

$$dm = \sum_{p=0}^{100} d\Delta p \Big/ \sum_{p=0}^{100} \Delta p$$

Table VI-5 SAMPLING SITES OF RIVERBED MATERIALS

Site No.	River Name	Distance from Estuary (km)	Location
B-1	Chama	165	200m upstream of the Mucuruba Hydrological Station
B-2	Chama	150	1.5 km downstream of the confluence with La Mucuy River
B-3	Mucuy	---	1.8 km upstream of the confluence with the Chama River
B-4	Chama	136	150 m downstream of the El Chamita Bridge in Merida, 7.2 km downstream of the confluence with the Mucujun River
B-5	Mucujun	---	9.0 km upstream of the confluence with the Chama River
B-6	Chama	122	200 m upstream of the confluence with the Nuestra Senora River
B-7	Nuestra Senora	---	Near the town of El Morro, just confluence with the Mucusas River
B-8	Nuestra Senora	---	1.0 km upstream of the confluence with the Chama River
B-9	Chama	119	2.2 km downstream of the confluence with Nuestra Senora River
B-10	Gonzalez	---	1.0 km upstream of the confluence the Chama River
B-11	Chama	108	1.0 km downstream of the Puente Real Bridge
B-12	Chama	91	800 m upstream of the Chama No. 5 Bridge near the town of Estanquez
B-13	Mocoties	105	1.2 km upstream of the confluence with Sta. Cruz River
B-14	Chama	70	2.2 km downstream of the Chama Bridge in El Vigia City
B-15	Chama	65	Near the town of Aroa, 5.2 km downstream of the Chama Bridge in El Vigia City
B-16	Chama	48	Near the town of Los Naranjos
B-17	Chama	25	800 m downstream of the Puente Chama Bridge
B-18	Chama	10	Near the town of Sto. Domingo

Table VI-6 RESULTS OF SIEVE ANALYSIS FOR RIVERBED MATERIALS

SITE NO.	d10 (mm)	d50 (mm)	d60 (mm)	dm (mm)	Cu
B-1	4.4	118.0	150.0	116.0	34.0
B-2	0.8	32.0	60.0	73.0	75.0
B-3	1.5	200.0	250.0	168.0	167.0
B-4	0.8	25.0	40.0	46.0	53.0
B-5	2.9	58.0	100.0	107.0	35.0
B-6	0.5	34.0	68.0	67.0	136.0
B-7	0.8	14.0	24.0	32.0	30.0
B-8	1.6	39.0	58.0	50.0	36.0
B-9	0.9	9.0	17.0	41.0	20.0
B-10	1.9	130.0	200.0	125.0	105.0
B-11	0.8	12.0	19.0	22.0	25.0
B-12	0.6	4.0	6.0	9.0	11.0
B-13	0.5	21.0	29.0	28.0	54.0
B-14	0.6	13.0	17.0	19.0	28.0
B-15	---	0.6	0.7	---	---
B-16	---	---	---	---	---
B-17	---	---	---	---	---
B-18	---	---	---	---	---

Remarks: d10 : Effective diameter corresponding to 10% of the grain size accumulation curve.

d50 : Median diameter corresponding to 50% of the grain size accumulation curve.

d60 : Diameter corresponding to 60% of the grain size accumulation curve.

dm : Mean diameter as given below:

$$dm = \sum_{p=0}^{100} d\Delta p \,/\, \sum_{p=0}^{100} \Delta p$$

Cu : Hazen's uniformity coefficient as given below:
Cu = d60/d10

Note: No sieve analysis was performed at sites of B-16 to B-18, because all the grains were passed by the minimum sieve of 0.5 mm in diameter.

Table VI-7 AVERAGE GRAIN SIZE DISTRIBUTION FOR RIVERBED MATERIALS

(Unit: %)

Site No.	Average Grain Size Components		
	Silt and Sand	Gravel	Cobble
B- 1	11	30	59
B- 2	25	39	36
B- 3	16	27	57
B- 4	30	48	22
B- 5	14	42	44
B- 6	37	28	35
B- 7	31	57	12
B- 8	20	55	25
B- 9	40	38	22
B-10	17	23	60
B-11	38	58	4
B-12	54	46	0
B-13	34	59	7
B-14	35	63	2
B-15	90	10	0
B-16	100	0	0
B-17	100	0	0
B-18	100	0	0

Remarks: Silt : Less than 0.1 mm
Sand : 0.1 mm - 5 mm
Graval : 5 mm - 80 mm
Cobble : More than 80 mm

