JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

MINISTRY OF PUBLIC WORKS, TRANSPORT AND HOUSING (SOPTRAVI)
MINISTRY OF INTERNATIONAL COOPERATION (SETCO)
NATIONAL EMERGENCY COMMITTEE (COPECO)
NATIONAL SERVICE AUTHORITY FOR WATER SUPPLY AND SEWERAGE (SANAA)
MIINISTRY OF NATURAL RESOURCES AND ENVIRONMENT (SERNA)
MUNICIPALITY OF THE CENTRAL DISTRICT (AMDC)

THE STUDY

ON FLOOD CONTROL AND LANDSLIDE PREVENTION IN TEGUCIGALPA METROPOLITAN AREA OF THE REPUBLIC OF HONDURAS

FINAL REPORT

MAIN REPORT

MAY 2002

PACIFIC CONSULTANTS INTERNATIONAL
NIKKEN CONSULTANTS, INC.

Foreign Currency Exchange Rates Applied in the Study

Currency	Exchange Rate/USD
Honduran Lempiras (Lps)	15.84
Japanese Yen (JPY)	122.44

(Rate as of November 1, 2001)

PREFACE

In response to a request from the Government of the Republic of Honduras, the Government of Japan decided to conduct the Study on Flood Control and Landslide Prevention in Tegucigalpa Metropolitan Area of the Republic of Honduras and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA selected and dispatched a study team headed by Mr. Mitsuo Miura of Pacific Consultants International (PCI) and composed of staff member of PCI and NIKKEN Consultants,Inc. to Honduras, two times between January 2001 and December 2001. In addition, JICA set up an advisory committee headed by Mr. Katsushige Masukura, Japan Construction Information Center, between January 2001 and May 2002, which examined the Study from specialist and technical points of view.

The team held discussions with the officials concerned of the Government of the Republic of Honduras, and conducted field surveys in the study area. Upon returning to Japan, the team conducted further studies and prepared this final report.

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

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

May, 2002

Takao Kawakami
President
Japan International Cooperation Agency

THE STUDY ON FLOOD CONTROL AND LANDSLIDE PREVENTION IN TEGUCIGALPA METROPOLITAN AREA OF THE REPUBLIC OF HONDURAS

May, 2002

Mr. Takao Kawakami
President
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

Dear Sir,

We are pleased to submit you the final report entitled "The Study on Flood Control and Landslide Prevention in Tegucigalpa Metropolitan Area of the Republic of Honduras". This report has been prepared by the Study Team in accordance with the contracts signed on18 January 2001, 25 January 2002 and 1 May 2002 between the Japan International Cooperation Agency and the Joint Study Team of Pacific Consultants International and NIKKEN Consultants,Inc.

The report examines the existing conditions related to flood and landslide in Tegucigalpa metropolitan area, proposes a master plan for the disaster mitigation and presents results of the feasibility study for priority projects, which was identified in the master plan.

The report consists of the Summary, Main Report, Supporting Report, Data Book, GIS Operation Manual and Maps. The Summary summarizes the results of all studies. The Main Report contains the existing conditions, the proposed master plan, the results of the feasibility study, and conclusions and recommendations. The Supporting Report includes technical details of contents of the Master Plan. The Data Book contains basic data used in the Study. The GIS Operation Manual includes explanations and handlings of database constructed in this Study. The Maps contains principal maps.

All members of the Study Team wish to express grateful acknowledgement to the Japan International Cooperation Agency (JICA), JICA Advisory Committee, Ministry of Foreign Affairs, Ministry of Land, Infrastructure and Transport, Embassy of Japan in the Republic of Honduras, and other donors, and also to Honduran officials and individuals for their assistance extended to the Study Team. The Study Team sincerely hopes that the results of the study will contribute to the promotion of the disaster mitigation of Tegucigalpa metropolitan area, and that friendly relations of both countries will be promoted further by this occasion.

Yours faithfully,

三浦 光夫

Mitsuo Miura
Team Leader

EXECUTIVE SUMMARY

FLOOD/LANDSLIDE DAMAGE MITIGATION MASTER PLAN

1. EXISTING PROBLEMS AND TARGETS OF THE MASTER PLAN

The study revealed that 30% of the Target Area for Disaster Prevention is occupied by flood or landslide hazardous area and 15% of the total population live in those dangerous areas. The target of the Master Plan is to minimize the damage and avoid any loss of human lives by flood and landslide even with a hurricane of the Mitch scale. In order to attain this goal, a master plan composed of non-structural measures and structural measures was formulated.

2. MASTER PLAN PROJECTS

The Master Plan has been planned to achieve the targets by the projects in Table 1.

Table 1 Mater Plan Projects

	Flood Damage Mitigation	Landslide Damage Mitigation	Common
Structural Measures	Choluteca River Improvement (target: 15-year flood) Pescado Lake Outlet Improvement	Berrinche Reparto Bambu	-
Non-structural Measures	Watershed Management Land Use Plan/ Land Use Regulation Structural Code Application Forecasting/Warning/Evacuation	Land Use Plan/ Land Use Regulation Forecasting/Warning/Evacuation	Education/Enlightenment/Training (including preparation and publication of hazard maps) Disaster Management Information System

3. FACILITY PLANNING OF STRUCTURAL MEASURES

Major facility planning for the master plan structural projects is as shown in Table 2.

Table 2 Summary of Facility Planning for Mater Plan Projects

Projects	Components	Descriptions
Flood Damage Mitigation	Choluteca River Improvement	Excavation: L=7km, 750,000 m^3 River Widening: L=200 m (Including Counter Fill, Horizontal Boring, Concrete Shaft) Revetment: L=9 km Dike: L=3 km Bridge Reconstruction: 1 bridge
	Pescado Lake Outlet Improvement	Slope Trimming, Gabion
Landslide Damage Mitigation	Berrinche	Soil Removal, Surface Drainage, Sub-surface Drainage, Drainage Well
	Reparto	Soil Removal, Surface Drainage, Sub-surface Drainage, Drainage Well
	Bambu	Surface Drainage

4. PROJECT COSTS

The project costs for the proposed master plan are as shown in Table 3.

Table 3 Project Costs of Proposed Master Plan

Name of Projects	Project Costs (1,000 USD)
Flood Damage Mitigation	52,437
Landslide Damage Mitigation	8,308
Common	3,166
Total	63,911

5. FINANCIAL PLAN

The financial plan was made referring the loan conditions of BID and assuming the project period between 2002 and 2015. The maximum annual disbursement amount is USD 37.46 million in 2006 and the maximum annual repayment is USD 2.91 million in 2027.

6. ORGANIZATION PLAN

The organization plan for the implementation of the master plan projects were proposed.

- Overall Coordination: Coordination Committee
- Flood Control Structural Measures: AMDC (SOPTRAVI)
- Landslide Prevention Structural Measures: AMDC (SERNA, SOPTRAVI)
- Watershed Management: AMDC (SANAA,SERNA,COHDEFOR)
- Land Use Plan/Land Use Regulation/Structural Code : AMDC (COPECO,CODEM)
- Education/Enlightenment/Training: CODEM (COPECO)
- Preparation and Publication of Hazard Maps: CODEM (COPECO,SOPTRAVI,SERNA)
- Forecasting/Warning/Evacuation: COPECO,CODEM (SERNA,SMN)

7. SELECTION OF PRIORITY PROJECT

By comparing the master plan projects in terms of urgency, significance, schedule, economical, aspects, a part of the river improvement, all of the landslide prevention projects, forecasting/warning/evacuation, education/enlightenment/training, and disaster management information system were selected as the priority projects.

8. EVALUATION OF MASTER PLAN AND RECOMMENDATION

The proposed Master Plan was judged to be feasible from the viewpoints of economic(EIRR=10.49%), financial, managerial, technical, environmental and social aspects. The Study recommended that the related Honduran organizations should coordinate closely to implement the master plan in order to create a safe capital against natural disasters.

FEASIBILITY STUDY ON THE PRIORITY PROJECT

1. CONTENTS OF THE PRIORITY PROJECTS

The contents of the priority projects for the feasibility study are as follows:

(1) CHOLUTECA RIVER IMPROVEMENT

Excavation	:	750,000	m^3
River Widening	:	200	m
(including counter fill, horizontal boring, concrete shaft)			
Revetment	:	3	km
Dike	:	1	km

(2) PESCADO LAKE OUTLET IMPROVEMENT

Slope Trimming	:	9,000	m^3
Gabion	:	630	m^3

(3) BERRINCHE LANDSLIDE PREVENTION

Drainage Well	:	8	places
Water Collection Boring	:	4,000	m
Drainage Boring	:	370	m
Drainage Channel	:	1,840	m
Soil Removal	:	184,000	m^3

(4) REPARTO LANDSLIDE PREVENTION

Drainage Well	:	1	place
Water Collection Boring	:	500	m
Drainage Boring	:	230	m
Drainage Channel	:	2,330	m
Soil Removal	:	40,000	m^3

(5) BAMBU LANDSLIDE PREVENTION

Gabion	:	690	m^3
Drainage Channel	:	260	m

(6) FORECASTING/WARNING/EVACUATION

Rainfall/Water Level Gauging Station (for Flood Damage Mitigation)	:	3	places
Rainfall Gauging Station (for Landslide Damage Mitigation)	:	4	places

(7) EDUCATION/ENLIGHTENMENT/TRAINING

Education/enlightenment/training program for disaster management administrators, educators and public.

(8) DISASTER MANAGEMENT INFORMATION SYSTEM

Data base of hazard map information, flood/landslide forecasting and warning information, emergency disaster information, and optical fiber cable system through which the responsible organizations are connected to the data base.

2. *PROJECT COSTS AND FINANCIAL PLAN*

The total project cost is estimated at USD 36 million. The breakdown is shown in Table4.

Table 4 Project Costs

Item	Amount (thousand USD)
Direct Construction Cost	25,020
Engineering Service Cost	3,615
Contingency	6,332
Compensation Cost	473
Administration Cost	1,251
Grand Total	36,691

From the table above, compensation cost and administration cost are not covered by foreign loan or grant. Therefor, the total project cost subject to loan or grant is USD 35.0 million. Remaining USD 1.7 million should be prepared by Honduran government.

3. *PROJECT EVALUATION*

The EIRR=13.44% and the total project cost is USD 37 million, thus the project is economically and financially feasible.

Ten houses are to be relocated for the implementation of Reparto landslide prevention works but those houses are located in the dangerous area. Thus, it was judged that the house relocation compensation is possible because relocation would give them safer place to live.

Environmental Impact Assessment was made and influenced factors were selected and it was judged that all items could be dealt with by mitigation measures in the implementation stage.

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CHAPTER 6 FEASIBILITY STUDY OF PRIORITY PROJECTS

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ABBREVIATIONS

AMDC	: Municipality of the Central District
COPECO	: National Emergency Committee
CODEM-DC	: Municipality emergency committee of central district
COHDEFOR	: Honduran Corporation of Forest Development
DECA	: Directorate of Environmental Evaluation and Control
EIA	: Environmental Impact Assessment
F/S	: Feasibility Study
GDP	: Gross Domestic Product
IDB	: Inter-American Development Bank
JICA	: Japan International Cooperation Agency
M/P	: Master Plan
SANAA	: National Service Authority for Water Supply and Sewerage
SERNA	: Ministry of Natural Resources and Environment
SETCO	: Ministry of International Cooperation
SOPTRAVI	: Ministry of Public Works, Transport and Housing
UNDP	: United Nations Development Program
USAID	: United States Agency for International Development
USGS	: United States Geological Service

Chapter 1

Introduction

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Tegucigalpa is the capital city of Honduras, having a population of around 1 million in 2001. The urban area of the city is located in a mountain area with the altitude between 900 m and 1,400 m. The Choluteca River flows through the center of the city from the south to the north.

The natural conditions surrounding the city are from the beginning unfavorable in terms of flood and landslide. Four tributaries having the same scale of basin areas and river lengths converge at the center of the city and rainfall run off is prone to concentrate at the same time. The topography is mountainous and complex with the valleys of tributaries. The geology in and around the city is also complex being composed of Valle de Angeles Group in Cretaceous Period, Matagalpa Formation in Paleogene Period, Padre Miguel Group in Tertiary Period and Quaternary volcanic deposit. The geological boundaries of these different geological structures are often weak and prone to trigger landslides in the area.

The capital of Honduras was transferred to Tegucigalpa in 1880 from Comayagua, which is 84 km to the northwest of Tegucigalpa. In the year 1900, the urban area of Tegucigalpa was confined to a small area of the present Distrito Centro and Comayaguela. Since then, in these one hundred years of development of the city, the population has increased and the urban area has expanded to the south, west and east. New communities have been expanding by developing the hilly areas and the river terraces. This uncontrolled development is making the city more and more vulnerable to flood and landslide disasters.

In October 1998, Hurricane Mitch attacked the whole area of Central America. Honduras was the country most devastated by the hurricane. Casualties were reported as over 13,000 in the whole country and over one thousand people lost their lives or were missing in Tegucigalpa.

After Hurricane Mitch, a large number of foreign countries and international organizations provided this area with various assistance. The Honduran Government has been working hard to recover from casualties. However, as of now still serious disaster problems remain. The mal capacity of the Choluteca River has not been improved at all. Most of the landslide areas are intact and many houses are still at high risk.

However, it is impossible nor appropriate to solve all the flood and landslide problems with only structural measures such as river improvement or landslide prevention works, because of budget constraints, etc. Consequently, an integrated disaster prevention master plan composed of structural and non-structural measures is urgently needed.

Another important background of the study is the large number of related governmental entities involved. There are many agencies such as the Ministry of Public Works, Transport and Housing (SOPTRAVI), the Ministry of International Cooperation (SETCO), the National Emergency Committee (COPECO), the National Service Authority for Water Supply and Sewerage (SANAA), the Ministry of Natural Resources and Environment (SERNA), and the Municipality of the Central District (AMDC), all of which are relevant to disaster prevention.

And much more, several donor countries and international organizations such as the World Bank, the Inter-American Development Bank (IDB), UNDP, USAID, the United States Geological Service (USGS) and so on are conducting aid projects for disaster prevention.

Therefore, it is necessary to establish good coordination among the relevant national, as well as foreign and international organizations for the preparation and the implementation of the comprehensive disaster prevention master plan.

1.2 OBJECTIVES OF THE STUDY

The objectives of the Study are:

(1) To formulate a master plan for flood damage mitigation and landslide damage mitigation in the Tegucigalpa Metropolitan Area of the Republic of Honduras,

(2) To conduct a feasibility study on the urgent and priority project(s), and

(3) To transfer technology to the counterpart personnel of participating agencies such as SOPTRAVI, SETCO, COPECO, SANAA, SERNA and AMDC in the course of the Study.

1.3 STUDY AREA

The Study Area covers the Choluteca River basin upstream from point A as shown in *Figure 1.1*. The Target Area for Disaster Prevention covers the Tegucigalpa Metropolitan Area as shown in *Figure 1.2*.

1.4 STUDY ORGANIZATION

The Study was conducted under the following organizational scheme:

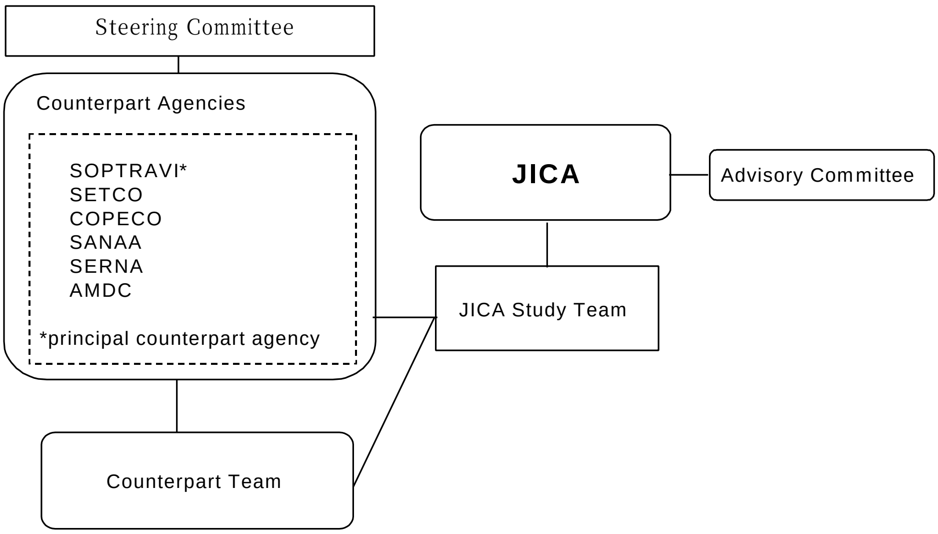

Figure 1.3 Study Organization

The Study Team is composed of the following sixteen (16) members:

Name	Task
- Mr. Mitsuo MIURA	- Team Leader/Disaster Prevention Planning
- Dr. Kozo TAKAHASHI	- Landslide Prevention
- Mr. Takuro TERASHIMA	- Flood Control
- Dr. Chaisak SRIPADUNGTHAM	- Hydrology/Hydraulics
- Mr. Kaoru NAKAZATO	- Landslide Topography/Geology
- Mr. Hiroshi TANAKA	- Land Use Planning
- Dr. Valerio GUTIERREZ	- Watershed Management
- Mr. Kazuhiro ISHIZUKA	- Geodetic Survey
- Mr. Kouji OOIKE	- GIS (1)
- Mr. Takahiro GOTO	- Facilities Design/Cost Estimate
- Mr. Ryo MATSUMARU	- Socioeconomy/Project Evaluation
- Dr. Somasundaram JAYAMOHAN	- Environment
- Mr. Yoshiaki KANEKO	- Organization/Institution
- Mr. Hideo SAKURABA	- Interpreter
- Mr. Yoshitaka ISHIKAWA	- Interpreter
- Mr. Kenji MORITA	- Study Coordination/GIS (2)

The Advisory Committee consists of three (3) members as follows:

- Mr. Katsushige MASUKURA	- Chairman of the Committee
- Mr. Hidetomi OI	- Committee Member
- Mr. Yasuo ISHII	- Committee Member

The government of Honduras has organized a counterpart team consisting of the following members:

Name	Organization
- Mr. Martin Perez	- SOPTRAVI
- Ms. Rosa Maria Bonilla	- SOPTRAVI
- Mr. Gustavo Suazo	- SOPTRAVI
- Mr. Marcio Fiqueroa	- SOPTRAVI
- Mr. Rafael Alduvin	- SETCO
- Mr. Mario Aguilera	- COPECO
- Ms. Martha Flores	- COPECO
- Mr. Rodolfo Ochoa	- SANAA
- Ms. Miriam Narvaez	- SANAA
- Ms. Gladis Rojas	- SANAA
- Mr. Adrian E. Oviedo	- SERNA
- Mr. Hector Fonseca	- AMDC
- Mr. Carlos Gutierrez	- AMDC

The Steering Committee was established with the following members:

Name	Organization
- Ms. Yasmina Deras	- SOPTRAVI
- Ms. Juana Elisa Granados	- SOPTRAVI
- Ms. Nora Derez Suazo	- SOPTRAVI
- Mr. Martin Perez	- SOPTRAVI
- Mr. Yolanda Madrid	- SETCO
- Mr. Hugo Arevalo	- COPECO
- Mr. Marcio Rodriguez	- SANAA
- Mr. Kenneth Rivera	- SERNA
- Mr. Mario Castañeda	- SERNA
- Mr. Rafael Trimino	- AMDC

1.5 STUDY SCHEDULE

The time schedule of the Study is shown in *Figure 1.4* together with the staffing schedule.

