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THE REPUBLIC OF VENEZUELA

STUDY
ON
CHAMA RIVER BASIN CONSERVATION PROJECT

VOLUME 2
SUPPORTING REPORT

FEBRUARY 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

THE REPUBLIC OF VENEZUELA

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SUPPORTING REPORT

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I. SOCIOECONOMY

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1. NATIONAL DEVELOPMENT PLANS

For a more vigorous economy, the Venezuelan government has, so far, formulated seven national development plans since 1960. These plans cover a period of four or five years, and the latest one is the Seventh National Development Plan covering the period from 1984 to 1988.

The Seventh National Development Plan of five years considers three major strategies; namely, to accelerate the nation's development and economic expansion, to raise the living standards of all Venezuelans, and to distribute income more equitably. Although these are the same as the traditional strategies, it is recognized through the economic recession experience that the axioms on which the strategies were based are to be changed for a more productive nation.

The axioms are cooperation between the public and private sectors, boosting up of the bolivar's value based on non-oil economy, investment of oil earnings in the development of oil resources, establishment of economic freedom and responsibility, and price stabilization by raising productivity and increasing supply. The annual growth rate of the GDP, unemployment rate and other significant indices during the period were estimated by the Plan, as presented in Table I-1.

2. POPULATION

National censuses have been conducted in 1971 and in 1981, and the national and regional population increase has been estimated until 2000 by the Central Office of Statistics and Information (OCEI in Spanish abbreviation).

As estimated, the national population reaches to some 18.76 million with a density of 20 persons/km^2 in 1988, about 80% of which is concentrated in urban areas. The annual growth rate is 2.8% on an average during 1980-1988.

The upper and middle reaches of the Chama River with an area of 3,517 km^2 extend to the eight districts or 28 municipalities of Mérida State, and account for about 31% of the State's total area of 11,300 km^2. In Mérida State are located four urban areas with a population of more than 22,000 in 1988; namely, Mérida, the capital of the state, El Vigía, Ejido and Tovar. Population concentration in these areas is 68% of the 28 municipalities and 51% of the state's total.

The annual growth rate in the upper and middle reaches is 3.0% during 1981-1988, which is higher than the state's average of 2.6% and the national average of 2.8%. Between the urban and rural areas, the former shows a growth rate of 3.5%, higher than that of the latter (2.0%). Population density is 101 persons/km^2, which is almost twice and five times the state and national averages, respectively. (See Table I-2.)

The lower basin is located in Uribarri Municipality of Colon District, Zulia State. There exists only one rural area in this municipality with a population density of 22 persons/km^2. The annual growth rate is 1.6% during 1981-1988, which is much lower than the national level.

3. REGIONAL ECONOMY

Regional economy of the state of Mérida is much dependent on the tertiary sector by 57% in terms of the gross regional product in 1979, followed by the secondary sector by 31% and the primary sector by 12%. Moreover, the secondary and tertiary sectors are growing rapidly as witnessed by the high interannual growth rates of 10.0% and 5.0% during 1970-1979, respectively. (See Table I-3.)

The major agricultural products of Mérida State and the neighboring states (Zulia and Tachira) are plantain and vegetables which contribute to the national production by 46% and 18%, respectively. After being collected at El Vigía, 74% and 87% of their totals are distributed to other regions such as Caracas and Maracaibo (see Table I-4). The distribution ratio is in Table I-5.

Commodity prices in ten major cities have escalated in these five years at the interannual rate, ranging from 14.3% to 19.3%, and 17.2% on the average. Price escalation rate in Mérida is almost the same as the average, i.e., 17.6% as shown in Table I-6.

4. LAND USE

Mérida State, called "Techo de Venezuela" (Roof of Venezuela), is mostly covered by mountainous areas. Thus, the area with natural vegetation accounts for as much as 75% of the state, while about 24% is used for agriculture and cattle raising as presented in Table I-7.

Land use in the upper and middle reaches shows almost the same pattern as the state, although the ratio of urban and industrial areas is a little higher. The areas of agricultural and pasture lands are about 600 and 440 km^2, respectively; the other area is uncultivated land, as shown in Fig. I-1.

The fertile land in Venezuela, suitable for agriculture and cattle raising, shares only 2% of the national territory, of which 30% is concentrated in the region south of Maracaibo Lake where the lower reaches of the Chama River are located. The area of 1,890 km^2 sandwiched by the Escalante and Mucupeje rivers is fully utilized, mainly by plantain plantations and cattle raising, sharing 14% and 77%, respectively, as shown in Fig. I-2. Their annual productivity was reported at 25,000-30,000 Bs/ha and 6,000-9,000 Bs/ha, respectively.

5. ROAD NETWORK

Three important national roads, Routes 2, 3 and 7, run in the Chama River Basin. Route 7 traverses the upper reaches, connecting the major cities of Mérida and Tovar via Estánquez. In the lower and middle reaches runs Route 2 which joins Route 7 near Estánquez, and links the major cities of El Vigía and El Moralito. Route 3 runs between Tovar and El Vigía via Zea in the west side of Route 2. Route 1, although running out of the basin, starts from El Vigía and leads to Caracas City, the capital of Venezuela.

A new highway is now under construction between Estanquez and El Vigía as a part of the Mérida-Panamerican Highway, and the construction will be completed in 1991. This highway runs along the Chama River, with a tunnel portion of about 20% of its length. After completion, travel time between Estánquez and El Vigía will be shortened by about 70% compared with Route 2.

The daily traffic volume amounts to more than 8,000 between Mérida and El Vigía, and ranges between 3,000 to 4,500 between Tovar and Estanques. Details of the daily traffic volume are shown in Fig. I-3.

6. ORGANIZATION

The Government of Venezuela is made up of the central government formed by the Office of the President and the 16 ministries, and the local government formed by the state and local governments. With regard to river basin conservation, the following agencies are involved in the study, planning, project execution, rescue and disaster control activities. The organization charts of MARNR, Zona 5 and Zona 16 of MARNR, MTC, MAC and local government are presented in Figs. I-4 to I-9. The organization chart for Rescue and Disaster Mitigation by the Defensa Civil is presented in Fig. I-10.

- Study and Planning

  MARNR, MAC, MTC, state governments and others (Corpoandes, CIDIAT, etc.)

- Project Execution

  MARNR, MAC, MTC, state governments

- Rescue and Disaster Mitigation

  Ministry of Interior, state governments

Among the activities of these agencies, the following are specified.

<u>River Management</u>

The Chama River is managed by the two district offices of the MARNR, Zone Office No. 5 and No. 16. These offices manage the portion of the basin in the states of Mérida and Zulia, respectively.

Since there is no specific river structure to be managed for disaster prevention along the river course in Mérida State, Zone Office No. 16 does not perform periodical inspection work on the river channel except monitoring work on water level at Ejido gauging station which is informed to Zone Office No. 5 during flood time.

Zone Office No. 5 makes periodical inspection, every two weeks, of the levee which was constructed in 1975 in a stretch of 12 km on the left bank. River dredging works was once conducted in 1985 in the stretch of 2 km from the river mouth at a cost of 8 million bolívares. Riverbed materials are excavated near El Vigía for use as construction materials under the supervision of this office.

Flood Forecasting and Flood Fighting

The responsibility for flood forecasting and flood fighting is tasked to the Office of Civil Defence of the Ministry of Interior. However, flood forecasting works are rarely performed, and rescue and restoration works are conducted only when a disaster occurs.

Flood fighting works to protect the dike from failure is executed by Zone Office No. 5 when the water level at the Ejido gauging station is over 2 m. The information on water level is relayed from the station to Zone Office No. 5 by telephone.

Land Use Regulation

Although the problem on land use and potential damage on the landslide area, flood prone area and other areas have been studied under several cases by the MARNR, the MINAS, the Ministry of Interior, etc., and several regulations have been prepared, the realization of such regulations has been hardly promoted as discussed hereafter.

7. RELATED LEGISLATIONS

Regulations Related to Land Use

The following land use regulations were enacted in this country:

- Forestal law on soil and water;
- Rules and regulations for forestal law on soil and water;
- Law on environment;
- Law on agrarian reform; and
- Law for the territory ordinance.

The outline of the regulations, together with the related agencies, is summarized in Table I-8.

Land Use Regulation in the Chama River Basin

The MARNR which is the main agency responsible for the regulation of land use has been taking the following actions in the Chama River basin, especially the upper reaches from Mérida City.

- In the National Park covering 50% of the upper basin of the Chama River from Mérida City, the present condition is strictly maintained without further land development.

- For other areas, it is necessary to obtain permission for land development from MARNR and large scale development is not permitted.

- To promote river basin conservation among the inhabitants, education and training with materials and necessary expenses are provided.

- To discourage illegal activities, periodical inspections are taken in cooperation with the military.

In addition to the above, the study to delineate the new national park in the northern part of the basin is being carried out for basin conservation.

Land Use Regulation in Mucujún Basin

In specific river basins regarded as significant in preserving the natural environment, special ordinances are prepared to strictly regulate land use. In the Mucujún River Basin which plays an important role as the municipal water supply source to Mérida City as well as the residential and recreation area, an ordinance was issued in October 1986 with the following contents.

The river basin is classified into four (4) categories depending on the location and vegetation condition:

Zone 1: Flat and lowland area along the river course.
Zone 2: Transition area between Zone 1 and forestal area.
Zone 3: Forestal area.
Zone 4: Highland area above the forestal limit.

Land use for the classified zones are regulated as follows:

- Zone 4 is used only for educational or recreational purposes, strictly preserving present conditions.

- Zone 3 was designated as a preservation area of the present conditions. Any activity for land development is not permitted.

- For Zone 1 and 2, several kinds of activities such as livestock farming, construction of houses, recreation, and so on are allowed under the following conditions:

  (a) Agriculture and Livestock Farming

  The production unit for agriculture and livestock farming must be more than 3 ha and 4 ha, respectively. The allowable number of cattle to be grazed per hectare is two heads and it is possible to increase the number up to eight heads by putting up additional facilities with a developed grazing system.

Grazing of goats is allowable when facilities with developed grazing system are provided.

Livestock farming for pig and chicken is not permitted.

(b) Construction of Houses and Hotels

In case of construction of houses, the area of one unit must be more than 1,000 m^2 with building to area ratio of less than 18%.

One unit area for construction of hotel must be more than 5 ha with 50% of forestal area, 35% of open space and 6% of building.

Table I-1 PRINCIPAL ECONOMIC INDICES OF THE SEVENTH NATIONAL DEVELOPMENT PLAN

Item	1984	1985	1986	1987	1988
1. Annual Growth Rate of GDP (%) *	-1.5	4.3	5.3	4.4	4.0
2. Unemployment Ratio (%)	14.5	12.3	10.8	9.9	9.3
3. Increase Rate of Living Cost (%)	15.0	13.0	12.0	11.0	10.0
4. Operating Reserve (thousand million US$)	3.5	2.5	1.9	2.1	2.7
5. Foreign Exchange Reserve (thousand million US$)	12.2	11.4	12.2	12.4	13.0
6. Public Debts (thousand million US$)	26.0	24.5	24.0	23.2	22.3

Note *: Excluding the sector of Central Government.
Source: VII PLAN DE LA NACION, 1984-1988

Table I-2 DEMOGRAPHIC CHARACTERISTICS OF THE CHAMA-MOCOTIES RIVER BASIN

Coverage	Area (km2)	Population (Thousand) 1981	1984	1988	Annual Growth Rate	Population Density in 1988
1. Venezuela	921,050	15,484.7	16,851.2	18,757.4	2.8%	20
2. Merida State	11,300	498.0	538.6	594.4	2.6%	53
3. Upper & Middle Reaches (Merida State)	4,480 *	366.1	401.5	451.2	3.0%	101
- Alberto Adriani Dist.	561	50.1	57.1	67.5	4.4%	120
- Pinto Salinas Dist.	392	18.8	19.6	20.6	1.3%	53
- Campo Elias Dist.	798	40.3	42.1	44.4	1.4%	56
- Libertador Dist.	1,086 *	176.7	198.0	228.1	3.7%	210
- Miranda Dist.	381 *	18.7	19.9	21.6	2.1%	57
- Rangel Dist.	837	19.8	20.8	22.0	1.5%	26
- Rivas Davila Dist.	137 *	9.0	9.5	10.2	1.8%	74
- Tovar Dist.	288	32.7	34.5	36.8	1.7%	128
4. Lower Reaches (Zulia State)						
- Uribarre Municipality	965	18.6	19.5	20.8	1.6%	22

Note *: Total areas of the municipalities in which the Chama-Mocoties River basin is located.
Source: "Proyecctiones de Poblacion, 1980-2000", OCEI
"Conversion de la Division Politico Territorial de los Estados de la Region de Los Andes", CORPOANDES

Table I-3 GROSS REGIONAL PRODUCT OF MERIDA STATE AND DISTRIBUTION BY SECTOR

(Unit: million Bs. at 1963 constant price)

Sector/Activities	1970	(%)	1973	(%)	1976	(%)	1979	(%)	Annual Growth
1. PRIMARY SECTOR	113.1	18.6%	102.3	16.8%	105.4	14.5%	121.2	12.3%	0.8%
- Agricurture	112.7	18.6%	101.7	16.7%	104.7	14.4%	118.3	12.0%	0.5%
- Mining	0.5	0.1%	0.6	0.1%	0.8	0.1%	2.9	0.3%	21.6%
2. SECONDARY SECTOR	128.1	21.1%	178.2	29.3%	199.8	27.4%	301.4	30.5%	10.0%
- Manufacturing	55.4	9.1%	69.7	11.5%	84.4	11.6%	107.3	10.9%	7.6%
- Construction	64.7	10.7%	104.0	17.1%	84.1	11.5%	147.7	15.0%	9.6%
- Electricity & Water Supply	8.0	1.3%	4.4	0.7%	31.2	4.3%	46.4	4.7%	21.6%
3. TERTIARY	365.9	60.3%	327.9	53.9%	424.2	58.2%	565.3	57.2%	5.0%
- Commerce	78.6	12.9%	76.7	12.6%	82.3	11.3%	122.0	12.3%	5.0%
- Transport & Communication	45.2	7.4%	61.0	10.0%	80.8	11.1%	145.0	14.7%	13.8%
- Services	242.1	39.9%	190.2	31.3%	261.1	35.8%	298.2	30.2%	2.3%
T O T A L	607.1	100.0%	608.4	100.0%	729.4	100.0%	987.9	100.0%	5.6%

