THE REPUBLIC OF VENEZUELA

STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

VOLUME 1

MAIN REPORT

FEBRUARY 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

THE REPUBLIC OF VENEZUELA

STUDY
ON
CHAMA RIVER BASIN CONSERVATION PROJECT

VOLUME 1

MAIN REPORT

FEBRUARY 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

PREFACE

In response to a request from the Government of the Republic of Venezuela, the Japanese Government decided to conduct a study on Chama River Basin Conservation Project and entrusted the study to Japan International Cooperation Agency (JICA).

JICA sent to Venezuela a survey team headed by Mr. Mitsuo Nakahiro, CTI Engineering Co., Ltd. composed of members from the CTI Engineering Co., Ltd. and Nippon Koei Co., Ltd. from November, 1988 to March, 1989 and June to September, 1989.

The team held discussions with concerned officials of the Government of Venezuela and conducted field surveys. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Venezuela for their close cooperation extended to the team.

February, 1990

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

JICA STUDY TEAM
STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT

February 28, 1990

Mr. Kensuke Yanagiya
President
Japan International
Cooperation Agency
Tokyo, Japan

Dear Sir:

<u>LETTER OF TRANSMITTAL</u>

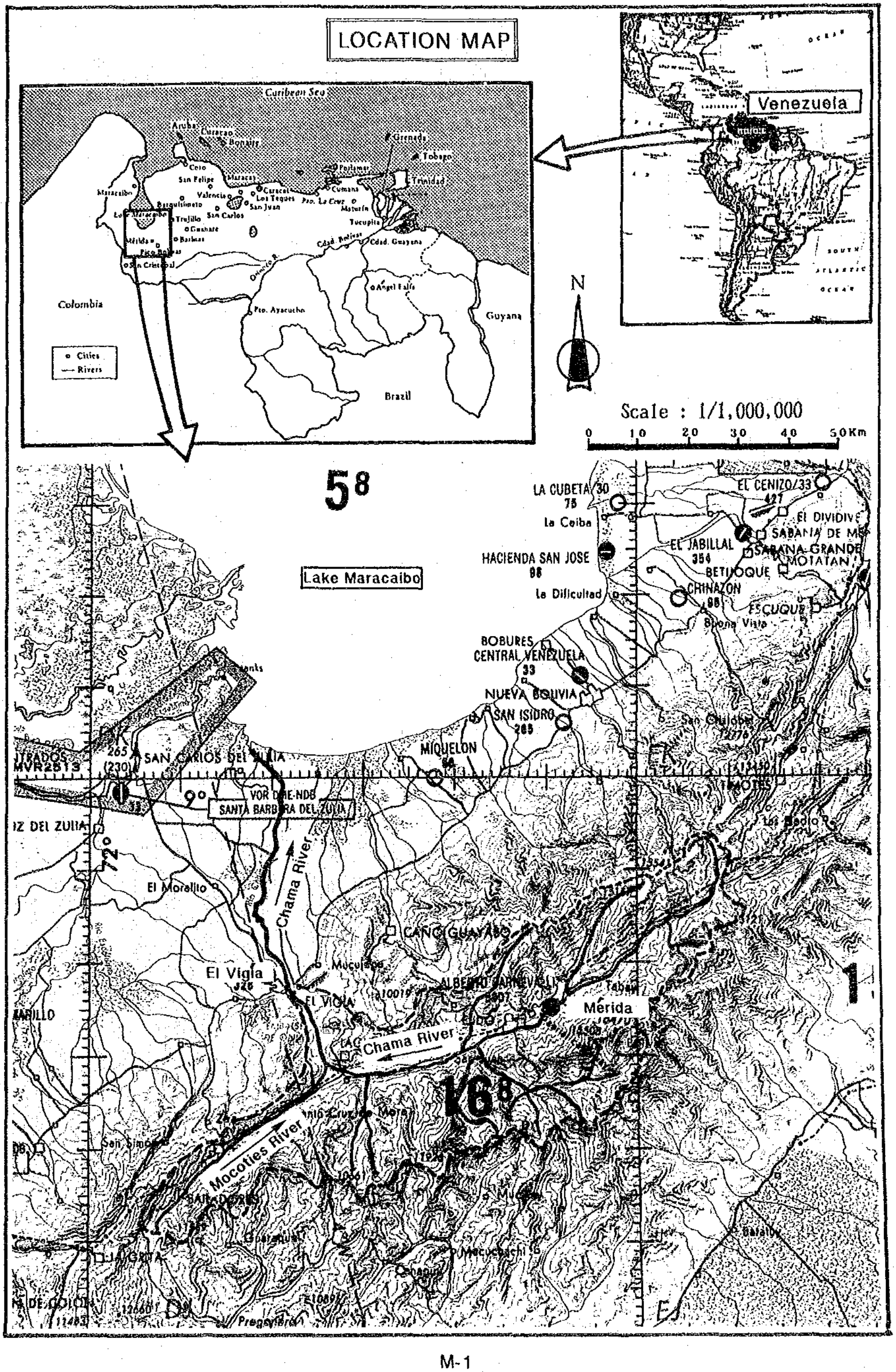
We are pleased to submit herewith the Final Report for the Study on Chama River Basin Conservation Project, which dealt with the formulation of a master plan and an action plan for urgent projects selected within the framework of the master plan, aiming at sediment and erosion control, debris flow control and flood control in the Chama River Basin.

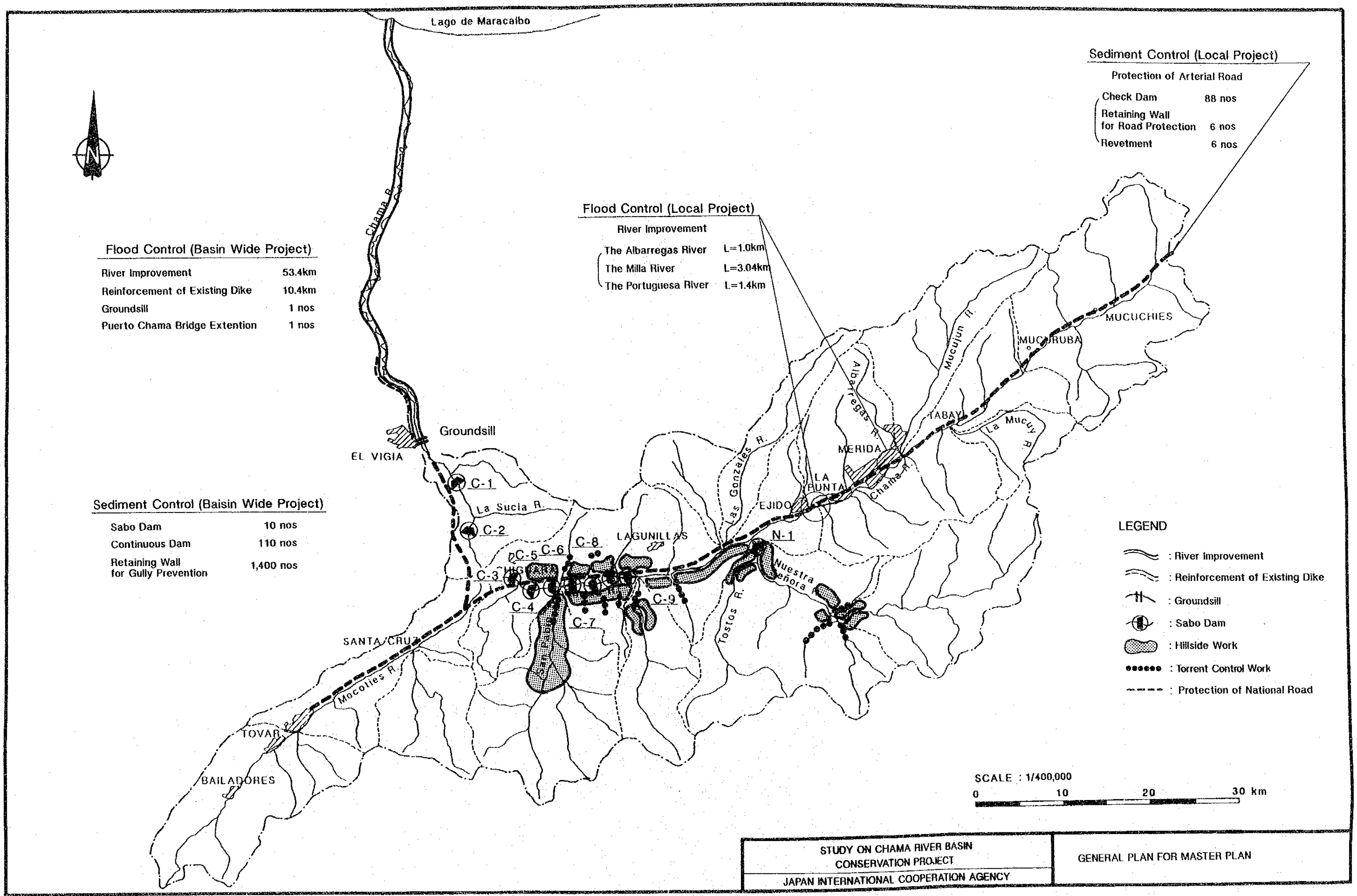
The Final Report consists of four (4) volumes. Volume I is the Main Report presenting the summary of all the study outcomes, details of the project formulation process, conclusion and recommendations. Volume II is the Supporting Report discussing sector-wise technical details. Volume III (Drawings) compiles the related maps and structural drawings, and Volume IV (Data Book) includes site observation records, hydrological data and calculation output.