Table VI-8 COMPARISON OF SIEVE ANALYSIS RESULTS BETWEEN ARMOR COAT AND RIVERBED MATERIALS

(Unit: mm)

	B-1 Site		B-11 Site		B-14 Site	
	Armor Coat	Riverbed	Armor Coat	Riverbed	Armor Coat	Riverbed
d10	54	4.4	9	0.8	1.1	0.6
d50	220	118	70	12.0	25	13
d60	250	150	100	19.0	29	17
dm	210	116	84	22.0	25	19

Remarks: d10: Effective diameter corresponding to 10% of the grain size accumulation curve.

d50: Median diameter corresponding to 50% of the grain size accumulation curve.

d60: Diameter corresponding to 60% of the grain size accumulation curve.

dm: Mean diameter as given below;

$$dm = \sum_{p=0}^{100} d\Delta p \Big/ \sum_{p=0}^{100} d\Delta p$$

Table VI-9 RECORD OF SUSPENDED LOAD MEASUREMENT AT MUCURUBA STATION

Measurement Date	Discharge (m3/s)	Concentration by Weight (%)	Measurement Date	Discharge (m3/s)	Concentration by Weight (%)
Nov.22 1973	7.73	0.0050	Feb.14 1980	1.45	0.0004
Oct.27 1976	5.24	0.0020	Apr.25	2.77	0.0020
Nov.23	2.94	0.0020	May 15	5.60	0.0050
Feb.22 1977	1.22	0.0050	Oct. 7	6.68	0.0062
Mar.22	1.17	0.0030	Oct.22	4.53	0.0069
Jan.30 1978	1.36	0.0040	Apr.22 1982	7.06	0.0809
Feb.28	1.24	0.0060	May 14	7.27	0.0011
Mar.15	0.93	0.0016	Jun.29	6.76	0.0022
Apr.17	7.90	0.0050	Jul.20	11.19	0.0030
May 26	4.96	0.0013	Jul.28	11.96	0.0033
Jun.27	13.31	0.0060	Aug.20	7.39	0.0082
Jul.27	9.85	0.0040	Nov.27	3.33	0.0062
Aug.10	9.39	0.0040	Dec.16	1.67	0.0040
Aug.15	13.87	0.0020	Feb.24 1983	1.34	0.0019
Sep.27	8.77	0.0020	Mar.24	1.58	0.0083
Oct.19	4.00	0.0090	May 4	8.18	0.0018
Nov.24	2.47	0.0044	Jun.28	5.42	0.0025
Dec.12	2.64	0.0043	Jul.14	9.96	0.0022
Jan.17 1979	1.58	0.0014	Aug.24	5.45	0.0033
Feb.12	1.48	0.0041	Sep.23	9.11	0.0038
Mar.16	1.42	0.0041	Oct.24	2.00	0.0104
Mar.22	1.15	0.0020	Nov.28	3.08	0.0040
Apr.20	1.67	0.0001	Dec.16	2.64	0.0025
May 23	8.09	0.0042	Jan.31 1984	1.82	0.0036
Aug.29	3.65	0.0039	Feb.14	1.44	0.0022
Sep.26	4.08	0.0063	Mar.29	1.09	0.0026
Oct.25	9.22	0.0040	Apr.26	0.87	0.0070
Oct.31	5.62	0.0030	May 22	1.69	0.0064
Nov.15	5.53	0.0019	Jun.27	7.40	0.0070
Nov.29	3.37	0.0018	Aug.16	5.42	0.0019
Jan.16 1980	1.75	0.0018	Sep.27	9.10	0.0003
Jan.23	1.77	0.0027			