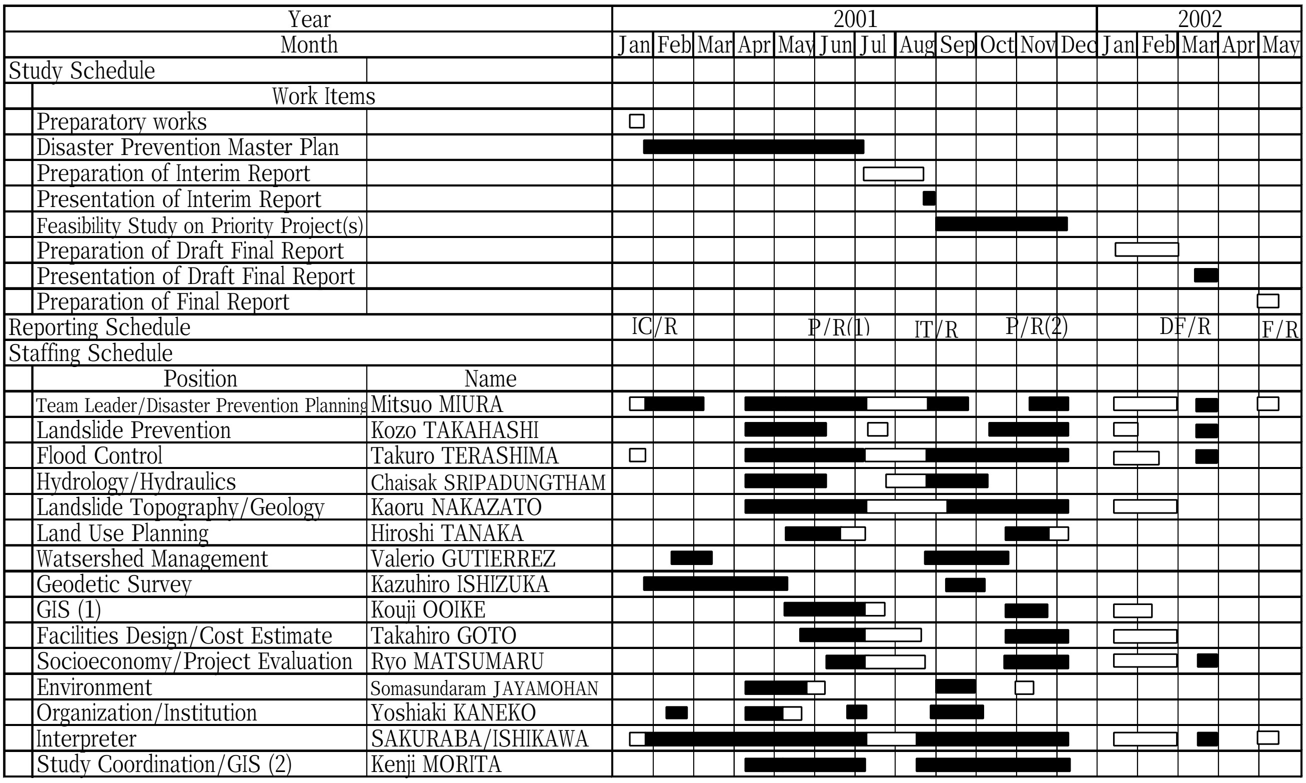

Figure 1.4 Study Schedule

1.6 COMPOSITION OF THE REPORT

The Final Report is composed of the following components:

<u>Main Report</u>

The main report contains all the Study results including the Master Plan and the result of the Feasibility Study of the Priority Projects.

<u>Supporting Report</u>

Each field of the Study is accounted in detail in seventeen (17) supporting documents as follows:

- Supporting A Aerial Photo Mapping/River and Ground Survey
- Supporting B Geological Survey
- Supporting C Hydrological/Hydraulic Analysis
- Supporting D River Bed Material Survey
- Supporting E Environmental Consideration
- Supporting F Flood Damage Mitigation Plan
- Supporting G Landslide Damage Mitigation Plan

- Supporting H Hazard Map and Risk Map by GIS
- Supporting I Watershed Management
- Supporting J Land Use Plan
- Supporting K Facility Planning/Cost Estimate
- Supporting L Organizational/Institutional Consideration
- Supporting M Participatory Workshop
- Supporting N Flood/Landslide Damage Survey
- Supporting O Economic/Financial Analysis
- Supporting P Education/Enlightenment and Training Plan
- Supporting Q Disaster Management Information System

Data Book

The Data Book contains the data obtained in Study.

GIS Operation Manual

The GIS Operation Manual contains the instruction to handle the GIS data base created in the Study.

Maps

The Maps contain seven important maps created in the Study.

Summary

The summary report captures the essence of the Study in compact form.

1.7 HOME PAGE OF THE STUDY

A home page of the Study was created and put up in the web-site. The home page was transferred to SOPTRAVI for future utilization for disaster prevention and maintenance of the site. The address of the home page is as follows;

URL:http://www.hondutel.hn/jica/index.html

Chapter 2

Existing Conditions

CHAPTER 2 EXISTING CONDITIONS

2.1 NATURAL CONDITIONS

2.1.1 TOPOGRAPHY AND GEOLOGY OF THE STUDY AREA

The Study Area is located in the upper basin of the Choluteca River and in a mountainous area with the altitude between 900 m and 2,200 m. (*Figure 1.1*) The area is approximately 820 km2 and divided into the sub-basins of the Choluteca River, namely, the Guacerique River basin, the Grande River basin, the San Jose River basin and the Chiquito River basin.

The geology in and around the Study Area is roughly divided into the Valle de Angeles Group in Cretaceous Period, the Matagalpa Formation in Paleogene Period, the Padre Miguel Group in Tertiary Period and Quaternary volcanic deposit. Basalt lavas of early Quaternary period exist covering Padre Miguel Group and Matagalpa Formation. The base rocks are covered by terrace deposit, talus deposit, and river deposit of Quaternary period with limited amounts. *Figure 2.1* shows the geological map of the Study Area.

2.1.2 TOPOGRAPHY OF THE TARGET AREA FOR DISASTER PREVENTION

The Target Area for disaster prevention is Tegucigalpa urban area, as shown in *Figure 1.2*. The total area is 105 km2 and the elevation is between 900 m and 1,400 m. The area has a basin topography composed of valleys of the Choluteca River and its tributaries. *Figure 2.2* shows the topography of the Target Area for Disaster Prevention.

Figure 2.3 shows the elevation map of the area. There exists a comparatively flat land with the elevation between 940 m and 1040 m, where most of the urban area of the city lies. Outside of that flat area, there exist mountain ranges with the elevation higher than 1040 m, where the density of inhabitants is low.

Figure 2.4 shows the slope angle distribution of the area. The area of steep slope with the angle larger than 30 degree occupies 8% of the total area. The area with steep slope is distributed along the main trunk and the tributaries of the Choluteca River.

2.1.3 GEOLOGY OF THE TARGET AREA FOR DISASTER PREVENTION

(1) General Geology

The geology of the Target Area for disaster prevention is also composed of theValle de Angeles Group in Cretaceous Period, the Matagalpa Formation in Paleogene Period, the Padre Miguel Group in Tertiary Period and Quaternary volcanic deposit. The succession of strata in the Target Area is roughly as follows:

- Sedimentary rocks of Cretaceous age as the base,
- Volcanic rocks of tertiary age covering the Cretaceous rocks, and
- Volcanic rocks and sedimentary rocks of Quaternary covering the Tertiary rocks.

(2) Stratigraphy

The stratigraphy of the Target Area is shown in *Table 2.1*. *Table 2.1* was prepared through a detailed field survey in this area. The characteristics of each formation are described as follows:

Valle de Angeles Group

Villa Nueva Formation (Kvn)

These red layers are the basal formation of Valle de Angeles Group. These layers are mainly quartz conglomerates of sandy matrix with pebbles and some fine grain layers intercalated. Some quartz conglomerates are very hard and others are softer. The color of these layers varies from red in finest part to purple in coarse stuff.

The thickness of these layers varies from 10 cm to 200 cm. The age is estimated as Aptian to Albian (By Finch, 1972). In some places, it contains a lot of gypsum vein developed in fractures and in folding structures. The sedimentary structure is with normal grading and plain lamination. The materials of this layer are strong in general but the boundaries of layers are fragile and become potential slip-surfaces of landslide.

Rio Chiquito Formation (Krc)

These rocks overlie the Kvn layers with conformity. They are distinguished from Kvn due to their fine grain size.

They are inclined and folded in various directions. The deformation of this layer makes it very soft and susceptible to weathering, triggering many landslides in the Target Area. The thickness of this layer varies from 2 cm to 30 cm or more. The age of this layer identified by pollens is Upper Cretaceous. Its sedimentary structure is plain lamination and normal grading.

The boundary between Krc and Padre Miguel Group is particularly unstable. Sometimes the erosion of this layer causes the fall of the hard and fractured volcanic rock of Padre Miguel that overlies it.

Matagalpa Formation (TM)

This formation is composed of basalt and andesite lavas and some layers of basic tuffs. They are widely altered by weathering and hydrothermal alteration. Most of the outcrops have green color and some are reddish. Feldspar is altered to white clay (argilized) and amphibol and pyroxene are altered to chlorite and epidote. This formation is identified by the light gray soils developing on it.

They are susceptible to weathering and easily become fragile. Many cases of landslides are seen in this type of formation and at boundaries with upper layers.

Padre Miguel Group

This group is composed of the most common rocks in Tegucigalpa area. These are mainly volcanic rhyolitic tuffs , rhyolitic lavas and sedimentary layers of volcanic composition.

Tpml member:

This member is a sedimentary chaotic deposit of yellow color. No sedimentary structures are found in it and coarse and finer grains are distributed randomly. The matrix is composed of silt and volcanic ash. Pebbles are mainly of rhyolitic and dacitic tuff. With less proportion there exist pebbles of red sandstone of Krc, greenish gray andesitic tuff (Tm), and Basalts. Pebbles are either angular or sub-rounded and the size varies from 0.1 cm to 40 cm with the average 2 to 4 cm.

The deposit is filled with fine and medium sands matrix. This member was defined not as lahar but as high viscosity mud flow, because clast is not contemporaneous with a volcanic eruption. The matrix is composed mainly of volcanic ash and silt, and boulders and pebbles are mainly volcanic and in less proportion sedimentary.

Tpm-1:

This is the lower ignimbritic sequence. In this member, mainly rhyolitic pumice tuffs and dacitic/andesitic tuffs are found. Sometimes it looks like a sandy pumice tuff. Color varies from white, pale yellow to green or pale pink.

In this member, mainly rhyolitic pumice tuffs and dacitic/andesitic tuffs are found. Color varies from white, pale yellow to green or pale pink. These are massive tuffs15 to 20 meters thick in some outcrops. The pumice fragments are 0.5 to 3.0 cm thick in average, and few lithics is found.

The boundary between this layer and Krc is susceptible to landslides.

Tpm-2 :

This is the middle member of the ignimbritic sequence. These layers are relatively soft and banded tuff appears in many areas of Tegucigalpa. The thickness of this layer varies from 1 to 20 m.

Banded layers of this member are susceptible to landslide. Several landslides occurred on those banded layers in the area.

Tcg :

This member is characterized by rhyolitic lavas and dacitic welded tuffs. It is the hardest member of Padre Miguel group and easily recognizable by the vertical fractures. The Rhyolitic lava flows included in this member are characterized by the prevalence of flow structures.

This member forms high crops and extremely steep slopes, and many cases of slope failures occur in this member.

Tep:

This is a volcanic member of Padre Miguel Group. It often overlies Tcg and Tpm with conformity. Tep is characterized by the presence of sedimentary structures, such as paleo channels, lamination, normal graduation imbrication in clasts, cross lamination and others, and by a well-selection of clasts. This member is rather stable.

Tpm-3 :

This member is lithologically similar to Tpm-1 and is defined as pumice tuffs that overlies Tep. It overlies Tep and Tcg.

The boundary between this layer and Krc is susceptible to landslides.

<u>Quaternary</u>

Qa :

This formation is marked by the presence of andesitic lava, andesitic tuffs and some rhyolitic tuffs.

This andesitic lavas have a dark gray color and the majority of them are porous. Joint interval varies between 10 and 40 cm. They have porphyritic texture and some have fine grains. The rock is very hard and brakes in sharp pieces. Andesitic tuffs have different colors from pale yellow and yellow to reddish brown.

This formation is easily weathered and deteriorated. Tuff material is mainly pumice and fine ash. Banded planes have intervals of approximately 30 cm. The thickness of this formation is between 50 and 100 m. There are several big landslides with this formation.

Qb :

This formation consists of Basaltic lava flows with small crystals and some pyroclastics escorias.

Terrace deposits:

Many terrace deposits are located in the Target Area. Depending on their elevation, they are divided into Qe1, Qe2, and Qe3. Qe2 is divided into 2 different units because of the different kinds of clast consisting it. Qe2a is marked by inclusion of purplish soils whose origin is Krc. Qe2b is marked by inclusion of gray or light gray materials.

Qal :

These are younger alluvial deposits, located in many areas along the rivers.

Dt :

These deposits are located mainly on high slopes along a valley and at the foot of slope.

(3) Geological Map of the Target Area

The results of the geological field study were compiled as a complete geological map with the scale 1/10,000. *Figure 2.5* shows the geological map of the Target Area.

Figure 2.6 shows typical geological profiles of the Target Area.

2.1.4 HYDROLOGY

(1) General

The annual rainfall amount in the Study Area varies between 800 mm and 1,500 mm and the area average is 1,000 mm. *Figure 2.7* shows an isohyetal map of the area. According to the figure, rainfall amount is as large as 1,200 mm to 1,400 mm in the basin of the Guacerique River, the Grande River and in the La Tigra Mountains. On the other hand, rainfall amount in the area of southeast; the basins of the Sabacuante River and the Las Canoas River are as small as 850 mm. The annual evaporation estimated by the annual rainfall amount and the annual run-off is 800 mm.

(2) Rainfall

Rainfall data are available at the meteorological stations of SMN and SANAA in the basin as follows:

Table 2.2 Rainfall Stations in the Study Area

Basin	Station	Recorded Data	
		years	Range
Grande	Concepcion La Brea	10 15	1990 - 1999 1972 - 1986
San Jose	Villa Real El Aguacate	10 18	1991 - Present 1973 - 1990
Guacerique	Batallon Quiebra Montes	38 9	1963 - Present 1992 - Present
Chiquito	Nuevo Rosario	9	1993 - 1999
Tegucigalpa	Toncontin	50	1951 - Present

Source: SMN and SANAA

Rainfall data are recorded regularly 4 times a day at 6:00, 12:00, 18:00 and 24:00. The daily rainfall is the summation of these recorded data.

The maximum, minimum and annual average rainfall are shown in *Table 2.3*.

Table 2.3 Annual Rainfall in the Study Area

Basin	Station	Rainfall (mm/year)		
		Maximum	Minimum	Average
Grande	Concepcion	1,563	409	920
San Jose	Villa Real and El Aguacate	1,377	314	846
Guacerique	Batallon and Quiebra Montes	1,620	316	981
Chiquito	Nuevo Rosario	2,619	1,301	1,719
Tegucigalpa	Toncontin	1,274	453	866

(3) Water Level and Discharge

Data on water level and discharge are available at the stream gauging stations of SANAA and SERNA in the Study Area as shown in *Table 2.4*.

Table 2.4 Stream Gauging Stations in the Choluteca River Basin in Tegucigalpa

Basin	Station	Type	Recorded Data	
			years	Range
Grande	Concepcion	Non-daily	14	1977 - Present
San Jose	El Incienso	Daily and Non-daily	16 7	1971 – 1986, 1993 - Present
	El Aguacate	Daily and Non-daily	29	1970 - Present
Guacerique	Batallon	Daily	10	1964 - 1973
	Quiebra Montes	Daily and Non-daily	11	1990 - Present
	Guacerique	Daily and Non-daily	19	1982 - Present
	Los Laureles	Daily	2	1999 - Present

Source: SANAA

The locations of rainfall and stream gauging stations are shown in *Figure 2.8.*

In general, data on water level are recorded regularly twice a day in the morning and afternoon; these data are called daily data. However, some stations were severely damaged by Hurricane Mitch in 1998 and the measurement was conducted irregularly; these data are called non-daily data.

The annual maximum, average and minimum discharge of the main stations recorded are shown in *Table 2.5*.