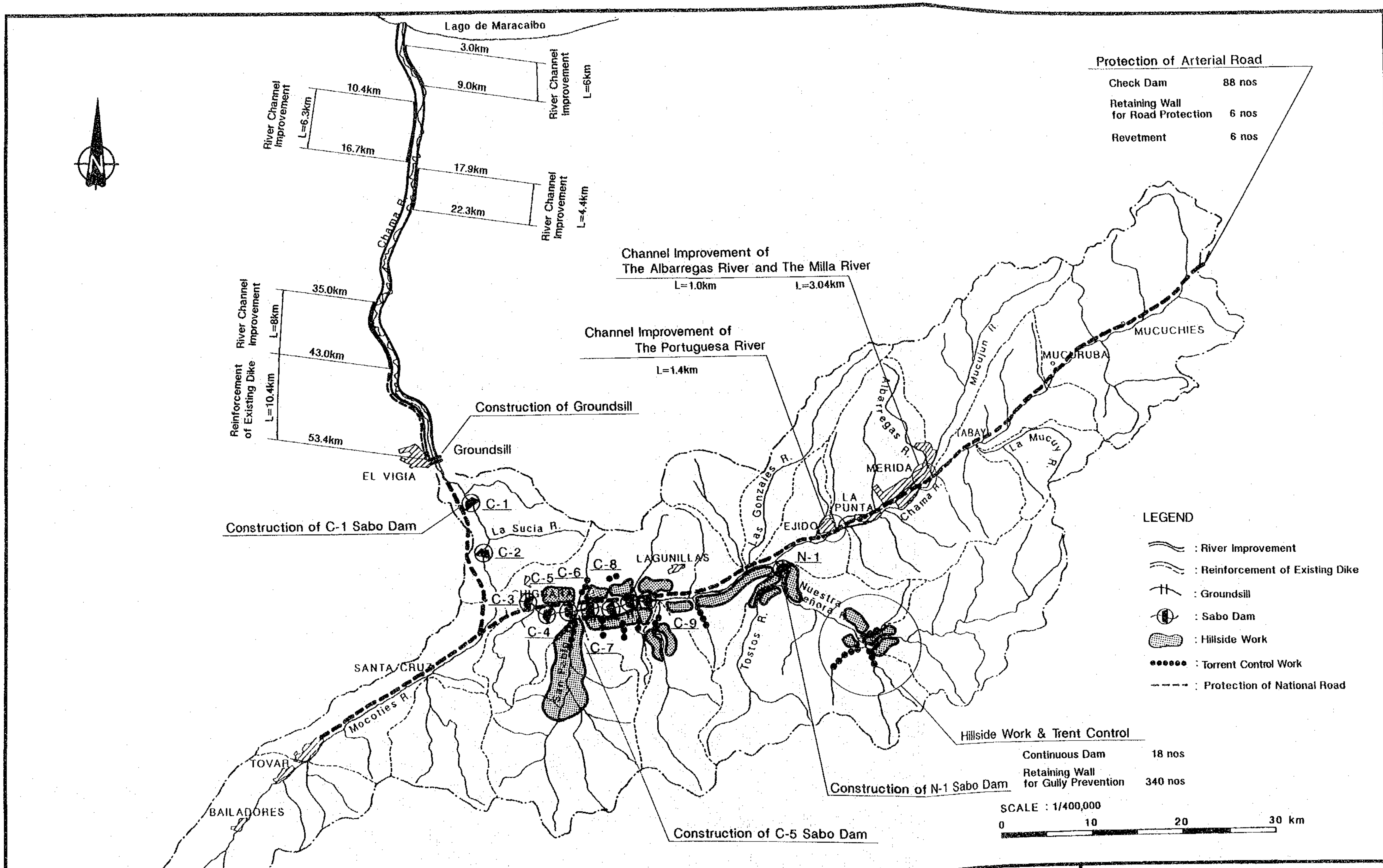
We would like to express our grateful acknowledgement to the officials of the Japan International Cooperation Agency, the Advisory Committee, the Ministry of Foreign Affairs, the Ministry of Construction, the Embassy of Japan in Venezuela, and the officials concerned of the Goverment of Venezuela for their assistance and advice extended to the Study Team. We sincerely hope that the study results would contribute much to the socio-economic development of the Chama River Basin.

Sincerely yours,

MITSUO NAKAHIRO
Team Leader


LOCATION MAP
Venezuela
Caribbean Sea
Colombia
Guyana
Brazil
Cities
Rivers
N
Scale : 1/1,000,000
0 10 20 30 40 50Km
5⁸
Lake Maracaibo
LA CUBETA/30
La Ceiba
HACIENDA SAN JOSE
La Dificultad
EL CENIZO/33
EL JABILLAL
BETIJOQUE
CHINAZON
ESCUQUE
SABANA GRANDE
MOTATAN
BOBURES
CENTRAL VENEZUELA
NUEVA BOLIVIA
SAN ISIDRO
MIQUELON
SAN CARLOS DEL ZULIA
VOR DME-NDB
SANTA BARBARA DEL ZULIA
9°
72°
El Moralito
Chama River
El Vigia
EL VIGIA
Mérida
Chama River
Mocoties River
16⁸
1


Lago de Maracaibo
Chama R.
Groundsill
EL VIGIA
Flood Control (Basin Wide Project)
River Improvement 53.4km
Reinforcement of Existing Dike 10.4km
Groundsill 1 nos
Puerto Chama Bridge Extention 1 nos
Sediment Control (Baisin Wide Project)
Sabo Dam 10 nos
Continuous Dam 110 nos
Retaining Wall for Gully Prevention 1,400 nos
Flood Control (Local Project)
River Improvement
The Albarregas River L=1.0km
The Milla River L=3.04km
The Portuguesa River L=1.4km
Sediment Control (Local Project)
Protection of Arterial Road
Check Dam 88 nos
Retaining Wall for Road Protection 6 nos
Revetment 6 nos
MUCUCHIES
MUCURUBA
Mucujun R.
Albarregas R.
TABAY
La Mucuy R.
MERIDA
LA PUNTA
Chama R.
EJIDO
Las Gonzales R.
LAGUNILLAS
N-1
Nuestra Señora R.
Tostos R.
C-1
C-2
C-3
C-4
C-5
C-6
C-7
C-8
C-9
La Sucia R.
SANTA CRUZ
Mocoties R.
TOVAR
BAILADORES
LEGEND
: River Improvement
: Reinforcement of Existing Dike
: Groundsill
: Sabo Dam
: Hillside Work
: Torrent Control Work
: Protection of National Road
SCALE : 1/400,000
0 10 20 30 km
STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY
GENERAL PLAN FOR MASTER PLAN



STUDY ON CHAMA RIVER BASIN CONSERVATION PROJECT	GENERAL PLAN FOR ACTION PLAN
JAPAN INTERNATIONAL COOPERATION AGENCY	

SUMMARY

1. BACKGROUND OF THE PROJECT

The Chama River Basin has always been suffering from sediment and flood disasters due to its fragile geologic condition. Although the Government of Venezuela has been making efforts through rehabilitation, maintenance and prevention works, the situation has hardly improved, because of the continuing agricultural development and urbanization, and damage is expected to increase in the future. In recognition of the urgent necessity to provide effective countermeasures, the Study on the Chama River Conservation Project has been conceived.

2. OBJECTIVES

The Study aims at the formulation of a master plan and an action plan for urgent projects selected within the framework of the master plan for sediment and erosion control, debris flow control and flood control in the Chama River Basin.

3. PRINCIPLES OF FORMULATION

The master plan of the Chama River Basin Conservation Project is formulated at the target year 2020, while the action plan for urgent projects selected from the master plan is formulated at the target year 2000. The assets to be protected are the following:

- Agricultural land in the lower reaches;
- Arterial road Routes 2 and 7; and
- Urban areas of Mérida and Ejido.

Since there is much difference in size among the planning areas to protect these assets, it is difficult to formulate the disaster prevention plan for each planning area at the same level. For a more objective approach, the river basin conservation project is divided into two sub-projects, namely the basin-wide project and the local project, as presented in the following table. The master and action plans for the sub-projects are formulated separately, but project evaluation is done for both projects as a whole.

Sub-Project	Target Assets	Planning Area	Objective
1. Basin-wide Project	Agricultural Land in the Lower Reaches	Whole River Basin	Sediment and Flood Control
2. Local Project	Routes 2 & 7 of Arterial Road	Stream and Slope	Sediment Control
	Urban Areas of Mérida & Ejido	Stream	Flood Control

4. MASTER PLAN

4.1 Project Formulation

The master plan is composed of sediment and flood control works. The design conditions and optimum plans are as summarized hereinafter.

4.1.1 Basin-Wide Project

Sediment Control

The design annual sediment discharge at El Vigía is 9,600,000 m^3 consisting of sediment inflow of 5,850,000 m^3 and channel erosion of 3,750,000 m^3. The design sediment discharge of 9,600,000 m^3/year is allotted to the respective control structures, i.e., 2,580,000 m^3/year of sediment regulation and 3,750,000 m^3/year of erosion control by ten sabo dams, 1,150,000 m^3/year of production control by torrent control and hillside works, and 2,120,000 m^3/year of transportation by river improvement.

From the rate of sediment production by torrents and slope erosions, the work quantities of torrent and hillside works were estimated at 110 sites for torrents works consisting of continuous low dams and 1,400 sites for hillside works.

Flood Control

The design discharge for the downstream of the Chama River is determined at 2,300 m3/s corresponding to a 100-year return period which will be controlled by river improvement works.

A new alignment and longitudinal profile is designed for the downstream portion of about 53.4 km along the center line of the meandering portion of the present river course. The cross section is of a single section type with a width of 600 m.

The main work items of river improvement consist of excavation of the riverbed, construction of dike, revetment, groin and groundsill, and extension of the Puerto Chama Bridge.

4.1.2 Local Project

Sediment Control

Disasters brought about by sedimentation occur along arterial road Routes 2 and 7. Debris and sediment flow, slope failure and channel bank erosion are often seen along these roads.

Potential sediment disaster sites were identified at 170 locations. About 100 of these sites are vulnerable to the design rainfall of a 100-year return period. The disaster prevention works were selected depending on the type of sediment disaster, as follows:

- Debris/Sediment Flow : Check Dam
- Slope Failure : Retaining Wall
- Bank Erosion : Revetment/Wall

Flood Control

The flood control plan for the inundation areas at Mérida and Ejido along the Albarregas, the Milla and the Portuguesa rivers was formulated by employing river channel improvement of 1,000 m, 3,040 m and 1,400 m, respectively.

4.2 Construction Schedule

The master plan consisting of the basin-wide and local projects is scheduled to be completed at the target year 2020. In view of their significance, the local project shall be implemented simultaneously with the basin-wide project. The construction schedule of both the basin-wide and the local projects was determined according to project priorities in consideration of technical, social and economic feasibility.

4.3 Project Cost

The project cost consisting of direct cost, cost for land acquisition, administration and engineering services, and physical contingency was estimated at the price level of January 1989. The project costs for both sub-projects are as follows.

Basin-Wide Project	:	3,503 million bolivares
Local Project	:	48 million bolivares
Total	:	3,551 million bolivares

4.4 Project Evaluation

The annual average benefit was estimated at 231 million bolivares at the year 2020 onwards, considering the future land use in the possible inundation area and the increase of traffic volume on the arterial road Routes 2 and 7.

The economic viability of the master plan was assessed using three indicators, i.e., internal rate of return (IRR), cost-benefit ratio (B/C), and net present value (NPV); a discount rate of 8% per annum was applied for the calculation of the latter two indicators. The economic viability was thus figured out, as follows:

Internal Rate of Return	:	10.7%
Cost-Benefit Ratio	:	1.22
Net Present Value	:	244.22 million bolivares

Justification for infrastructure projects is generally based on economic viability. The master plan has a high IRR, and other indicators also show high values. From the economic viewpoint, the master plan is justifiably viable for implementation.

5. ACTION PLAN

5.1 Project Formulation

The action plan for the urgent project was formulated within the framework of the master plan by narrowing down the project components to those included in the first 10-year construction schedule which can be realized within the target year 2000. These components were given top priority from the technical and economical aspects as urgently required against sediment and flood disasters in the Chama River Basin.

5.1.1 Basin-wide Project

<u>Sediment Control</u>

Sediment control works in the action plan were selected to cover one-third of the required works for the master plan. These consist of three sabo dams (C-1, C-5 and N-1); 18 continuous low dams; and 340 retaining walls. Among the applicable structures and materials, the gravity type of rubble concrete was selected for C-1 and N-1 dams, while sabo dam C-5 proposed on the Bocono fault is of steel frame type. The gravity type of wet masonry was adopted for all continuous low dams and retaining walls.