Note: Figures may not add up to totals due to rounding.
Source: CORPOANDES,"Estadisticas del Edo.Merida",1984

Table I-4 AGRICULTURAL PRODUCTS AND THEIR DISTRIBUTION IN THE STATES OF MERIDA, ZULIA AND TACHIRA

Agricultural Products	National Production (TM)	* States' Production (TM)	Contribu-tion to the National (%)	Distribu-tion Volume (TM)	Distribu-tion Ratio (%)
Vegetables	114,610	21,200	18.5	15,703	74.1
Tubers	596,230	26,100	4.4	14,571	55.8
Fuits					
- Plantain	448,570	208,100	46.4	180,000	86.5
- Bananas	1,003,980	153,100	15.2	5,856	3.8
- Other Fruits	---	32,000	---	25,000	78.1

Note *: Including the states of Merida, Zulia and Tachira.
Source: CORPOANDES

Table I-5 DISTRIBUTION RATIOS OF AGRICULTURAL PRODUCTS BY THE REGION

(Unit: %)

Region	Plantain	Banana	Other Fruits	Vegetables	Tubers
Maracaibo	20	14	9	3	---
Caracas	29	28	16	2	32
Centro	17	10	20	23	4
Barquisimeto	9	40	9	5	24
Oriente	10	1	---	---	---
Region los Andes	15	7	46	67	40
T o t a l	100	100	100	100	100

Source: CORPOANDES

Table I-6 INTERANNUAL PRICE ESCALATION RATES IN MAJOR CITIES

(Unit: %)

Major Cities	Interannual Price Escalation Rates				
	1983-1984	1984-1985	1985-1986	1986-1987	Average
METRO CARACAS AREA	---	11.4	11.6	28.1	16.8
BARINAS	15.6	14.1	11.3	35.2	19.7
BARQUISIMETO	10.3	10.8	11.0	21.3	14.3
COIDAD GIAUAMA	---	12.1	10.6	36.9	19.3
MARACAIBO	13.9	15.2	11.4	21.1	15.8
MERIDA	12.7	15.4	11.9	25.9	17.6
PUERTO LA CRUZ-BARCELONA	12.4	14.3	11.5	25.0	16.8
SAN CRISTOBAL	12.6	12.7	12.7	27.1	17.3
VALENCIA	12.8	13.2	11.8	26.9	17.1
VALERA	14.8	14.9	12.3	26.5	17.7
AVERAGE	13.1	13.4	11.6	27.4	17.2

Source: ANUARIO ESTADISTICO DE VENEZUELA 1987, OCEI

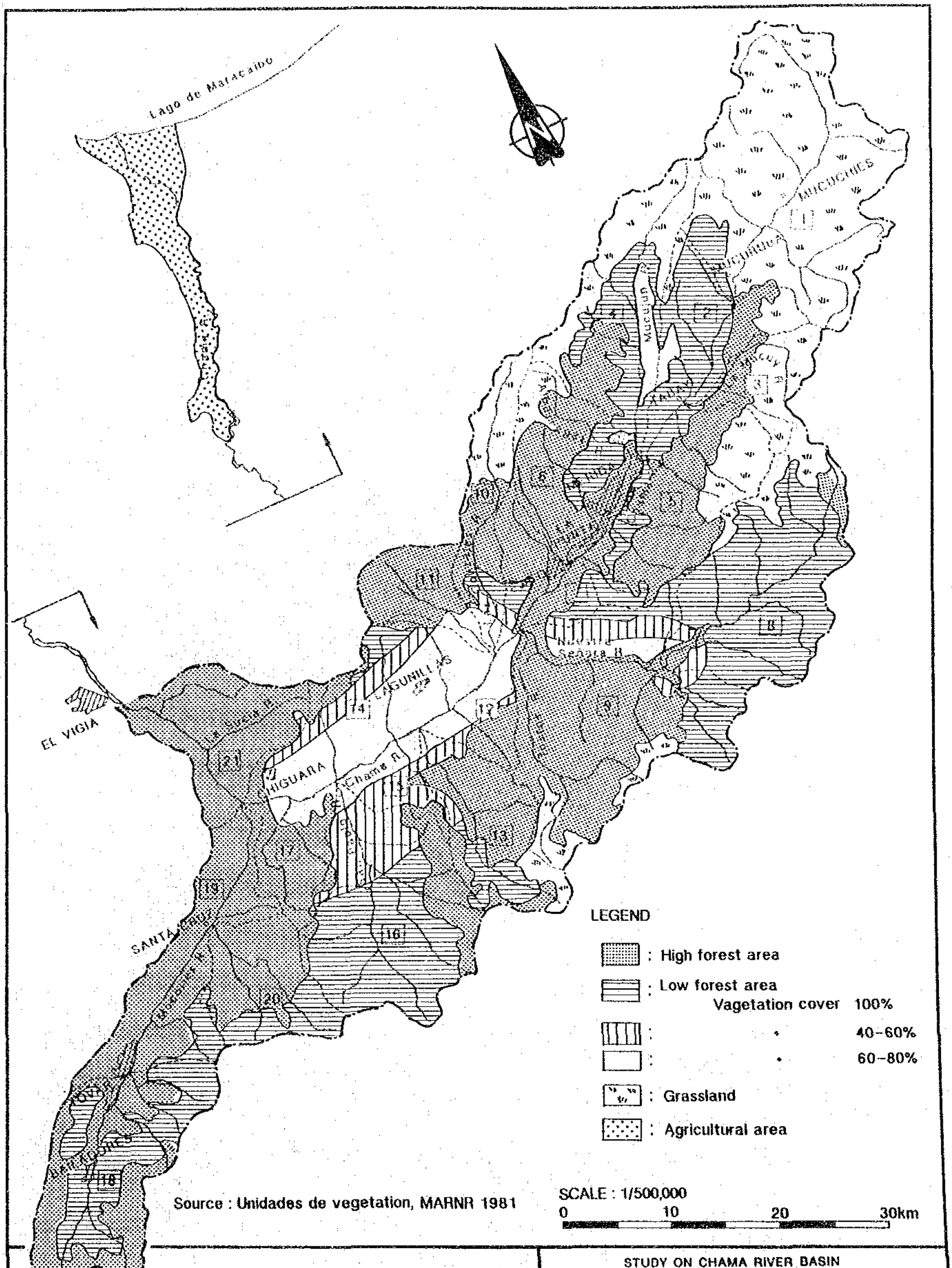
Table I-7 LAND USE IN MERIDA STATE IN 1983

Category	Area* (ha)	Ratio (%)
1. Agriculture & Cattle Raising	264,663	24.4%
- Vegetal Agriculture	47,443	4.4%
- Cultivated & Natural Pasture	145,898	13.4%
- Agriculture & Livestock Raising (for the residents living)	71,322	6.6%
2. Natural Vegetation (including forests & bleak plains)	812,697	74.8%
3. Urban & Industrial	7,859	0.7%
4. Infrastructure	1,033	0.1%
T O T A L	1,086,252	100.0%

Note *: The total area does not include 43,748 ha of rivers, lakes, etc.
Source: Comision de Ordenacion del Territorio "Plan de Ordenacion del Territorio del Estado Merida", 1988.

Table I-8 OUTLINE OF REGULATIONS RELATED TO LAND USE

Name of Law	Year in Effect	Objective	Related Agencies	Remarks
Fundamental Law for Environment	15/06/76	To establish the concept for preservation of favorable environment	Most of all agencies relating to matters on environment	Lay Organica
Forestal Law on Soil and Water	30/12/75	To show the basic concept for the protection of forestal area, delineation of the protection zone and national park and regulation of land use, and to prevent the illegal action against this law	MARNR INPARQUES INOS GARDE NATIONAL	
Rules and Regulations for Forestal Law on Soil and Water	12/04/77 20/01/83 (Modification)	To concretely describe the rules and regulations for realization and execution of the forestal law on soil and water	MARNR INPARQUES INOS GARDE NATIONAL	
Law on Agrarian Reform	19/03/60	To reform the agrarian structure in this country through encouragement of land possession by small holders	MAC IAN MARNR GARDE NATIONAL	
Fundamental Law for Territory	26/07/83	To promote equal development and investment to modify imbalance among districts or states and between urban area and rural area	All the agencies	Ley Organica