Table 2.5 Average Discharge in the Choluteca River Basin in Tegucigalpa

Basin	Station	Discharge (m^3/s)		
		Maximum	Minimum	Average
Grande	Concepcion	9.96	0.072	0.895
San Jose	El Incienso	36.70	0.005	0.359
	El Aguacate	88.80	0.001	0.427
Guacerique	Quiebra Montes	10.90	0.040	0.566
	Guacerique	217.00	0.011	1.393

(4) Existing Meteorological Observation Facilities

The existing meteorological observation facilities are shown in *Table 2.6.*

Table 2.6 Existing Meteorological Observation Facilities in the Study Area

Catchment	Station	Item	Duration	Method	Frequency
Grande	Concepcion	Rinfall	1990 - Present	HMO	Daily
		Water Level	1997 - Present	HP	Non-daily
	Labrea	Rainfall	1972 - 1986	PV	Daily
	Lepaterique	Rainfall	1969 - Present	PV	Daily
Sabacuante	Villa Real	Rainfall	1991 - Present	HMO	Daily
	El Aguacate	Rainfall	1973 - 1990	HMO	Daily
		Water Level	1970 - Present	HP	Daily and Non-daily
Guacerique	Batallon	Rainfall	1963 - Present	HMO	Daily
		Water level	1964 - 1973	HP	Daily
	Guacerique II	Water level	1982 - Present	HP	Daily and Non-daily
	Quiebra Montes	Rainfall	1992 - Present	HMO	Daily
		Water level	1990 - Present	HP	Daily and Non-daily
	Los Laureles	Water Level	1999 - Present	LN	Daily
Tatumbla	El Incienso	Rainfall	1970 - 1990	HMO	Daily
		Water level	1971 - 1986 1993 - Present	HP HP	Daily Non-daily
Chiquito	Nuevo Rosario	Rainfall	1993 - Present	PV	Daily
Choluteca	Toncontin	Rainfall	1951 - Present	HMP	Daily
	Chile	Rainall	2001 – Present	LN	Daily

Note
HMO = Ordinary Hydro-meteorological system
PV = Pluviometer system
HMP = Principal Hydro-meteorological system
HP = Principal Hydrometric system
LN = Telemetering System

The problems on the existing meteorological observation facilities are as follows:

- There are only three telemetering stations in the Study Area, Los Laureles station in the Gaucerique River basin, Concepcion station in the Grande River basin and Choluteca station at the lower reach, but they are newly established and have only a short-range record.
- Rainfall and water level data from the other stations are recorded by automatic recorders or manually by the staff of SERNA or SANAA. However, many stations were damaged severely by Hurricane Mitch and have not been repaired.
- After Hurricane Mitch, water levels in many stations have been manually measured by

using staff gauges twice a day. But these data are not useful in the analysis because they do not represent the flow characteristics such as the maximum, minimum or average.

- Because of the manual recording, some data were missing or wrong.

Considering the importance of meteorological information to cope with the flood and landslide problems in this area, it is necessary to improve the meteorological observation network.

2.1.5 NATURAL ENVIRONMENT

The riverine environment of Tegucigalpa is severely deteriorated. The rivers in the city are essentially black in color and emanate offensive odor.

The rivers of the city, similar to those of other Latin American cities, serve as open sewers for the discharging of untreated wastewaters resulting from all types of urban uses of domestic, institutional, commercial and industrial origin. Also, this continued disposal of untreated wastewaters in the rivers has resulted in the pollution of riverbeds with the surface of riverbeds being virtually formed with wastewater sludge rather than natural soil, in particular in those river reaches with low flow velocity. In effect, the rivers in the city are essentially ecologically dead with no beneficial uses other than as open sewers for the discharge of untreated wastewaters.

Because of this deteriorated environment, fauna and flora in and along the Choluteca River are poor in the Target Area for disaster prevention.

2.2 SOCIOECONOMIC CONDITIONS

2.2.1 GENERAL

The Republic of Honduras is located in the Central American region, and is bounded by the Republic of Guatemala on the West, El Salvador on the South and Nicaragua on the East and Southeast. It has a territorial extension of 112,492 km^2 and a population of approximately 6 million.

It is a developing country with agriculture as its economic base. It has one of the lowest Gross Domestic Products (GDP) in Central America. Its major exports are bananas, coffee, and lumber. These agricultural based industries employ over 60 percent of the common workers and provide 80 percent of its exports.

2.2.2 POPULATION OF TEGUCIGALPA METROPOLITAN AREA

The latest authorized population data is the National Census of Population and Household conducted by the General Directorate of Statistics and Census (DGEC) in 1988. The final result of the census conducted in 2001 has not been published yet. The census concluded that the urban population of Tegucigalpa in 1988 was 577,661. After the census in 1988, the population has been projected in various ways; however, there is a substantial difference among them and each one has little solid justification. Due to the lack of proper resident registration system in Honduras, the present population is only an estimated value.

The latest reliable estimated population has been presented in the project titled “The Study on Water Supply System for Tegucigalpa Urban Area,” (hereinafter referred to as "the Water Supply Study"), which was conducted by JICA in 2000. The Water Supply Study has estimated the population of Tegucigalpa in 2000 as 932,000, based on the number of households given by the pre-census 2000, which DGEC prepared for the Census 2000, and the average size of household given by the Permanent Multiple Purpose Questionnaire Survey of Families (EPHPM) conducted by DGEC in March 1999.

2.2.3 GDP AND OTHER ECONOMIC INDICATORS

Honduras is the fourth poorest country in Latin America with per capita annual income of around $650; more than 65% of its population is in poverty. The GDP per capita in 1999 fell by 4.6% reflecting the worsening economic situation caused by Hurricane Mitch. *Table 2.7* shows the GDP of Honduras in the last ten years.

Table 2.7 GDP of Honduras

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
GDP (million US$)	3,091	3,191	3,371	3,581	3,534	3,678	3,811	4,004	4,122	4,044
GDP per Cap (US$)	633.5	634.7	650.7	671.1	643.3	650.6	655.3	669.5	670.5	640.3

Source: IDB WEB site, www.iadb.org/int/sta/ENGLISH/brptnet/english/hndbrpt.htm

For the city of Tegucigalpa, the regional GDP per capita reached almost $900 in 2000.

Since the government of Honduras could not cover the whole cost to manage and to develop the country by their income tax revenue, it is necessary to bring in external finance source to the country. *Table 2.8* shows the external debts of Honduras.

Table 2.8 External Debts

Unit: million USD

Year	1991	1992	1993	1994	1995	1996	1997	1998
Total debts	3,396	3,614	4,077	4,436	4,570	4,533	4,710	5,002
Bilateral public loan	1,089	1,163	1,307	1,470	1,455	1,412	1,368	1,404
Multilateral public loan	1,658	1,801	1,952	2,062	2,153	2,109	2,312	2,379
Total debt service	307	377	361	433	553	564	505	505
Debt service for bilateral loan	55	68	73	82	135	69	106	108
Debt service for multilateral loan	186	229	214	262	262	336	219	211

Source: IDB WEB site, www.iadb.org/int/sta/ENGLISH/brptnet/english/hndbrpt.htm

The Honduran economy has been suffering from a severe inflation like other Latin American countries. *Table 2.9* shows annual growth rate of consumer price index (CPI). The average annual inflation rate during 1990s was 19.0% a year.

Table 2.9 Consumer Price Index

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Annual growth rate of CPI (%)	23.3	34.0	8.7	10.8	21.7	29.5	23.8	20.2	13.7	11.6
CPI (year 1990 = 100)	100	134	146	161	196	254	315	379	430	480

Source: The Study on Water Supply System for Tegucigalpa Urban Area, JICA, 2000

2.2.4 LAND USE

(1) Land Use in the Study Area

The latest land use map of the Study Area was made in 1983 as a part of the study on soil property and vegetation features of the Department of Morazan. (Estudio de Suelos a Recomocimiento del Departamento de Francisco Morazan/Informe Technico de Vegetacion del Departamento de Francisco Morazan, 1983, Direccion Ejecutiva del Catastro Nacional). Based on this land use map and also on the aerial photo in March 1999, the present land use map of the Study Area of 820 km^2 was prepared as shown in *Figure 2.9.* In the map, the portion of the urban area was revised based on the land use data obtained from the orthophoto prepared in the Study. *Table 2.10* shows the land use of the Study Area.

Table 2.10 Present Land Use in the Study Area

Land use category	The Study Area	
	Unit: ha.	Ratio
Forest & Shrubs	37,534.2	45.80%
Bush Lands	13,152.7	16.05%
Pasture & Grass Lands	18,566.2	22.65%
Agriculture Lands	4734.0	5.77%
Water Bodies	290.3	0.35%
High Density Urbanized Area	6,140.7	7.49%
Settlement Areas	1,488.7	1.82%
Airport	59.0	0.07%
Total	81,965.8	100.00%

(2) Land Use in the Target Area

The present land use of the Target Area for disaster prevention was investigated based on the orthophoto with the scale of 1/10,000 taken in February 2001 and the topographic map with the scale 1/5,000 created from the orthophoto.

Figure 2.10 shows the present land use of the Target Area for disaster prevention. *Figure 2.11* shows the distribution of the built-up area in the Target Area for disaster prevention. *Table 2.11* shows the present land use of the Target Area for disaster prevention.

Table 2.11 Present Land Use of the Target Area

Land Use category	Area (ha)	Ratio
Commercial	310.1	3.0%
Protocol & Business Area	27.8	0.3%
Public Facility	157.0	1.5%
Residential: R-1 to R-5	2,880.7	27.4%
Industrial Area	121.5	1.2%
Military Facility	132.7	1.3%
Airport	59.0	0.6%
Roads & Streets	1,940.5	18.5%
Park & Green Area	201.8	1.9%
Cemetery	25.5	0.2%
Sports Field	51.9	0.5%
Forest & Shrubs	973.5	9.3%
River Reserve Area	389.5	3.7%
Reservoir	46.3	0.4%
Vacant Space	3,178.3	30.3%
Total	10,496.0	100.0%

Residential area by classification	Area (ha)	Ratio
R-1: Residential 250 pers. / ha	1,876.2	65.1%
R-2: Residential 400 pers. / ha	643.4	22.3%
R-3: Residential 500 pers. / ha	179.1	6.2%
R-4: Residential 800 pers. / ha	147.2	5.1%
R-5: Residential >800 pers. / ha	34.8	1.2%
Total	2,880.7	100.0%

Note: The threshold values were determined through discussion with Metro Plan of the municipal office.

2.2.5 HISTORICAL AREA

The cities of Tegucigalpa and Comayaguela have a great number of buildings with historical value declared as National Monuments according to the municipal agreement in April 1977.

In April 1994, the municipal mayor's office of the Central District and the Honduran Institute of Anthropology and History signed an agreement for the "Conservation of the Historical Area of Tegucigalpa/Comayaguela and Neighboring Areas" as shown in *Figure 2.12*.

2.3 RIVER CONDITION

2.3.1 WATERSHED

As a consequence of the urban expansion of Tegucigalpa, there has been a continuous deforestation in areas for housing, industries or other facilities. Forests have been logged over to fulfill the need of firewood in zones near the urban areas. Another problem is the many forest fires that are generated every dry season. Forest fires leave the topsoil without vegetative cover, making it prone to erosion.

In the Study, the erosion characteristics of the soil were estimated using the Universal Soil Loss Equation (USLE). The Study Area was divided into 27 micro-basins and USLE was applied for each micro-basin to assess the soil erosion distribution. (Refer to Supporting I)

Figure 2.13 shows the distribution of potential erosion in the Study Area. It can be observed that there are six (6) micro-basins, namely Chiqquito, Mololoa, Chuluteca, Qda.Grande, Sabacante and Laguna del Pescado, classified as having heavy potential erosion. Therefore, the remaining ones correspond to moderate and slight potential erosion. The average sediment yield of the whole Study Area is 0.4 mm/year and according to this estimation, the degree of soil erosion of the basin is not so serious.

2.3.2 RIVER FEATURES

(1) Choluteca River

The Choluteca River originates in Tegucigalpa City and flows toward north. It turns the course toward south in the middle reaches and finally flows into the Gulf of Fonseca in the Pacific Ocean. Its total length is 320 km and the catchment is 7,465 km^2.

The upper reach of the Choluteca River in the Target Area flows down from south to north in Tegucigalpa City. The main trunk of the Choluteca River is called Grande in its upper reach and is joined by its tributaries such as the San Jose, the Guacerique, the Chiquito, the Sapo and the Cacao Rivers. *Figure 2.14* shows the Choluteca River in the Target Area with the river survey milestone numbers. Bank condition and hinterland along the Choluteca River in the Target Area are shown in *Table 2.12.*

(2) Grande River

It is the main trunk of the upper reach of the Choluteca River. Its catchment area is 258 km^2 and its slope is 1/30-1/60. The Concepcion Dam operated by SANNA is on the river. The dam is equipped with a free flow spillway with a capacity of 950m^3/s. During Hurricane Mitch, flood with peak value of about 850m^3/s was discharged through the spillway. On its tributary so called Qu La Lagura stream, there is a lake named the Pescado Lake, which was created by landslide in the past.

(3) San Jose River

It flows down from southeast into the Choluteca River. The catchment area is 169 km^2 and its slope is 1/10-1/50. No dam exists in the basin, but SANAA is studying to construct a dam in Sabacuante.

(4) Guacerique River

It flows down from west mountains into the Choluteca River in the Tegucigalpa urban area. Its catchment area is 244 km^2 and its slope is 1/30. The Los Laureles dam of SANAA is located on the river. The spillway of the dam is equipped with a rubber gate 3 m high and 68 m long. During Hurricane Mitch, the rubber dam had not been shrunk and the flood flow overtopped the rubber dam as well as the side dam making the peak discharge from the dam approximately 1,200m^3/s.

(5) Chiquito River

It flows down from east hillside in Tegucigalpa City. The catchment area is 90 km^2 and its slope is 1/10-1/50. The topography of the basin is rather flat and there is no plan of dams in the basin. Consequently, there is no designation of conservation area for water resources development for this basin and recently many housing developments are on-going.

(6) Sapo River

It is located at western hilly area in Tegucigalpa City. Its slope is as steep as 1/50. The catchment area is 3 km^2. Its lower part is an artificial concrete channel 5 m wide and 3 m deep. The confluence with the Choluteca River is located at C51. Its outlet is a pipe culvert with adiameter of 3 m. The pipe culvert is 600 m long with a slope of 1/80.

During Hurricane Mitch, the outlet was filled up by sediment of the Choluteca River and flood occurred near the inlet of the pipe culvert. As the outlet of the pipe culvert is still half submerged, making the discharge capacity of the Sapo River smaller than before.

Illegal dumping of garbage in both river courses is widely prevalent. Sometimes, the inlet of the pipe culvert is clogged by garbage and it causes overflow and inundation of the neighboring areas.

(7) Cacao River

Its confluence with the Choluteca River is located at downstream from the Chile Bridge at C39. Its slope is about 1/8 and its catchment area is 3 km^2. Its waterway is mostly composed of artificial concrete walls with natural gravel and cobblestone bed. The width of the channel is about 8 m and the depth is 2 m. The channel changes its course to the north perpendicularly near the Choluteca River and its mal-formation causes sudden decrease of flow velocity and sediment deposit in the area. During Hurricane Mitch, some houses along the river were destroyed by the debris flow.

(8) Bambu River

It is located on the Chiquito River 2 km upstream from the confluence with the Choluteca River. Its catchment is 0.3 km^2. It is connected to the Chiquito River by a culvert with a diameter of about 1m. The length of the culvert is 400 m. During Hurricane Mitch, floodwater overflowed the culvert and caused inundation in the neighboring area.

(9) Pescado Lake

It is a small lake of about 100,000 m^2 located along the Qu La Lagura stream, which is one of the tributaries of the Grande River, about 1.3 km upstream from the confluence with the Grande River. The Pescado Lake was formed by landslide that stopped the flow of the river in the past. During Hurricane Mitch, a natural dam was formed at the outlet of the lake by a new landslide and consequently, it was overtopped by the flood. The maximum lake water level at that time was about 8 m higher than the present level. The break of the dam and subsequent violent flow caused flood damage downstream.

The area of the lake decreased from 0.3 km^2 before the event to 0.15 km^2 afterwards, shrinking to half its former size. It is estimated that the water volume of more than 1.5 million m^3 generated a maximum discharge flow of 1,000 m^3/s.

2.3.3 RIVER CAPACITY

In order to understand the river features, an intensive river survey was carried out along the river. The width, the profile and the present capacity of each section of the river was studied for the length of 30 km including the Choluteca, the Guacerique, the Chiquito and the Sapo Rivers.

Figure 2.15 shows the width of the present river. It shows that at 4.8 km and 4.9 km from point A, the river width is very small compared to the other portion of the river. These two points correspond to the river course near the Berrinche landslide where the landslide mass is intruding into the river course and squeezing the width. Except these two points, the width of the river is wide enough compared to the design width described later.

Figure 2.16 shows the profile of the present river. It shows that the original river has a rather uniform profile with a slope of 1/190 to 1/250.

Figure 2.17 shows the discharge capacity of each section of the river calculated by a non-uniform flow model. It shows that the river capacity is comparatively small at between 3 to 10 km from point A. Especially, at C48 and C49, the discharge capacity is 300 m^3/s and its return period is less than one year. If this is compared with *Figure 2.15*, it is understood that the mal-capacity of the river is not because of the narrow width of the channel but because of the sediment of the river, except C48 and C49, where the Berrinche landslide is intruding into the river.

Therefore, two main causes of the mal-capacity of the Choluteca River are:

- Narrow channel at Berrinche (5 km from point A, C48-C50), and
- Sediment between 3 km and 10 km from point A (C30-C100).