<u>Flood Control</u>

The flood control plan was formulated at the project scale of a 10-year return period flood to facilitate project realization. Partial river improvement by one-side embankment of a 24.7 km stretch with the river width of 600 m will be carried out, together with the reinforcement of 10.4 km of the existing dike. In this connection, earth materials obtainable from the construction sites are applicable for the dike.

To protect the dike from erosion, groin of gabion cylinder was selected for the section with high current velocity and revetment of wet masonry for the water colliding front. In addition, a groundsill by gravity type of rubble concrete is proposed to prevent scouring of the riverbed in the vicinity of the foundation of the Chama Bridge.

5.1.2 Local Project

Sediment Control

To protect the arterial roads from sediment disasters, the sediment control plan with the project scale of a 100-year return period was formulated, corresponding to the same work volume as the master plan. Through the comparative study to select the optimum type of sediment control structures consisting of 88 check dams, 6 retaining walls and 6 revetments, the gravity type with wet masonry was selected.

Flood Control

In consideration of the volume of work and cost, the contents of the flood control project in the master plan were adopted for the action plan in the form of excavation, embankment and widening. These projects are the river improvement of 1.0 km stretch for the Albarregas River, 3.04 km for the Milla River, and 1.4 km for the Portuguesa River.

5.2 Construction Schedule

The action plan is scheduled to be completed at the target year 2000, in accordance with the priority given by the study on technical, social and economical aspects.

5.3 Project Cost

As in the master plan, the project cost of the action plan was estimated at the price level of January 1989. The project costs of both sub-projects are as follows.

- Basin-wide Project	1,055 million bolivares
- Local Project	48 million bolivares
Total	1,103 million bolivares

5.4 Project Evaluation

The annual average benefit was estimated at 126 million bolívares at the year 2000 onwards in the same manner as the master plan, considering the future land use and increase of traffic volume. The economic viability of the action plan was figured out under the following indicators which show that the action plan has a high economic feasibility for implementation.

Internal Rate of Return	:	13.2%
Cost-Benefit Ratio	:	1.58
Net Present Value	:	346.5 million bolívares

5.5 Non-Structural Measures

Non-structural measures can be used to mitigate sediment and flood disasters until the time when the structural measures are completed. They may also be used as supplementary measures even after completion of the structural measures. For the Chama River Basin, the following are selected as the applicable non-structural measures:

- Land use regulation to control the disorderly development in the basin;

- Flood forecasting and warning system; and

- Consolidation of management of river structures and flood fighting.

6. CONCLUSION AND RECOMMENDATIONS

The master plan for the Chama River Basin Conservation Project, consisting of sediment and flood control works, was formulated at the target year 2020. Within the framework of this master plan, the action plan for urgent projects selected from the components of the master plan was formulated at the target year 2000, aiming at early realization of such projects.

The results of the study show that the action plan is technically sound, financially viable and economically feasible with the internal rate of return (IRR) of 13.2%, and the realization of the project will give favorable impacts to society. Therefore, it is strongly recommended that the project be promoted to the detailed design and construction stages at the earliest possible opportunity.

Since it may be difficult to implement the action plan with only the currently allocated budget of the MARNR, a special fund or a loan from an international financing agency is needed. In this connection, it is recommended that the necessary arrangements be made by the Venezuelan government with the establishment of a committee for this purpose.

PROJECT FEATURES

1. MASTER PLAN

1.1 Basin-Wide Project

Sediment Control

(a) Design Sediment

- Project Sediment Discharge : 9,600,000 m^3/year
- Allowable Sediment Discharge : 2,120,000 m^3/year
- Design Sediment Discharge : 7,480,000 m^3/year

°Discharge Retention : 3,750,000 m^3/year
°Regulation : 2,580,000 m^3/year
°Production Control : 1,150,000 m^3/year

(b) Control Structures

- 10 Sabo Dams for Discharge Retention and Regulation : C-1, C-2 and N-1 (rubble concrete); C-3 to C-9 (steel frame)

No.	Dam Name	Height (m)	Length (m)		Dam Volume (m^3)	Capacity (10^3m^3)
			Top	Bottom		
1	C-1	22	170	100	62,500	6,830
2	C-2	22	120	60	40,500	3,520
3	C-3	11	150	80	17,100	1,620
4	C-4	11	200	150	27,000	2,540
5	C-5	9	230	70	14,600	1,510
6	C-6	11	200	130	25,100	2,330
7	C-7	11	200	100	22,000	2,190
8	C-8	11	150	80	17,100	1,510
9	C-9	11	250	120	27,200	2,090
10	N-1	22	180	120	65,000	1,350

- 110 Torrent Control Works : Low Continuous Dam, Wet Masonry
- 1,400 Hillside Works : Retaining Wall, Wet Masonry

Subbasin Number	Name of Tributary	No. of Low Dam Sites	No. of Retaining Walls
8	Upper Nuestra Señora	18	230
9	Lower Nuestra Señora	9	110
12	Arbolote, etc.	15	190
13	La Vizcaína	6	80
14	Maruchi, El Molino, El Anis	14	180
15	La Joya, etc.	18	230
16	San Pablo	30	380
Total		110	1,400

Flood Control

(1) Design Flood

- Project Scale : 100-year return period

- Design Peak Discharge : 2,300 m^3/s

(2) Flood Control Measure

- Improvement of River Channel : 53.4 km (total)

(3) Structures and Works

- Improvement of River Channel

°Alignment and Longitudinal Profile : Along the center line of meandering of present river course.

°Standard Cross Section : Single Cross Section; Width: 600 m

- Excavation : 1.1×10^6 m^3 for reforming remarkable meandering.

- Dike; Earth Embankment : 3,993,000 m^3 (total)
  Slope : 1:2.0
  Maintenance Road : Width: 3 m
  Gravel Pavement: 64,100 m^3

- Revetment : Wet Masonry: 30,800 m

- Groin : Gabion Cylinder; L=10 m; 1,370 nos. in total

- Groundsill : 1 unit at Chama Bridge; Rubble Concrete

- Extension of Puerto Chama Bridge : L=480 m

1.2 Local Project

<u>Sediment Control</u>

- Protection of Trunk Road

°Debris/Sediment Flow	:	88 sites; Check Dam, Gravity Type of Wet Masonry
°Slope Failure	:	6 sites; Retaining Wall of Wet Masonry
°Bank Erosion	:	6 sites; Revetment of Wet Masonry

<u>Flood Control</u>

- Improvement of Rivers in the Urban Area

Particulars	Albarregas River	Portuguesa River	Milla River
Project Scale (Return Period)	100-year	100-year	50-year
Design Discharge (m^3/s)	180	130	60
Improvement Stretch (m)	1,000	1,400	3,040
Improvement Method	Embankment	Widening & Excavation	Excavation
Standard Cross-Section			
Width (m)	6	5	-
Height (m)	3.5	2.5	-

2. ACTION PLAN

2.1 Basin-wide Project

<u>Sediment Control</u>

(1) Sabo Dam

- Three Sabo Dams : C-1, C-5 and N-1

Item No.	Dam Site	Height (m)	Length (m) Top	Length (m) Bottom	Type	Material
1	C-1	22	170	100	Gravity	Rubble Concrete
2	C-5	9	230	70	Steel frame	Steel and Gravel
3	N-1	22	180	120	Gravity	Rubble Concrete

(2) Torrent Works

- 18 Continuous Low Dams for 3 torrents : Mucusás (10), Mucusós (3), and Mucusurú (5); Gravity Type of Wet Masonry

(3) Hillside Works

- 340 Retaining Walls : Gravity Type of Wet Masonry

Sub-basin Number	Name of Tributary	No. of Retaining Wall
8	Upper Nuestra Señora	230
9	Lower Nuestra Señora	110

Flood Control

(1) Design Flood

- Project Scale : 10-year return period
- Design Peak Discharge : 1,450 m^3/s

(2) River Improvement

- Embankment : 24.7 km in total for one-side bank, with a river width of 600 m
- Reinforcement of Existing Dike : 10.4 km

(3) Structure and Works

- Dike; Earth Embankment : 745,000 m^3
  Slope : 1:2.0
  Maintenance Road : 3 m in width

- Excavation : 664,000 m^3
- Revetment : Wet Masonry; 10,300 m
- Groin : Gabion Cylinder; 325 in number
- Groundsill : 1 unit at Chama Bridge; Rubble Concrete

2.2 Local Project

Sediment Control

(1) Structure and Works

- Check Dam : Gravity Type of Wet Masonry, 88 in number
- Retaining Wall : Wet Masonry; 6 in number
- Revetment : Wet Masonry; 6 in number

Flood Control

- Improvement of Rivers in the Urban Area

Particulars	Albarregas River	Portuguesa River	Milla River
Project Scale (Return Period)	100-year	100-year	50-year
Design Discharge (m^3/s)	180	130	60
Improvement Stretch (m)	1,000	1,400	3,040
Improvement Method	Embankment	Widening & Excavation	Excavation
Standard Cross-Section			
Width (m)	6	5	-
Height (m)	3.5	2.5	-

TABLE OF CONTENTS

Page

Page

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND GLOSSARY

Organizations and Institutions

1. MARNR	=	Ministerio del Ambiente y de los Recursos Naturales Renovables (Ministry of Environment and Natural Resources)
2. MTC	=	Ministerio de Transporte y Communicaciones (Ministry of Transportation and Communications)
3. MINDUR	=	Ministerio de Desarrollo Urbano (Ministry of Urban Development)
4. MOP	=	Ministerio de Obras Publicas (Ministry of Public Works)
5. MAC	=	Ministerio de Agricultura y Cria (Ministry of Agriculture and Breeding Activities)
6. MINAS	=	Ministerio de Energia y Minas (Ministry of Energy and Mining)
7. CORPOANDES	=	Corporacion de los Andes (The Andes Corporation)
8. DEFENSA CIVIL	=	Defensa Civil (Civil Defense)
9. ULA	=	Universidad de los Andes (University of the Andes)
10. IFLA	=	Instituto Forestal Latino Americano (Institute of Latin American Forest)
11. JICA	=	Japan International Cooperation Agency (Agencia de Cooperacion Internacional de Japon)
12. BID	=	Banco Inter-Americano de Desarrollo (Inter-American Development Bank)
13. BCV	=	Banco Central de Venezuela (Central Bank of Venezuela)
14. CIDIAT	=	Centro Inter-Americano de Desarrollo Integral de Aguas y Tierras (Center of Inter-American Integrated Development of Water and Land Resources)
15. INOS	=	Instituto Nacional de Obras Sanitarias (National Institute of Sanitary Works)
16. OCEI	=	Oficina Central de Estadisticas y Informacion (Central Office of Statistics and Information)
17. CORDIPLAN	=	Central Office of Coordination and Planning (Oficina Central de Coordinacion y Planificacion)

ABBREVIATIONS AND GLOSSARY

Length

mm	=	millimeter
cm	=	centimeter
m	=	meter
km	=	kilometer

Area

ha	=	hectare
km^2	=	square kilometer

Volume

m^3	=	cubic meter
mcm	=	million cubic meter

Currency

Bs.	=	Venezuelan Bolivar(es)
US$	=	United States Dollar(s)

Weight

g	=	gram
kg	=	kilogram
t	=	ton

Time

sec, s	=	second
min, m	=	minute
hr, h	=	hour

Combined Measurement

m^3/s	=	cubic meter per second
t/d	=	ton per day

Others

GDP	=	Gross Domestic Product
GNP	=	Gross National Product
GRP	=	Gross Regional Product

CHAPTER 1. INTRODUCTION

1.1 Background of the Project

The Chama River rises at an altitude of about EL 4,400 m in Piedras Blancas in northwestern Venezuela. It flows for some 110 km along the Andes Range, the highest mountain system in the country, and after flowing through a flat terrain, it pours into the Maracaibo Lake. The total catchment area of the Chama River is 3,785 km^2.