Table VI-10 RECORD OF SUSPENDED LOAD MEASUREMENT AT PUERTO CHAMA BRIDGE

Measurement Date	Discharge (m3/s)	Concentration by Weight (%)	Measurement Date	Discharge (m3/s)	Concentration by Weight (%)
Jan.26 1977	22.15	0.0300	Aug.26 1980	52.98	0.1210
Feb.23	17.46	0.0180	Sep.25	66.09	0.3530
May 26	43.67	0.1050	Oct. 7	159.10	0.3050
Jun.20	37.03	0.0360	Oct.14	82.99	0.3010
Jul.19	37.55	0.0430	Oct.28	46.97	0.0520
Aug.23	53.73	0.3600	Nov.12	63.64	0.1500
Sep.20	96.36	0.1220	Nov.24	76.64	0.2140
Oct.25	44.70	0.0530	Dec. 8	39.50	0.2040
Nov.15	112.80	0.2440	Dec.16	56.51	0.1360
Dec.20	24.52	0.1020	Jan.14 1981	30.36	0.1160
Jan.24 1978	18.86	0.0740	Jan.22	32.17	0.0930
Feb.21	19.59	0.0560	Jan.29	23.27	0.0650
Mar.28	30.62	0.0720	Feb. 9	26.67	0.0220
May 23	55.19	0.2440	Feb.18	22.43	0.0200
Aug.29	87.72	0.2320	Feb.25	48.41	0.1090
Jan.22 1979	25.30	0.0510	Mar.24	20.56	0.0220
Jan.30	24.00	0.0520	Sep.29	56.78	0.1610
Jul.25	81.47	0.2260	Oct.28	82.20	0.1390
Aug.29	54.14	0.1900	Nov.18	66.27	0.0490
Sep.25	56.78	0.0720	Nov.25	65.05	0.0580
Oct.25	156.12	0.3890	Sep.28 1982	83.82	0.0150
Nov.20	121.26	0.4120	Oct. 6	44.92	0.0600
Feb.12 1980	34.98	0.1840	Dec. 8	96.64	0.1100
May 28	89.95	0.5000	Apr.12 1983	46.86	0.0500
Jul.15	53.90	0.1500	May 17	99.10	0.3100
Aug.20	99.12	0.6290	Mar.27 1984	11.48	0.0270

Table VI-11 ANNUAL SUSPENDED LOAD DISCHARGE

Year	Water Discharge (m3/s)		Annual Sediment Discharge (1000 ton/year)	
	Maximum	Mean	Puerto Chama	Mucuruba
1967	452	54.3	9,275	7.9
1968	565	95.8	41,109	16.3
1969	887	93.2	51,329	16.1
1970	763	91.7	41,014	15.2
1971	411	59.6	11,628	8.4
1972	548	50.0	15,026	7.6
1973	303	49.2	8,935	7.6
1974	432	43.4	7,060	6.5
1975	303	58.5	8,624	9.0
Total		595.7	194,000	94.6
Average	518	66.2	21,550	10.5

Table VI-12 COMPARISON OF RIVERBED ELEVATIONS IN THE ALLUVIAL FAN

Section No.	Distance from Chama Bridge (km)	Riverbed Elevation (m)		Difference (m)
		1989	1975	
S-2	1.36	99.56	99.34	0.22
S-3	1.86	95.36	95.35	0.01
S-4	2.36	91.69	91.55	0.14
S-5	2.86	88.99	88.08	0.91
S-6	3.36	86.71	85.76	0.95
S-7	3.86	83.22	82.51	0.71
S-8	4.36	81.01	80.51	0.50
S-9	4.86	77.95	77.04	0.91
S-10	5.36	75.76	74.28	1.48
S-11	5.86	73.07	71.56	1.51
S-12	6.36	69.65	68.47	1.18
S-13	6.86	67.26	66.24	1.02
S-14	7.37	66.71	65.68	1.03
S-15	7.87	61.42	60.66	0.76
S-16	8.31	62.81	61.93	0.88
S-17	8.81	61.31	60.41	0.90
S-18	9.31	60.55	59.88	0.67
S-19	9.81	58.82	58.56	0.26
S-20	10.32	58.82	57.97	0.85
S-21	10.81	57.91	57.17	0.74
S-22	11.31	56.73	56.29	0.44
Average				0.77

Table VI-13 PARAMETERS FOR COMPUTATION OF SLOPE EROSION

No.	Sub-basin Area (km2)	Vegetation Cover Forest (km2)	Vegetation Cover Grass (km2)	Vegetation Cover Denuded (km2)	Gully Density (m/km2)	Gully Ave.Length (m)	Slope Gradient
1	365.0	14.7	350.3	---	3,000	400	0.674
2	134.2	111.6	22.6	---	2,000	150	0.732
3	102.4	28.6	73.8	---	2,000	350	0.874
4	205.7	112.6	93.1	---	1,500	200	0.772
5	192.7	149.8	42.9	---	1,000	150	0.734
6	130.0	109.1	20.9	---	1,500	150	0.736
7	98.0	93.8	0.6	3.6	1,500	250	0.518
8	304.8	265.9	34.8	4.1	7,000	400	0.760
9	338.0	292.5	30.4	15.1	5,000	400	0.790
10	118.6	103.4	8.7	6.5	1,500	250	0.570
11	63.2	58.5	---	4.7	1,000	250	0.362
12	58.8	42.8	---	16.0	2,500	300	0.596
13	136.6	120.1	11.9	4.6	5,000	300	0.716
14	191.5	119.0	---	72.5	2,500	300	0.794
15	45.4	28.5	---	16.9	2,500	350	0.602
16	270.7	252.9	---	17.8	4,000	350	0.766
17	74.7	67.6	---	7.1	1,000	300	0.720
18	241.0	241.0	---	---	---	---	0.880
19	173.5	173.5	---	---	---	---	0.536
20	119.9	119.9	---	---	---	---	0.752
21	152.3	152.3	---	---	---	---	0.308
Total	3,517.0	2,658.1	690.0	168.9			