2.3.4 RAINFALL BY HURRICANE MITCH

(1) Rainfall Pattern

There is only one rainfall station in the area where the hourly rainfall data during Hurricane Mitch was obtained. The hourly rainfall pattern at Toncontin station during Hurricane Mitch had its peak at 120 mm on October 30, 1998, and the total rainfall in 72 hours was 256 mm. The rainfall pattern is as follows:

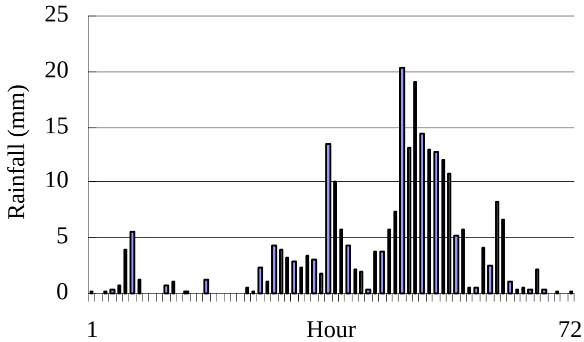

Figure 2.18 Recorded Rainfall at Toncontin during Hurricane Mitch

(2) Rainfall Distribution in the Area

During Hurricane Mitch, although the storm period was about 3 days, the continuous rainfall was found to be about 48 hours in the entire region. The distribution of rainfall for 2 days from all stations was apparently uniform. Comparison of 1-day and 2-day rainfall is shown in *Table 2.13.*

Table 2.13 Maximum Rainfall during Hurricane Mitch

Basin	Station	1-Day Rainfall (mm)	2-Day Rainfall (mm)
Grande	Concepcion	220.3	289.30
San Jose	Aguacate & Villa Real	236.3	275.20
Guacerique	Batallon & Quiebra Montes	215.0	232.80
Chiquito	Nuevo Rosario	145.7	245.40
Choluteca in Tegucigalpa	Toncontin	120.4	240.70

(3) Return Period of the Rainfall Amount

As the 2-day rainfall amount is uniform in the area as shown in the above table, the maximum 2-day rainfall was calculated and analyzed. The return period analysis at Toncontin station is shown in *Figure 2.19*. According to the figure, the return period of the rainfall by Hurricane Mitch is around 500 years.

2.3.5 FLOOD BY HURRICANE MITCH

(1) High Water Mark Survey

In this Study, high water marks during Hurricane Mitch were surveyed. The survey was carried out at all river survey cross sections. The interval of survey is 100 m and in Comayaguela where a large area was inundated, the depth was surveyed at every crossroad of the area.

The survey was conducted through interviews with the residents who experienced Hurricane Mitch. The elevation of high water mark was surveyed from the known points of the river survey.

The result of the high water mark survey is shown in *Figure 2.20*. Detailed survey result is contained in the Data Book.

(2) Flood Condition and Damage Survey by USGS

The USGS conducted a preliminary flood condition and damage survey after the Hurricane Mitch in 1998. The sequence of flood damage was as follows:

Table 2.14 Flood Condition and Damage during the Hurricane Mitch

Date	Time	Condition and Damage
October 30	22:45	Spillway of the Los Laureles dam overflowed
October 30	23:00	Pescado Lake collapsed
October 30	22:00 – 24:00	Severe erosion and landslide occurred at El Country bridge
October 30 - 31	23:00 – 6:00	Outflow was at peak at the Concepcion dam
October 30	24:00	Flood at peak in the Chiquito River
October 30 - 31	24:00 – 1:00	Landslide occurred in many locations
October 31	1:00	Flow at Chile Bridge at peak
October 31	Morning	Landslide at Berrinche occurred

Source: "Survey Response to the Hurricane in Honduras in 1998" by USGS

(3) Flood Survey in the Study

In the Study, interviews were made to the residents regarding the time of the peak flood discharge at Mallol Bridge. It was found out that the highest water level there appeared between 24:00 on October 30th and 1:00 on October 31st, while the closure of the Choluteca River by Berrinche landslide occurred at the daybreak of October 31st. By this observation, it was found out that the water level rising caused by Berrinche landslide was lower than the maximum water level throughout the flood phenomenon.

2.3.6 FLOOD SIMULATION OF HURRICANE MITCH

A mathematical model of the present Choluteca River was constructed and the inundation phenomenon during Hurricane Mitch was simulated. The model procedure is explained in Supporting C.

(1) Rainfall Model

The maximum 2-day rainfall at Toncontin station was used in the analysis because:

- Toncontin station has the longest data range (50 years) and is considered as the most reliable data for the analysis of up to 50-year return period,

- Maximum 1-day rainfall at Toncontin station was comparatively low. This was because the period 1 day was set for 24 hours of 1 calendar day from 0:00 to 24:00. However, peak rainfall during Hurricane Mitch occurred at night on October 30, 1998, and continued until October 31, 1998. In this case, 1-day rainfall could not cover the actual rainfall period. As a result, maximum 2-day rainfall was considered more applicable to represent the actual rainfall during Hurricane Mitch.

The design rainfall pattern at each sub-basin during Hurricane Mitch was constructed by multiplying the rainfall pattern at Toncontin station with the ratio of the total amount of 2-day rainfall.

(2) Run-off Model

The storage function model was made by using the rainfall pattern of each sub-basin. The estimated peak discharge at point A, the lowest end of the Study Area, is approximately 4,000 m^3/s.

(3) Hydraulic Model

A hydraulic model was constructed by using a software called MIKE11, a one-dimensional unsteady flow program, developed by the Danish Hydraulic Institute.

(4) Model River Sections

For the hydraulic model, the river cross sections surveyed in the Study in 2001 were used. There is an argument that the peak discharge during Hurricane Mitch appeared before the landslide of Berrinche and before the large sediment in the river was accumulated. However, the comparison of the riverbed elevations between the survey result in 2001 and the one taken from the topographic map created from an aerial photo taken in 1996 shows little difference. Therefore, the usage of the river sections in 2001 to simulate the inundation during Hurricane Mitch is justified. (Refer to *Figure 2.21* and *Figure 2.22*)

(5) Effect of the Berrinche Landslide

It was also pointed out that the inundation at the center of the city during Hurricane Mitch might be caused by the closure of the Choluteca River due to the Berrinche landslide. However, the simulation in the Study showed that the peak inundation level at the center of the city before the Berrinche landslide is higher than the inundation level caused by the dam up by the landslide. This is because when the landslide blocked off the river, the peak of the flood was over and the discharge amount was much smaller. It coincides with the result of interviews with the residents on the peak discharge time at the center of the city. *Figure 2.23* shows the comparison of two inundation levels. Therefore, it is justified to calibrate the hydraulic model without the effect of the Berrinche Landslide by the inundation survey result, which indicates the highest water level observed in the incident.

(6) Influence of Dam Break at the Pescado Lake

It was reported that the natural dam at the Pescado Lake collapsed during Hurricane Mitch on October 30, 1998 at 22:00-23:00. The discharge from this disaster was taken into consideration in the model. From the reference and topographic map, the dimension of the Laguna was as follows:

Table 2.15 Dimension of the Pescado Lake

Lake	Dimension
Surface Area	88,688 m^2
Depth	8 m
Storage Volume	709,504 m^3

Note: Surface area, measured from the topographic map
Depth, referred to Informe de Visita a la Laguna del Pescado in 1999

From the field investigation, the outlet of the Laguna after the dam-break had a width of about 20 m and depth of 8 m. The peak discharge from the lake was calculated at approximately 1,000 m^3/s. The hydrograph of this Laguna was included in the hydraulic simulation as well.

The hydrograph in the upstream and downstream during Hurricane Mitch were compared in order to check the extent of the impact of the dam-break as shown in *Figures 2.24* and *2.25*.

The hydrograph in the upstream had 2 peaks during October, 30 – 31, 1998; the higher peak was at 23:00 on October 30, while that in the downstream had the higher peak at 2:00 on October 31. This can be interpreted that the impact of the dam-break was only in the upstream before the confluence with the San Jose River basin.

(7) Model Calibration

The hydraulic model was calibrated with the inundation survey result. Necessary parameters in the storage function model shown in the following *Table 2.16* were calibrated by using the above condition.

Table 2.16 Parameters in the Rainfall-runoff Analysis

Parameter	Value
k	17.0
p	0.3333

(8) Simulation Result

Figures 2.26 and *2.27* show the comparison between the hydraulic model simulation and the result of the inundation survey. *Figure 2.26* is the highest water level distribution along the river and *Figure 2.27* shows the inundation area.

2.3.7 FLOOD HAZARD MAP

Figure 2.28 is the hazard map showing the inundation area along the river by flood with scales 1/5, 1/10, 1/25 and 1/50. This map shows the without-project condition and by the implementation of the river improvement proposed by this Study, the inundation area will be smaller.

SERNA has been working with USGS in creating a flood hazard map with the return period of 50 years. Discussions were made between the Study team and USGS to make the flood hazard maps consistent each other.

Figure 2.29 is the hazard map showing the inundation area by a flood with a scale of Hurricane Mitch. The total number of households in those inundation areas (2 km^2) is approximately 3,000 and the number of residents is estimated at 15,000.

2.3.8 SEDIMENT TRANSPORT IN THE RIVERS

A riverbed material survey was carried out at about 1 km interval in the Choluteca River and the Chiquito River, 12 sites of the Choluteca River and 3 sites of the Chiquito River. Details of riverbed material survey is described in Supporting D. According to the survey result, the riverbed materials are coarse, d60 being 30 mm and 40 mm in the Choluteca River and the Chiquito River respectively. Therefore, both rivers have capacity of flushing out fine sediment less than 30-40 mm.

The sediment transport capacity was calculated along the river taking the present configuration of the river into consideration. The capacity was evaluated by the sediment transport capacity of the discharge 1,000 m3/s with the return period of 1 year and the sediment model with diameter of d60=30 mm. The calculation result is shown in *Figure 2.30*. It shows that in the present river, the sediment transport capacity is low in the upstream of Berrinche area (C50 – C55) because of low energy gradient of the river.

2.4 LANDSLIDE

In Japan, the disaster caused by the movement of earth is classified into three categories, namely “landslide”, “slope failure” and “debris flow” and the same classification was applied in this Study. In “landslide” generally, the movement is slow (less than 1 cm/minute) and the movement last long or the movement repeat itself. On the other hand, in “slope failure”, the movement velocity is more than 1 m/second and the movement lasts only one hour or less. There are also differences in the scale of the movement and the slope gradient of the original slopes between them.

Vanes(1978) classified slope movements into “Topple”, “Slide”, “Spread”, “Fall” and “Flow”. The classification in Japan focuses on the damage degree by the scale and the movement velocity of the land mass and it is not necessarily possible to compare with the classification by Vanes. However, the “landslide” in the Study roughly corresponds to “Slide” by Vanes. The “slope failure” in the Study roughly corresponds to small scale “Slide” and “Fall” by Vanes.

In the target area of disaster prevention in the Study, most earth disasters are “landslide” and “slope failure” with few examples of “debris flow”. Therefore, only “landslide” and “slope failure” are studied here.

2.4.1 LANDSLIDE PROBLEMS IN THE AREA

(1) Landslides during Hurricane Mitch

USGS has analyzed the actual landslides caused by Hurricane Mitch based on the aerial photos taken in March 1999. It is a rather accurate data as the photo was taken soon after the disaster and the scars were still fresh. The location map of landslide during Hurricane Mitch is shown in *Figure 2.31(1)*.

(2) Aerial Photography Interpretation

The aerial photographs with the scale of 1/10,000 were scrutinized together with the orthophoto to interpret the topographic features of landslide. Typical landslide topographic features were identified and designated as susceptible landslide blocks.

(3) Landslide Pattern

Those landslides in the Target Area were classified according to the geological patterns that triggered them. *Figure 2.32* shows several geological structures of landslide in the area. Those structures are classified as follows:

Pattern 1) A banded layer is underlaid by hard welded tuffs. Those banded surfaces are prone to become slip-surfaces.

Pattern 2) Faults exist in the base rock. The fault becomes a slip surface or the fault blocks the flow of groundwater and raises the groundwater level, inducing landslides.

Pattern 3) Comparatively hard and light tuff layer (Tpm-3))overlays Chiquito formation (Krc) which is prone to be weathered. When the dip slope structure forms in Krc layers, a large-scale landslide is anticipated.

Pattern4) The TM formation is underlaid by Qa and Tcg. The upper layer is comparatively hard and the lower layer is weak and prone to be weathered . In this case, andesite of Quarterly with high density overlies the layer of Matagalpa Formation (TM), which is prone to be weathered. Also the lower layer becomes impermeable and raises the groundwater level in the mass, triggering a large-scale landslide.

(4) Classification of the Degree of Landslide Danger

The degree of landslide danger is judged according to the following items:

- Present movement: whether it is moving at present or the movement occurred in recent years
- Type of landslide mass: weathered rock or soil/ clay or sand
- Groundwater condition: whether the influence of groundwater is eminent or not

Among above conditions, the present movement of the landslide mass is the most important factor. In field reconnaissance, the recent movement was judged by observing the deformation of existing structures and micro topography of the area. Observations coming from the residents were also an important source of information. In the Study, the micro topography of the area and the record of movement were collected and judged accordingly.

Table 2.17 shows classification of the degree of landslide danger.

The degree of danger was classified into three categories, namely, A, B and C. Definition of each category is as follows:

Rank A

There are evidences of present or recent movement of the landslide mass. The landslide blocks are those which moved during Hurricane Mitch or those judged as having moved in these past ten years. The slip scarp is not covered by any vegetation and clear outcrop exists. Cracks are observed at the boundaries. Misalignment of structures is observed. The bottom part of the landmass is swelling out or small, tongue-shaped slope failure is observed.

Rank B

Although the typical landslide topographic features are observed, it is judged that there has been no movement in recent years (the slip scarp or side cracks are covered by vegetation). Without any typical landslide topographic features observed, still following observations are made:

- there are examples of recent landslide with a similar geological formation in the neighborhood,
- the structure of the land mass is composed of clay or colluvium deposit and weak.

Rank C

Although the landslide topographic feature is observed, the age of the slide occurrence is old and the block is stable at present. The slip scarp forms a terrace but is covered by debris and surface soil without revealing the original shape. A swelling is observed at the bottom but no new collapse or deformation of structures. There is no symptom of landslide according to the residents.

(5) Distribution of Landslides

Figure 2.33 shows the distribution of landslide masses with each danger rank.

In the figure, many landslide masses distribute in the north of the area. *Figure 2.34* shows the northern part of the area in a larger scale and with the distribution of lineaments. Lineaments means the linear structure observed in a topographic map or an aerial photo. It often represents fault or geological weakness. This figure shows that prominent landslides such as Berrinche, Campo Cielo, San Martin and Bambu lie on the lineament structure and it is known that faults and fractured zone are triggering landslides.

(6) Affected Area by a Landslide

When making a hazard map of landslide, it is necessary to identify the affected area for each landslide mass. The affected area means the area where the part of the landslide mass may reach and destroy the houses and infrastructures.

The affected area for each landslide mass were estimated taking into account the configuration of the landslide mass and the surrounding topography (Refer to Supporting B)

As the estimation of the affected area is based on experiences in Japan, it is necessary to accumulated more data and improve the accuracy of estimation in future.

In the hazard map of the landslide, the affected areas were indicated as well as the landslide masses themselves and considered as dangerous areas.

2.4.2 SLOPE FAILURE PROBLEMS IN THE AREA

(1) Slope Failures during Hurricane Mitch

USGS has analyzed the actual slope failures caused by Hurricane Mitch based on the aerial photos taken in March 1999. The location map of slope failures during Hurricane Mitch is shown in *Figure 2.31(2)*.

(2) Identification of Slope Failure Dangerous Area

The slope failure phenomenon in the Target Area was studied in terms of gradient and geological features of the slope. *Figures 2.35* and *2.36* show this two-pronged classification respectively.

By looking at these two figures, it is judged that slope failure phenomenon is categorized into patterns with the combination of geological features and slope gradient. Thus, prominent slope failures in the Target Area were selected for further study. The total number of the selected slope failures is 173. For these slope failures, the gradient of the original slope, the slope height and the arrival distance of deposit by the failure were measured from the orthophoto.

The results of the processed data are shown in *Table 2.18* and *Figures 2.37* and *2.38*. By using these information, threshold values of slope failure danger were set for each geological classification. *Table 2.19* shows the threshold value to judge danger of slope failure. The affected area by the slope failure was also estimated from the analysis of actual slope failure example and the extent of the affected area. (Refer to Supporting B)

The above two categories of slope failure danger, namely, “dangerous slope” and “the affected area by a slope failure” are all indicated in the hazard map of slope failure.

The details of this analysis is described in Supporting B.

2.4.3 HAZARD MAP OF LANDSLIDE AND HAZARD MAP OF SLOPE FAILURE

The hazard map of landslide is shown in *Figure 2.39(1).* In the landslide hazard map, all the landslide masses with the grade of A, B and C together with the affected areas are indicated. The total area of Rank A landslide and the affected area (1 km^2) occupies 1% of the whole Target Area. The number of households in Rank A landslide masses and their affected areas are shown in *Table 2.20.* The total number of households in Rank A landslide is 1,500 and the number of people affected is estimated at 7,500.

The hazard map of slope failures is shown in *Figure 2.39(2).* As for slope failures, “dangerous slope” and “the affected area by a slope failure” are shown in *Figure 2.39(2).* The area covered by these two categories (26 km^2) occupies 25% of the whole Target Area. The total number of households in those three categories is 25,000 and the number of people affected is estimated at 125,000.

2.5 ORGANIZATION

2.5.1 GENERAL

There is a substantial number of government agencies and other institutions involved or concerned with, or to undertake activities in the disaster prevention sector. The degree of their involvement, the extent of their participation and the nature of their activities vary from one agency to the other.

The National Emergency Committee (COPECO) was created in 1991 for the natural disaster prevention at national, regional and municipal levels. Municipality Emergency Commission of Tegucigalpa under COPECO was established in 1998 just a few months before Hurricane Mitch struck. During Hurricane Mitch, even though there existed these organizations for disaster prevention, huge damage was brought about.

The natural disaster prevention works in Tegucigalpa were originally under jurisdiction of Municipality of the Central District. After Hurricane Mitch, SOPTRAVI and SERNA are put in charge of flood mitigation and landslide prevention in Tegucigalpa. However, the demarcation of jurisdiction for these sectors (flood mitigation, sediment control or landslide prevention) is not clear.