The Chama River Basin is favored with a variety of climatic conditions and subsequent land use. The upper and middle reaches under arctic, temperate and tropical climate are enjoying the agricultural production of maize, potato, carrots and other crops; while, the lower reaches under a tropical climate are mainly occupied by plantain plantations and pastures.

Administratively, the basin belongs to the states of Mérida and Zulia. Three cities are located; namely, Mérida, the capital of the state of Mérida, El Vigía, and Tabay. The basin has a population of 500,000 as of 1987, and the cities of Mérida, El Vigía and Tabay have 216,000, 46,000 and 24,000, respectively.

The basin has a mountainous topography with a fragile geologic condition. Heavy rainfalls bring about serious sediment and flood disasters on houses and household effects, infrastructures and agriculture, causing much inconvenience to transportation with a debilitating effect on social and economic activities.

The Government of Venezuela has been carrying out rehabilitation, maintenance and prevention works to cope with such disasters. However, the situation has hardly been improved because of the continuing agricultural development and urbanization. Damage is then expected to increase in the future.

Under the above circumstances, the necessity of providing effective countermeasures has been recognized, and this Study has been conceived.

1.2 Outline of the Study

1.2.1 Objective

The Study aims at the formulation of a master plan and an action plan for urgent projects selected within the framework of the master plan for sediment and erosion control, debris flow control and flood control in the Chama River Basin.

1.2.2 Study Area

The Study Area is the entire Chama River Basin with an area of 3,785 km^2.

1.2.3 Scope of Work

The scope of work of the Study is as follows.

<u>Collection and Review of Existing Data</u>

- Topography and geology;
- Meteorology and hydrology;
- Land use and water use;
- Sedimentation and water quality;
- Existing facilities related to flood, sediment and erosion control;
- Damages by flood, erosion and sedimentation;
- Existing plan or study of disaster prevention works;
- Administrative and socioeconomic conditions; and
- Others, if any.

<u>Field Survey</u>

- Survey on past damages caused by flood, debris flow and slope failure;
- River survey; and
- Hydrological observation.

Study and Analysis

- Hydrological and hydraulic analysis;
- Study on sediment and discharge;
- Study on river flow capacity and probable flood inundation area;
- Study on flood damage rate; and
- Others, if any.

Formulation of Master Plan

(1) Sediment and erosion control plan, debris flow control plan and flood control plan.

  - Setting up a basic concept;
  - Basic layout of structures;
  - Preliminary design of major structures;
  - Operation and maintenance program and organization;
  - Economic evaluation and financial plan;
  - Implementation program and cost estimation;
  - Forecasting and warning system; and
  - Socioeconomic impact.

(2) Identification of the priority area.

(3) Recommendation of urgent projects.

Formulation of Action Plan for Recommended Urgent Project

- Preliminary design;
- Operation and maintenance plan;
- Cost estimation and implementation schedule;
- Evaluation of the project; and
- Evaluation on social and environmental impact.

1.2.4 Study and Staffing Schedules

The Study has been carried out in accordance with the schedule shown in Fig. 1.2-1. The staffing schedule is presented in Fig. 1.2-2.

CHAPTER 2. PRESENT CONDITION OF THE STUDY AREA

2.1 Topography and Geology

2.1.1 Topography

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 Range that is generally called the Venezuelan Andes. A graben formed by many fault structures extends on a northeast-southwest direction at the center of 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 for 10 km southward through the U-shaped valley formed by glaciers, and reaches 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. A tributary, the Mocoties River, extends northeastward to Estánquez running for about 40 km and 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. From El Vigía to the downstream, it flows northward for about 73 km into the Maracaibo Lake, forming an alluvial fan and a delta.

The longitudinal profile of the Chama River and major tributaries (Fig. 2.1-1) 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.

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.

Topographical Condition

The topographical map of the basin is presented in Fig. 2.1-2. The Mérida mountains is divided into two mountain ranges by the graben. 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.

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.

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. On both banks, especially the right bank of the middle reaches of the Chama River between Tabay and Estánquez, river terraces have developed with steep cliffs of 100 to 200 m high.

2.1.2 Geology

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 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.

The Bocono fault is a large and significant active fault. It is a right-strike-slip fault with dip-slip, and runs for about 450 km long in

NE-SW direction. 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.

Geological Formation

The geology of the Chama River Basin contains all geological ages from the Pre-Cambrian Era to the Cenozoic Era. The geological map of the Chama River Basin is presented in Fig. 2.1-3; a cross section is shown in Fig. 2.1-4.

The formations of the Cenozoic Quaternary Period are composed of unconsolidated sedimentary layers such as glacial deposits, talus deposits, terrace deposits, alluvial river deposits, etc. On the other hand, the formations of the Tertiary Period are composed of sedimentary rocks such as sandstone, clay stone, 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, silt stone 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, silt stone and others, without metamorphic rocks. However, the Carboniferous Mucuchachi formation which is the lowest formation of the Paleozoic Era, 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 Mocoties River. The slate in this formation has a strong fissility, therefore, gully erosions and rockfalls are seen in many places.

The Pre-Cambrian formations consist of the Tostós and the Sierra Nevada formations. These formations are made up of metemorphic rocks such as slate, phyllite, schist and gneiss. 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.

2.1.3 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) the presence of faults, (2) the fissility of rocks, (3) the artificial causes such as road construction and livestock breeding, and (4) the lack of vegetation due to climatic condition.

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, the supply of sediment to rivers is caused mainly by rockfalls and gully erosions. Most of the sediments remain at the slopes of mountains, but they flow gradually into the rivers.

Table 2.1-1 gives the record of slope failure and debris flow in the Chama River Basin. Some of them are supposed to be unstable at present but have the possibility to inflict serious damage to the structures in the future.

2.2 Meteorology and Hydrology

2.2.1 General Meteorology

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

In accordance with the month-to-month distribution of rainfall influenced by the aforesaid large-scale circulations, two generic precipitation patterns occur. These are (1) the Llanos Pattern which has a single maximum occurrence, and (2) the Semi-Annual Pattern which completes the two cycles of wet and dry seasons during the year.

The Llanos Pattern is a characteristic of the entire central part of Venezuela, while the Semi-Annual Pattern is mostly prevalent over the coastal areas and also at elevations above 1,000 m where the mountain climate type is expected. The valley of the Chama River is mostly under the Semi-Annual Pattern, however, the uppermost basin, with Mucuchíes in the center, enjoys the Llanos Pattern with an influence from inland Venezuela.

The annual mean temperature in the most upstream area at Mucuchíes is 11.3°C, while it is 19.0°C at Mérida Aeropuerto. In the lower reaches, the annual mean temperature at El Vigía is relatively high at 27.9°C. The difference between the daily maximum and minimum temperature is large at about 10°C for all the stations. Annual evaporation rate at San Juan de Lagunillas in the semi-arid zone was recorded at 2,008 mm, while that at Tovar was only 1,248 mm.

2.2.2 Annual and Monthly Rainfall

The annual rainfall amount is quite different among the various areas in the basin. As illustrated by the isohyetal map in Fig. 2.2-1, the semi-arid zone, an area with about 600 mm rainfall, stretches from the confluence between the Chama and La Vizcaína rivers to El Morro in the Nuestra Señora River Basin.

The middle reaches which is situated upstream of the semi-arid zone and the Mocotíes River Basin enjoy higher annual rainfalls in the basin, reaching to 1,800 mm. The uppermost stream areas of the Chama River Basin have moderate rainfalls varying from 800 to 1,000 mm. The downstream of El Vigía receives much rainfall amounting to more than 2,100 mm. The annual average rainfall at the entire Chama River Basin is 1,030 mm.

The annual rainfall patterns at major stations in the basin are presented in Fig. 2.2-2. Páramo de Mucuchíes, the most upstream area, presents a single maximum in July and August, while the other stations have two peaks, in May and October at Mérida and in April and November at El Vigía. At San Juan de Lagunillas, in the middle reaches, the monthly rainfalls are small at about 80 mm even in the rainy season in April, May, October and November.

2.2.3 River Discharge

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

The annual average flow of the Chama River is 24.0 m^3/s (2.1 $m^3/s/100\ km^2$, runoff height of 670 mm) at Ejido and 5.12 m^3/s (1.4 $m^3/s/100\ km^2$, runoff height of 440 mm) at Mucurubá.

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

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

2.3 Sedimentation

2.3.1 Sediment Production Source

Erosion

Data sampling was carried out on river topography, geologic conditions, vegetation, sediment characteristics and sediment volume, at 11 sites on five major tributaries; namely, the Mucujún, La Mucuy, the Nuestra Señora, La González and the Mocotíes rivers. The results of the survey are summarized in Table 2.3-1 and the survey locations are as shown in Fig. 2.3-1.

The Mucujún River Basin is generally covered by thick and high forests and the channels of its streams are stable. Gullies and rills are rare and no slide nor glide was observed. At the site of sampling, the riverbed is covered with boulders and gravels of 200 cm at maximum and 30 cm on an average. The river bank is formed with old debris deposits.

The riverbed at the sampling sites of La Mucuy and a tributary, the Desbarrancadero River, consists of debris flow formed in the olden times and small scale secondary erosions are common occurrences. Gully erosions on the debris flow lobes are rare.

The Nuestra Señora River Basin is covered with only a sparse forest, grass and occasionally, with farm lands. Gullies are developing and hence gully erosions play a significant role in the production of sediment. The Mucusurú River, a tributary of the Nuestra Señora, is heavily loaded with sediment produced mainly by gully erosions along the river channel. Around the sampling sites, many gullies and gliding slopes causing deposition in the channel were observed.

La González River Basin has two distinct vegetation covers. The upstream area is covered with thick and high forests, while the downstream area, particularly around the confluence of La Gonzalez River with the Chama River, has only a sparse forest, grass and cactuses. Comparing the grain size of riverbed materials in the lower stream to that in the upper stream, it was determined that the 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 is relatively free from gully erosion due to the thick vegetation cover.

The Mocotíes River Basin is covered with a very dense and high forest. Except the artificial causes of erosion such as agricultural practices, urbanization and road construction, only small erosions take place. At the sampling sites on the tributaries Tabacal and Casiguito, channel erosions were observed. These are mainly because of the down-cutting and side erosion by flood flow where debris flow has once taken place. Although sediment deposits were observed, the volume was rather small.