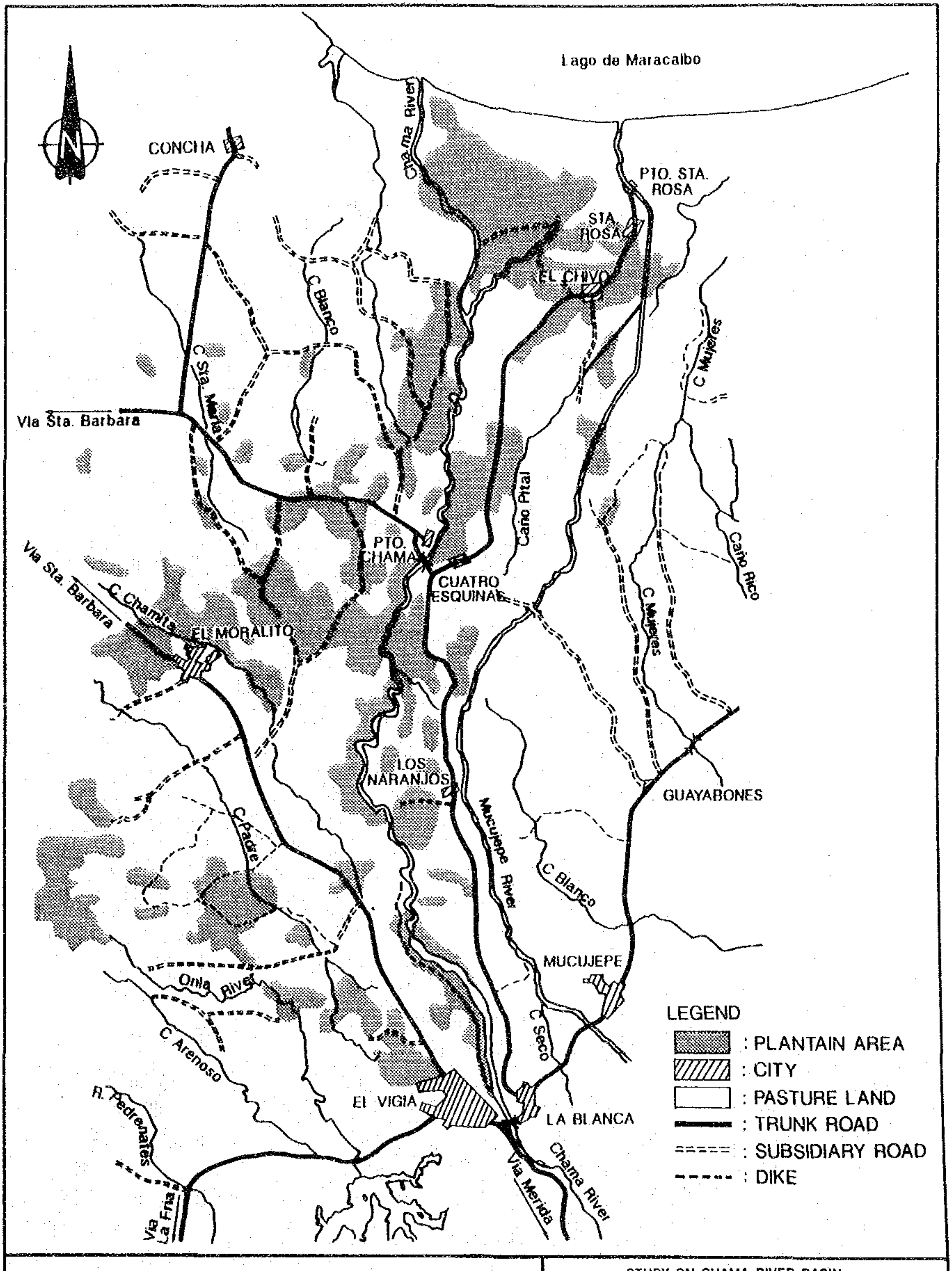


LAND USE MAP IN THE UPPER/MIDDLE REACHES

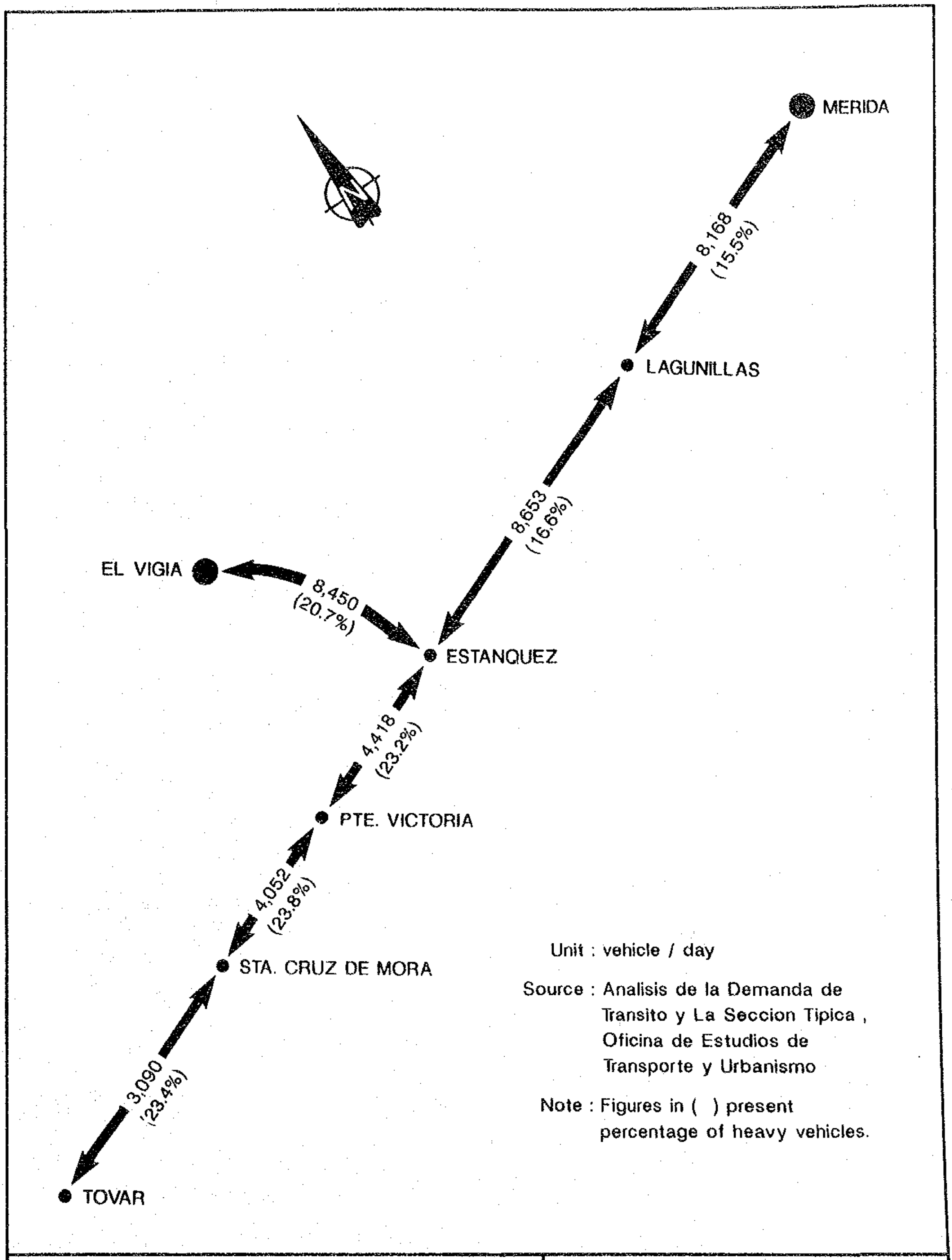
Fig. I-1

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY



LAND USE MAP IN LOWER REACHES	STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT
Fig. I-2	JAPAN INTERNATIONAL COOPERATION AGENCY