Table VI-14 PARAMETERS FOR COMPUTATION OF SLOPE FAILURE

Sub-basin Number	Slope Failure Density (Site/km2)	Length (m)	Width (m)	Depth (m)	Non-effective Rainfall (mm)
1	5.0	250	20	1	100
2	1.3	100	30	2	100
3	0.5	200	100	5	30
4	0.3	70	20	1	100
5	0.5	150	80	5	50
6	0.3	150	30	1	100
7	1.5	100	30	2	100
8	---	---	---	---	50
9	---	---	---	---	50
10	0.3	100	70	5	100
11	---	---	---	---	100
12	---	---	---	---	30
13	---	---	---	---	30
14	3.0	200	100	1	30
15	---	---	---	---	30
16	---	---	---	---	100
17	4.0	70	10	2	125
18	4.0	100	10	2	125
19	3.0	70	10	2	125
20	2.0	70	10	2	125
21	0.5	100	20	3	100

Table VI-15 PARAMETERS FOR COMPUTATION OF TORRENT EROSION

Sub-basin No.	Torrent/Stream Density (m/km2) 1st Order	2nd Order	3rd/More	All	Mean Diameter of Bed Load Materials (mm)
1	1,355.5	328.1	351.6	2,035.2	116
2	118.8	156.3	2,068.7	2,343.8	73
3	2,460.9	781.3	1,210.9	4,453.1	168
4	531.3	1,093.8	484.3	2,109.4	107
5	648.4	312.5	218.8	1,179.7	46
6	1,210.9	609.4	500.0	2,320.3	46
7	1,015.6	750.0	1,437.5	3,203.1	67
8	1,377.6	328.1	325.6	2,031.3	32
9	1,320.3	687.5	401.6	2,409.4	50
10	1,175.8	343.8	718.7	2,238.3	125
11	750.0	593.8	500.0	1,843.8	125
12	1,500.0	515.6	312.5	2,328.1	22
13	2,187.5	609.4	531.2	3,328.1	22
14	328.1	179.7	445.3	953.1	22
15	1,343.8	218.8	234.3	1,796.9	22
16	2,148.4	566.4	734.5	3,449.3	22
17	1,234.4	359.4	406.2	2,000.0	22
18	750.0	593.8	265.6	1,609.4	28
19	1,359.4	406.3	453.1	2,218.8	28
20	632.8	109.4	476.6	1,218.8	28
21	640.6	343.8	343.7	1,328.1	19

Note: Torrent gradients were assumed same as slope gradients shown in Table VI-13

Table VI-16 ANNUAL SEDIMENT PRODUCTION

Year	Rainfall (mm)		Sediment Production (1000 m3)		
	Annual Total	Maximum Daily	Annual Total *	Coarse Material	Maximum Daily
1967	1,129.7	17.1	25,282	5,596	772
1968	1,246.6	21.4	40,026	8,611	1,540
1969	1,432.4	31.6	69,372	14,579	2,674
1970	1,165.4	8.7	21,408	4,826	572
1971	1,327.8	22.5	24,650	5,434	1,135
1972	1,172.5	19.4	27,690	6,094	889
1973	1,165.0	19.1	21,037	4,707	650
1974	1,125.6	16.2	11,554	2,642	510
1975	1,287.7	11.1	17,267	3,849	782
1976	1,124.0	24.3	21,768	4,722	1,202
1977	923.6	22.7	17,901	3,932	1,074
1978	1,208.7	16.8	14,379	3,256	491
1979	1,337.7	10.6	34,734	7,782	957
1980	875.4	10.8	11,525	2,599	491
1981	1,436.9	17.7	47,366	10,036	1,339
1982	1,184.4	19.6	19,238	4,248	582
1983	986.4	14.8	19,962	4,403	721
1984	1,082.2	8.0	32,097	2,713	680
1985	1,227.8	10.5	16,442	3,703	656
1986	1,159.1	16.4	14,004	3,178	451
1987	941.8	26.5	28,985	3,174	1,446
Total	24,540.7	---	536,687	110,084	---
Maximum	1,436.9	31.6	69,372	14,579	2,674
Average	1,168.6	17.4	25,557	5,242	934

Note *: Including fine and coarse materials.