Mass Wasting

Eleven sites for the survey on mass wasting were selected from the upstream areas of La Sucia (Chiguara), La Portuguesa and La González rivers, 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. The results of the survey are summarized in Table 2.3-2.

Two large-scale landslides were identified in the uppermost stream area of La Sucia River, in the vicinity of El Guamo. The area is covered by a dense and high forest and is geologically formed with meta-black shale. 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 may be gradually conveyed to La Sucia River and to the Chama mainstream.

There are two landslides identified along the trunk road from Mérida to Jají in the upstream area of La González and La Portuguesa rivers. The area is also covered with a dense and high forest and the bedrock is mainly composed of granitic sandstone. Although topography around the area shows many traces of landslide in the olden times, many of them are now rather stable covered with forest and grasses. The debris volume produced by the landslides is estimated at approx. 4,500 m^3 and 20,500 m^3 for La González and La Portuguesa rivers, respectively.

There are totally seven large-scale mass wastings along the Chama River, all located inside the semi-arid zone. Three among the seven are classified into debris flow lobe and levee, while the other four are slope glides.

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. Furthermore, 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 along the Chama River which are located at González, S. Onofre, Higuerones and Pte. Viejo, three debris flows (except at Pte. Viejo) occurred due to the heavy rainfall 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.

Rockfall Materials

Rockfall zones are mainly distributed in the middle reaches of the Chama River Basin. Sampling for rockfall materials was carried out along the Nuestra Señora, the San Pablo and La Vizcaína rivers, and the main stream of the Chama River (locations are in Fig. 2.3-2) where sediment production due to slope erosion was predominantly observed through the field investigation.

Grain size accumulation curves of the sampled materials are given in Fig. 2.3-3. The mean diameter of grain size at the R-1 site in the Nuestra Señora River is estimated at 13.1 mm, while those at the San Pablo and La Vizcaína rivers are 9.1 mm at the R-3 site and 6.2 mm at the R-2 site, respectively. Rockfall materials are mainly composed of sand and gravels; especially, the sand component occupies more than 60% of rockfall materials in the San Pablo and La Vizcaína rivers.

2.3.2 Riverbed Sediment

To understand the characteristics of riverbed sediment, the riverbed material and sediment deposit in the alluvial fan were sampled and analyzed as follows.

Riverbed Materials

The sampling was made at a total of 18 sites and their locations are shown in sequence as B-1 to B-18 from the upstream site in Fig. 2.3-4. Typical grain size accumulation curves for the Chama and the Nuestra Señora rivers are given in Figs. 2.3-5 and 2.3-6.

Riverbed materials of 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 of coarse materials; the sand component increases gradually 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 mean diameter of grain size at the B-1 site is estimated at 116 mm. Those at the middle and the 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.

Armor coats usually cover the Chama riverbed. The grain size of armor coat materials is generally bigger than those of the riverbed materials. The armor coat is usually composed of coarse materials, because fine sediment is transported to the downstream and the coarse sediment remains.

Sediment in the Alluvial Fan

The alluvial fan materials were sampled at two sites as shown in Fig. 2.3-2. As shown in Fig. 2.3-7 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 materials and the alluvial fan materials are composed of sand.

The field investigation was conducted in the downstream area of El Vigía, together with the sampling mentioned above, with the following observations.

- Coarse sand and fine gravels of about 10 mm in grain size are predominant from El Vigía to Los Naranjos.
- Height of the bank is 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 river mouth.

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

2.3.3 Suspended Load and Reservoir Deposit

Suspended Load Materials

The sampling of suspended load materials was made to measure the concentration of suspended sediment at the Mucurubá Hydrological Station and the Puerto Chama Bridge where the measurement of suspended load materials has been periodically conducted by the MARNR. The records at these two stations, together with the data obtained through this sampling survey, were plotted as given in Figs. 2.3-8 and 2.3-9.

Through the correlation analysis, the suspended load rating curves which express the relationship between sediment discharge and water discharge were constructed as expressed below:

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

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

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

Q : water discharge (m^3/sec)

With the use of the above rating curves, the annual sediment discharges were calculated for 9 years from 1967 to 1975 when the daily discharge data are available. 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 with a catchment area of about 302 km^2 was constructed on the Onia River in 1973 and has been in operation under the MARNR. The Onia dam basin is adjacently located in the north of the Mocotíes River Basin.

Through the field investigation, it was found that in about 10 years the reservoir had already deposited in the planned sediment space for 50 years and that the surface level of deposited sediment is now over the designated design water level.

The annual sediment yield of the reservoir is estimated on the basis of the deposited condition of the reservoir at about 1.0×10^6 m^3 and the average specific annual sediment yield is estimated to be about 3,300 m^3/km^2/year.

2.3.4 Sediment Deposition in the Lower Reaches

Alluvial Fan

An alluvial fan is a deposit of predominantly coarse sediments ranging from gravel to sand. The alluvial fan is formed in the lower reaches of the Chama River downstream of El Vigía. The deposited volume in the alluvial fan was preliminarily 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 in about 12 km of river reaches between El Vigía and Los Naranjos. On the basis of the comparison the riverbed elevation in the lower reaches of the Chama River has increased at 0.8 m on the average in a period of 12 years. Assuming that the fan area extends from 50 to 90 km^2, the total sediment volume deposited over the fan is estimated at 40 to 72×10^6 m^3. Therefore, the annual sediment deposit is estimated at 3.3 to 6×10^6 m^3.

River Mouth

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. The expanded sand bar has a sediment volume of approx. 38×10^6 m^3, taking into account the portion under the lakewater stage. The annual sediment volume deposited at the estuary is estimated at 12×10^6 m^3.

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

2.3.5 Sediment Transportation and Deposition Mechanism

In view of the survey results presented above, the Chama River and tributaries can be 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 stream channels of major tributaries such as the Mucujún, La Mucuy, the Mocotíes, the Albarregas, La González and the Nuestra Señora rivers are also categorized under this section. These rivers have steep bed gradients of more than 1:50, and maximum river widths are around 10 m. Armor coats are usually formed over the riverbed.

Sediment Semi-deposition Section

This section is located at the middle reaches of the Chama main channel from the confluence with the Mucujún 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 downstream.

The sediment deposition 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 temporarily deposited sediment in the river channel become a source of secondary sediment production to be re-eroded. In addition, bank erosions occur resulting in new sediment production.

Sediment Deposition Section

This section is located in the lower reaches of the Chama River from El Vigía. Sediment transported from this section is deposited over the widely spreading alluvial fan.

Riverbed materials consist of fine sand, silt and clay. Since the sediment transport capacity is poor, the riverbed tends to aggrade when the sediments conveyed from the upper reaches during floods exceed the transport capacity.

2.4 River Condition

2.4.1 Condition of River Channel

Upper and Middle Reaches

In the upper reaches from Tabay, the Chama river course and its longitudinal profile are stable. The river channel running down the steep and narrow valley has a sufficient flow capacity, except at points where bridges cross the channel or where the elevation of the road running along the river is relatively low.

In the middle reaches from Tabay to Estánquez, the Chama river channel is wide at about 200-300 m. The river course and its longitudinal profile are unstable due to the supply of sediment from the tributaries. Bank erosion can be seen at several points, especially on the right bank. The Mocotíes River is stable with favorable vegetation condition at the basin.

Lower Reaches

The Chama River flows out to a flat plain at El Vigía and form an alluvial fan by the sediment supplied from the upper/middle reaches. The river then flows down in an alluvial delta to the Maracaibo Lake. In the lower reaches the following features were deduced from the previous studies, collected data, and interview-survey results.

- The Chama River was once included in the Escalante River system in the 1870s and had sometimes shifted its course developing the alluvial fan.

- In the past 20 years the river has steadily maintained its course with minor changes in the shape of meandering.

- Although the shape of meandering has changed, the features of the meandering such as amplitude and length remain within a certain range of the previous ones. Amplitudes are within 600 m.

- The change of meandering occurred at more than 15 points among about 50 points in 4 years from 1973 to 1977 corresponding to

4 points of the change per year on an average (refer to Fig. 2.4-1).

- Aggradation of the riverbed still continues, which is proven by the fact that the excavated channel in 1985 returned to its previous condition full of sediment before long. The riverbed at the Puerto Chama Bridge has also aggradated.

As for the development of the alluvial fan, the contour line map based on the topographic map in 1968 is shown in Fig. 2.4-2. Fig. 2.4-3 shows the longitudinal profile along the course connecting El Vigía to the river mouth of the Chama River, the river mouth of the Mucujepe River and Sta. Barbara. From these figures, it is deduced that the alluvial fan has been developing downwards from El Vigía, drawing a concentric circle by the counter line.

2.4.2 River Use

In the Chama River Basin, river water is mainly used for irrigation, domestic water supply and also for the trout culture industry.

The irrigation system in the upper and middle reaches can be seen in the hilly land for the cultivation of carrot, maize, cassava and so on. The domestic water supply system has been developed mainly in Mérida and Ejido cities in the middle reaches using the river water from the tributaries such as the Mucujún and Albarregas rivers. Besides, small scale intake facilities with distribution system for irrigation and domestic water supply are seen in the Mocotíes River Basin.

As for water utilization in the lower reaches, river water is not used for irrigation and municipal water. Domestic water is taken from deep wells or the other river system such as the Mucujepe River.

Riverbed materials have been taken for construction purposes from several places in the Chama River Basin, especially in the middle reaches of La Mucuy River. The volume of riverbed materials taken from the lower reaches near El Vigía amounted to 97,500 m^3 in 1985, 100,000 m^3 in 1987 and 200,000 m^3 in 1988.

2.5 Sediment and Flood Disasters, and Prevention Works

2.5.1 Disaster in the Lower Reaches

Historical Floods

Floods have occurred every year in the lower reaches, but those in 1972, 1982 and 1988 were in particular very serious. The flood inundation areas which are indicated in Figs. 2.5-1, 2.5-2 and 2.5-3, were estimated at 7,400, 8,500 and 15,800 ha, respectively, based on the disaster reports and the results of interviews with the residents.

The flood prone areas are (1) the areas downstream of El Vigía City to Los Naranjos, (2) the areas just downstream of Puerto Chama, and (3) the areas downstream of La Fortuna to the river mouth at the Maracaibo Lake. The inundation depth varied between 0.3 and 1.5 meters, but mostly within one meter. The inundation duration also varied from several hours to a few days in the southern area of El Vigía City, while it was around one week in the northern area near the Maracaibo Lake because of the flat terrain.

The lower reaches is mostly covered by the plantain plantations and pastures. The major damaged assets due to inundation are plantains, pastures, livestocks, houses and agricultural machinery. Among them, damage to plantain is extremely serious because of its weakness to inundation. The other assets, on the other hand, suffer no serious flood damage.