For disaster prevention including preventive measures, emergency operation and rehabilitation in Tegucigalpa, many agencies are concerned. Among them are SOPTRAVI, SERNA, SANAA, COHDEFOR, COPECO, CODEM, AMDC, and SETCO.

2.5.2 KEY AGENCIES AND INSTITUTIONS WITH CONCERNS IN DISASTER PREVENTION

The following are major responsible agencies or organizations for natural disaster prevention in the Metropolitan Area. Supporting L provides details.

(1) National Emergency Committee (COPECO)

The National Emergency Committee (COPECO) was created in 1991 by Legislative Decree No. 528-91 succeeding "COPEN" and is the organization under the direct control of the President of the Republic, which is in charge of the disaster prevention. The major objective of the COPECO is to cope with emergency and disaster caused by the change of a natural phenomenon at the national, regional and district levels.

The whole country is divided to seven regions for disaster prevention at the regional level and each region has one Municipality Emergency Committee (CODEM).

Especially after Hurricane Mitch, this organization has been revised and reorganized. Before Hurricane Mitch, COPECO was in charge of only emergency problems; at present, however, it is responsible for preventive measures, emergency operations and rehabilitation measures against natural disasters.

The competence of COPECO is directed toward the following:

1) To request the executive to declare a state of emergency, disaster or calamity in the affected regions.2) To adopt measures to guide the people for the rehabilitation and reconstruction of the damaged areas.
2) To adopt measures to guide the people for the rehabilitation and reconstruction of the damaged areas.
3) To draw applicable policies for the attention and management of the emergencies in the country.
4) To receive, register, coordinate and distribute materials, human and financial resources given by national and international cooperation organizations through the President.
5) To acknowledge the magnitude of the emergency, disaster or calamity depending on an evaluation of the damages and how causes and consequences are established in order to take not only the appropriate measures to solve the present problem, but also to prevent future events.
6) To approve the Operational Plan of short, medium and long term made by the National Executive Committee.
7) To approve the National Emergency Committee budget of incomes and outcomes project.
8) To acknowledge, analyze and approve the feasibility studies on projects elaborated and presented by the National Executive Committee.
9) The other competence allocated in Article 7 of the law that may be applicable.

(2) Municipality Emergency Committee (CODEM)

The Municipality Emergency Committee (CODEM) was constituted in July 1998 just three months before Hurricane Mitch struck. A regional level organization for disaster prevention activities, CODEM is a substructure of COPECO and plays an important role especially in natural disaster emergencies. There are seven (7) regions for CODEM and the CODEM of Municipality of Central District is included in Region 7. The CODEM is not only an internal organization of municipality but also a transversal organization including various governmental organizations such as SOPTRAVI and SANAA, among other groups.

Region 7 includes Departments of Francisco Morazan and El Paraiso. The Municipality of Central District has an area of 1,396.5 km^2 in which 201.5 km^2 is an urban area and 1,195 km^2 is rural area. In the urban area, there are twenty-nine (29) sectors including barrios and colonias, and in the rural area, there are thirty (30) zones and sectors including barrios, colonias, caserios and aldeas. Total population of the Municipality is 932,288. Under the CODEM of this Municipality, there are thirty-nine (39) CODELs that are functioning at the village community level.

(3) Ministry of Public Works, Transport and Housing (SOPTRAVI)

The Ministry of Public Works, Transport and Housing (SOPTRAVI) is the biggest government agency in infrastructure construction. It is composed of General Direction of Roads, General Direction of Public Works and Housing Programs and Projects Unit. It is the State's construction arm responsible for the planning, design, construction and maintenance of infrastructure facilities, particularly national highways, flood and sediment control, and other public works in accordance with national development objectives. The Department of Hydraulic Works under General Direction of Public Works is in charge of flood and sediment control works. Under the Sub-Secretariat of Transportation, there are National Geographical Institute, General Direction of Civil Aeronautics and General Direction of Transport. The Service of National Meteorology is held by General Direction of Civil Aeronautics. ENEE which is in charge of hydrological observation for dam is also included in SOPTRAVI.

The number of staff of SOPTRAVI is about 3,600. The annual budget of the year 2000 was about 2.1 billion Lempiras. National fund is about 72% of total budget and external fund is about 28%. The construction works of flood and sediment control is included in the public works and the budget of direction of public works is 290,000 US dollars.

(4) Ministry of Natural Resources and Environment (SERNA)

The Ministry of Natural Resources and Environment (SERNA) was created in 1996 by Decree No. 218 as an organization for production, management, implementation and evaluation regarding the use and conservation of water resources, mineral resources and reusable energy. It is also in charge of conservation of environment, ecosystem, plants and animals in the natural reserve and national park. Hence, any type of environmental investigation and pollution control are executed by SERNA. It consists of Undersecretariats of Environment and Natural Resources/Energy.

The service in the sector of disaster prevention is held by Section of Territorial Regulation (AOT) under Planning and Management Evaluation Unit (UPEG), which evaluates flood and landslide damage.

Total number of staff of SERNA is 594 and the year 2000 budget was 547,000,000 Lempiras.

(5) National Service Authority for Water Supply and Sewerage (SANAA)

SANAA was established by the Government Decree No.91/61 in order to integrate competence in the field of water supply and sewerage into one centralized organization. The decree attributes the necessary faculties for water supply and sewerage services to SANAA, which include the study and planning of hydraulic resources, construction and operation and maintenance of facilities related to water supply and sewerage services, formulation and revision of regulations, and setting and revision of tariff.

The Metropolitan Division of SANAA is responsible for the water supply and sewerage services in Tegucigalpa. Currently the Financial and Planning Divisions under the headquarters of SANAA perform financial, commercial, and planning functions related to the Metropolitan Division.

As of April 2000, SANAA has 1,788 employees of which 832 currently belong to the Metropolitan Division.

(6) Municipality of the Central District (AMDC)

Under Direction of General Management, there are four sections; Urban Development Management, Financial Management, Administration Management and Social Development Management. Among them, the Urban Development Management is in charge of natural disaster prevention. The SOPTRAVI is in charge of disaster prevention projects at the national level. The disaster prevention in Tegucigalpa City, however, is under jurisdiction of AMDC. After Hurricane Mitch, this jurisdiction is under revision because disaster prevention works in the central district is extremely important not only for the Municipality but also for the nation and the countermeasures against natural disaster will need enormous budget.

(7) Ministry of Techniques and International Cooperation (SETCO)

The Ministry of Techniques and International Cooperation (SETCO) is a public administrative organization created recently by the Legislative Decree No. 218-96. SETCO is in charge of determination of priority and objectives of program of the investment and public expenses.

2.6 RELEVANT LAWS AND REGULATIONS

(1) Law of Contingencies (December 1990)

This law is the juristic foundation of COPECO, which was created in 1991. In Article 1, it is referred that the COPECO is the organization responsible for coordinating the efforts of the public and private sectors to plan, organize, direct, to execute and control the actions guided to prevent the disasters caused by the alteration of natural phenomenon in the country and to offer aid to population sectors threatened by the disasters. This law is now under revision.

(2) Law of Municipalities (November 1990)

The Law of Municipalities (Article 25), grants to the Municipality the faculty that under certain circumstances and conditions, it may declare Public Emergency or Calamity Status in its own jurisdiction, when necessary, and to order appropriate measures.

(3) Temporary Law for Uninhabitable Areas (December 1998)

Article 1 of this Law prohibits the construction of houses, residential buildings and industrial plants in the areas located in river or creek beds and in areas with geologic faults, undercuts, landslides, hillsides with unstable soils that were affected by Hurricane Mitch. The respective Municipality should elaborate in three (3) months, starting from the validation date of the present Law, a complete study to define its uninhabitable areas. This study has to be done by qualified specialists.

(4) General Law of the Environment (June 1993)

Article 5 of this general environmental law establishes that the projects, industrial installations or any other public or private activity, with tendency to contaminate or degrade the environment, natural resources or the nation's historic-cultural patrimony, shall be preceded by an Environmental Impact Evaluation, which allows to mitigate potential adverse environmental effects. Accordingly, consequent to these evaluations, it is mandatory to carry out environment and natural resources protective measures in the execution phase and during the lifespan of works and installations.

Basically concerning disaster mitigation, per Article 28, the Executive Power, by means of the Secretary of State in the Office of the Environment and the other Secretaries of State and competent decentralized institutions, is responsible for the following:

1. The prevention and control of disasters, emergencies and other environmental contingencies that impact negatively in a part or in the whole national territory;
2. The classification of the hydrographic basins;
3. The implementation of the National System of Basins, considering the natural resources in general

Moreover, Article 48 stipulates that the lands of the national territory should be used in a rational and compatible way with their natural vocation, and Article 50 declares that the soils located in steep-sloped lands, which use may lead to erosion or landslides, will stay with permanent vegetative cover.

It is enunciated in Article 51 that the use of the urban land will be object of planning by the respective municipalities. This planning will include the regulation of the construction and the development of housing programs, the appropriate localization of public services and roads of urban communication, the localization of green areas and the forestation of the public roads.

Article 66 describes that solid and organic residuals arising from domestic, industrial or agricultural sources, cattle raising, mining, public and other uses, will be technically treated to avoid alterations in soils, rivers, lakes, lagoons and, in general, in the marine and terrestrial waters, as well as to avoid atmospheric pollution.

Article 78 stipulates that natural or juridical, public or private people who want to carry out any work or activity liable to alter or seriously deteriorate the environment, including the natural resources, are obligated to inform the competent authority on the matter and to formulate an Environmental Impact Assessment (EIA) in accordance with Article 5 of this Law. Within these activities are urban developments and human settlements.

Article 101 establishes that Territorial Classification Plans will be developed for appropriate land use of forest, agricultural, cattle-grazing and coastal lands to guarantee sustainable development, conservation, protection and appropriate use of the national territory. The Secretary of Environment and Natural Resources will be responsible for preparation of these plans.

(5) Law of National Waters Exploitation (1927)

According to the Law of National Waters Exploitation, dated from 1927 and still in use, the State has full control of the rivers excepting those small streams that rise and end at a private property (Article 1). Regarding the water use, this old law authorizes the free use of waters running along natural and public rivers, either for drinking, washing clothes, containers or other objects, to take baths or drinking for livestock (Article 9).

A new law on water resources is being elaborated from several years ago. Since last year, the draft of the General Law of Water has been under consideration of several institutions like SANAA, SERNA, ENEE, SAG and CIEL (Computing Center of Legislative Studies of the National Congress). It is expected that the National Congress will give its final approval very soon.

(6) Forestry Law (1972)

The Forestry Law was established in 1972. It states that the forest zones of the rivers and streams, which comprise the water system of Tegucigalpa, are Protected Forest Zones (Article 138). Besides, this Decree establishes the prohibition of cutting or destroying trees in a belt of 150 m of each side of permanent rivers or lakes (Article 95). Furthermore, it states that by no means shall the State hand over control of the public forest areas to private persons without the concurrence of the State Forestry Administration (Article 37).

This law also introduced the concepts of special areas and national parks, and makes compulsory the protection of forests against fires and plagues.

In 1974, the COHDEFOR was created. All the activities related to forestry sector (exploitation, industrializing, and commercializing) were transferred to it, as state activities.

At present, this law is being reviewed by the National Congress based on a law project submitted to it by the Secretariat of Agriculture. Purpose of the new law is to avoid legal dispersion or overlapping of regulations, to promote a sustainable forestry development and to provide better incentives for the conservation of forest and its industry.

(7) Law of Territory Ordinance (draft)

Draft of this law was sent at middle of 2001 from SERNA to the National Congress as a project of law for its approval.

The socio-ecological-economic zoning will determine 9 areas as follows:

1) Areas of strategic importance on the environment: economic, social, touristic, cultural-historic, biological and others
2) Agro-ecological spaces to orientate the location of agriculture exploitations including activities of livestock, fishing, forestry
3) Areas of sustainable use for the formulation of strategies and watershed management plans
4) Areas of sustainable use for the formulation of strategies and management plans for seashores,
5) Areas for use of human settlements
6) Areas for mining and industrial settlements
7) Sites for storage and treatment of waste
8) Territorial areas under special regulation
9) Corridors or territorial belts for road system, transportation of energy, telecommunications, oil-lines, etc.

(8) By-Laws of Zoning, Urbanizing, Lots Division and Construction (1992)

According to this by-law of the Municipality of the Central District, all the lands with gradients less than 20% and elevation less than EL 1,150 can be urbanized, excepting areas of landslides (Article 1). All the areas which do not fit into the previous category or those within the limits of landslides are considered forestation areas (Article 2).

Besides, it obligates developers to plant trees in the corresponding streets and keep up maintenance of them for at least three years (Article 134). It is also compulsory for the housing developers to afforest the hills with gradients larger than 20%, with the appropriate species in order to avoid erosion and sedimentation (Article 136).

(9) Decree on River Reserve Area (1997)

The municipal government enacted the Decree regarding river reserve areas on January 1977. Riverside banks, which are designated by a certain distance from the river axis, shall be left free from any construction activities. The restricted distances for the rivers are shown *Table 2.21*.

Table 2.21 Construction-Free Distance on Rivers in Tegucigalpa

Distance from Axis(m)	Total Width (m)	Rivers and Gulches
50 m	100 m.	Grande de Choluteca, Chiquito, Guacerique, San Jose, Sabacuante and Las Canoas
12.5 m	25 m	Guajiniquil, Los Jutes, Jucuapa, Quebrada Grande, Jutiapa, Los Limones, Quebrada Seca, Cucuare, Zepate, Salada, El Cajon, Agua Dulce and La Soledad
7.5 m	15 m	Las Anonas, Salgado, el Guayacan, Monoloa, Las Burras, Las Pilitas, Las Lomas, Seca, Orejona, Zanja del Bocon, Don Pedro, Candelaria, Las Majadas, El Cordoncillo, Las Joyas, and El Sapo

Source: La Gaceta No. 26,832, Friday, August 28th, 1992

(10) Special Law on Expropriation (1999)

This law's objective is to establish the land property expropriation within the areas where the works must be carried out to mitigate the damages to the land and infrastructure caused nationwide by Hurricane Mitch and the present danger of another natural disaster occurrence. The area located along the right side of the Choluteca River, from the Cervantes Avenue to the old Olancho road crossways, described in the geographical points as shown in *Figure 2.40* will be expropriated based on the law.

2.7 DISASTER RECORD

2.7.1 INTRODUCTION

Historical record of natural disaster was studied. A damage survey was conducted in the Study for the areas of floods/landslides. The result of the survey was used to estimate damage amounts both with and without projects together with the results of flood simulation and landslide analysis. The estimated damage value and reduction amount by the project was basic information for the economic analysis.

2.7.2 DISASTER RECORD

(1) Historical Disaster

Historical disaster of the Study Area is summarized as follows:

Table 2.22 Summary of Historical Disaster in Tegucigalpa

Year	Name of Hurricane	Summary of Damage
Oct.-1933		Whole country was flooded by continuous rainfall of 30 hours. Destruction in the capital city including landslide at Berrinche, and about 100 houses were washed out.
Sep.-1974	Fifi	Approx. 90,000 persons were affected in whole country. Economic loss was estimated at US$300-400 million.
Sep.-1989	Hugo	Floods in whole country. Damage to infrastructure and agricultural lands.
Sep.-1993	Gert	Floods in the whole country but mainly in the northern part of the country. Damage to infrastructure and agricultural lands.
Oct.-1998	Mitch	Damage extended to whole country. More than 13,000 people died and 1.5 million persons were affected. 250,000 houses and 215 bridges were destroyed. Economic loss reached US$3,600 million.

Source: Study report by ENEE and others

(2) Hurricane Mitch

1) Damages to Whole Country

In October 1998, the Hurricane Mitch attacked whole country and caused the worst damage by a hurricane to the country. The human toll has been reported at 5,657 deaths, 8,058 missing, 12,272 injured and a total of 1.5 million people (of the 6 million total population) affected (evacuated). United Nations' ECLAC estimated material losses at around US$3.6 billion, of which US$2.05 billion affected productive sectors while the rest represents damage to social infrastructure (US$ 1.02 billion) and economic infrastructure (US$ 0.51 billion).

The damage in each department is shown in *Table 2.23*. The breakdown of damages caused by Hurricane Mitch and the estimated replacement cost by sectors are shown in *Table 2.24.*

Table 2.23 Damages Caused by Hurricane Mitch in the Departments of Honduras

Departments	Death	Victims	People in Shelters	Destroyed Bridges	Damaged Roads
Choluteca	1,200	92,647	136,500	17	4
Fco. Morazán	1,000	404,225	26,000	49	6
Yoro	911	131,620	62,776	19	5
Cortés	709	381,716	116,686	11	3
Valle	625	46,602	4,600	9	3
Atlántida	610	120,516	8,000	9	2
Sta. Barbara	495	106,307	12,193	14	4
Comayagua	395	71,171	5,000	3	2
El Paraíso	111	85,275	6,000	3	2
Intibuca	11	46,015	4,600	6	2
La Paz	4	32,960	2,000	6	2
Colón	455	96,279	25,000	16	3
Olancho	403	80,099	13,000	16	3
Gracias a Dios	29	10,638	5,000	2	1
Copán	17	96,086	1,054	1	1
Islas de la Bahía	16	11,665	11,000	2	1
Ocotepeque	13	32,842	2,132	2	1
Lempira	3	85,819	3,704	4	2
TOTAL	7,007	1,932,482	445,245	189	47

Source: Study report by ENEE

Table 2.24 Damages Caused by Hurricane Mitch and Estimated Replacement Cost

Unit: million US$

	Direct Damage	Indirect Damage	Total Damage	Replacement Costs
Total	**2,177.4**	**1,461.1**	**3,638.5**	**4,987.7**
Social Sectores	**305.4**	**719.4**	**1,024.8**	**580.5**
Housing	259.1	675.3	934.4	484.0
Health	25.6	36.7	62.3	64.5
Education	20.7	7.4	28.1	31.2
Infrastructure	**347.6**	**164.2**	**511.7**	**713.2**
Roads, Bridges, Telecommunications	314.1	140.0	454.1	571.4
Water and Sanitation	24.2	7.2	31.3	118.6
Energy	9.3	17.0	26.3	23.2
Productive Sectors	**1,477.6**	**577.1**	**2,054.8**	**3,694.0**
Agriculture, Livestock, Fisheries and Forestry	1,387.3	274.2	1,661.5	2,990.7
Manufacturing	15.8	196.3	212.1	381.8
Trade, Restaurants, Hotel	74.5	106.7	181.2	326.2
Environment	**46.8**	**0.4**	**47.2**	**n.a**

Source: Technical Annex for a Proposed Credit of SDR 144.3 million to the Republic of Honduras for a Hurricane Emergency Project, December 14, 1998, World Bank

2) Damages in Tegucigalpa

There is no complete information on the damages in Tegucigalpa City caused by Hurricane Mitch. However, according to the report prepared by the World Bank, about 40 percent of its capital was damaged, half of its 1 million inhabitants were affected, and the city was cut off from the rest of the country for almost a week.