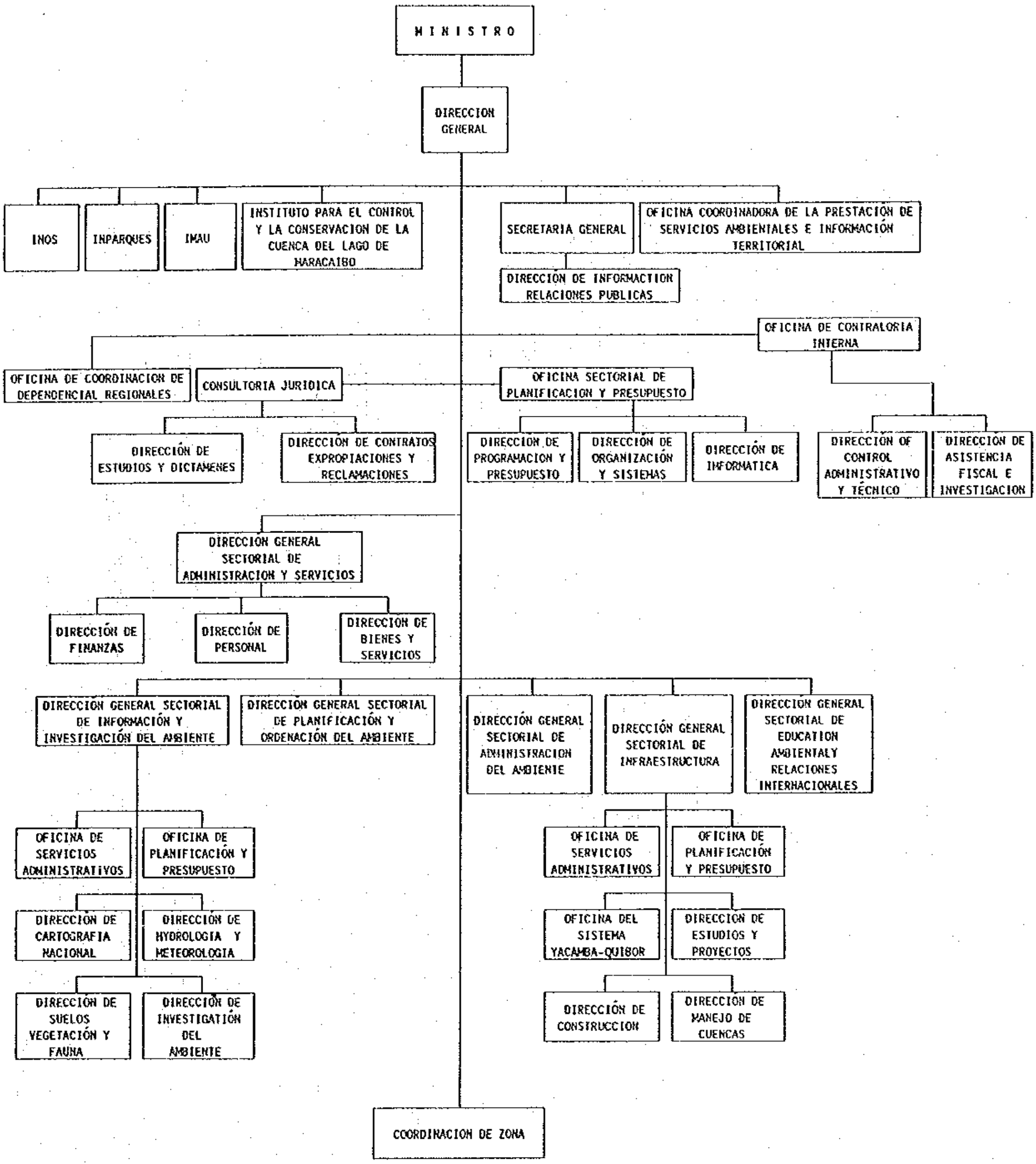


TRAFFIC VOLUME OF ARTERIAL ROAD ROUTE 2 AND 7 IN 1985

Fig. I-3

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

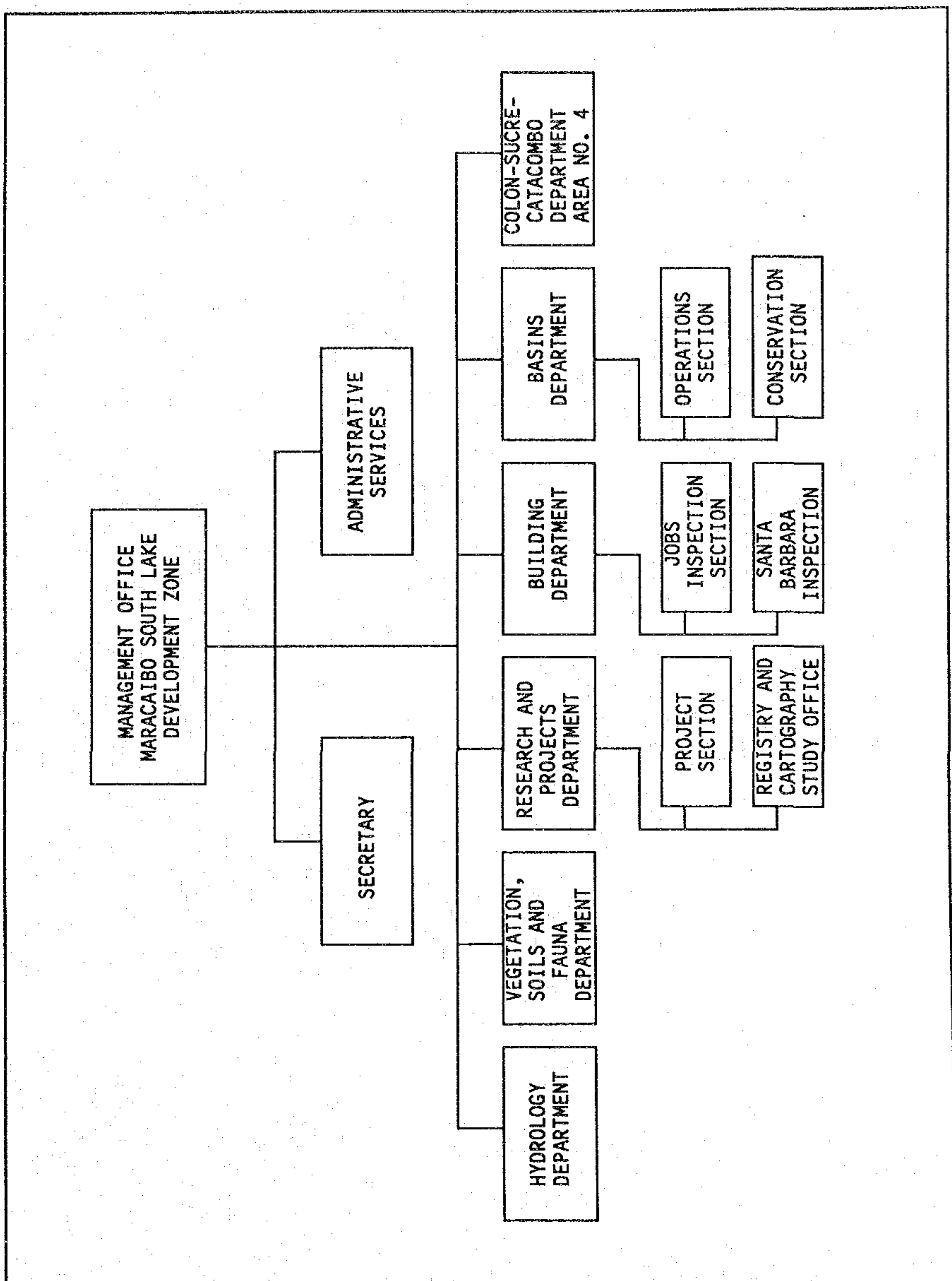


ORGANIZATION CHART OF MARNR

Fig. I-4

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

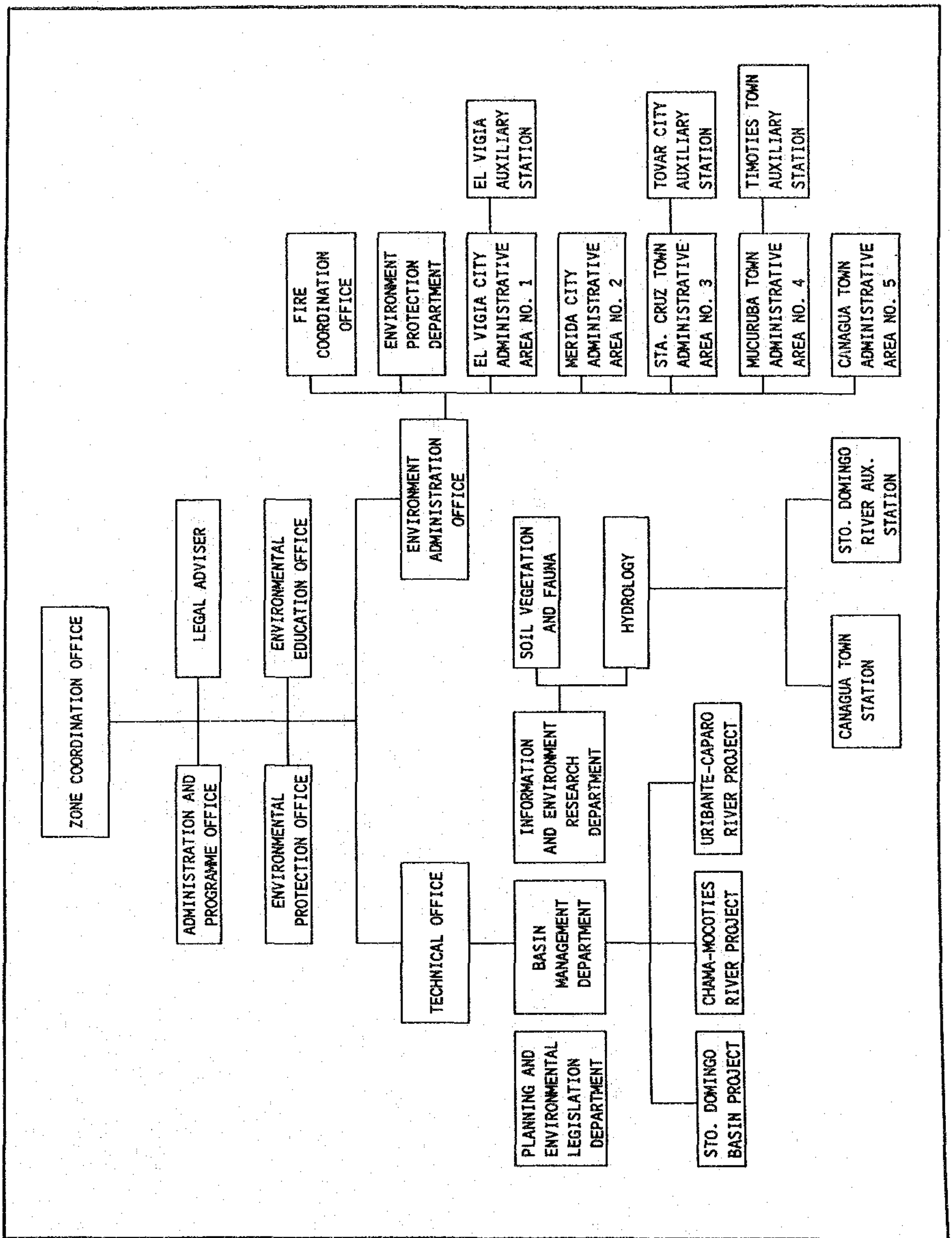


ORGANIZATION CHART OF ZONA 5, MARNR

Fig. I-5

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

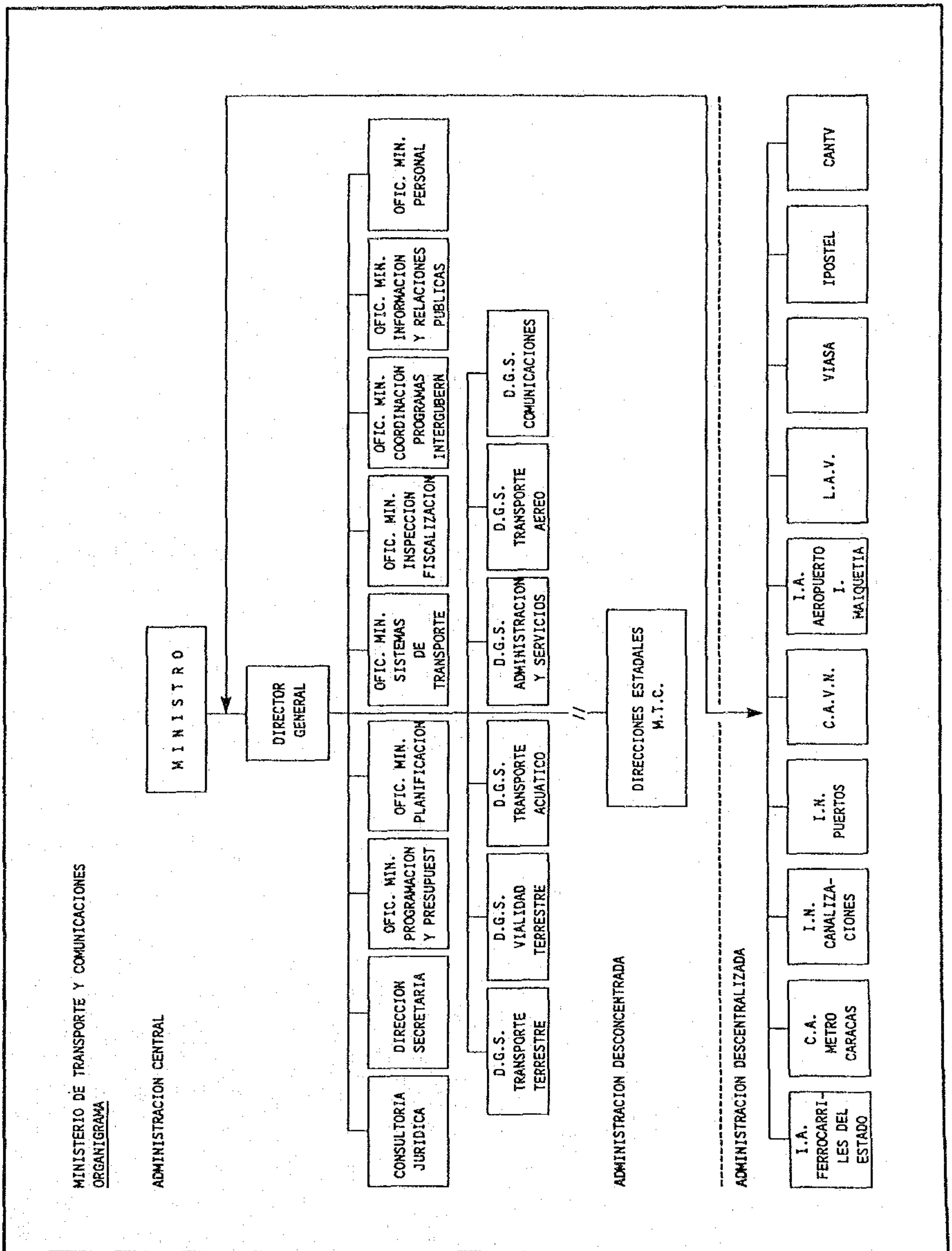


ORGANIZATION CHART OF ZONA 16, MARNR

Fig. I-6

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

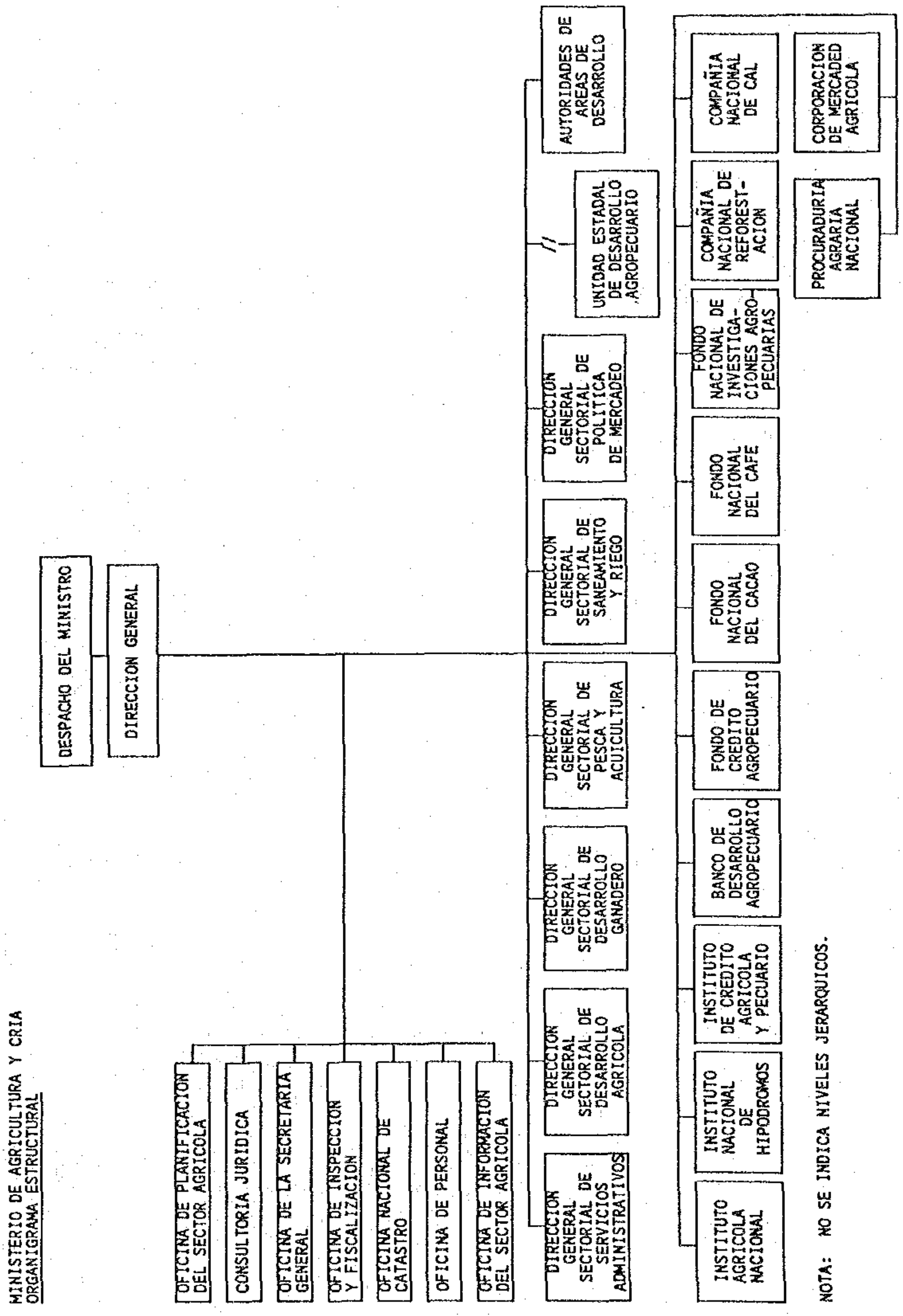


ORGANIZATION CHART OF MTC

Fig. I-7

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY



ORGANIZATION CHART OF MAC

Fig. I-8

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

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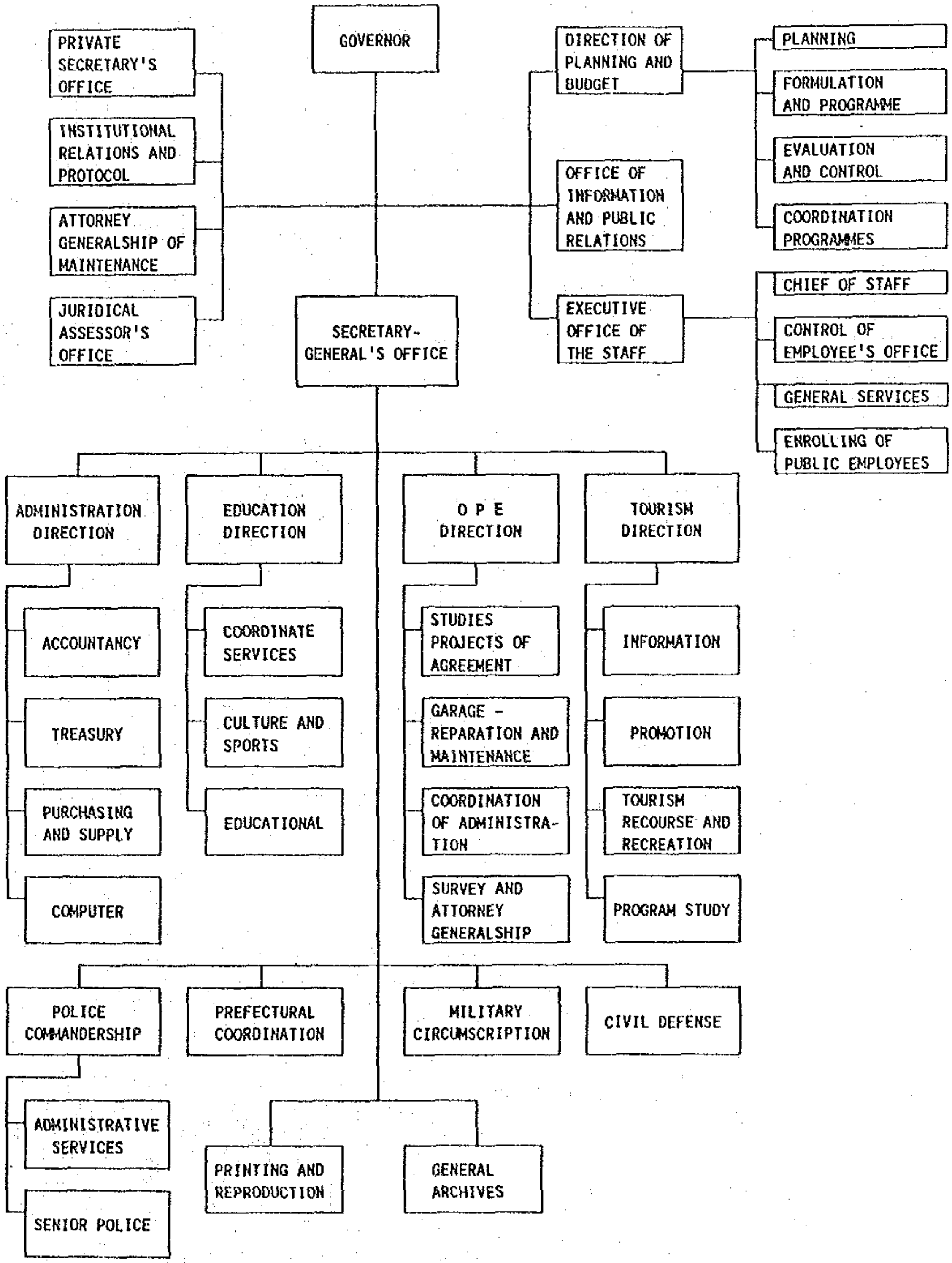
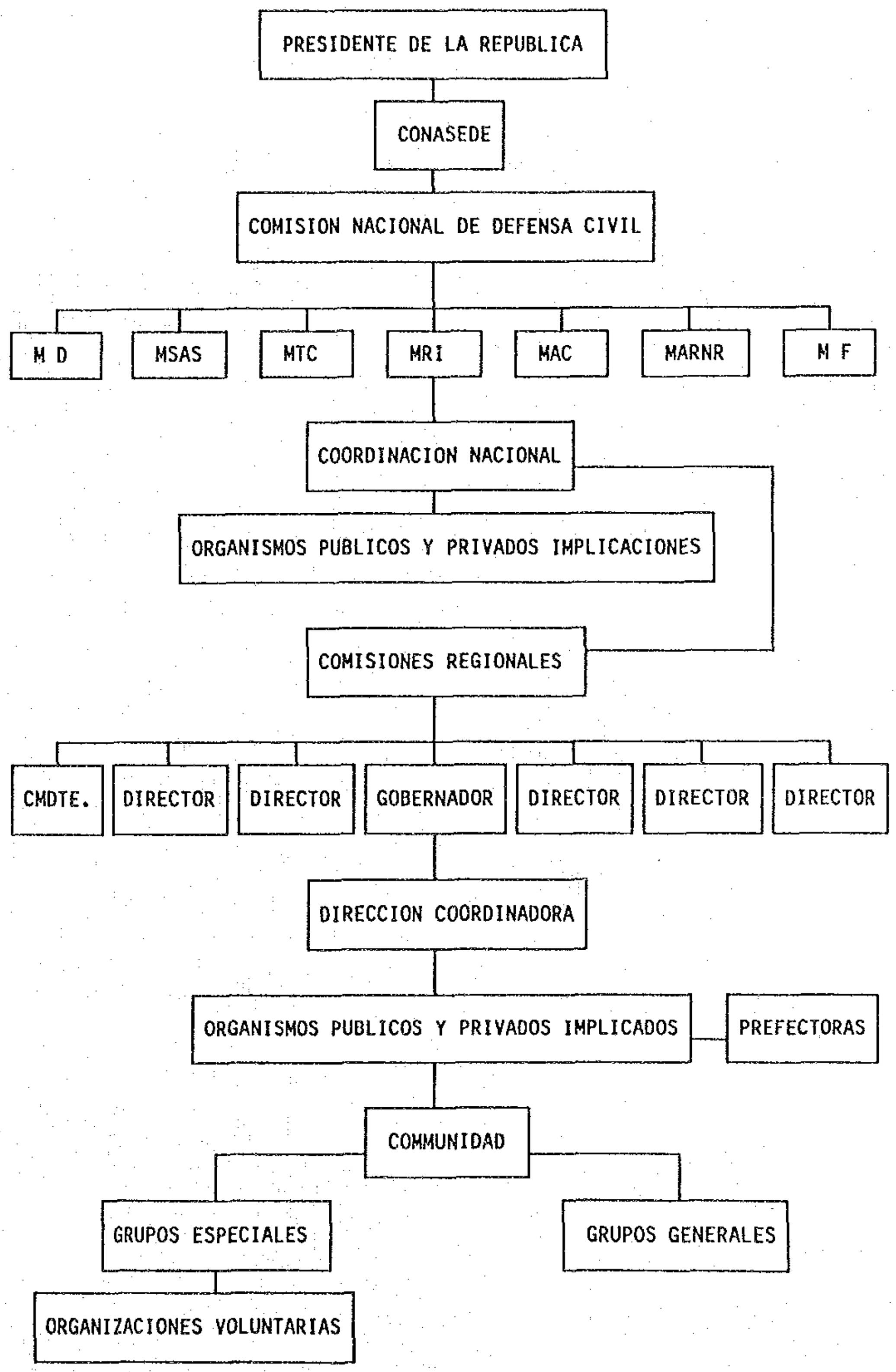