Damage

The plantain plantations inundated in the floods of 1972, 1982, and 1988 were estimated at 4,900, 5,900and 8,900 ha, respectively. The damage by the respective floods was estimated from the parameters of the inundation area, production rate (12,000 kg/ha/year), unit price (2.5 Bs/kg), restoration cost (4,200 Bs/ha), and damage rate (50%), and considering that the damage on minor assets and indirect damages are 20% of the direct damage, at 101 million bolívares, 121 million bolívares, and 183 million bolívares, respectively.

2.5.2 Disaster in the Upper/Middle Reaches

Disaster Records

The number of disasters in the upper/middle reaches has been increasing year by year. The serious damage in 1987 and 1988 in the Chama River Basin has been precisely recorded, so that these data have been adopted for the study of past disasters in these reaches.

The locations of disasters in 1987 and 1988 and the remarkable ones in the past are indicated in Fig. 2.5-4, and the damage conditions are presented in Table 2.5-1. With regard to the road disaster, only the damage to arterial roads was picked up because of its significant social impact.

Damage on Road

As mentioned above, road disasters are most common in the upper and middle reaches, and they occur at various places along the Chama River. Road traffic was interrupted for over a week in 1979, but the recent interruptions were settled within one day, and the most common duration was between one and three hours owing to the improvement of road restoration activities.

Road destruction causes interruption or delay in transportation, and the damage by interruption of traffic can be divided into distance damage and time damage. Distance damage is estimated on the basis of traffic volume, traveling distance and traveling cost; while, time damage is estimated from the GRDP, traveling time, traffic volume and average number of commuters. The damage by national road disasters in 1988 was estimated at 1.8 million bolivares, based on the above assumptions.

Other Damages

Flood or debris flow sometimes attack houses located around cities such as Tabay, Mérida and Ejido, but no large scale disaster had occurred in the past. Only a few houses, usually 10 in number, are slightly inundated.

As for the local roads, disasters occur more often than in the national roads and since they are not maintained in good condition, the interruption is longer. However, the volume of traffic on local roads is not much and there is no serious affect on social conditions. Local electric and domestic water supply facilities are sometimes damaged by sediment, because these are simply installed and get easily damaged.

The population of the cities of Mérida and Ejido is increasing year by year, and the residential areas are expanding towards the flood prone areas along the Albarregas and Montalbán rivers. Although about 10,000 inhabitants of the area are presently protected from floods by the concrete dike, there is a strong possibility that the area will suffer from flood damage.

Total Damage

The amount of other damages is assumed at 20% of the damage on arterial roads, and the estimated total damage in the upper/middle reaches amounts to 2.2 million bolivares.

2.5.3 Disaster Prevention Works

To cope with the chronic disasters caused by flooding and sedimentation, private entities and the Government of Venezuela had been undertaking various kinds of prevention works. The MARNR is principally responsible for the implementation of the works and specifically, Zone Office No. 16 has been undertaking all sediment control works in the upstream area of El Vigía and Zone Office No. 5 has been concentrating on the flood control works in the downstream of the Chama River.

Sediment Control in the Upstream Area

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 stream channel control. Soil conservation has been initiated as one of the important components of a rural development project by the MAC.

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 159,500 bolívares, were mainly composed of water tanks, small ponds and diversion canals to convey stream water to farm lands.

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

Stream channel control works in the Chama River Basin are mainly composed of check dams, retaining walls and groundsills. In the last five years from 1984 to 1988, the MARNR had invested 21,763,384 bolívares for the works which have been concentrically undertaken for the rivers that are expected to affect urban or populated areas (refer to Table 2.5-2). These works were provided mainly to protect specific areas from sediment disasters, instead of basin-wide control of sediment.

Flood Control in the Downstream

The main flood control works undertaken by Zone Office No. 5 was a 12-km earth dike constructed in 1975 at a cost of 23 million bolívares along the left bank of the Chama River from the Chama Bridge towards the downstream. The dike aims at preventing inundation to the westside plantain plantation, the residential area and roads.

River dredging was also undertaken in 1985 to remove sediment deposits around the river mouth. Dredging was done for a stretch of about 2.0 km from the river mouth at a cost of 8.0 million bolívares.

2.6 Vegetation

2.6.1 Present Condition of Vegetation

Vertical Distribution of Vegetation

The relationship between the elevation of land and the annual mean temperature in the Chama River Basin is shown in Fig. 2.6-1 where the basin is classified into five zones by annual mean temperature; namely, tropical zone, temperate zone, arctic zone, páramo zone as a characteristic of the Andes Mountains, and frigid zone. The natural forest limit is bounded on the páramo zone, which is covered with weeds of the Poaceae such as Calamagrostis, Festuca, Agrostis, etc.

The relationship between annual rainfall and vegetation form is shown in Fig. 2.6-2. Land in the tropical zone of less than 1,000 m in elevation with annual rainfall of more than 2,000 mm has tropical rain forest of 30 to 50 m high. Thornscrub low forest of 2 m high covers the semi-arid area.

Areal Distribution and Characteristics of Vegetation

The vegetation map of the Chama River Basin is shown in Fig. 2.6-3, where vegetation is classified into high forest, low forest and grassland. Trees of 20 to 40 m high with big trunks comprise the high forest. On the other hand, low trees of 2 to 3 m high and branched off at the root dominate the low forest.

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

(1) Upper Reaches

Climate in the Upper Reaches belongs to the temperate, arctic, and páramo zones, and the former two zones are composed of low forest of 15% and high forests of 5% of the whole area of the Upper Reaches. The páramo zone located higher than the other two zones is composed of grassland which shares 76% of the Upper Reaches.

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

(2) Middle Reaches I

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

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

(3) Middle Reaches II

Climate in most parts of Middle Reaches II falls under the tropical zone. The mountains of 2,000 to 3,000 m around the watershed has the annual rainfall of 1,000 mm to 1,200 mm, and climate falls under the arctic or the páramo zone. A wide semi-arid area with the annual rainfall of 600 to 800 mm lies along the Chama River.

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

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

(4) Middle Reaches III

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

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

(5) Lower Reaches

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

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

2.6.2 Soil Conservation Works

Afforestation Works

To reduce sediment production, soil conservation works by afforestation to expand the forest area was performed from 1955 to 1981. After that period, supplemental afforestation works on 115 ha at Lagunillas in 1982 to 1988 and 147 ha at Mérida City in 1988 were carried out.

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

Protection Works on Mountain Slope

Around the mountainside areas near the town of Mucuchíes in the upper reaches of the Chama River, trenching works were carried out at a certain interval along the contour line. This method was applied also for the afforestation area near Mucuchíes with some improvements. It was found to be useful for the conservation of steep slope areas, except for cases in extreme waste land or of unsuitable selection of seed for afforestation.

Slope Protection Works for Road

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

2.7 Socioeconomic Conditions

2.7.1 National Development Plans

The Seventh National Development Plan for the period from 1984 to 1988, the latest development plan of Venezuela, 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 bolívar'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 2.7-1

2.7.2 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. Four urban areas are located in Mérida State; namely, Mérida, the capital of the state, El Vigía, Ejido and Tovar, with a total population of more than 300,000 in 1988. 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 2.7-2).

The lower basin is located at the municipality of Uribarri in Colón 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.

2.7.3 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 inter-annual growth rates of 10.0% and 5.0% during 1970-1979, respectively (see Table 2.7-3).

The major agricultural products of Mérida State and the neighboring states (Zulia and Táchira) 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 total production are distributed to other regions such as Caracas and Maracaibo (see Table 2.7-4). The distribution ratio is in Table 2.7-5.

Commodity prices in ten major cities have escalated in these five years at the inter-annual 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 2.7-6.

2.7.4 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 2.7-7.

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. 2.7-1.

The fertile land in Venezuela that is suitable for agriculture and cattle raising shares only 2% of the national territory. About 30% of this land is in the region south of the Maracaibo Lake where the lower reaches of the Chama River is located. The area of 1,890 km^2 sandwiched by the Escalante and the Mucujepe rivers is fully utilized, mainly by plantain plantations and cattle raising, sharing 14% and 77% as shown in Fig. 2.7-2. Their annual productivity was reported at 25,000-30,000 Bs/ha and 6,000-9,000 Bs/ha, respectively.

2.7.5 Road Network

Two important arterial roads, Routes 2 and 7, run in the Chama River Basin. Route 7 traverses the upper reaches, connecting the major cities of Mérida and Tovar via Estánquez. Route 2 which joins Route 7 near Estánquez, runs in the lower and middle reaches and links the major cities of El Vigía and El Moralito.

A new highway is now under construction between Estánquez and El Vigía as a part of the Mérida-Panamerican Highway, and the construction is scheduled to 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 Estánquez. Details of the daily traffic volume are shown in Fig. 2.7-3.

2.7.6 Budgetary Conditions

The national budget during the Seventh National Development Plan (1984-1988) has increased at the current prices from 75,041 million bolívares in 1984 to 185,122 million bolívares in 1988 with about 25% annual average growth (see Table 2.7-8). The bulk of the national budget is allocated to the Executive Branch (98%), while the rest is distributed to the Legislative and the Judicial branches (0.7% and 0.9%), as presented in Table 2.7-9.

The Executive Branch contains 16 ministries at present. Three of the ministries, Finance, Education, and Interior Relations, are in the top orders of budgetary allocation, sharing 35.0%, 15.0% and 14.7% of the national budget. The Ministry of Finance uses about 85% of its budget for amortization and payment of interests for loans.

The Ministry of Environment and Natural Resources Conservation (MARNR) is in the ninth order, sharing 2.8% of the national budget, but its annual increase rate is 36.5% on the current price basis, which is much higher than the average of the total. The proportion of the national budget to GDP ranges from 18.8% to 24.8% during 1984-1987, and about 22% on an average.

In connection with the Chama River Basin conservation, the offices in charge are Zone Office No. 16 of the MARNR and the office organized under Zone Office No. 5 for the region south of the Maracaibo Lake, which are located in Mérida and El Vigía, respectively. (Management by Zone Office No. 16 actually covers the whole state of Mérida.) The amounts of public investment for the MARNR and these offices are compared with the per capita investment in Table 2.7-10.

The per capita investment of Zone Office No. 16 is averaged at Bs 29, lower than the national level of Bs 41. On the contrary, that of the region south of the Maracaibo Lake reaches Bs 386. This is because a national project is now going on in this region.

2.8 Organization and Regulation

2.8.1 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. MARNR, MAC, MTC and the state governments are involved from the study to the execution of river basin conservation projects; Corpoandes and CIDIAT are involved in the study and planning stages.

River Management

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 in the state of Mérida, Zone Office No. 16 does not perform periodical inspections on the river channel except the monitoring of water level at the Ejido gauging station.

Zone Office No. 5 makes periodical inspections, every two weeks, of the left bank levee. River dredging works was once conducted in 1985 in the stretch of 2 km from the river mouth at a cost of 8 million bolivares, and 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 Defense of the Ministry of Interior Relations. However, flood forecasting is not 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.

2.8.2 Regulations

Regulations Related to Land Use

The regulations concerning land use in Venezuela are the forest law on soil and water, the rules and regulations for the forest law on soil and water, the environmental law, the law on agrarian reform, and the law on territorial ordinance.

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 in 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, permission from the MARNR is necessary for land development; large scale development is not permitted.