Based on the monetary loss to the whole country and national GDP and regional GDP of Tegucigalpa, the damage in Tegucigalpa City caused by Hurricane Mitch would be estimated at between US$410 million～US$760 million.

3) Flood/Landslide Damage Survey

The objectives of the Flood/Landslide damage survey are to comprehend the flood/landslide damage by Hurricane Mitch and assets in the hazardous area. The collected information was processed and used for estimating the damage caused by floods/landslides and the benefit derived from the project.

The surveys were carried out by the counterpart agencies of the Study through interviews with habitants who are living in the possible flood and landslide area of the Study Area. The questionnaires of the survey are shown in the Data Book. The agencies in charge and the numbers of households to be surveyed are as follows:

Table 2.25 Agencies in Charge of the Survey

Survey	Agencies in Charge	Numbers Interviewed
Flood Damage Survey:	AMDC	330
Landslide Damage Survey:	SANAA	330

2.7.3 Socio-Economic Impact of Hurricane Mitch

Economic estimates indicated that in 1999 the decline in GDP would be around 2.5%. The inflation rate was reaching to 10% during the second half of the year, while the average rate at the whole year was 11.6%, down from 13.7% in 1998. In the year 1999, the economy was suffering from full impact of destruction over productive capacity and exports. It was also the year when major effort to reconstruct and transform the Honduran economy was launched with the cooperation of the international community of donors and development financial agencies.

2.8 Project by Other Donors

2.8.1 General

There are many disaster-related projects by other donors on-going. Those are shown in *Table 2.26* and projects closely related with this Study are described in detail below.

2.8.2 Integrated Program Statement on Risk Management (USAID)

This study aims to support the consolidation of the national risk management system and strengthen risk management capacities at national, regional, municipal and local levels. This study is still on-going conducted by USAID. The major items to be studied are as follows:

(1) Support the consolidation of the national risk management system

1) Strengthen the national risk management institution (COPECO)

- promote and support the institutional development plan process
- support the development and implementation of the institutional action plan
- support the development of human resources within the institution
- equip the National Emergency Operation Center with facilities
- provide emergency radio equipment that will link various levels of system - national,

regional, municipal and local

- develop a GIS incorporating disaster preparedness and response information as a part of the National Emergency Plan

2) Support the development of new legal framework

- review and provide technical /legal assistance for new legislation, regulations and procedures
- review and update emergency or cooperation agreements in accordance with new legal framework

3) Support the review, updating and implementation of National Emergency Plan

4) Support development of national mitigation policies in close coordination with sectoral mitigation policies

5) Support the development of Regional Emergency Commissions (COERS)

- establish roles, procedures and relationships of the COERS
- equip the COERS offices with facilities

(2) Support and strengthen risk management capacities at the municipal level

(3) Improvement of forecasting capacities of risk management system

(4) Environmental management

(5) Provision of information and specific tools for risk management

It is proposed that these work/tasks be carried out coordinated by a team composed of representatives from various international cooperation agencies and local government agencies.

2.8.3 NATURAL DISASTER VULNERABILITY REDUCTION PROJECT (WB)

This project was commenced in November 2000 and is to be completed in April 2005. The project is composed of three components as follows:

Strengthening of Monitoring, Forecasting, Early Warning and GIS-based Information Management:

This component will provide SERNA with technical assistance to develop capacity for early warning, hydrological and meteorological monitoring, and forecasting of floods and landslide hazards. Specific activities include:

(1) Design of fully integrated national flood forecasting and decision support system (DSG) to promote sustained and effective flood forecasting and early warning, effective communication channels with local communities, as well as long-term flood mitigation measures and watershed management.

(2) Development of thematic mapping on GIS and database integration, building upon the system Nacional de Informacion Ambiental (SINIA), to establish a repository node of information generated by municipal risk mapping exercises and other project activities.

(3) Study of the changes in fluvial geomorphology caused by Hurricane Mitch, to determine

the volume of sediment deposited on hill slopes, floodplains and channels, identify risks from flooding and associated landslide, erosion, sediment transport and deposition to populated areas and economic activities, and monitor the long-term geomorphic recovery of the river basin.

(4) Study of capacity to monitory and to mitigate seismic events to review existing capabilities and to propose ways to improve technical and institutional capacity.

Strengthening of National Capacity to Support Emergency Response at Municipal Level

Under this component, the project will finance studies and technical assistance to strengthen response capacity of Municipal Emergency Management Committees (CODEMS) in the 60 cities/municipalities identified as most vulnerable to floods and landslides.

(1) A diagnosis of equipment needed for communication and emergency rescue, its cost, including costs for maintenance and training in equipment use.

(2) A review and comparative evaluation of various existing disaster awareness plans and curricula, which have been developed by Honduran agencies, UNDP, and other donor agencies.

(3) Provision of disaster response training to CODEMs in the 60 municipalities identified as most vulnerable to floods and landslides.

(4) Delivery of disaster education and awareness campaigns in the 60 priority municipalities.

(5) Technical assistance to COPECO to assess current computerized system of tracking receipt and distribution of donations to municipalities, to identify and provide software development need, and to train COPECO staff in its use.

(6) A revision of the draft building code to reduce risks of failure following natural disaster events including a study of existing building code to reduce risk of failure following natural disaster events including a study of existing building codes, of current proposals for modernization and development of a plan for updating both the codes and their applications.

Building up Capacity in Disaster Mitigation at Local Government Level

This component is composed of the following items:

(1) Preparation and publication of materials for risk analysis and participatory hazard mapping exercise.

(2) Production of base maps of municipal centers and outlying areas of future expansion for participating municipalities at appropriate scale.

(3) Training for interested NGOs and municipal leaders in managing participatory risk analysis and vulnerability reduction exercises.

(4) Contracting consulting NGOs and private consultants to work with local officials and community leaders in developing risk management plans, identifying and controlling areas at risk, developing mapping “disaster preventive” land use plan, and identifying and

prioritizing mitigation works.

(5) Contracting qualified NGOs and engineers to design, implement and train communities in the use of locally managed flood warning system.

(6) Contracting of consultants to work with FHIS to develop pre-feasibility studies of priority works.

(7) Development of a national database of municipal vulnerability ranking and steps taken in disaster prevention including risk mapping, and action plans for disaster mitigation.

2.8.4 Hazard Map Preparation for Forty Municipalities (USGS)

The USGS has been working on establishing hazard maps targeting 40 municipalities in Honduras including Tegucigalpa since 1999. Their activities will be finishing in early 2002 and the products for Tegucigalpa are as follows:

- orthophoto with the scale of 1/10,000 covering the urban area of Tegucigalpa;
- flood hazard map with the scale of 1/10,000 corresponding to a flood with a return period of 50 years;
- landslide hazard map with the scale of 1/10,000 including areas prone to landslide and slope failure.

Their final report is supposed to be submitted to the Honduran government in January 2002.

As their study is closely related to this JICA Study, repeated discussion and exchange of information were carried out throughout the study period in order to perform the Study on the same basic information.

2.8.5 Berrinche Landslide Study (US Corps of Engineers)

The US Corps of Engineers has been working on Berrinche landslide since 1998. They were supposed to submit the final report to SERNA in 2001 but it has not been submitted as of December 2001. Their activity includes:

- field reconnaissance of the landslide
- geological boring in the area
- installation of piezometer and inclinometer
- monitoring of piezometer and inclinometer
- study on landslide mechanism
- study on structural countermeasures

This study is also closely related with the JICA Study and exchange of information was made through SERNA. Discussion was held between the JICA Study Team and the team leader of the Corp of Engineers on the mechanism of the landslide.

2.8.6 Plan of New Bus Terminal along the Choluteca River

AMDC has a plan to construct a new bus terminal. Bus terminal is planned at the left side of the existing river course of the Cholteca River between Mallol Bridge and Carias Bridge. Elevation of bus terminal is 918 m, which is lower than the design water level at this point of 920 m. Width of bus terminal is 40 m.

2.8.7 PLAN OF NEW BRIDGE ACROSS THE CHOLUTECA RIVER

The Swedish Government funded the planning of a new bridge construction between Mallol Bridge and Morina Bridge. The bridge is planned to have 5 spans, a length of 150 m and a slope of 5.5%. It will serve as a link between the urban area of Commayagüela, which is three blocks upstream of the Mallol Bridge, and Calle Coheles.

2.9 DEFINITION OF PROBLEMS

From all the study on the present conditions, it is concluded that the problems on flood and landslide in the Target Area are as follows:

2.9.1 FLOOD PROBLEMS

The problems of flood in the Target Area are summarized as follows:

- The two-day rainfall amount in Tegucigalpa during the Hurricane Mitch has a return period of 500 years.
- The inundation of the urban area during Hurricane Mitch was brought about by an abnormal rainfall with a return period of 500 years, but the present river capacity itself is less than the flood with a return period of 1 yearbetween C48 and C50 because of Berrinche landslide is squeezing the river course.
- The causes of mal capacity of the Choluteca River are:
  (1) narrow channel width at Berrinche landslide (C48-C50)
  (2) sediment in the river between C30 and C100
- The natural dam break of the Pescado Lake caused a significant impact on downstream flood.
- The flood along the Sapo River and the Bambu River were caused by the clogging of their pipe culvert outlets by sediment in the main river course and by garbage.
- The soil erosion from the whole basin is not so large, although deforestation is on-going in some sub-basins of the area.
- The sediment transport capacity of the Choluteca River and the Chiquito River are comparatively uniform except between C50 and C55.
- The number of households in the inundation area (2 km^2) by a storm with the scale of Hurricane Mitch is approximately 3,000 and the number of affected people is 15,000.

2.9.2 LANDSLIDE PROBLEMS

The problems of landslide in the Target Area are summarized as follows:

- The mountainous topography and complex geological structures make the area prone to landslides and slope failures triggered by a large amount of rainfall.
- Rank A landslide masses and their affected area (1 km^2) cover 1% of the whole Target Area and the number of households in it is 1,500.
- Slope failure dangerous area (26 km^2) covers 25% of the whole Target Area and the number of households in it is 25,000.

2.9.3 DAMAGE BY HURRICANE MITCH

The amount of damage and reconstruction cost, brought about by Hurricane Mitch, for the whole country are estimated at US$3,638.5 million and 4,987.7 million respectively. The damage in Tegucigalpa City caused by Hurricane Mitch would be estimated at between US$410 million～US$760 million.

2.9.4 ORGANIZATIONAL/INSTITUTIONAL ASPECTS OF THE PROBLEMS

There are various organizations involved in disaster prevention activity for the city of Tegucigalpa. However, according to the orientation of the recent organizational set-up of the Honduran Government, COPECO and CODEM are the key organizations for the integrated disaster prevention plan.

As for the legislations, there exist various laws and decrees that seem to be very relevant and important for comprehensive disaster prevention plan. The problem seems that those relevant laws and decrees are not implemented properly. One of the important reasons of it must be the lack of concrete data when those regulations are to be applied.

2.9.5 RELATED PROJECTS

There are many related projects completed or in their implementation stages. The disaster prevention master plan which is prepared in the Study should take into account the results and the interim results of all the related studies. It is also necessary to make a recommendation for the further study of results in those projects that are on-going.

Chapter 3

Planning Basis

CHAPTER 3 PLANNING BASIS

3.1 CONCEPT OF THE PLAN

As analyzed in Chapter 2, the huge amount of damage and large number of human loss in the Target Area were brought about by Hurricane Mitch, intensified by conditions both natural and social. The unfavorable natural conditions are the abnormal rainfall amount, the river features, and the topographic and geological features of the area. The problematic social conditions are the uncontrolled development of the urban area into the dangerous areas of flood and landslide. According to the Study, the dangerous area defined in the Study occupies 30% of the whole Target Area. The number of people living in dangerous areas is over 150,000 and it is 15% of the total population. This is the reality of Tegucigalpa City.

The most effective solution is permanent resettlement of houses in the dangerous areas. However, it is impossible to solve the problem of the anticipated disaster completely by relocating the houses in the dangerous area in a short time. It is also impossible to solve the problem completely by large-scale civil works to make all the present dangerous area safer.

Therefore, the goal of the plan is defined as follows:

- The damage caused by a disaster in the Target Area should be minimized and no human lives should be lost even by a storm with a scale of Hurricane Mitch.

And the strategy is:

- The above goal should be attained by an optimum combination of structural and non-structural measures.
- As a large scale resettlement of people from dangerous area is unrealistic, the main focuses of non-structural measures are prohibition of new house development in dangerous arrears and forecasting/warning/evacuation during emergencies.

3.2 TARGET YEAR

As this is a master plan, the target year should have a long range. However, the key factors for the target year, namely, population distribution and land use, cannot be projected for a long range because of lack of integrated regional development plan nor urban development plan covering the Target Area.

The latest population projection was made in the project titled "The Study on Water Supply System for Tegucigalpa Urban Area in the Republic of Honduras" (2001, JICA) for the year 2015. As this population projection is backed up with a comprehensive water supply master plan, it is reliable, considering that water supply is one of the most critical constraints on the population growth.

Therefore, the target year of the Master Plan was set as 2015 and the same population projection will be applied.

3.3 SOCIAL FRAMEWORK

As the basis of the planning, the social framework, that is, population in the target year, was set up. The total urban population in 2015 is estimated at 1,376,822.

The land use plan was created in the Master Plan from the viewpoint of disaster prevention in order to allocate the future population in the area properly.

3.4 ITEMS TO BE CONSIDERED IN THE MASTER PLAN

(1) Realistic Plan

It is necessary to make a realistic plan from the viewpoint of finance and social environment. The total project cost should be within the range, which will be set by the affordability of the central as well as the local government. A large-scale land acquisition or resettlement is impossible so that the structural measures should be planned to minimize the land acquisition and resettlement.

(2) Integration with the Related Projects

As there are many related projects on-going, the Master Plan should take into account all the information on those projects. Especially, the projects being carried out by USGS and the US Corp of Engineers are to be coordinated in the Master Plan.

Chapter 4

Master Plan

CHAPTER 4 MASTER PLAN

4.1 INTRODUCTION

The Master Plan for disaster prevention in Tegucigalpa metropolitan area is composed of three components, namely, flood damage mitigation measures, landslide damage mitigation measures and the common non-structural measures for flood damage/landslide damage mitigation.

Both the flood damage mitigation plan and the landslide damage mitigation plan were made through mechanism analysis of both disasters. The alternative solutions of both structural and non-structural were studied in order to solve the problems.

Structural measures were selected only when they are realistic considering the cost of civil works compared to the benefit, which will be brought about as well as the land acquisition and resettlement problems accompanying the civil works.

Non-structural measures were selected when they are more realistic considering the cost of structural measures, difficulties of land acquisition and resettlement for structural measures.

The opinions of the Meteorological Department, ENEE, COHDEFOR, and other donors such as BID, World Bank, USAID, USGS, Corp of Engineers were asked and incorporated in the final plan.

The proposed Master Plan Projects are shown in *Table 4.1*. Location map of the Master Plan Projects (structural measures) is shown in *Figure 4.1*.

FLOOD DAMAGE MITIGATION PLAN

The flood damage mitigation plan started from the analysis of the river features and hydrological/hydraulic simulation during Hurricane Mitch. In order to understand the river features, an extensive river survey was carried out along the river. The width, the profile and the present capacity of each section of the river was studied for the length of 30 km including the Choluteca, the Guacerique, the Chiquito and the Sapo Rivers. This Study showed a clear picture of the hydraulic features of the river.

The process of hydraulic model set-up was carried out based on two important pieces of information. One is the hourly rainfall record at Toncontin station and the other is the high water mark during Hurricane Mitch. Hydraulic model was constructed by using the river survey result with rainfall record and calibrated based on the high water mark survey result. By using the model, hydraulic simulation was made corresponding to various rainfall phenomena with different return periods.

Through the analysis of configuration of the river and hydraulic model simulation, the flood mechanism in Tegucigalpa City has become clear.

After understanding the flood mechanism, alternative study was made to select an appropriate choice of design flood. Here design flood was selected taking into account the constraints of land acquisition and resettlement when the river had to be widened. River improvement works were planned to accommodate the design flood in the river course safely.

The hydraulic simulation was done again assuming the completion of the structural measures proposed, and the inundation area was identified should a storm of scale larger than the design flood would come. The non-structural measures were planned analyzing the inundation area along the river even after the completion of the structural measures proposed.

The watershed management plan was made through the erosion analysis of each sub-basin of the Study Area.

LANDSLIDE DAMAGE MITIGATION PLAN

Landslide damage mitigation measures were planned through two aspects: one is the understanding of the geological features of the whole area and the other is the observation of landslide phenomenon which occurred during Hurricane Mitch.

New geological map with the scale 1/10,000 was prepared covering the whole area of Target Area of disaster prevention. The geological study revealed topographic and geological features of the area, which is prone to landslide.

The disasters caused by soil and rock movement are classified into "landslide," "slope failure" and "debris flow" in Japan. As "landslide" and "slope failure" are dominant in the Target Area, these two phenomena were taken up separately in the Study.