Table VI-17 BASE POINTS FOR SEDIMENT BALANCE CALCULATION

Base Point	Location
BP-1	Chama River at the Mucuruba Hydrological Station
BP-2	La Sucia River at the confluence with the Chama River
BP-3	Chama River near the town of Tabay
BP-4	La Mucuy River at the confluence with the Chama River
BP-5	Chama River upstream of the confluence with the Mucujun River
BP-6	Mucujun River at the confluence with the Chama River
BP-7	La Gavidia River at the confluence with the Chama River, near the city of Merida
BP-8	Albarregas River at the confluence with the Chama River
BP-9	Chama River upstream of the confluence with the Albarregas River, near the town of Ejido
BP-10	Nuestra Senora River at the confluence with the Mucusas River, near the town of El Morro
BP-11	Tostos River at the confluence with the Nuestra Senora River
BP-12	Nuestra Senora River at the confluence with the Chama River
BP-13	Montalban River at the confluence with the Chama River
BP-14	Chama River upstsream of the confluence with La Gonzalez River
BP-15	La Gonzalez River at the confluence with the Chama River
BP-16	La Sucia River at the confluence with the Chama River
BP-17	Chama River upstream of the confluence with the La Vizcaina River, near the town of Puente Real
BP-18	El Arbolote River at the confluence with the Chama River
BP-19	La Vizcaina River at the confluence with the Chama River
BP-20	Chama River upstream of the confluence with the San Pablo River, near the town of San Pablo
BP-21	El Molino River at the confluence with the Chama River
BP-22	La Joya River at the confluence with the Chama River
BP-23	San Pablo River at the confluence with the Chama River
BP-24	Chama River upstream of the confluence with the Sto. Domingo River, near the town of Estanquez
BP-25	Sto. Domingo River at the confluence with the Chama River
BP-26	Mocoties River near the town of Tovar
BP-27	Mocoties River upstream of the confluence with the Mejias River, near ;the town of Sta. Cruz
BP-28	Mejias River at the confluence with the Mocoties River
BP-29	El Diamante River at the confluence with the Mocoties River
BP-30	Mocoties River upstream of the confluence with the Chama River
BP-31	Chama River upstream of the confluence with La Sucia River
BP-32	La Sucia River at the confluence with the Chama River
BP-33	Chama River near the city of El Vigia

Table VI-18 CATCHMENT AREA OF DIVIDED SUB-BASIN

Section No.	Sub-basin	Catchment Area (km2)
1	Chama	365.0
2	Local rivers	134.2
3	La Mucuy	102.4
4	Mucujun	205.7
5	Local rivers	192.7
6	Albarregas	130.0
7	Local rivers	98.0
8	Upper N. Senora	304.8
9	Lower N. Senora	338.0
10	La Gonzales	118.6
11	La Sucia	63.2
12	Local rivers	58.8
13	La Vizcaina	136.6
14	Local rivers	191.5
15	Local rivers	45.4
16	San Pablo	270.7
17	Sto. Domingo	74.7
18	Upper Mocoties	241.0
19	Lower Mocoties	173.5
20	Mejias	119.9
21	Mocacay & La Sucia	152.3
TOTAL		3,517.0

Table VI-19 DIMENSIONS OF DIVIDED CHANNEL SECTIONS

Channel No.	Location *1)	Length (km)	Width (m)
1	Chama River Qd. Estiti to La Mucuy River	12.00	38
2	Chama River La Mucuy River to Mucujun River	7.75	78
3	Chama River Mucujun River to Montalban River	13.26	105
4	Nuestra Senora Qd. Mucusuru to Chama River	16.25	66
5	Chama River Montalban River to La Gonzalez River	12.75	93
6	Chama River La Gonzalez River to La Viscaina River	10.50	116
7	Chama River La Viscaina to San Pablo River	10.25	210
8	Chama River San Pablo River to Mocoties River	9.75	138
9	Mocoties River Qd. San Francisco to Qd. Mejias	14.63	18
10	Mocoties River Qd. Mejias to Chama River	13.50	38
11	Chama River Mocoties to La Sucia River	6.88	75
12	Chama River La Sucia River to El Vigia	11.50	210

Note: Location of the channel section is indicated with rivers or streams of which confluences are located at upstream and downstream ends of the section.