- To promote river basin conservation among the inhabitants, education and training 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.

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 for land use was issued in October 1986.

2.9 Related Projects

Among the completed and ongoing projects in and around the Chama River Basin, the following are specifically related to the project under study.

Project at the South of Maracaibo Lake

In 1963, the MARNR, then MOP, started implementation of an agricultural development project which includes flood control, road improvement and drainage system improvement for the area of 630,000 ha located at the south of the Maracaibo Lake. The project consists of river improvement of 486 km, construction of the Onia Dam, drainage system improvement of 323 km and road construction of 247.4 km.

As a part of the flood control component, the MARNR has been promoting the river improvement of main rivers in the area such as the Zulia River, Catatumbo River, Escalante River and Chama River on the project scale ranging from 50 to 100-year return period.

Out of the projected 486 km, the river improvement stretch completed as of 1988 amounts to 327 km. The total construction cost for this basin development project was estimated at 1,100 million bolívares as of 1979 which was almost equivalent to the then total annual budget of the MARNR.

As for the Chama River, the river improvement works were suspended due to the problem on sedimentation from the middle and upper reaches. Fig. 2.9-1 shows the outline of the proposed river improvement stretch.

Diversion Channel Project from Chama River to Mucujepe River

As a part of the flood control plan of the aforementioned project, the river improvement project along the Chama River course was firstly formulated to mitigate the flood damage in the lower reaches. Then, the diversion channel project connecting the Chama River has taken over in 1972 because of the technical and economical advantages over the improvement project. In this diversion channel project, it was proposed that all the flood discharge flowing down the Chama River be diverted to the Mucujepe River at 12 km downstream of El Vigía. The plan of the proposed diversion channel is shown in Fig. 2.9-2.

The design discharge of 1,500 m^3/s with a 100-year return period was adopted for the diversion channel stretch of approximately 40 km, and the total construction cost was estimated at 215 million bolívares as of 1980. Although channel excavation works on the Mucujepe River was executed for 10 km from the river mouth, the project was suspended due to the problems on sedimentation.

Milla River Improvement Project

The Milla River flowing through Mérida City is causing the inundation problem on roads and houses along the river course. To find a solution to this problem, Zone Office No. 16 of the MARNR had conducted the study on river improvement in 1985, and construction has commenced on the project with a design discharge of 50-year return period.

Pan-American Highway Project

This project was proposed to provide a shorter route between El Vigía and Estánquez. At a construction cost of 1,200 million bolívares to be financed by the Venezuelan government (MTC), 20 km of the road including a 4-km tunnel is to be constructed during 1978-1990. In this project, the earth volume of about 2,000,000 m^3 out of the 3,500,000 m^3 from the excavation works is supposed to have been abandoned into the Chama River.

Sediment Control Project for 1989-93

For sediment control in the future, Zone Office No. 16 of the MARNR has 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 total cost of all the works was tentatively projected at 31,691,788 bolívares. 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.

CHAPTER 3. STUDY AND ANALYSIS

3.1 Hydrological Analysis

3.1.1 Rainfall Analysis

Rainfall Producers

Rainfalls in the Chama River Basin are predominantly locally concentrated short-period showers. Rainfalls in June and July, the peak of the Llanos pattern, are mainly of thunderstorms induced by cold fronts from the Southern Hemisphere. Such rainfalls are found in the most upstream area of the basin.

The westward propagating easterly wave brings rainfalls in May-June and October-November. This period is the rainy season of the semi-annual type, the climate type prevailing widely in the Chama River Basin except in the most upstream areas. The rainfall in the basin is thus characterized as locally concentrated showers.

Hurricanes were not considered for establishing the flood hydrograph in this study, since there is no possibility for hurricanes to strike the area.

Areal and Time Distribution of Rainfall

Isohyetal maps of daily rainfalls on April 27, 1972 and on May 2, 1982 when notable floods occurred in the lower reaches are shown in Fig. 3.1-1. These isohyetal maps reveal that areal distribution of rainfall which cause floods in the lower reaches tend to present relatively heavy rainfall areas: one in the middle reaches of the Chama with Mérida in the center, and the other near the basins' divide of the Chama and Mocotíes rivers. The scale of the basin's average daily rainfall during floods is small at less than 30 mm.

Hourly rainfall record in the basin were compiled only after 1983. Fig. 3.1-2 shows the hourly distribution of rainfall at principal stations during the flood on September 6, 1988, together with the observed flood hydrograph of the Chama River at Ejido. Available data show that the rainfall which cause flood is in the scale of less than 30 mm/day with durations at about a few to several hours.

Annual Maximum Basin's Average Daily Rainfall

Probable values of basin's average rainfall for various return periods are calculated by Iwai's methods based on the data from 1967 to 1988 as presented in the following table.

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

Rainfall Intensity-Duration Curve

Duration curve for the 100-year return period point rainfall intensity at the stations in the basin is grouped into four lines as illustrated in Fig. 3.1-3.

The duration curve with the highest intensity was derived from the stations at Tovar, El Meson, San Pedro Chiguara, La Palmita, El Vigía in the area from the Mocotíes basin, except those in the most upstream areas, to the lower reaches of the Chama River.

The next curve is from those at Valle Grande, Mérida, Mesa de Ejido, Jají, San Juan de Lagunillas, Tostós, Páramo El Molino in the middle reaches of the Chama River. El Morro, the station in the Nuestra Señora River Basin, presents a curve with small intensities. The lowest curve is of the stations at Páramo de Mucuchíes, Páramo Pico El Aguila and Mucubají in the most upstream area of the Chama River Basin.

Annual rainfalls at El Morro, Tostós and San Juan de Lagunillas in the semi-arid zone of the middle reaches of the Chama River are about

500 to 600 mm. Among them, Tostós and San Juan de Lagunillas present almost the same intensity as Mérida, Mesa de Ejido, Jají, etc., where the annual rainfall is 1,000 to 1,800 mm.

3.1.2 Flood Runoff Model

Storage Function Model for River Basin

The storage function model was applied to simulate the design floods in this study. The storage function model has been developed to express non-linear characteristics of runoff phenomena introducing the following function between the storage volume (S_1) of a basin and the discharge (Q_1) from the same.

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

where, K and p are constants.

This is the equation of motion which expresses runoff as proportional to the exponent of storage volume. Runoff calculation is performed in combination with the following equation of continuity for a basin.

$$\frac{dS_1}{dt} = \frac{1}{3.6} \cdot f \cdot r_{ave} \cdot A - Q_1$$

where,

S_1 : apparent storage volume in the basin ($m^3/s \cdot hr$)
f : inflow coefficient
r_{ave} : basin's average rainfall (mm/hr)
A : area of the basin (km^2)
$Q_1 = Q(t + T_1)$: direct runoff height with lag time (m^3/s)
T_1 : lag time (hr)

In the storage function model, it is assumed that in the early stages of rainfall, f is f_1 and accumulated rainfall exceeds Rsa, then f = 1.

Storage Function Model for River Channel

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

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

where,

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

Division of the Basin

The Chama River Basin has been divided into 21 sub-basins. In addition, four river channels have been introduced in the model as presented in the model diagram shown in Fig. 3.1-4.

K, p and T_1 of Basin

As explained in the previous part, the basin's storage function is expressed as:

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

Constants K and p are determined as follows:

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

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

where, I : average gradient of the catchment.

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

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

α in the above formula was determined by simulation on actual floods at 25. Accordingly, K of $S = KQ^p$ is expressed as the following formula:

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

Lag time T_1, explained in the previous part, has been determined by the following formula:

$$T_1 = 0.0470\ L - 0.56 \qquad (L \geq 11.9\ km)$$

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

K, p and T_1' of River Channel

Four river channels were considered in the model as presented in the model diagram (Fig. 3.1-4). Only the time lag was considered for Channels No. 1, 2 and 4, and storage effect was given for Channel No. 3.

Storage function for Channel No. 3 was determined assuming the flow as Manning's uniform flow.

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

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

$$S_1 = 36.4\ Q_1^{0.6}$$

f1 and Rsa

f1 and Rsa were estimated on the basis of the observed and simulated cumulative runoff height curves. The runoff rate for estimation of design hydrograph was assumed at 0.6 for forests and grassland areas and 0.8 for bare land, not relating to the rainfall amount.

Summary of Parameters

Various constants by each sub-basin and river channel for storage function model were determined, as tabulated in Table 3.1-1.

Specific Peak Discharge Plot

Fig. 3.1-5 shows the specific peak design discharges of 100-year return period for rivers in the area of southern Maracaibo Lake. Those for the Chama River at El Vigía are 0.4 or less according to the illustration.

3.1.3 Design Flood Hydrograph at El Vigía

Duration and Amount of Design Rainfall

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

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

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

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

The probable value for annual maximum basin's average 1-day rainfall was calculated on the basis of 22-year data from 1967 to 1988 as presented in the previous section.

Areal and Time Distribution of Design Rainfall

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

Limitation by Duration Curve

Design rainfalls were prepared by enlarging the actual observed rainfall as discussed above. However, the maximum amount by duration is given referring to the intensity of point rainfall. Aerial reduction factor by Fretcher's method was applied to obtain probable areal rainfall from the probable point rainfall.

Design Flood Hydrograph

Flood hydrographs were prepared by applying the design rainfalls obtained above to the storage function model of the sub-basins and river channels. The calculated flood hydrographs at El Vigía are shown in Fig. 3.1-6; the peak values are as follows:

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

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

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

3.1.4 Design Discharges Along the Chama River Course

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

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

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

3.1.5 Design Discharges at Upstream Tributaries

Subject Tributaries

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

	Milla	Albarregas	Montalbán	Portuguesa
Catchment Area (km^2)	7.7	39.5	14.8	20.0
River Length (km)	5.5	16.0	6.0	9.8
Average Gradient	1/4.5	1/6.3	1/2.5	1/4.7
Concentration Time (hr)	0.44	1.27	0.48	0.78

Design Rainfall

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

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

Design Discharges

The peak discharges with a 100-year return period for the Albarregas, the Montalban and the Portuguesa rivers and a 50-year return period for the Milla River were determined as follows on the basis of the calculations using the storage function model:

	Milla	Albarregas	Montalbán	Portuguesa
Design Discharge (m^3/s)	60	180	110	130

3.1.6 Daily Discharge

Available Data

Available data of daily discharge in the Chama River Basin are limited, as follows:

Chama-Ejido (simulated)	1953-1975
(observed)	1976, 1978-1986
Chama-Mucurubá (observed)	1975-1976, 1978-1987
Mocotíes-La Victoria (simulated)	1953-1975

Daily Discharge

From the data period presented above, daily discharges were prepared for 1967-75. The following conversion rates were applied to estimate the daily discharge from the Chama-Ejido and the Mocotíes-La Victoria data.

Zone	Sub-basin	Annual Rainfall (mm)	Conversion Rate
Zone 1	1, 2, 3, 4, 5, 6, 7, 10,11	1,200	1.0 against Ejido
Zone 2	8, 9, 12, 13, 14, 15	650	0.54 against Ejido
Zone 3	16 to 21	1,170	1.0 against La Victoria

The monthly average daily discharges obtained from the calculation above are presented by sub-basins in Table 3.1-2.