ORGANIZATION CHART OF LOCAL GOVERNMENT

Fig. I-9

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY



ORGANIZATION CHART FOR RESCUE AND DISASTER MITIGATION BY DEFENSA CIVIL

Fig. I-10

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

II. TOPOGRAPHY AND GEOLOGY

SUPPORTING REPORT

II. TOPOGRAPHY AND GEOLOGY

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1. TOPOGRAPHY

1.1 River Condition

The Chama River Basin is located in northwestern Venezuela and forms the central part of the Mérida Mountains, the northern part of the Andes Ranges that is generally called the Venezuelan Andes.

The Mérida mountain range extends in the area between the Maracaibo Lake and the Orinoco Plains on a total length of about 500 km from the Caribbean Sea in the northeast to the Venezuela-Colombian border. The average elevation of the mountain range is 4,000 m and the highest peak, Pico Bolívar, is 5,007 m above sea level.

The mountain range is generally divided into the northern mountains called Sierra de la Culata and the southern ones called Sierra Nevada by a graben. The graben which is formed by many fault structures, extends on a northeast-southwest direction between the two mountains. An active fault, called the Bocono fault, runs on the same direction.

The Chama River, about 200 km long, originates in the high mountainous area of about EL 4,400 m in Piedras Blancas, near El Aguila Pass in the eastern end of the basin, and flows down the graben. The uppermost reaches of about 10 km from its headwaters is called the Mifafí River which runs from the northeast to the south through the U-shaped valley formed by glaciers, and reaches to Apartaderos at EL 3,400 m.

From Apartaderos to Estánquez through Mérida for about 80 km, it runs almost straight down southwestward in the graben along the Bocono Fault, where river terraces are widely developed. A tributary, the Mocotíes River, extends northeastward to Estánquez running about 40 km passing Tovar, also along the fault.

In the area between Estánquez and El Vigía, the Chama River runs for about 20 km toward the north through the V-shaped valley in the northwest boundary of the Mérida mountains which are formed by the Tertiary formation. The river then flows into the Maracaibo lowland at El Vigía which is located at the head portion of the alluvial fan formed by the river. Finally, from El Vigía to the downstream, it flows northward for about 90 km into the Maracaibo Lake, forming the alluvial fan and a delta.

The Chama River Basin in the mountainous area upper than El Vigía covers a total area of about 3,500 km^2. According to the map of drainage system shown in Fig. II-1, the Chama River Basin generally shows a dendritic drainage pattern. The primary and secondary streams are mostly under the control of a joint system of bedrock, while the main streams, i.e., the Chama and the Mocoties rivers, are affected by a large scale geological structure.

In the past, the Mocoties River ran through the channel of the Santo Domingo River and joined the Chama River at Estánquez. However, it had totally changed through river capture and now flows into the Chama River at the valley between Estánquez and El Vigía.

The longitudinal profile of the Chama River and major tributaries (Fig. II-2) indicates that the mainstream practically shows the profile of a graded river; however, a knock point is seen in the gorge between Estánquez and El Vigía, where the riverbed gradient changes abruptly and the downstream current becomes faster than the upstream. In the upper reaches, sedimentation generally develops. The factors forming the knock point are: (1) presence of geological structures, e.g., a fault or a joint system; (2) difference of resistivity of rocks against erosion; and, (3) rejuvenation due to earth movement and/or change in sea level.

Generally, the longitudinal profile of graded rivers, where erosion and sedimentation are well-balanced, forms a concave slope. On the contrary, the San Pablo, La González and the Tostós rivers which are all major tributaries of the Chama River, show convex-slope profiles. This means that these tributaries have not reached the condition of graded rivers and are still under active erosion.

1.2 Topographical Condition

The topographical map of the basin is presented in Fig. II-3, while typical topographical cross sections of the Chama River Basin are shown in Fig. II-4. The Mérida mountains is divided into two mountain ranges by the graben as mentioned before, and the Chama River runs between these two mountain ranges. The northern range called Sierra de la Culata is 3,000-4,000 m above sea level and the southern one known as Sierra Nevada is 4,000-5,000 m above sea level as shown in Fig. II-3.

The areas exceeding the altitude of 3,500 m in both mountain ranges are barren, with exposed rocks and with less or no vegetation. These mountains become lower to the west; the Sierra de la Culata descends to 1,500-1,000 m at the gorge between Estánquez and El Vigía, and the Sierra Nevada decreases to 3,000-2,500 m near the headwaters of the Mocotíes River.

There are many plateaus in the highlands over an altitude of 2,000 m in both mountains. The plateaus between 2,000 and 3,000 m on the Sierra Nevada are erosion surfaces. The plateaus existing at over 3,000 m in elevation in the central areas of both mountains and near the headwaters of the Chama River were formed by glaciation, being covered with moraines.

Gentle slopes are seen in the upper reaches of La González and La Sucia rivers, which were formed by small and middle scale landslides. Landslide configurations had also developed on both banks at the gorge between Estánquez and El Vigía, especially on La Sucia River where a large scale landslide exists. This river is different from the river of the same name mentioned above.

On both banks, especially the right bank of the middle reaches of the Chama River between Tabay and Estánquez, river terrraces have developed with steep cliffs of 100 to 200 m high. River terraces are also seen narrowly in the upper reaches of the Mocotíes River between Bailadores and Tovar.

2. GEOLOGY

2.1 Geological Structure

The Mérida mountain range has been receiving several tectonic movements since the Pre-Cambrian Era. Its present condition started with the Alpine Orogeny in the Mesozoic Era.

The geological structure of the Chama River Basin is extremely complicated. The main direction of the structures is almost parallel to the extension of the graben. The major fault structure is the Bocono fault located almost in the center of the graven, and the Chama and Mocotíes rivers almost coincide with this fault.

The Bocono Fault is a large and significant active fault in the Mérida mountains. This is a right-strike-slip fault (lateral movement) with dip-slip (vertical movement), and runs for about 450 km long from the Barquisimeto (NE of the basin) to the Tachira Basin (SW of the basin). During the Quaternary Period, lateral transformations amounted to hundreds of meters, and a transformation at about 100 m for the last 10,000 years is especially recognized.

The earth movement of the Mérida mountains is presently continuing widely. Both the Sierra de la Culata and the Sierra Nevada are uplifting and river plains in the basin (graben) are relatively subsiding. A lot of eroded surfaces formed by earth movements are found at elevations of about 1,500 to 3,000 m, and those situated in elevations of more than 3,000 m are mostly of depositional surfaces (moraines) formed by glaciers.

2.2 Geological Formation

The geology of the Chama River Basin contains all geological ages from the Pre-Cambrian Era to the Cenozoic Era. Furthermore, the area has an extremely complicated geological condition because of the repeated tectonic movements. The geological composition of the Chama River Basin and its distribution are shown in the Geological Map of the Chama River Basin (Fig. II-5) and in the Geological Cross Section of the Chama River Basin (Fig. II-6).

The formations of the Cenozoic Quaternary Period are composed of unconsolidated sedimentary layers such as glacial deposits (moraines), talus deposits, terrace deposits, alluvial terrace deposits, and others. On the other hand, the formations of the Tertiary Period are composed of sedimentary rocks such as sandstone, claystone, conglomerates, shale, etc.

The formations of the Mesozoic Era mainly consist of Cretaceous limestone and the Jurassic La Quinta formation which is generally composed of red sandstone, siltstone and conglomerates. In the area of the Tertiary-Mesozoic formations, many landslides have occurred.

The formations of the Paleozoic Era mainly consist of sedimentary rocks such as sandstone, siltstone and others, without metamorphic rocks. However, the Carboniferous Mucuchachi formation which is the lowest formation of the Paleozoic Era in the area, is composed of metemorphic rocks such as slate, metasandstone, green schist, etc. The Mucuchachi formation extends widely in the Chama River Basin; along the middle to upper reaches of the Nuestra Señora River and on the right bank of the Mocotíes River. The slate in this formation has a strong fissility, therefore, gully erosions and rockfalls are seen in many places.

The Pre-Cambrian formations which are the basement of the Chama River Basin, consist of the Tostós and the Sierra Nevada formations. These formations are made up of metemorphic rocks such as slate, phyllite, schist and gneiss, which are most widely developed in the Chama River Basin. Gully erosions and rockfalls due to the strong fissility of these rocks are seen in many places, and they are especially remarkable in the páramo area located at more than 3,000 m above sea level.

In the Chama River Basin, small masses of plutonic intrusions appear at places. Granitic rock masses in the Sierra de la Culata, the eastern part of the basin, are most predominant of all. Surface landslides and rockfalls are seen in various places in the areas of the granitic rocks in the páramo area.

The detailed explanations for the formations of each geological age are as follows.

Pre-Cambrian Formation

The Pre-Cambrian stratum is composed of two formations, the Sierra Nevada formation and the Tostos formation from lower to upper. Both formations consist mainly of gneiss and schist of regional metamorphic rocks. Since these formations had experienced tremendous tectonic movements, many fold and fault structures exist. These are distributed in the middle and upper reaches where damsites C-4 to C-9 and N-1 are located.

Gneiss of the Sierra Nevada formation varies from white granitic rock comprising a high percentage of quartz to highly gneissose rocks formed mainly by mafic minerals. It forms alternation beds with schist in some parts.

Biotite in gneiss has a tendency to become clayey materials which is easily weathered. Moreover, while gneiss in this formation is a hard rock, it has a rather clear gneissose structure with many joints in general. Therefore, small rockfalls caused by the above features are seen in several places, and debirs can be seen at the foot of slopes formed by gneiss.

While the black schist of both formations is hard and metasedimentary rocks, it becomes fragile when graphitization reaches high grade. Black schist in high metemorphic grade becomes mica schist which is a coarse grained rock with compositional banding. Green schist which is metamorphosed igneous rock is also hard rock, but it is easily weathered and becomes clayey because it contains chlorite. When metamorphism reaches an advanced stage, both black and green schists change into gneiss. In the Chama River Basin, the distribution of schists is complicated and schists and gneiss sometimes form alternating beds.

Both schists have very clear schistosity. Therefore, while they are strong enough to resist perpendicular stress to schistosity, they are easily split under parallel stress to schistosity, causing many small rockfalls. Other than the above, both formations contain phyllite, slate and migmatite.

Paleozoic Formation

The Paleozoic is made of Carboniferous Mucuchachi formation, Sabaneta formation, and Permian Palmarito formation from lower to upper. It is composed of sedimentary rocks such as sandstone, siltstone, conglomerates, etc.

The Mucuchachi formation is widely distributed on the south of the Bocono fault (southwest area in the Chama River Basin). The Sabaneta and Palmarito formations are scatteredly distributed on the north of the Bocono fault. Damsites, except the step dam near El Morro, are not planned on these formations. The step dam site is located on the Mucuchachi formation.

The Mucuchachi formation consists mainly of slate and hard sandstone. Although this formation had experienced metamorphism and tectonic movements, these effects are not as remarkable as in the Pre-Cambrian formations. Sandstone is extremely hard. Slate shows strong schistosity and easily cleaves in thin layers, often causing large scale rockfalls. In view of the poor resistibility to parallel stress on the schistosity surface, the debris of slate is broken into many small fragments and/or fine materials, and deposits. Therefore, the deposits are carried away immediately by flow water, and large talus deposits are not formed on the slopes or foot of the slopes. The areas formed by slate are the main sources of river sedimentation in the Chama River Basin.

The Sabaneta and Palmarito formations are made up of sedimentary rocks which have not experienced metamorphism. The Geological Map of the Chama River Basin (Fig. II-5) shows that these formations are distributed in the north of the Bocono Fault, bordering complicatedly on Tertiary and Mesozoic formations in areas where a number of faults exist.

Mesozoic Formation

The Mesozoic is divided into eight formations in the Chama River Basin. All of these formations are Cretaceous, except La Quinta formation which is Jurassic. La Quinta formation is distributed in the northern part of the middle reaches of the Chama River, while the other Cretaceous formations are distributed in the surrounding areas of the gorge between Estanquez and El Vigía, as well as in the upper reaches of La Gonzales River which runs in the north of the middle reaches of the Chama River. Many fault structures develop in the above areas as shown in the Geological Map of the Chama River Basin (Fig. II-5).