As for "landslide" problems, aerial photo analysis was made to identify typical topographic features of landslide masses. They were classified into three categories according to degree of danger taking into account the field observation and landslide record during Hurricane Mitch. Seventeen landslide masses were identified as Rank A, which means the risk is highest. All the landslide masses in the Target Area with their degree of risk were shown in the hazard map of landslide. After categorizing those landslide masses, non-structural and structural measures were studied for each block with high risk. Most of the blocks were judged to be not appropriate for structural measures and thus non-structural measures were proposed. Three landslide blocks of rank A were selected for structural measures prevention works and civil works were proposed.

For "slope failure" problems, slope analysis was made together with the geological features for all the actual slope failures occurred during Hurricane Mitch and the threshold values of dangerous slope were determined for each geological classification in the Target Area. By using the threshold values for each geological classification and the geological map, the hazard map of slope failure was created for the Target Area. The structural measures were not appropriate to cope with these vast slope failure risk areas and only the non-structural measures were proposed.

4.2 FLOOD DAMAGE MITIGATION PLAN

4.2.1 GENERAL

A hydraulic model of the Choluteca River was constructed based on the river survey. After the completion of the hydraulic model, simulation calculation was made. Alternative study was made to select the design flood discharge for flood control plan. After determining the design flood discharge, river improvement plan was made to accommodate the design discharge. The non-structural measures were studied to cope with the inundation caused by the flood with a scale larger than the design discharge for the river improvement works.

4.2.2 HYDROLOGICAL ANALYSIS

(1) Frequency Analysis of Rainfall

At first, the frequency analysis was conducted for the 1-day rainfall data at Toncontin station from 1951 to 1999. The maximum daily rainfall at Toncontin station is shown in *Table 4.2*. After that, the maximum 2-day rainfall was calculated and analyzed. Maximum 1-day and 2-day rainfall, and return period at Toncontin station are shown in *Figure 4.2 and Figure 2.19* respectively.

The hourly rainfall pattern at Toncontin station during Hurricane Mitch had its peak at 120 mm on October 30, 1998, and the total rainfall in 72 hours was 256 mm. The rainfall pattern is shown in *Figure 2.18*.

The design rainfall pattern at each return period at Toncontin station was constructed from the hourly rainfall pattern during Hurricane Mitch. The design maximum 2-day rainfall at each return period is shown as follows:

Table 4.3 Design Maximum 2-Day Rainfall in the Choluteca River Basin in Tegucigalpa

Return Period (Year)	Design Maximum 2-Day Rainfall (mm)
500 – 600 (Mitch)	240.70*
5	109.21
10	128.98
25	153.95
50	172.48

Note: Asterisk (*) indicates measured data during Hurricane Mitch, not calculated value

These design maximum rainfalls, together with the synthetic rainfall pattern, were used in the rainfall-runoff analysis for the entire river basin including the Grande, the San Jose, the Guacerique, the Chiquito and the Choluteca River basin.

(2) Rainfall - Runoff Analysis

Rainfall-runoff analysis was conducted by using a standard storage function method.

Hourly rainfall data at Toncontin station during Hurricane Mitch were used to construct the design rainfall pattern for the entire river basin. The measured data from rainfall stations from the sub-basins were not used to calculate the runoff in those basins because the recorded data were not sufficiently long.

The synthetic rainfalls were then input into the rainfall-runoff model for the calculation of runoff.

The run-off in the target year 2015 was calculated according to the predicted land use plan of the Study Area but the rainfall and run-off relationship did not make significant difference so that the present rainfall and run-off relationship was utilized to make the Master Plan.

(3) Calibration of the Model

The storage function model was calibrated by using the actual flow at the Concepcion dam during Hurricane Mitch with the condition as follows:

- Peak flow at the dam was 827 m^3/s,

- The storage volume was at its full capacity, thus the inflow was assumed to be the same as outflow, and
- The drainage area above the dam was 139.51 km^2.

(4) Runoff in the Entire Basin

The parameters from the calibration were then used in the calculation for the entire river basin of 819.65 km^2.

By using the maximum 2-day rainfall at each return period as mentioned in the previous section, the rainfall pattern was constructed and input into the model to calculate the peak runoff in the entire basin at each return period.

Relationship of the rainfall and simulated hydrograph from the storage function method is shown in *Figure 4.3*. Simulated hydrograph during Hurricane Mitch is shown in the following figure. Relationship of the runoff (peak of the simulated hydrograph) and its return period is shown in *Figure 4.4* and a summary is also shown in the following *Table 4.4*.

Table 4.4 Runoff in the Choluteca River Basin in Tegucigalpa

Return Period (Year)	Runoff (m^3/s)
Mitch	3,954
5	1,508
10	1,867
25	2,328
50	2,673

4.2.3 HYDRAULIC SIMULATION

Hydraulic simulation was conducted by using a software called MIKE11, a one-dimensional unsteady flow program, developed by the Danish Hydraulic Institute.

A river model of the Choluteca River and its tributaries was set up by using mainly the river survey in April 2001 and complementarily, the topographic map in 1996.

(1) Simulation Cases

Simulation was done for 2 cases as follows:

Table 4.5 Calculation Cases

Case	Name	River Configuration	Discharge
I	Without Project	2001 (river survey result)	5, 10, 25, 50 years and Mitch
II	With Project	Design Cross Sections	5, 10, 25, 50 years and Mitch

Case I Without project in 2001 (After Hurricane Mitch)

The river model was set up from the river survey in April 2001. This case is equivalent to the present situation without the flood control project, and the river configuration (river course and cross sections) is after Hurricane Mitch.

Case II With project (Design Sections)

The river model was set up by using the design cross sections for flood control, which will be described later in **4.2.4**. This case is equivalent to the river condition after the structural measures are completely implemented, and the river configuration (river course and cross sections) is the designed one.

In each case, the simulation was conducted for 5 different return periods of 5, 10, 25 and 50-year, and during Hurricane Mitch.

(2) Model Set Up Analysis

1) River Network

The river network model was set up from the river coordinates and the cross sections along the river. Cross sections were set up in compatible with the calculation cases as follows:

Table 4.6 River Network Set-up

Case	Name	Cross section Set-up
I	Witout project	The river bed was adjusted roughly based on the present condition.
II	With project	The design sections were set up based on the discharge

The river model is shown in *Figure 4.5.*

2) Calibration of the Model

Calibrate the parameters in the model to make the least error between the simulated water level and observed water level at the bridges of Mallol and Chile during Hurricane Mitch. Water level at these bridges during Hurricane Mitch were as follows:

Table 4.7 Water Level during the Hurricane Mitch

Location	Water Level (m)
Mallol Bridge	927.9
Chile Bridge	924.5

The high-water-level survey was conducted in this Study in July 2001 and the result was also used for calibration.

3) Parameters and Boundary Condition

The parameters and boundary condition in the model are:

- Manning roughness, n = 0.036 in accordance with the riverbed material survey and calibration,
- At the upstream end, hydrographs at the Grande, the San Jose, the Guacerique and the Chiquito Rivers during Hurricane Mitch (with the same pattern as in *Figure 4.3*, but different magnitude) were used as the boundary condition,
- At the downstream end, free flow was set as the boundary condition,
- Time step in the calculation = 5 seconds.

4) Set-up of Dam-break at the Pescado Lake

It was reported that the natural dam at the Pescado Lake collapsed during Hurricane Mitch on October 30, 1998 at 22:00-23:00.

From the field investigation, the outlet of the Laguna after the dam-break had a width of about 20 m and a depth of 8 m.

The flow from the Laguna was estimated by using the equation as follows:

$$Q = CBH^{3/2}$$

where Q = flow rate, m^3/s, B = gate width, m,

H = water level, m, C = constant = 2.65

From this equation, the maximum flow rate is as follows:

Q_{max}= 1,139 m^3/s

From this peak flow and the storage volume, it is estimated that the Laguna would discharge all storage by 10.4 minutes. However, since the outflow from the Laguna was not constantly at peak all the time and other dimensions were roughly estimated, time in the calculation was set at about 1 hour.

The hydrograph of this Laguna was included in the hydraulic simulation as well.

(3) Hydraulic Simulation Results

Peak flow at each sub-basin can be summarized as follows:

Table 4.8 Peak Flow in the Sub-basins from Hydraulic Simulation

Sub-basin/Location	Peak Flow in the Sub-basins (m^3/s)					
	Mitch	5-Year	10-Year	15-Year	25-Year	50-year
Choluteca Upstream (Grande)	1,459.8	473.9	584.7	646.4	727.4	834.3
After confluence with San Jose	2,092.0	825.7	1,010.7	1,147.1	1,249.6	1,428.8
After confluence with Guacerique	3,337.6	1,318.3	1,603.9	1,700.4	1,971.8	2,261.7
Choluteca Downstream	3,878.3	1,505.8	1,823.8	1,905.6	2,231.5	2,601.5

It should be noted that these peak flows were calculated from the hydraulic simulation that peak times were taken into consideration. The peak flow after any confluence was not necessarily the summation of the peak flow of those sub-basins before the confluence.

A summary of water level in Cases I and II during Hurricane Mitch in the Choluteca River is shown in *Figure 4.6.*

4.2.4 ALTERNATIVE STUDY OF FLOOD CONTROL

(1) General

Alternative study of flood control plan was made. Five alternative design floods with different peak values were generated and relevant river improvement plan to accommodate the peak discharge was worked out. The peak discharge values were related with their return period from the table prepared separately.

The river improvement plans were made considering methods such as dredging of the river, enlargement of the channel width, construction of parapets and construction of revetments. Required land acquisition was also studied and compared for each alternative.

(2) Flood Control Facilities Considered

For flood control purpose, not only the improvement of the river course but also flood water storage structure was taken into account.

Retarding Pond

According to the river survey result and the inundation survey result during Hurricane Mitch, there is no appropriate open space along the river for flood storage utilized as a retarding pond. Therefore, the idea of a retarding pond was abandoned as an alternative.

Dam

As for flood storage in the upper reach, Sabacuante Dam was studied. In the Study on Water Supply System in Tegucigalpa Urban Area by JICA in 2001, the dam was studied as a single purpose dam for water supply. It was not adopted in the water supply master plan but in the course of the study, the idea of making it a multi-purpose project was raised. Therefore, in this Study, a preliminary study was made to turn Sabacuante Dam into a multi-purpose dam.

Sabacuante dam is planned as follows:

- Catchment area	;	80 km^2
- Gross Storage Capacity	;	36,700,000 m^3
- Effective Storage Capacity	;	24,000,000 m^3
- Storage Capacity for Flood Control	;	12,00,000 m^3
- Storage Capacity for Water Supply	;	12,000,000 m^3
- Reduction of Flood Peak Discharge	;	411m^3/s to 75m^3/s (return period 15 years)
- Construction Cost	;	US$34,500,000
- Cost Allocated for Flood Control	;	US$17,250,000

As the site is located at upper reach of the river and the catchment area is as small as on tenth of the whole catchment area, the flood control capability of the dam is limited. The effect of the dam is to reduce peak discharge by 336 m^3/s. The cost for flood control is much larger than the cost increment by increasing the river capacity through dredging operation.

Pescado Lake Outlet Improvement

According to the hydraulic simulation, the effect of the natural dam break at the outlet of the Pescado Lake is significant in the upper reach. As treatment of the outlet was studied, it was found that the civil works would not be so difficult to carry out, to prevent repetition of the incident again. Therefore, it was planned to treat the outlet of the lake so that flood caused by natural dam break will be eliminated by some measures.

(3) Alternative Design Flood Discharges

The peak discharge of the flood at point A (the downstream end of the Study Area) is 4,000 m^3/s according to the run-off simulation. And it is known that the return period of two-day rainfall during Hurricane Mitch is approximately 500 years.

On the other hand, the bank-full capacity of the Choluteca River at point A is 2,000 - 3,000 m^3/s. Considering the built-up area along the Choluteca River in Centro and Comayaguela area, it is difficult to enlarge the river width in a large scale.

Thus as peak flood discharge, five alternatives, namely, 1000, 1500, 2000, 2500 and 3000 m^3/s, were selected for study.

The design flood distributions were prepared for each alternatives based on the proportion of run-off simulation. *Figure 4.7* shows each design flood distribution.

(4) Design Profile of the Choluteca River

The longitudinal profile of the Choluteca River was designed based on the existing river profile. The planned riverbed slopes are 1/200, 1/250, 1/190 at 2.7-5.1 km, 5.1-11.4 km, 11.4-15.5 km respectively. The design profile is shown in *Figure 4.8*.

(5) Design Cross Sections of the Choluteca River

The design cross sections were planned to accommodate each design peak flood (1,000 m^3/s～3,000 m^3/s) taking into account the design profile set above and the design cross sections for each design peak flood discharge. The width of the channels for each case is as follows:

Table 4.9 Width of Channels

Reach	27-51	51-56	56-67	67-93
Discharge (m3/s)	River Width (m)			
1,000	35	36	32	24
1,500	48	49	45	32
2,000	61	63	56	39
2,500	73	76	68	47
3,000	86	89	80	54

(6) Planned Alignment of the Choluteca River

The design alignment of the Choluteca River followed the existing alignment of the river, except C48 and C49 (the river course adjacent to Berrinche landslide), where the river width is very narrow and the capacity of the channel is small. Between C48 and C49, the river course was planned to be shifted to the right-hand side by fixing the left periphery of the river in order not to disturb the large landslide mass of Berrinche. (Refer to *Figure 4.9(1)*)

(7) Selection of Design Flood Discharge

Five alternatives were compared in terms of return period, amount of civil works and land acquisition. *Table 4.10* shows the comparison of each alternative.

The amount of civil works is proportional to the amount of peak discharge and the project cost is also proportional to the peak discharge.

On the other hand, the problem of land acquisition varies from one case to another. As the narrow river at Berrinche is the control section of the river flow, it is necessary to enlarge that particular portion in order to accommodate the peak discharge safely. As explained above, the widening of the river course is limited by the position of the landslide mass of Berrinche and the river must be widened toward the right side. However, there exists a built-up area along that side of the river that makes it necessary to acquire new land for a new river course. Hurricane Mitch and the Berrinche landslide caused severe damage to the area and just after the hurricane, the Planning Department of Tegucigalpa City prepared a regulation stating that the damaged portion of the land is to be acquired as river area. Therefore, it is rather easy to utilize that area for the new river course, while additional land acquisition is rather difficult considering the existing structures such as a church, a school and a police station.

This problem was discussed with municipal authority in charge of the urban planning, and it was concluded that alternatives 4 and 5 are quite difficult in terms of land acquisition. Thus, alternative 3 with a peak discharge of 2,000 m^3/s was selected as the flood control master plan. The corresponding return period is 15 years.

The design cross sections of the river in alternative 3 are shown in *Figure 4.9(2).*

Table 4.10 Comparison of Alternative Design Flood Discharge

No	Q (m3/s)	Return period (year)	Excavation(m3)	Land Acquisition	Overall Evaluation
1	1,000	1	320,000	Ready	
2	1,500	5	520,000	Ready	
3	2,000	15	750,000	Ready	X
4	2,500	35	920,000	Difficult	
5	3,000	80	1,420,000	Difficult	

4.2.5 RIVER IMPROVEMENT PLAN FOR THE CHOLUTECA RIVER

(1) General

River improvement plan for the Choluteca River is composed of the following items:

- Riverbed excavation L= 7 km, V=750,000 m^3
- River widening L= 200m (with concrete shaft)
- Revetment construction L= 9 km
- Dike construction L= 3 km
- Bridge reconstruction 1 bridge

Each item is explained below.

(2) Riverbed Excavation

Excavation was planned to obtain the required river cross section and required river profile. However, the lower reach of the river between the cross section number 0 and number 27 (approximately 3 km) was eliminated from this operation as there is no house or agricultural land to be protected in the area.

Thus the riverbed excavation is planned between cross section number 27 and number 93. The total length of the river for the operation is approximately 7 km and the total excavation volume is 750,000 m^3, of which 40,000 m^3 is rock excavation.

The excavated material was planned to be hauled to downstream of the river and to be filled up along the Choluteca River. At that location, the river has a wide valley and the pile of soil will not give any adverse effect on the flood upstream.

(3) River Widening at Berrinche

The only place where river widening is required is the neighborhood of Berrinche landslide. The required width to accommodate the design flood is 61 m and additional 40 m of widening is necessary. The total length of river widening along the river is approximately 200 m and the excavation volume is 50,000 m^3.

It is necessary to protect the left side of the river against the landslide of Berrinche. In this Master Plan Project, counterweight fill (C45-C46.5) and shaft works (C46.5-C50) were planned to prevent the destabilization of the left bank of the Choluteca River. The diameter of the concrete shaft is 4.0m and the average length of the shaft is 16 m. The concrete shaft is planned to be constructed with an interval along the river by 400 m and the total number of shafts is 52. The volume of the counterweight fill is 40,000 m^3. The layout of the structures is shown in *Figure 4.10*.

The right side of the river is planned to be protected by a vertical wall with earth anchors in order to minimize the area of land acquisition.

(4) Revetment

Revetments along the river are needed to stabilize the bank against erosion and sliding where built-up area is just next to the river. The revetment structure is planned as stonemasonry as it is a common practice in Tegucigalpa. The height of the structure is 8 m. Total length of the structure along the river is 9 km. The locations of revetment are shown in *Figures 4.11* to *4.15*. The layout of the structures is shown in Figure *4.16*.

(5) Dike

According to the hydraulic simulation, there are some parts along the river where the inland elevation is low and it is necessary to protect it by dike construction. The proposed structure is concrete parapet walls along the river stretching 3 km. The locations of dike are shown in *Figures 4.11* to *4.15*.

(6) Bridge Replacement

As the existing Mallol Bridge is hampering flood flow because of its bulky structure, it was planned to reconstruct it so that the flood discharges at the point smoothly. The layout of the existing bridge and that of the proposed new bridge are shown in *Figure 4.17*. The proposed new type was taken from the Carias Bridge, which is located downstream from the Mallol Bridge.

This idea was discussed in the counterpart meeting as well as in the steering committee and with the Honduran Institute of Anthropology and History. The idea of the bridge reconstruction was agreed upon but it was concluded that the new type of bridge should be discussed further in the later stage of the project, probably in the feasibility stage when the environmental impact assessment is done.