Table VI-20 ASSUMED RIVER CONDITIONS BY BASE POINT FOR BED LOAD TRANSPORT ESTIMATION

Base Point	Reference	Assumed Sites of Riverbed Materials	Riverbed Slope
BP- 1	Sub-basin 1	B-1	1/15
BP- 2	Sub-basin 2	B-3	1/10
BP- 3	Channel 1	B-2	1/20
BP- 4	Sub-basin 3	B-3	1/10
BP- 5	Channel 2	B-4	1/25
BP- 6	Sub-basin 4	B-5	1/25
BP- 7	Sub-basin 5	B-3	1/10
BP- 8	Sub-basin 6	B-5	1/30
BP- 9	Channel 3	B-6	1/50
BP-10	Sub-basin 8	B-7	1/30
BP-11	Sub-basin 9	B-7	1/10
BP-12	Channel 4	B-8	1/20
BP-13	Sub-basin 7	B-5	1/20
BP-14	Channel 5	B-9	1/50
BP-15	Sub-basin 10	B-10	1/25
BP-16	Sub-basin 11	B-10	1/25
BP-17	Channel 6	B-11	1/66
BP-18	Sub-basin 12	B-10	1/8
BP-19	Sub-basin 13	B-10	1/5
BP-20	Channel 7	B-11	1/66
BP-21	Sub-basin 14	B-10	1/25
BP-22	Sub-basin 15	B-10	1/5
BP-23	Sub-basin 16	B-10	1/5
BP-24	Channel 8	B-12	1/66
BP-25	Sub-basin 17	B-13	1/44
BP-26	Sub-basin 18	B-13	1/30
BP-27	Channel 9	B-13	1/50
BP-28	Sub-basin 20	B-13	1/150
BP-29	Sub-basin 19	B-13	1/10
BP-30	Channel 10	B-13	1/100
BP-31	Channel 11	B-14	1/80
BP-32	Sub-basin 21	B-13	1/150
BP-33	Channel 12	B-14	1/100

Table VI-21 GRAIN SIZE DISTRIBUTION FOR RIVERBED MATERIALS

(Unit: %)

Sampling Site No.	Grain Size (mm)								
	d>200	200>d>100	100>d>50	50>d>30	30>d>10	10>d>5	5>d>1	1>d	Total
B-1	30	26	9	7	11	6	7	4	100
B-2	13	20	10	7	18	7	11	14	100
B-3	50	5	8	7	10	4	9	7	100
B-4	0	16	18	13	17	6	16	14	100
B-5	26	14	13	11	14	8	11	3	100
B-6	10	18	21	2	10	3	13	23	100
B-7	0	6	20	10	20	13	19	12	100
B-8	0	15	30	10	20	5	14	6	100
B-9	0	21	6	5	16	12	28	12	100
B-10	40	16	10	5	6	6	12	5	100
B-11	0	0	13	17	22	10	24	14	100
B-12	0	0	1	3	24	18	34	20	100
B-13	0	0	22	17	22	6	15	18	100
B-14	0	0	6	11	37	11	20	15	100

Table VI-22 CONSTANTS FOR BED LOAD RATING CURVE BY BASE POINT

Base Point	Constants A	Constants B	Base Point	Constants A	Constants B
BP-1	1,395	1.05	BP-18	2,829	0.96
BP-2	2,113	1.01	BP-19	2,878	0.88
BP-3	1,315	1.01	BP-20	575	1.00
BP-4	2,113	1.01	BP-21	559	1.13
BP-5	1,304	0.99	BP-22	2,878	0.88
BP-6	845	1.06	BP-23	2,878	0.88
BP-7	2,113	1.01	BP-24	746	0.96
BP-8	674	1.07	BP-25	844	1.00
BP-9	497	1.03	BP-26	1,277	0.97
BP-10	1,232	0.98	BP-27	714	1.01
BP-11	2,905	0.90	BP-28	169	1.07
BP-12	1,640	0.99	BP-29	2,961	0.90
BP-13	1,128	1.05	BP-30	501	1.00
BP-14	662	1.01	BP-31	224	1.04
BP-15	559	1.13	BP-32	1,243	1.07
BP-16	559	1.13	BP-33	379	1.01
BP-17	575	1.00			