La Quinta formation is made up of red sandstone, siltstone and conglomerate. Red sandstone shows very low resistivity to weathering, and is eroded remarkably. This formation is the main source of terrace deposits which are distributed on the right bank in the middle reaches of the Chama River. Damsite C-3 is located on this formation.

The Cretaceous formations, except the Colon formation which is the uppermost formation, are composed mainly of limestone, calcareous shale and sandstone. These rocks are generally hard when fresh.

The Colon formation is made up of shale, which has a tendency to become clayey. Therefore, big landslides are often seen in the area formed by this formation.

Tertiary Formation

The Tertiary is composed of Miocene Isnotu formation, Palmar formation, etc., which are distributed in the middle to lower reaches of the gorge between Estanquez and El Vigía. These formations are made up mainly of sandstone, mudstone and shale, which are rather low-strength compared with the Pre-Tertiary rocks, called soft rocks in general. Damsites C-1 and C-2 are located in the area formed by these formations.

The geological structure in this area is fairly simple, and has not experienced large tectonic movements. Distributions of folds and faults are therefore very rare. Shale has a strong tendency to become clayey soft materials by the weathering, causing landslides in many places. However, movement speed of these landslides is expected to be very slow as compared with rockfalls in the Pre-Tertiary formations which show rapid rock mass movement. Debris caused by landslide does not flow into the river immediately, but mostly remain on the slopes in general.

Quaternary Deposit

The Quaternary deposits are composed of lower terrace deposit, alluvial river deposit, riverbed deposit, talus deposit and debris flow deposit, which are all loosely consolidated or unconsolidated deposits.

The lower terrace deposit presents 100 m high terrace cliffs on the right bank in the middle reaches of the Chama River. This terrace deposit is composed of boulders of 20 to 30 cm in average diameter and rarely of more than 2 m, and fine sandy matrix which is loosely consolidated. In general, the cut slopes with inclination of more than 60 degrees from horizontal along the existing roads show a stable condition.

Talus deposit and debris flow deposit show nearly similar grain size distribution to that of the lower terrace deposit; however, these deposits are generally slightly consolidated or unconsolidated layers.

Alluvial river deposit which has developed below the riverbed is also in similar condition to that of the above talus and debris flow deposits, which form alluvial terrace surface along the present river channel, especially in the middle to lower reaches of the Chama River. The present river channel is generally covered by gravelly layers with boulders.

3. ROCKFALL, LANDSLIDE AND EROSIONS

There are many rockfalls and landslides in the Chama River Basin. Rockfalls occur mainly in the area of metamorphic rocks, while landslides are seen in the region of the Tertiary and Mesozoic sedimentary rocks.

In the upper reaches, some large-scale gully erosions exist. However, these are presently inactive due to efforts on soil conservation such as reforestation, hillside works and so on.

In the middle reaches, many rockfalls were seen in the Nuestra Señora River Basin. These rockfalls are located in the area of Paleozoic slate. The factors affecting rockfalls are: (1) presense of faults, (2) fissility of rocks, (3) artificial causes such as road construction and livestock breeding, and (4) lack of vegetation due to climatic condition.

The biggest scale rockfalls are located in the Mucuy River Basin. The volume of fallen rocks and fragments is about 3,400,000 m^3, but this is an unusual case in the Chama River Basin. Other rockfalls in the basin are very small.

In the V-shaped valley between Estánquez and El Vigía, in the region of Tertiary and Mesozoic sedimentary rocks, the most notable landslides concentrically occurred on both banks.

In the Chama River Basin, supply of materials to the river depends mainly on rockfalls and gully erosions. Most of the sediments remain at the slopes of mountains, but a part of these sediments flow gradually into the rivers.

Table II-1 shows the record of slope failures and debris flows in the Chama River Basin. These were observed along National Road Route Nos. 2 and 7, which are mostly small scale but have done some damage to the roads and bridges in the past. Some of them are supposed to be in unstable condition at present and have the possibility of inflicting damage to such artificial structures in the future, on which some protection works will be required.

4. GEOLOGY AT DAMSITE

The proposed sabo dams and step dams on the mainstreams of the Chama River and the Nuestra Señora River are as follows:

- Sabo Dam : C-1 to C-9 on the main channel of the Chama River, and N-1 on the Nuestra Señora River.

- Step Dam : On the Mucusas, Mucusuru and Mucusos rivers which are the tributaries of the Nuestra Señora River.

The location of each damsite is shown in the Location Map of Damsite (Fig. II-7). Geological layers and formations distributed at the damsites are summarized in Table II-2. Explanation for rock classification is presented in Table II-4. The geological conditions of each site are shown in the Geological Map and Cross Sections of Damsite (Figs. II-8 to II-18) and the Summary of Geological Condition for Each Damsite (Table II-3). These conditions are described as follows.

Damsite C-1

Damsite C-1 is located at the lower reaches of the gorge between Estanquez and El Vigía. The bedrock is fine sandstone of Tertiary Miocene Isnotu formation, which is a well consolidated soft rock. Talus deposit of more than 10 m in thickness develops in the left bank, which is unconsolidated and loose, composed of many gravels of 20 to 30 cm in average diameter, rarely of boulders of about 3 m in maximum diameter, and fine sandy matrix.

Sandstone outcrops in the right bank. The bedding of this is N40°W/35°, and major joints are N45°W/65°E and N85°E/30°N. Sandstone is strong enough for the foundation of a 20-m high concrete dam. The talus deposit on the left bank may not be desirable for such a dam foundation, and may need some deep excavations. Alluvial river deposit under the present riverbed deposit is supposedly about 20 m thick. (Refer to Fig. II-8.)

Damsite C-2

Damsite C-2 is located in the middle reaches of the gorge between Estanquez and El Vigía. The bedrock consists of an alternation of sandstone and shale, both characterized as soft rocks, of Tertiary Miocene Palmar formation. Sandstone is a well-consolidated rock, while shale has turned into clayey materials under weathering and yields some rockfalls along the joints.

On the left bank, the outcrops of the bedrock are as high as 5 m above the present riverbed; upper than that is covered with talus deposit, 15 to 20 m thick. The bedding of the bedrock is N50°E/60°NW, and the major joint directions are N40°W/50°E and N60°W/90°.

Talus deposit is mainly composed of gravels of 20 to 30 cm in average diameter, rarely of boulders of 1 m in maximum size, and fine sandy matrix. This layer is unconsolidated and in loose condition.

On the right bank, talus spreads all over, and no outcrop of bedrock was found. However, the thickness of talus deposit seems to be comparatively thin.

The bedrock, alteration of sandstone and shale, is suitable for foundation of a 10 to 20-m high dam. Meanwhile, talus deposit distributed on the left bank had better be avoided for dam foundation. Alluvial river deposit under the present riverbed is estimated to be as thick as 10 m.

A large landslide exists on the left bank of the upstream about 300 m from the damsite where the bedrock distributes. (Refer to Fig. II-9.)

Damsite C-3

Damsite C-3 is located in the uppermost reaches of the gorge between Estanquez and El Vigía. The bedrock consists of conglomerate and conglomeratic sandstone of the Mesozoic Jurassic La Quinta formation.

The left bank is formed by a reddish conglomerate, the matrix of which becomes soft and loose due to weathering. The bedding is

N10°E/80°SE, and major joints are N50°E/45°N and N65°W/80°N in the left bank.

The right bank is formed by blackish conglomerate and conglomeratic sandstone of La Quinta formation, which are all hard rocks. Conglomerate is composed mainly of 1 to 3 cm gravels of slate, quartzite and schist, and siliceous fine sandy matrix. Conglomeratic sandstone which has gravels of 2 to 5 cm in average diamater, is generally friable and it looks like a slate in some parts. The bedding is N55°W/50°NE, and major joints are N25°E/90° and N60°W/60°S. On the right bank at 100 m upstream from the site, there is a landslide of 150 m in width and approximately 250 m in length, which is supposed to be still active.

In view of differences on rock conditions, beddings and so on in both the left and the right banks, there may be a fault below the riverbed, running in the same direction as the river flow. Quaternary deposits such as talus and terrace deposits are rare on both banks. The riverbed deposit is also supposed to be extremely thin.

The bedrocks in both banks have sufficient strength for the foundation of a 10-m high dam. However, if the fault which is supposed to be below the riverbed has a thick fractured and weak zone, dental excavation of such zone will be required. (Refer to Fig. II-10.)

Damsite C-4

Damsite C-4 is located at just upstream of Estanquez in the mainstream of the Chama River. The right bank is formed by lower terrace deposit with a steep cliff of about 40 m in height, and alluvial terrace surface developed in the area at 5 to 6 m higher than that of the present riverbed between the lower terrace cliff and the river.

The lower terrace deposit which is generally lower consolidated layer, is composed of gravels of 20 to 30 cm in average diameter, rarely of boulders of 2 m in maximum diameter, and red sandy matrix. The alluvial river deposit of unconsolidated and loose layer is composed of gravels similar to those of the lower terrace deposit and a reddish to yellowish brown fine-medium sandy matix. The alluvial river deposit below the riverbed is estimated to be more than 20 m thick.

The left bank is formed by granitic gneiss of the Pre-Cambrian Sierra Nevada formation. In general, this rock is hard and its outcrop is also in good condition with schistosity of N40°E/60°SE, and major joints of N30°W/90° and N40°E/55°N. Quaternary deposit is rare on the left bank slope. Only alluvial terrace surface is seen narrowly in the present riverbed.

Granitic gneiss and lower terrace deposit are strong enough for foundation of a 10-m high concrete dam. However, it may require some deep excavation for the surface zone of alluvial terrace and for the loosened portion of the lower terrace deposit in the right bank.

Further, the active Bocono fault may exist below the riverbed. However, the dam foundation will be designed on the present riverbed which is formed by gravelly coarse materials, and below which thick alluvial river deposit develops. Therefore, the existence of the fault may not be considered in designing the dam. (Refer to Fig. II-11.)

Damsite C-5

Damsite C-5 is planned in the upstream area of Estanquez, at just downstream of the confluence of the San Pablo and the Chama rivers. The right bank is covered by lower terrace deposit and alluvial terrace surface. The lower terrace deposit forms a steep cliff of about 60 m high, and terrace surface of alluvial river deposit develops in the area between the lower terrace cliff and the river at 2 to 8 m higher than that of the present riverbed.

The lower terrace deposit is a well consolidated layer composed of many gravels of 40 to 50 cm in average diameter, rarely of boulders of 2 m in maximum diameter, and red sandy matrix with small gravels of 5 to 10 mm. The alluvial river deposit is unconsolidated or loosely consolidated and is composed of gravels of 10 to 20 cm in average diameter, rarely of boulders of 2 m in maximum diameter, and reddish brown fine sandy matrix with small gravels of 5 to 10 mm. The alluvial river deposit is supposed to be about 15 m thick. The present riverbed deposit which consists of gravelly coarse materials, has developed in the river channel on the alluvial river deposit.

The left bank is formed by black schist of the Pre-Cambrian Sierra Nevada formation. This rock is hard and its outcrops are in good condition, with schistosity of N55°E/75°NW, and major joints of N15°W/90° and N85°E/20°N. Although narrow alluvial terrace surface is seen both at the upstream and downstream foot of the left bank slope along the river, the bedrock outcrops well on the slope at the damsite.

The black schist and the lower terrace deposit are strong enough for the foundation of a 10-m high concrete dam. Some deep excavation may be required for the section where alluvial terrace develops. The Bocono fault may exist in this site as mentioned in damsite C-4, below the riverbed or the river bank. (Ref. Fig. II-12.)

Damsite C-6

Damsite C-6 is located near Los Aragues in the upstream of the confluence of the San Pablo and the Chama rivers. The bedrock in the right bank is green schist of the Pre-Cambrian Tostos formation, which has a schistosity of N45°E/20°N, and major joints of N70°E/78°N and N75°E/55°S. On the bedrock, lower terrace deposit is distributed at a height of 15 to 20 m from the present riverbed, and alluvial terrace surface develops near the riverbed at a height of about 10 m.

The lower terrace deposit is a well consolidated layer, composed mainly of gravels of 10 to 15 cm in average diameter, rarely of boulders of 0.8 to 1 m in maximum diameter, and red fine sand matrix. The alluvial terrace is formed by lower consolidated alluvial river deposit. Two layers of different conditions were observed in the outcrops below the alluvial terrace surface near the riverbed. The upper layer of 3 m in thickness just below the terrace surface is rather coarse, composed mainly of gravels of about 3 cm in diameter. The lower layer is comparatively fine, composed mainly of gravels of about 5 cm in diameter. The gravel content of each layer is approximately 80% in the upper layer and 60% in the lower layer. The matrix is grayish brown fine sand, and boulders of 0.8 to 2.5 m in diameter are rarely found in both layers. The alluvial river deposit below the riverved is estimated to be about 20 m thick.

The bedrock in the left bank is granitic gneiss of the Pre-Cambrian Sierra Nevada formation. The left bank is covered by very thick and large scale debris flow deposit which is composed of boulders of 30 cm in average diameter and rarely about 3 m in maximum, and reddish brown fine sand matrix. This deposit is unconsolidated and in loose condition.

Since both banks are thickly covered by the Quaternary deposits, some deep excavation may be required on both banks for the foundation of a 10-m high concrete dam. The Bocono fault may exist here also below the riverbed. (Refer to Fig. II-13.)

Damsite C-7

Damsite C-7 is located near Los Limos, approximately 2.5 km further upstream of the C-6 site. The bedrock of the right bank is black schist of the Pre-Cambrian Tostós formation, which is hard rock with schistosity of N55°W/58°N, and major joints of N25°E/90° and N55°W/30°S. The bedrock is well exposed on the right bank slope from the riverbed to the upper portion. Quaternary deposits are very rare on the slope.