3.2 Study on Sedimentation

3.2.1 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 where a large amount of sediment move only during an extraordinary flood. Therefore, sediment discharge has to be calculated on the yearly basis for the formulation of the sediment control plan.

The sediment production and transportation in a river channel was firstly estimated by applying the most suitable equation, and secondly, the sediment balance was studied for the computation of design sediment discharge at the reference point, namely El Vigía.

3.2.2 Production

Production Type

From the results of field investigations on topography, geology, soil and meteorology, sediment production in the Chama River Basin is believed to occur 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 annual rainfall is only around 600 mm. Due to the scarce rainfall, slope erosions are of 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.

Torrent erosion is predominantly observed along the Nuestra Señora, the San Pablo and La Vizcaína rivers, and their tributaries. Streams of more than second-order are the sources of eroded sediment which is deposited on the stream bed. Major streams of more than fourth-order have bank erosions.

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 various rainfalls and flow discharges.

- 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 equations were adopted for the calculation of sediment production volume:

(1) Slope Erosion

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

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

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

$q = 2.778 \times 10^{-7} \cdot f \cdot i \quad (m^3/s/m^2)$

E_V	:	eroded volume ($m^3/s/m^2$)
Ca	:	areal ratio of denuded land
Ce	:	erodability coefficient
f	:	runoff coefficient
i	:	rainfall intensity (mm/hr)
L	:	slope length (m)
d	:	mean size of sediment particle (mm)
So	:	slope gradient

(2) Slope Failure

The following equation developed by Uchiogi based on the continuous observation of slope failures in Japan has been adopted. The volume of slope failure C_V is expressed as follows:

$C_V = D \cdot K \cdot A\ (\sum r - r_n)^2 \qquad (m^3)$

where,

D	:	average failure depth (m)
K	:	coefficient (4.0×10^{-6})
r_n	:	failure non-effective rainfall (mm)
A	:	basin area (m^2)
$\sum r$	:	cumulative rainfall (mm)

(3) Torrent Erosion

The following equation derived from Brown's equation has been adopted for the calculation of torrent erosion.

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

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)

By using the above equations, sediment production volume was estimated as presented in Table 3.2-1. The annual sediment production volume is 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. Coarse material sediment production of 5,240,000 m^3 is composed of 2,775,000 m^3 by slope erosion, 55,000 m^3 by slope failure, and 2,410,000 m^3 by torrent erosion.

3.2.3 Transport and Balance

Procedure of Transport and Balance Study

Sediment transport and balance study along the Chama mainstream and major tributaries was conducted by a procedure shown in Fig. 3.2-1 to grasp the movement of sediment produced from slopes and torrents.

The reference point of the sediment control plan was set up at El Vigía, so that the sediment discharge was primarily computed at El Vigía. Some other points were defined as base points to understand sediment movement in the river basin.

The sediment discharges were calculated for the reference point as well as all base points, while the discharges themselves were estimated per unit year. Therefore, all the sediment production volumes from sub-basins were converted to sediment discharges measured in a unit of m^3/year, which were used for the sediment transport and balance analysis.

Base Point and Division of Basin

The 33 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. The Chama River basin was then divided into 21 sub-basins and 12 river channels as shown in the model diagram of sediment transport and balance (Fig. 3.2-2).

Sediment Discharge

Sediment discharge rating curves showing the relationship between river discharge and volume of riverbed materials to be transported in the river channel were developed at the base points applying a sediment transport formula on the basis of the grain size distribution obtained through 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 (refer to Supporting Report) 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.

The obtained rating curves at several base points are presented in Fig. 3.2-3. In addition, the determined constants of rating curves by base points are shown in Table 3.2-2.

Critical Discharge

Two conditions of the riverbed, namely fixed bed and movable bed were considered in the sediment transportation model. In the fixed bed section, the materials for sediment transportation are those produced in the basin and/or those transported from the upper channel. In the movable bed section, the riverbed materials in the channel are also subject to transportation.

However, as described in Section 2.3.2, armor coats have formed over the riverbed of the Chama River and major tributaries. Accordingly, the riverbed materials are not transported unless the armor coats are removed by a relatively high water flow. The materials composing the armor coat are forced to moved when the tractive force becomes higher than the friction force of materials. The tractive force at this condition is known as the critical tractive force.

The discharge to move the materials in the armor coat is herein called as the critical discharge. The critical discharges were estimated at the respective base points, as summarized in Table 3.2-3.

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. The procedure for sediment balance calculation for each river channel is explained hereinafter.

(1) Sediment Inflow

For sub-basins, sediment inflow was estimated on the basis of the sediment production yield from the catchment as computed in Subsection 3.2.2. Sediment inflow for channel sections was calculated by summation of the following:

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

(2) Sediment Outflow

Sediment outflows 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 using the sediment rating curve.

(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, scouring occurs.

(4) Condition of Balance Calculation

For the sediment balance calculation, two riverbed conditions, i.e., the fixed bed and the movable bed, were applied. In case of the fixed bed channel, scouring will not occur. The river channels of No. 1, 2, 3, 9 and 10 and all sub-basins are assumed to be of 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 the movable bed condition where both scouring 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 is 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 3.2-4.

Consequently, the sediment balance is estimated at -3,340,000 m^3/year, which is produced from the main stream by bed and bank erosion. The rate of sediment discharge to water discharge of 2 x 10^9 m^3/year on an average is calculated at approx. 0.5%.

3.2.4 Design Sediment Discharge

For the formulation of the master plan for basin-wide sediment control, sediment discharges are defined as follows.

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

- Allowable Sediment Discharge 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 to 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 are counted in the estimation.

<u>Project Sediment Discharge</u>

The project sediment discharge is estimated 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 sediment discharges of inflow, outflow and balance at all base points were calculated as schematically presented in Fig. 3.2-4. Major sediment sources concentrate in the middle reaches of semi-arid area, especially the Nuestra Señora, La Vizcaína and the San Pablo river basins.

Aside from the said sediment sources in the mountain slopes, there is another source in the main channel of the Chama River. Due to the erosion of the main channel, a sediment discharge of 3,750,000 m^3/s is produced.

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 aggradation nor degradation.

The proposed river improvement plan is featured as follows:

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 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 the alluvial fan.

The sediment volume computed by utilizing the model hydrograph of 1971 was 2,120,000 m^3/year at the representative section; hence, this volume 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 is consequently estimated at 7,480,000 m^3/year. This sediment discharge shall be controlled to avoid aggradation of the riverbed downstream of El Vigía. The sediment movements are schematically presented in Fig. 3.2-5.

3.2.5 Probability of Occurrence of Sediment Disaster

In the previous section, the design sediment volume to be used in formulating the sediment control plan for the reference point of El Vigía covering most of the Chama River Basin was estimated. On the other hand, sediment disasters occur even in the local area and it is necessary to clarify the basic design features of sediment for the formulation of the local sediment control plan.

Since there exists some 170 potential disaster sites (Fig. 3.2-6), it is difficult to estimate the sediment discharge for each site judging from the availability of accurate data and the purpose of formulation. Hence, a study was made to determine the number of probable sediment disaster sites with parameters of rainfall.

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 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, and the basin average daily rainfall at El Vigía of 15 mm/day corresponds to 60 mm/day of the maximum daily rainfall at a certain location.

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	17	4	6	27
5	7	2	6	15
2	0	0	0	0

Selection of Probable Disaster Sites

Probable disaster sites for each return period were selected from the 170 potential sites (Fig. 3.2-6), considering the degree of danger ranked on the basis of natural conditions such as catchment area, channel length, channel/slope gradient, geology and vegetation cover.

3.3 Study on Flood Inundation

3.3.1 Features of Flood Inundation

Inundation in 1972, 1982 and 1988

In view of the inundation condition in 1972, 1982 and 1988 (Fig. 2.5-1 to 2.5-3), the lower reaches was divided into five stretches: (1) stretch of 12 km from El Vigía with an embankment on the left bank; (2) stretch of 16 km in the further lower reaches; (3) stretch between 45 km and 32 km from the river mouth; (4) stretch of 16 km downstream from Puerto Chama Bridge; and (5) stretch of 16 km of the upper reaches from the river mouth.

According to the past inundation record, the area of inundation is large in stretches (1), (2), (4) and (5), while inundation in stretch (3) was reported to be not so large. Inundation water flowing down along the river course in stretch (1) and stretch (2) is presumed to return to the river course on its way to stretch (3).

Topographic Features of Inundation Area

The inundation areas are mainly in the alluvial fan which has developed downwards from El Vigía. Since the behavior of inundation water is dominated by the minor undulations of the area, a study on the minor undulations is essential.

Cross sections of the alluvial fan area where flood inundation water is assumed to flow down were obtained from the topographic map with the scale of 1/25,000, as shown in Fig. 3.3-1. From the study of these cross sections, it was found that natural levees with the channel width of between 200 and 1,500 m had formed along the Chama river course, and further micro-high land with the width of between 4,000 and 5,500 m can be seen.

In case of a small-scale flood, inundation water will be confined in this cross section within this natural levee in the range between 200 m and 1,500 m which is expected to have the flow capacity of about 500 m^3/s. The excess water over the said flow capacity in case of a big flood will mainly flow down with inundation width of between 4,000 and 5,500 m which may have the flow capacity of about 2,000 m^3/s. In the lower reaches of 16 km from the river mouth, such a natural levee is not found and floodwaters tend to spread over a wide area.

The probable inundation area based on the aforementioned consideration is shown in Fig. 3.3-2.

3.3.2 Flow Capacity of River Channel

Calculation Condition

Before the formulation of the flood inundation model, the flow capacity of the Chama river channel in the lower reaches from El Vigía was examined under the following conditions, using the results of the survey made during this Study.

- Non-uniform calculation method is applied;

- Manning's roughness coefficient of 0.035 is adopted, judging from the river conditions; and

- Three cases of discharge, 50, 100 and 150 m^3/s, are firstly examined for the whole stretch and the other three cases of 1,000, 2,000 and 3,000 m^3/s are applied for the stretch of 12 km with embankment, because this portion has a bigger flow capacity compared with the other stretch without embankment.

<u>Non-Uniform Calculation Method</u>

(1) Basic Equation

The following equation is used for the flood flow analysis:

$$[\ H_2 + \frac{1}{2g} \left(\frac{Q_2}{A_2} \right)^2 \ ] - [\ H1 + \frac{1}{2g} \left(\frac{Q_1}{A_1} \right)^2 \ ] = h_e \qquad \cdots (1)$$

$$he = \frac{1}{2} \left[\frac{N_1^2\ Q_1^2}{A_1^2\ R_1^{4/3}} + \frac{N_2^2\ Q_2^2}{A_2^2\ R_2^{4/3}} \right] \Delta X \qquad \cdots (2)$$

where, subscripts 1 and 2 indicate the dimensions of the upstream and downstream sections, respectively.

H = water level
g = gravity acceleration
Q = discharge
A = cross sectional area
R = hydraulic radius
ΔX = distance between two adjacent cross sections
n = roughness coefficient