Note: Qs=A*Q^B

where; Qs : Sediment discharge (m3/day)
Q : Water discharge (m3/s)

Table VI-23 CRITICAL TRACTIVE FORCE AND CRITICAL DISCHARGE AT BASE POINT

Base Point	dm (mm)	U*c (cm/s)	hc (m)	n	I	Qc (m3/s)
BP-1	210	41	0.26	0.04	1/15	11.6
BP-2	200	40	0.17	0.04	1/10	4.2
BP-3	150	35	0.25	0.04	1/20	7.6
BP-4	300	49	0.25	0.04	1/10	15.2
BP-5	130	32	0.27	0.04	1/25	7.9
BP-6	190	39	0.39	0.04	1/25	26.9
BP-7	200	40	0.17	0.04	1/10	4.2
BP-8	190	39	0.47	0.04	1/30	41.8
BP-9	120	31	0.50	0.04	1/50	30.9
BP-10	200	40	0.50	0.04	1/30	51.4
BP-11	200	40	0.17	0.04	1/10	4.2
BP-12	140	34	0.24	0.04	1/20	6.6
BP-13	190	39	0.31	0.04	1/20	15.6
BP-14	110	30	0.45	0.04	1/50	21.7
BP-15	230	43	0.47	0.04	1/25	50.2
BP-16	200	40	0.41	0.04	1/25	31.8
BP-17	90	27	0.59	0.04	1/66	3.9
BP-18	200	40	0.13	0.04	1/8	2.1
BP-19	200	40	0.08	0.04	1/5	0.7
BP-20	84	26	0.69	0.04	1/66	3.9
BP-21	200	40	0.41	0.04	1/25	31.8
BP-22	230	43	0.10	0.04	1/5	1.5
BP-23	230	43	0.10	0.04	1/5	1.5
BP-24	40	18	0.33	0.04	1/66	3.9
BP-25	150	35	0.43	0.04	1/44	26.6
BP-26	120	31	0.30	0.04	1/30	9.3
BP-27	100	28	0.41	0.04	1/50	15.9
BP-28	130	32	0.64	0.04	1/150	58.7
BP-29	130	32	0.11	0.04	1/10	1.0
BP-30	100	28	0.83	0.04	1/100	83.9
BP-31	25	14	0.31	0.04	1/80	2.1
BP-32	120	31	0.15	0.04	1/150	1.8
BP-33	25	14	0.31	0.04	1/100	2.1

Note; dm : Mean diameter of armor coat materials
U*c: Critical tractive force
hc : Critical water depth
n : Manning's roughness coefficient of riverbed
I : Riverbed slope
Qc : Critical discharge

Table VI-24 ANNUAL SEDIMENT DISCHARGE AND BALANCE

(Unit: 1000m3)

Year	Inflow	Outflow	Balance	River Runoff
1967	5,596	7,846	-2,250	1,712,405
1968	8,611	13,938	-5,327	3,021,149
1969	14,579	13,558	1,021	2,939,155
1970	4,826	13,331	-8,505	2,891,851
1971	5,434	8,606	-3,172	1,879,546
1972	6,094	7,237	-1,143	1,576,800
1973	4,707	7,117	-2,410	1,551,571
1974	2,642	6,267	-3,625	1,368,662
1975	3,849	8,462	-4,613	1,844,856
Total	56,338	86,362	-30,024	18,785,995
Average	6,260	9,596	-3,336	2,087,333

Table VI-25 SEDIMENT DISASTER PREVENTION WORKS (1984-1988)

Work Item	Work Volume	Total Cost (Bs)	Location
1. Sediment Control Works -Check Dam -Groundsill	470 ha	5,243,840	Mamon Romero, Granates, Barro, Chorro
2. Retaining Works -Retaining Wall -Embankment	3.95 km	11,779,544	Albarregas, Milla, Resbalosa
3. Channeling Works -Excavation -Embankment	-	4,590,000	Mocoties, Sucia
4. Reforestation and Maintenance	10 ha	150,000	San Juan De Lagunillas
5. Tree Nursery	-	-	-
6. Soil Conservation	-	-	-
Total		21,763,384	

Table VI-26 FIVE YEAR PLAN FOR SEDIMENT DISASTER PREVEVTION WORKS (1989-1993)