On the left bank, the bedrock is granitic gneiss of the Pre-Cambrian Sierra Nevada formation, which is also hard rock and covered by very thick debris flow deposit. This deposit is unconsolidated and loose, composed of gravels of about 10 cm in average diameter, rarely of boulders of about 40 cm in diameter, and reddish brown fine sandy matrix.

The alluvial river deposit which has developed below the riverbed is estimated to be about 15 m thick. Below the riverbed, the Bocono fault may exist.

The bedrock of granitic gneiss is strong enough for the foundation of a 10-m high dam, although some deep excavation will be required for the debris flow deposit on the left bank. (Refer to Fig. II-14.)

Damsite C-8

Damsite C-8 is planned at just upstream of the confluence of the Chama and El Molino rivers. The right bank is formed by black schist of the Pre-Cambrian Tostós formation. Its schistosity is N5°W/45°W, and major joints are N35°E/62°SE and N65°W/20°N. The bedrock of black schist is well exposed on the right bank slope from the riverbed to the upper part of the slope without Quaternary deposits.

On the left bank, very large scale debris flow deposit covers the bedrock. This deposit is unconsolidated and loose, composed of gravels of 15 to 20 cm in average diameter, rarely of boulders of 2 m in maximum diameter, and brown fine sandy matrix.

The alluvial river deposit below the present riverbed is estimated to be more than 30 m thick. Below the riverbed, the Bocono fault may exist.

The bedrock of black schist in the right bank has sufficient strength for the foundation of a 10-m high concrete dam. However, some deep excavation may be required for the debris flow deposit on the left bank. (Refer to Fig. II-15.)

Damsite C-9

Damsite C-9 is located near Puente Real in the downstream of the confluence of La Vizcaína and the Chama rivers. The bedrock of the right bank is black schist of the Pre-Cambrian Tostós formation, which has a schistosity of N85°E/60°S.

On the left bank, wide and thick talus deposit covers the bedrock. This deposit is unconsolidated and loose, composed of cobbles of about 20 cm in average diameter, rarely of boulders of 2 m in maximum diameter, and brown fine sandy matrix. The bedrock in the left bank is granitic gneiss of the Pre-Cambrian Sierra Nevada formation.

Alluvial river deposit below the riverbed is estimated to be about 30 m thick. The present riverbed deposit in the river channel is composed of gravelly coarse materials with few boulders. The Bocono fault may exist below the riverbed.

Black schist in the right bank is strong enough for the foundation of a 10-m high concrete dam. However, some deep excavation will be required for the talus deposit on the left bank. (Refer to Fig. II-16.)

Damsite N-1

Damsite N-1 is located in the lower reaches of the Nuestra Señora River just upstream of the confluence with the Chama River. The bedrock is an alternation of black schist and granitic gneiss of the Pre-Cambrian Sierra Nevada formation. On the left bank, the bedrock is thinly covered by talus deposit which is unconsolidated and loose. The bedrock in the left bank has the schistosity of N50°E/60°S, and major joints of N80°W/50°N and N55°W/90°.

On the right bank, the bedrock is in good condition and it is well exposed for about 30 m in height from the riverbed. The rocks in the right bank have the schistosity of N50°E/60°N, and major joints of N80°W/50°N and N85°E/30°S. The present riverbed deposit is composed of gravelly materials with some boulders, and below that, alluvial river deposit supposedly developed with the thickness of more than 10 m.

The bedrock has sufficient strength for the foundation of a 20-m high concrete dam. However, the talus deposit on the left bank shall be removed. Active and large scale landslide develops in the left bank, about 100 m upstream from the damsite. (Refer to Fig. II-17.)

Step Dam Site

The step dams are planned at three sites in the middle reaches of the Nuestra Señora River which is a tributary of the Chama River, near El Morro. These sites are located in the lower reaches of the Mucusas, the Mucusurú and the Mucusós rivers, respectively, which are all tributaries of the Nuestra Señora River.

Bedrocks are slate and sandstone of the Paleozoic Carboniferous Mucuchachi formation. While these are both hard rocks, slate has a strong tendency of fissility because of its schistosity. Therefore, small scale rockfalls and gully erosions have developed remarkably in the areas of these damsites. However, large scale talus deposits are not found.

The riverbed deposit is composed of coarse gravelly materials with boulder, and it is estimated to be 5 to 10 m thick in all damsites.

The bedrocks are strong enough for the foundation of a concrete dam several meters in height, and these are well exposed in both banks of all damsites. Therefore, there is no problem on the construction of step dams in all sites. However, it is necessary to remove talus deposit which is narrowly distributed at the foot of both bank slopes, and loosened rocks due to weathering. Typical geological sections are shown in Fig. II-18.

Table II-1(1/2) SLOPE FAILURES AND DEBRIS FLOW RECORDS IN THE CHAMA RIVER BASIN

No.	Location	Type of Failure	Year/ Month/ Date	Scale of Collapse and Debris Flow L*W*D (m)	V(m3)	Geological Condition
1.	Cacute	Slope failure	1988	(1) 30*15*3 (2) 40*15*3	1,350 1,800	talus deposit seems to be still active
		Bank erosion	1988	(1) 80*10*4 (2) 30*2*10	3,200 600	talus deposit damage to road
2.	Tabay	Debris flow	1988 Sep.	50(?)*2*2	200(?)	talus deposit with boulders of 1 m in max.
		Bank erosion		28*6*7	1,176	alluvial deposit damage to road
3.	Mesa de la Virgen	Slope failure		(1) 150*5*0.5 (2) 50*100*0.8	375 4,000	granite seems to de still active
4.	Qda. Los Higuerones	Debris flow	1988 Aug.	1,500*8*4	48,000	granite, fan deposit with boulders of 2 m in max
5.	Confluence of R.Chama & R.Nuestra Senora	Slope failure	1987	(1) 100*100*1.5 (2) 100*100*1.5	15,000 15,000	mica schist, quartz schist bedding:N50E/40N, joint:N60E/45S seems to be still active
6.	Qda. Los Limos	Debris flow		1,500*10*1.5	22,500	green schist; damage to bridge with boulders of 2 m in max.
7.	Qda. Maciqual	Debris flow		(1) 100*4*1.5 (2) 60*4*1.5	600 360	green schist; damage to bride & road with boulders of 1.5 to 2 m
8.	Arraquares	Debris flow		30*5*3	450	green schist with boulders of 2 m in max.
9.	Qda. La Jaya	Debris flow		1,000*12*1	12,000	green schist with boulders of 2 m in max.
10.	Qda. El Diablo	Bank erosion		5*10*1	50	sandstone and shale
11.	La Honda	Slope failure	1988	100*20*8	16,000	sandstone damage to road
12.	La Palmita	Slope failure	1989 Jan.6	90*20*5	9,000	sandstone damage to road
13.	La Providencia	Slope failure	1988 Dec.	10*40*1	400	sandstone damage to road
14.	Carabanchel	Debris flow		20*5*2	200	sandstone damage to road
15.	Qda. Romero	Slope failure	1988 Sep.	15*4*1	60	crystalline schist damage to road

Table II-1(2/2) SLOPE FAILURES AND DEBRIS FLOW RECORDS IN THE CHAMA RIVER BASIN

No.	Location	Type of Failure	Date	Scale of Collapse and Debris Flow L*W*D (m)	V(m3)	Geological Condition
16.	Qda. Cubalibre	Debris flow	1988 Sep.	(1) 30*10*1 (2) 100*8*1	300 800	crystalline schist damage to road
17.	Qda. Tabacal	Debris flow		200*15*2	6,000	crystalline schist damage to road
18.	Qda. Silencio	Debris flow	1988 Sep.	(1) 150*15*2 (2) 50*10*1	4,500 500	granite damage to road
19.	Qda. Caciquito	Debris flow		1,000*20*1	20,000	granite damage to road
20.	Qda. Penon II	Debris flow	1988 Sep.	100*9*1	900	granite damage to road & check dams

Table II-2 GEOLOGICAL LAYERS AND FORMATIONS DISTRIBUTED AT DAMSITE

Age	Layer and formation	Description
Cenozoic Quaternary Holocene	Riverbed deposit	Present riverbed deposit, unconsolidated, composed of mainly gravelly coarse materials.
	Talus deposit	Unconsolidated and very loose, formed by sandy materials with rock fragments in general.
	Debris flow deposit	Unconsolidated and loose, composed of sandy materials with gravels and boulders in general.
	Alluvial river deposit	Unconsolidated and loose, composed of sandy materials with gravels and boulders, which forms partry alluvial terrace.
Pleistocene	Lower terrace deposit	Lower consolidated, composed by sandy materials with gravels and boulders.
Tertiary Miocene	Isnotu formation	Fine sandstone (C-1)
	Palmar formation	Alteration of sandstone and shale (C-2)
Mesozoic Jurassic	La Quinta formation	Conglomerate and conglomeratic sandstone (C-3)
Paraeozoic Carboniferous	Mucuchachi formation	Slate and snadstone (Step damsites)
Pre-Cambrian	Sierra Nevada formation	Granitic gneiss (Left banks of C-4, C-6, C-7 and C-9) Black schist (Left bank of C-5) Alternation of granitic gneiss and black schist (N-1)
	Tostos formation	Green schist (Right bank of C-6, C-7) Black schist (Right bank of C-8 and C-9)

Table II-3(1/2) SUMMARY OF TOPOGRAPHICAL GEOLOGICAL CONDITION AT DAMSITE

Dam No. /Location	Valley Shape	Topography: Specific bank height(m) Right	Specific bank height(m) Left	Bank slope (Deg.) Right	Bank slope (Deg.) Left	Landslide and Rock Fall	Geology: Formation (Geologic age) Right	Formation (Geologic age) Left	Lithology Right	Lithology Left
C-1	V-shaped	140	200+	45	35	none	Isnotu F. (Miocene)		Fine Sandst(Soft Rock)	
C-2	V-shaped	200+	160	35	45	a landside exists at 300 m upstream on the left bank	Palmar F. (Miocene)		Aternating bed of Sand stone and shale (soft rock)	
C-3	V-shaped	200+	200+	30	45	a landside exists at 100 m upstream on the right bank	La Quinta F. (Jurassic)		Red conglo-merate	Conglo-meratic sandstone
C-4	U-shaped	65	160	60	45	none	Terrace deposit (Pleistocene)	Sierra Nevada F. (Precambrian)	Gravel, sand	Granitic gneiss
C-5	U-shaped	120	200+	10	40	none	Terrace deposit (Holocence)	Sierra Nevada F. (Precambrian)	Gravel, sand	Black schist
C-6	U-shaped	100	200+	60	15	none	Terrace deposit (Pleistocene)	Debris flow (Holocene)	Gravel, sand	Gravel, sand
C-7	V-shaped	200+	200+	45	20	none	Tostos F. (Precambrian)	Debris flow (Holocene)	Black schist	Gravel, sand
C-8	U-shaped	100	200+	40	30	none	Tostos F. (Precambrian)	Debris flow (Holocene)	Black schist	Gravel, sand
C-9	U-shaped	125	200+	45	30	none	Tostos F. (Precambrian)	Debris flow (Holocene)	Black schist	Gravel, sand
N-1	U-shaped	80	200+	35	45	a rockfall exists at 100 m upstream on the left bank	Sierra Nevada F. (Precambrian)		Granitic Gneiss with Schist	
Mucusos R.	V-shaped	200+	100	55	55	Numerons gullies exist on both banks	Mucuchachi F. (Paleozoic)		Slate	
Mucusuru R.	V-shaped	120	200+	45	40	a small scale rock fall exist at the dam site	Mucuchachi F. (Paleozoic)		Sandstone	Slate
Mucusas R.	V-shaped	200+	200+	40	70	numerous gullies exit on both banks	Mucuchachi F. (Paleozoic)		Slate	

*1) The first dip and strike is of stratification or schistosity.
*2) refer to Table II-4