WORK VOLUME	Work Volume	TOTAL COST (Bs)	LOCATION
1. Sediment Contorol Works -Check Dam -Groundsil	705 ha	13,356,810	El Diamante, Mejias, Cuba Libre, Tabacal, Gonzalez, Sucia, Penon 1 & 2, San Diego, Fria, Milla, Pedregosa
2. Retaining Works	-	-	-
3. Channel Works -Excavation -Embankment	8.9 km	6,550,000	Puerto Rico, La Vega, Cuba Libre Arenia, Villa Socorro, Totumal, La Playa, Potreritos
4. Reforestation and Maintenance	827 ha	5,320,000	Sn. Isidro, Paiva, Mesa de Las Palmas, El Porton, La Aguarura, San Juan de Lagunillas, Cerro San Benito, Las Colinas, El Llano, La Playa, Merida
5. Tree Nursery	1,261,000 nos	1,930,200	Bailadores, Lagnillas
6. Soil Conservation	607 ha	4,534,778	Sto. Domingo, Mesa, Las Palmas, Bodoque, Las Tapias, La Sucia, San Juan, Lagunillas, El Pueblo, La Munoz
Total		31,691,788	

Table VI-27 FEATURES OF SABO DAM

No.	Dam Name	Height (m)	Length(m) Top	Length(m) Bottom	Dam Volume (m3)	Capacity (10^3m3)	Efficiency (Ca/Dv)
1	C-1	22	170	100	62,500	6,500	104
2	C-2	22	120	60	40,500	3,720	92
3	C-3	11	150	80	17,100	1,620	95
4	C-4	11	200	150	27,000	2,540	94
5	C-5	9	230	70	14,600	1,510	103
6	C-6	11	200	130	25,100	2,430	97
7	C-7	11	200	100	22,000	2,190	100
8	C-8	11	150	80	17,100	1,610	94
9	C-9	11	250	120	27,200	2,090	77
10	N-1	22	180	120	65,000	1,600	25
Total					318,100	25,810	

Note: Efficiency is expressed in the following equation.

Efficiency = Capacity / Dam Volume

Table VI-28 SEDIMENT DISCHARGE BY EACH SUB-BASIN

Sub-Basin Number	Name of Tributaries	Sediment Discharge (m3)	Flow Discharge (m3/s)	
			Mean	Max.
1.	Upper Chama	122,800	7.3	58.3
2.	Mucuruba, El Cardenillo, etc.	11,700	2.7	21.4
3.	La Mucuy	64,300	2.1	16.4
4.	Mucujun	5,900	4.1	32.4
5.	San Jacinto, Mucunutan, etc.	0	3.9	30.8
6.	Albarregas	0	2.6	20.8
7.	La Gavidia, etc.	58,500	2.0	15.7
8.	Upper Nuestra Senora	900,900	3.7	26.8
9.	Lower Nuestra Senora	427,000	3.4	29.7
10.	La Gonzalez	76,100	2.4	18.9
11.	La Sucia	0	1.3	10.1
12.	Arbolote,etc.	743,000	0.7	5.2
13.	La Vizcaina	315,900	1.5	12.0
14.	Maruchi, El Molino, El Anis	702,000	2.1	16.8
15.	La Joya, ets.	895,000	0.5	4.0
16.	San Pablo	1,456,700	6.8	42.7
17.	Sto. Domingo	76,100	1.9	11.8
18.	Upper Mocoties	0	6.1	38.0
19.	Lower Mocoties	0	4.4	27.3
20.	Mejias	0	3.0	18.9
21.	La Sucia, Mocacay	0	3.8	24.0

Table VI-29 SEDIMENT PRODUCTIVE SUB-BASINS

Sub-basin No.	Catchment Area (km2)	Denuded Area (km2)	Torrent Length* (m)	Gully		Remarks (Tributaries)
				Density (m/km2)	Mean Length (m)	
8.	303.8	4.1	1,335	7,000	400	Upper Nuestra Senora
9.	330.0	15.1	5,947	5,000	400	Lower Nuestra Senora
12.	58.8	16.0	5,000	2,500	300	Arbolote, etc.
13.	136.6	4.6	2,444	5,000	300	La Vizcaina
14.	191.5	72.5	32,384	2,500	300	Maruchi, El Molino, etc.
15.	45.4	16.9	3,961	2,500	350	La Joya, etc.
16.	270.7	17.8	13,072	4,000	350	San Pablo
Total	1,336.8	147.0	64,143	---	---	
Average	---	---	---	3,142**	325**	

Note * : Torrent length is calculated only for the denuded area.
** : The figures show the average weighed by the ratios of denuded area in each sub-basin to the total.