Table II-3(2/2) SUMMARY OF TOPOGRAPHICAL AND GEOLOGICAL CONDITION AT DAMSITE

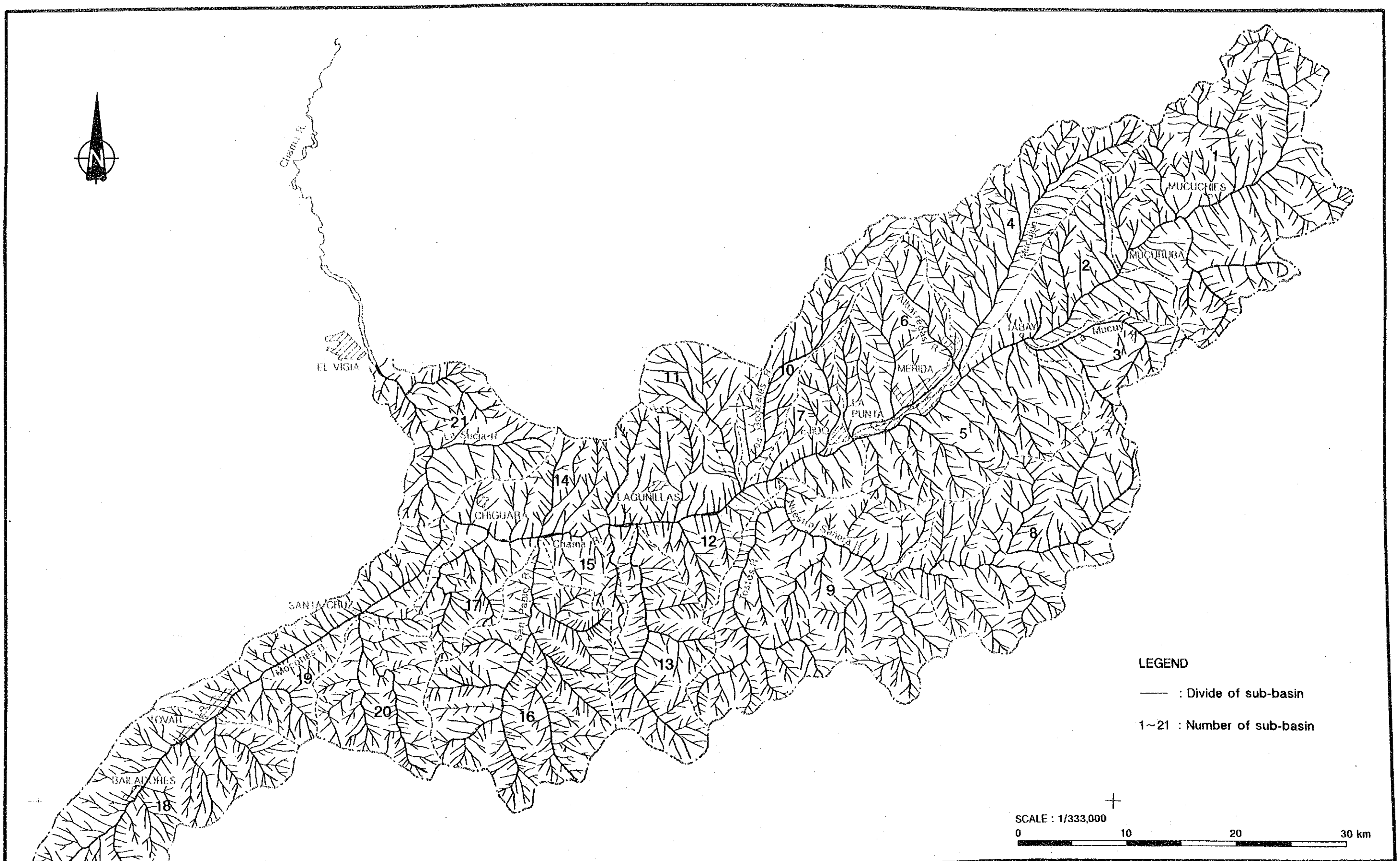
Dam No. /Location	Geology: Stratification, Schistosity and Joint of Rock, frequency of Joint (numbers/meter) *1) Right	Left	Rock classification *2) Right	Left	Fault	Thickness of talus and debris flow(m) Right	Left	River deposit thickness (m)
C-1	N40W,35E(2/m) N45W,65S(3/m) N35E,90 (2/m)	N65W,80S(2/m) N25W,65E(3/m) N85E,30N(3/m)	CL	CL	a small scale fault exists on riverbed	none	70	20
C-2	N50E,60NW(2/m) N40W,50E(5/m) N60W,90(3/m)		CL	CL	none	5	20	10
C-3	N60W,50NE(2/m) N60W,60S(3/m) N25E,90 (3/m)	N5E,80E(2/m) N50E,45N(5/m) N65W,80N(3/m)	CL	CM	a small scale fault exists on riverbed	10	none	0-5
C-4		N40E,60SE(5/m) N40E,55N(3/m) N30W,90(3/m)		CM	an active fault exists on riverbed	2	3	20
C-5		N55E,75NW(3/m) N85E,20N(3/m) N15W,90(2/m)		CH	- do -	none	none	15
C-6					- do -	none	80	20
C-7	N55W,58N(3/m) N55W,30S(3/m) N25E,90(5/m)		CM		- do -	none	60	15
C-8	N5W,45W(2/m) N35E,62SE(3/m) N65W,20N(3/m)		CH		- do -	none	140	30
C-9	N85E,60S(5/m) N50E,20S(3/m) N15W,80W(5/m)		CM		- do -	none	120	30
N-1	N50E,60N(10/m) N45W,80SW(5/m) N85E,30S(5/m)	N50E,60S(5/m) N80W,50N(3/m) N55W,90(2/m)	CM	CM	none	none	80	30
Mucusos R.	N65E,20N(10/m) N65E,50S(3/m) N5W,90 (3/m)		CM	CM	none	none	none	0-5
Mucusuru R.	N85E,60N(3/m) N85E,70S(3/m) N5W,90(3/m)	N65E,25S(20/m) N85E,70N(10/m) N20E,90(3/m)	CH	CM	a small scale fault exists on riverbed	none	none	10
Mucusas R.	N65E,25S(20/m) N85E,70N(10/m) N20E,90(3/m)	N65E,20N(10/m) N65E,50S(3/m) N5W,90(3/m)	CM	CM	- do -	40	none	5

*1) The first dip and strike is of stratification or schistosity.
*2) refer to Table II-4

Table II-4 Rock Classification

Rock class	Description
A	The rock mass is very fresh, and the rock forming minerals and grains undergo neither weathering nor alteration. Joints are extremely tight and their surfaces have no visible sign of weathering. Sound by hammer blow is clear.
B	The rock mass is solid. Their is no opening joint and crack (even of 1 mm). But rock forming minerals and grains undergo a little weathering and alteration in partly. Sound by hammer blow is clear.
CH	The rock mass is relatively solid. The rock forming minerals and grains undergo weathering except for quartz. The rock is contaminated by limonite, etc. The cohesion of joints and cracks is slightly decreased and rock blocks are separated by firm hammer blow along joints. Clay materials remain on the separation surface. Sound by hammer blow is a little dim.
CM	The rock mass is somewhat soft.The rock forming minerals and grains are somewhat softened by weathering, except for quartz. The cohesion of joints and cracks is somewhat decreased and rock blocks are separated by ordinary hammer blow along the joints. Clay materials remain on the separation surface. Sound by hammer blow is somewhat dim.
CL	The rock mass is soft. The rock forming minerals and grains are softened by weathering. The cohesion of joints and cracks is decreased and rock blocks are separated by soft hammer blow along the joints. Clay material remain on the separation surface. Sound by hammer blow is dim.
D	The rock mass is remarkably soft. The rock forming minerals and grains are softened by weathering. The cohesion of joints and cracks is almost absent. The rock mass collapses by light hammer blow. Clay materials remain on the separation surface. Clay materials remain on the separation surface. Sound by hammer blow is remarkably dim.

Source: CRIEPI, Central Research Institute of
Electric Power Industry in Japan



STUDAY ON CHAMA RIVER BASIN
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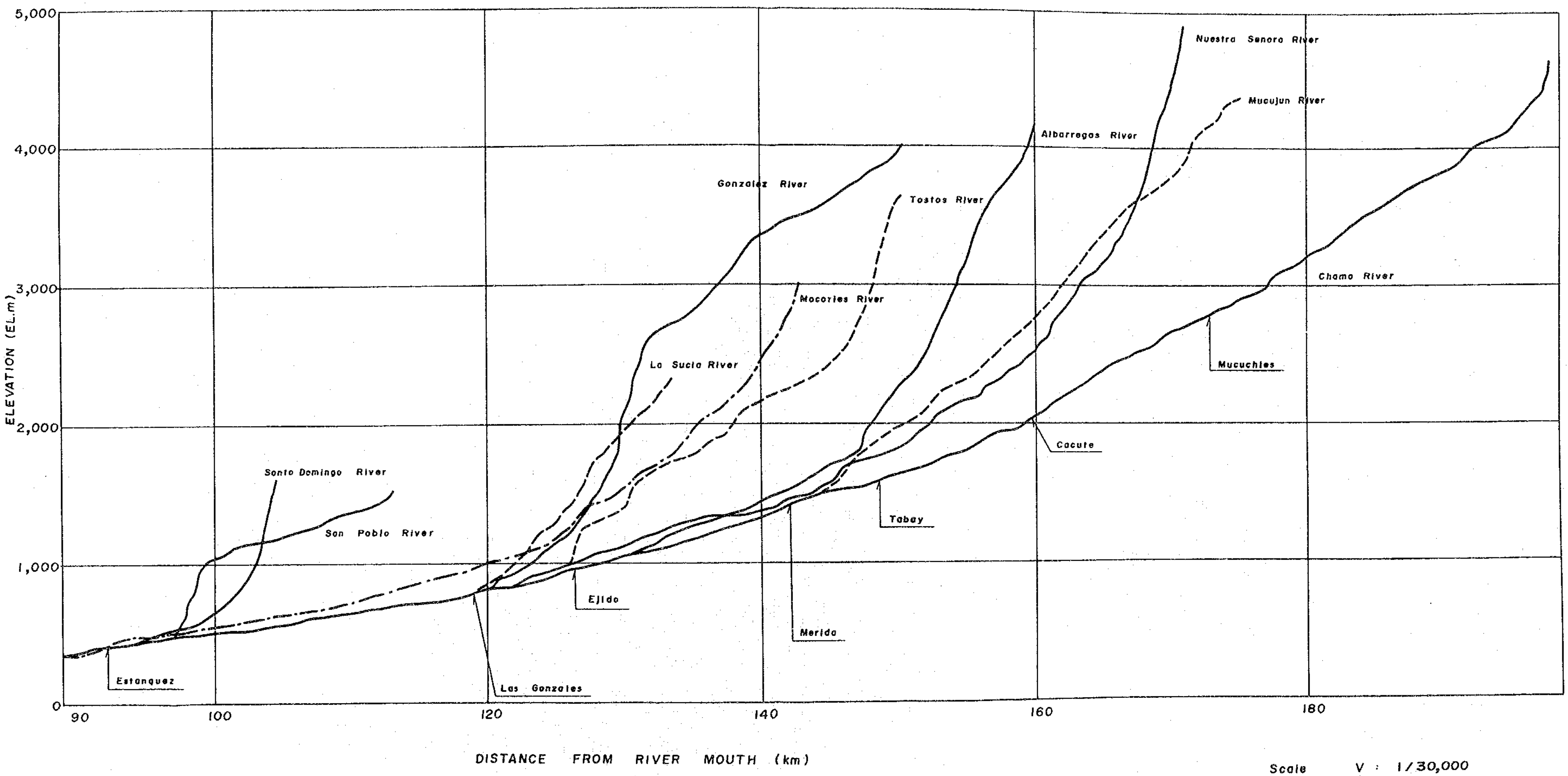
DRAINAGE SYSTEM OF THE CHAMA RIVER BASIN

Fig. II-1



Scale V : 1/30,000
H : 1/300,000

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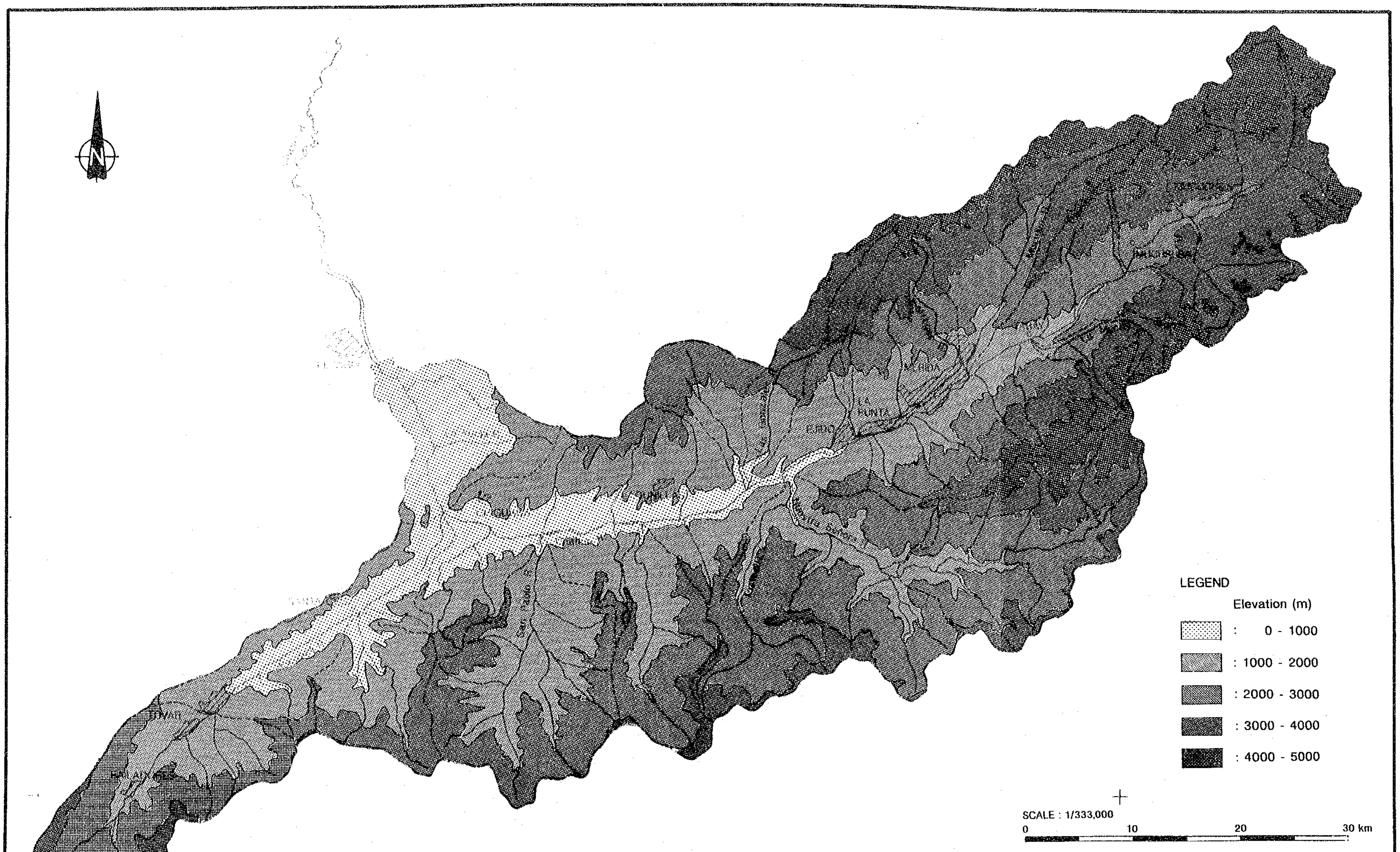
LONGITUDINAL PROFILE OF THE CHAMA RIVER AND MAJOR TRIBUTARIES

Fig. II-2



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TOPOGRAPHICAL MAP OF THE CHAMA RIVER BASIN

Fig. II-3