4.2.6 SEDIMENT CONTROLPLAN

(1) Erosion Control Plan (Watershed Management)

If the soil erosion in the watershed prevails and the amount of sediment into the river increases, the inflow and outflow balance of sediment in the river is disturbed and sediment accumulate in the river course. This will squeeze the river sections and lower the discharge capacity of the river leading to flood damage.

According to the field observation and the study of aerial photos, a large-scale housing development is on-going especially in the watershed of the Chiquito River, which is not designated as a water resources conservation watershed.

The soil characteristics, the land use patterns, the slope features and rainfall intensity for each sub-basin of the Study Area were analyzed. (Refer to Supporting I) It was found out that there are six micro-basins where the soil erosion potential is high and erosion control plan is necessary. These micro-basins are Choluteca, Chiquito, Sabacuante, Qebrada Grande, Laguna El Pescado and Mololoa as shown in *Figure 4.18*.

Among the six micro-basins above, the Chiquito micro-basin was selected as the pilot micro-basin for soil erosion control project in the Master Plan. This micro-basin was selected because its soil erosion potential is high and new housing development projects are expected in the basin.

The proposed measures are afforestation and micro Sabo dam construction. The proposal is shown in *Table 4.11*.

(2) Sediment Transport in the River

River planning which will make the river configuration stable for a long time in future is important. If constant dredging is needed to maintain the planned river configuration, maintenance cost will be high and become a burden to the Honduran Government.

The sediment transport capacity was calculated along the river taking the present and planned configuration of the river. Capacity was evaluated by the sediment transport capacity of the yearly maximum discharge, 1,000 m^3/s and the model sediment with a diameter of d_{60}=30 mm.

The calculation result is shown in *Figure 4.19*. It shows that in the present river, the sediment transport capacity is low in the upstream of Berrinche area where the river capacity is very low. On the other hand, in the planned river profile, the sediment capacity is uniform along the river. Therefore, improvement of the flood capacity of the river also improves the sediment transport capacity of the river.

Riverbed variation was simulated by using the model sediment and the yearly maximum discharge for 100 years for the planned river. The result is shown in *Figure 4.20*. It shows that the rising or falling of riverbed by sediment transport is within the range of 1 to 2 meters in 100 years. It means that the planned river profile is maintained without periodic artificial dredging.

4.2.7 RIVER IMPROVEMENT PLAN FOR TRIBUTARIES

(1) Sapo River

The Sapo River is a small tributary in the left flowing into the Choluteca River at C-50. The catchment area is approximately 3 km^2. The discharge capacity of the culvert portion is 15m^3/s, the return period of which is around 50 years and its capacity is enough to discharge the design flood.

Therefore, dredging of the Choluteca River and exposing the outlet completely will restore the flow capacity of the Sapo River and solve the inundation problem along the river. However, it is necessary to prevent clogging of the inlet of the culvert by garbage and to educate and create awareness among the people along the river to preserve the river course. It is also necessary for the municipal government to check the capacity of the culvert periodically and maintain it.

(2) Cacao River

Improvement of river alignment was proposed to mitigate the flood and debris flow damage of the Cacao River. As debris source along the river is several landslide masses with the width of 60 – 250 m and the length of 80 – 200 m , which is impractical to do anything about it, it was proposed to designate the area along the river as a risky area of debris flow and promote the resettlement of the people.

(3) Pescado Lake

The geology around the outlet of the lake consists of lava of Ignimbritas and tuff. Although the rock on the right bank appears to be basic rock formation, it is a large piece of rock that slipped down from the up-hill gradually in a very long period of several tens of thousands of years. Probably, the large rock piece seems to be stable for a short period of time. However, a large amount of talus material depositing around the rock piece suggests its deterioration in a long time span.

On the left bank, the lava of Ignimbritas is distributed along the ridge and talus material deposits on the downstream side. The talus material seems to include the material from the right bank in addition to the talus material from the left bank. This observation suggests that the outlet has been subjected to frequent blocking by the collapse of the right bank.

There is little fear of recurrence of landslide in near future but periodical observation of the slope in order to detect any symptoms of slope failure or landslide on the right bank of the outlet. It is proposed to improve the outlet of the Pescado Lake so that further landslide will be prevented in order to avoid filling up of the outlet and natural dam break. Concept of the outlet improvement is shown in *Figure 4.21*.

4.2.8 FLOOD FORECASTING/WARNING/EVACUATION

COPECO, CODEM and SERNA are working to construct a flood forecasting and warning system in Tegucigalpa with the help of USAID. The concept of the system is well established and only some recommendations are made in this Master Plan as follows:

- Three additional rainfall gauging/water level stations with the telemetric system are recommended to supplement the present observation network. This is because the present system covers the whole Choluteca River basin and the distribution density of the observation stations in the Study Area is not enough.
- Reorganize the institutional/organizational set-up for the forecasting/warning/evacuation in Tegucigalpa so that CODEM has more significant role in the work.

The location of the proposed new observation stations and the proposed system are shown in *Figures 4.22* and *4.23*.

By the implementation of the proposal, it would be possible to obtain more accurate data on rainfall and discharge in the Study Area and also it would be possible for CODEM to act more promptly to cope with flood emergencies.

COPECO is now making a detail emergency plan to cope with natural disasters including evacuation plan. For their reference, rough evacuation plan from flood was prepared based on the inundation simulation in this Study. *Table 4.12* and *Figure 4.24* show the evacuation destination from each probable inundation area if a storm with the scale of Hurricane Mitch strikes again.

Table 4.13 shows the names of the colonias and the number of endangered households numbers in each colonia. It is possible to identify the names of colonias with comparatively large number of endangered households and prioritize the colonias which should be warned during natural disasters.

4.2.9 FLOOD HAZARD MAP

The flood hazard map was prepared corresponding to the storm with scale of 5, 10, 25 and 50 years as shown in *Figure 2.28*. This hazard map shows the without-project situation. The inundation area with-project situation is shown in *Figure 4.25*. This map should be utilized to educate and enlighten the people to be aware of the danger of flood.

For the publication method of the hazard map, the following are proposed:

- To make a simple brochure carrying a simplified version of the hazard map and distribute to all the communities in the city;
- To make a full scale (1/10,000) hazard map and distribute to the community leaders in the dangerous areas;
- To make a full scale hazard map and leave it in the municipality offices so that anybody who is interested in it can observe;
- To make a digital version of the hazard map and publish it on an official website of the Honduran government. The website of COPECO will be an appropriate candidate site.

4.2.10 LAND USE REGULATION

After the completion of the river improvement plan, the hydraulic simulation was carried out again to see the expected inundation area by a storm with the scale of Hurricane Mitch with the Master Plan Project.

Figure 4.25 shows the result of the simulation. By overlaying the map on the base map of the area, it was found that the total number of households affected by the inundation is1,700. They are distributed along the river and if compared with the designation of the river preservation area of 100 m, most of them are within the designated area.

Therefore, it is considered that this Master Plan Study add to the decree imposed in 1997 a new meaning from the viewpoint of flood disaster prevention. It is proposed here that the decree of river reserve area imposed in 1997 should be applied strictly to eliminate all the structures within the limit in the long run.

The METROPLAN, the planning department of the municipal government, is in charge of zoning and land use planning within the territory of the municipal government. It is recommended that the flood hazard map be always referred to when a new zoning or land use plan is prepared.

In the Study, the land use plan for the Target Area was prepared based on the following policy taking into account the landslide and slope failure danger areas to be described later:

- The river reserve area is set along the Choluteca River with the width of 100 m and no structure is allowed,
- Future increase of population and their resettlement is distributed in the vacant area without any danger of landslide or flood, and
- Housing development applications presently submitted to the municipal government should be referred to the hazard map and be regulated properly.

Future land use projection is shown in *Table 4.14* and *Figure 4.26.*

Table 4.14 Future Land Use in the Target Area

Land Use category	Area (ha)	Ratio
Commercial	311.3	3.0%
Protocol & Business Area	27.5	0.3%
Public Facility	124.2	1.2%
Residential: R-1 to R-5	3,244.1	31.0%
Industrial Area	135.1	1.3%
Military Facility	130.6	1.2%
Airport	58.8	0.6%
Roads & Streets	1,782.6	17.0%
Park & Green Area	210.6	2.0%
Disaster Prevention Green Area	2,163.1	20.6%
Cemetery	25.4	0.2%
Sports Field	51.6	0.5%
Forest & Shrubs	543.9	5.2%
River Reserve Area	380.1	3.6%
Reservoir	46.1	0.4%
Vacant Space	1251.0	11.9%
Total	10,486.0	100.00%

Residential area by classification	Area (ha)	Ratio
R-1: Residential 250 pers. / ha	2,427.9	74.8%
R-2: Residential 400 pers. / ha	527.6	16.3%
R-3: Residential 500 pers. / ha	143.7	4.4%
R-4: Residential 800 pers. / ha	117.4	3.6%
R-5: Residential > 800 pers. / ha	27.5	0.9%
Total	3,244.1	100.0%

Note: Residential classification is applied to on-going planning criteria by the Metroplan of the Municipality

4.2.11 STRUCTURAL CODE APPLICATION

COPECO is working for revision of the structural code taking into account the damage by Hurricane Mitch. The revision work has not yet been finished and cannot be applied in this Master Plan. Therefore, in this plan, an example of a structural code application is proposed for the further discussion in the future.

Figure 4.27 shows the simulated inundation map in the central area of the city. It shows the inundation depth by a storm with the scale of Hurricane Mitch with the river improvement master plan.

Based on this inundation map, an example of the structural code application was proposed. *Figure 4.28* shows the zones where the structural code is applied. In the figure there are two zones proposed. One is the area where the new structure should have the floor level more than 1 m higher than the ground level and the other is the area where the floor level should be 0.5 to 1 m higher than the ground level.

This structural code should be applied together with the restriction of the River Reserve Area mentioned in **4.2.10.**

4.3 LANDSLIDE DAMAGE MITIGATION PLAN

4.3.1 GENERAL

According to the geological analysis, there are 17 landslide blocks ranked in category A, where the danger of landslide is significant. The number of households on and in the affected area of the A rank block is approximately 1,500. On the other hand, 25% of the total area in the Target Area falls in the slope failure danger area, and the estimated number of households on the dangerous slope is approximately 25,000. Therefore, totally 26,500 households are in danger. The total population will be 133,000 and it is 14% of the total population of Tegucigalpa.

Considering the large area and the large proportion of the population affected by the landslide including slope failure, the central part of the plan should be non-structural.

Among the various non-structural measures against landslide damage, the most effective and permanent way is permanent resettlement off the dangerous areas. However, the number of households in those areas is so large that it is not realistic to make a resettlement plan by expecting foreign loans. Therefore, the main non-structural measures are prohibition of housing development in dangerous areas of flood and landslide. Other non-structural measures are forecasting/warning/evacuation, publication of the risk map, education, enlightenment of the residents and land use regulation based on the risk map.

As for structural measures, three landslide blocks were selected from 17 Rank A landslide blocks. These blocks were Berrinche, Reparto and Bambu. As for other 14 Rank A landslide blocks and all slope failure danger areas are planned to be dealt with non-structural measures.

In the case of slope failure problem, all the cases were planned by non-structural measures as structural measures are comparatively costly compared to the number of houses to be protected.

4.3.2 Selection of Landslide Blocks for Structural Measures

Table 4.15 shows all the Rank A landslide blocks with their features and the possible countermeasures. According to the table, it will be difficult to cope with most of the blocks with structural measures because a large number of houses are located on the landslide masses themselves and house relocation is inevitable for the implementation of civil works. On the other hand, it is different in the case of Berrinche, Reparto and Bambu.

For Berrinche landslide, the structural measures are a must as the movement of the block may close the flow of the Choluteca River again and cause inundation of the center of the city. And fortunately, all the houses have been evacuated from the possible structural work area and there is no need of house relocation.

In the case of Reparto, there are still some houses in the landslide mass and there will be a need of some house relocation but the number will be small. The municipal government has tried once to relocate the houses below the landslide mass but it was not successful as the total number of houses affected is very large.

The case of Bambu is similar to Reparto and there will be no need of house relocation for the civil works while the number of houses affected is large.

Because of the reasons mentioned above, the three blocks, namely, Berrinche, Reparto and Bambu were selected as blocks planned by structural measures.

Honduran side commented on the draft final report saying that four areas namely, Zapote Norte, Campo Cielo, Nueva Esperanza and Covespul, are important and they would like to place priority on them. If structure measures are taken for these four blocks, they will definitely enhance the safety against sliding and there is no objection of the implementation of them when the Honduran side is willing to carry on the projects.

4.3.3 Landslide Prevention Facilities

(1) Berrinche

Berrinche slide is 400 m wide and 800 m long having a volume of 3 million m^3. It is one of the largest landslide masses in the area. It moved down during Hurricane Mitch and filled up the Choluteca River causing inundation of the central area of the city.

The main focuses on the landslide mechanism when the structural measures are planned are as follows;

- rainwater infiltration into the land mass and the rising of the groundwater triggered of the movement
- the area is divided into several landslide blocks and classified into large scale landslide blocks at high elevation and small scale landslide blocks along the Choluteca River

The basic idea of landslide prevention is as follows:

- to prevent rain water intrusion into the landslide mass
- to remove groundwater in the landslide mass
- to reduce the driving force of the landslide by removing the head part of the landslide mass
- to increase the resistance force of the landslide by applying counter fill and landslide deterrence works (shaft works or anchor works)

The basic idea of landslide prevention is as follows:

The sliding blocks were classified into two categories, namely small sliding blocks near the Choluteca River and large sliding blocks covering the whole sliding area. The plan safety factor for the small sliding blocks after completion of the structural measures was designed to be 20% larger than that of the state without any measures. On the other hand, the plan safety factor for the large sliding blocks after completion of the structural measures was designed to be 10% larger than that of the state without any measures. Detail stability calculations are shown in Supporting F, G and Data Book.

In the case of Berrinche, the planned facilities are as follows:

- Embankment
- Soil removal
- Surface drainage
- Sub-surface drainage
- Well drainage
- Horizontal boring drainage
- Concrete shaft

A location map of the facilities is shown in *Figure 4.29*.

(2) Reparto

The Reparto landslide is a landslide with an area of 30,000 m^2, 200 m long and 150 m wide. The top elevation of the land mass is EL 1,130 m and the toe elevation is EL 1,070 m. The western parts of steep slopes downward from western high land area of El Picacho changes to gently undulating hills at a road to El Picacho, and steep cliffs lie further east with streams. The geology along the road is tuff and the area lower than the road is covered with old landslide materials. The Reparto landslide is interpreted as one block of soil mass.

The main focuses on the landslide mechanism when the structural measures are planned are as follows;

- a natural stream had been filled up by a new road construction and it raised the

groundwater level in the area and destabilized the block
- rainfall infiltration into the mass raised the groundwater level during Hurricane Mitch and triggered the movement

The basic idea of landslide prevention is as follows:

- to prevent rain water intrusion into the landslide mass
- to remove groundwater in the landslide mass
- to reduce the driving force of the landslide by removing the head part of the landslide mass

The plan safety factor for the small sliding blocks after completion of the structural measures was designed to be 20% larger than that of the state without any measures. Detail stability calculations are shown in Supporting F, G and Data Book.

The planned facilities are as follows;

- Soil removal
- Surface drainage
- Sub-surface drainage
- Well drainage

Location and items of structural measures in Reparto are shown in *Figure 4.30*.

(3) Bambu

The landslide mass presents typical old age landslide topography composed of small fractured landslide masses broken up through a long period of movements. The size of those fractures is small and the thickness of the layer is of a few meters.

The main focuses on the landslide mechanism when the structural measures are planned are as follows;

- rainfall infiltration into the mass raised the groundwater level during Hurricane Mitch and triggered the movement
- surface water run off washed down small landslide blocks and created debris flow

The basic idea of landslide prevention is as follows:

- to prevent rain water intrusion into the landslide mass
- to discharge stream flow downstream quickly without causing erosion of landslide blocks

Proposed landslide prevention measures area as follows:

- open channels
- gabion

Figure 4.31 shows the location of civil works.

4.3.4 Hazard Map of Landslide and Hazard Map of Slope Failure

The landslide hazard map was prepared showing the risky area in terms of landslide and slope failure by a rainfall with the scale of Hurricane Mitch as depicted in *Figure 2.39.* This hazard map shows the without-project situation meaning including Berrinche, Reparto and Bambu. This map should be utilized to educate and enlighten the people to be aware of the danger of landslide. The publication method of the map should be the same as the case of the flood hazard map.

This map should be fully utilized by the authority in charge of the development permit in the municipal government. When the application of development is made infringing on one of the areas indicated in the hazard map, the authority has to make a more detailed investigation on the site from the viewpoint of slope stability by the action of development. When it is judged the development is dangerous, the application should not be approved considering the safety of the people who are going to live in the area.

4.3.5 RESETTLEMENT PROMOTION

A large number of houses are at risk of landslide and slope failure in the area. The total number of households is estimated as 26,500. Through the structural measures, only 800 of this number could be saved from the risk of landslide and the rest should be dealt with non-structural measures.

The most effective solution is permanent resettlement of houses in the dangerous areas. However, a large scale resettlement from dangerous areas to safe places is very difficult and unrealistic in short terms. Realistic idea is to prohibit any further housing development in dangerous areas by regulating the development permission by METROPLAN.

In the Master Plan, it was planned to take up some particular landslide blocks as pilot project of resettlement. The pilot projects are from landslide blocks where the risk is high and resettlement is urgent. Nueva Esperanza and Zapote Centro were selected. The total number of households to be resettled is approximately 200.

The resettlement process should be promoted as follows:

- Preparation of a risk map
- Publication of the risk map to the people living in risky areas
- Education and enlightenment of residents in the areas
- Land preparation for resettlement destination
- Utility preparation for resettlement destination
- Promotion of new occupation for the people who are going to resettle
- Resettlement of people
- Consultation and care of the resettled people

4.3.6 LAND USE REGULATION

Based on the risk map prepared, land use regulation should be imposed strictly. As it is very difficult to relocate people once they have already settled in an area, the important thing is to prevent housing development in dangerous areas. The hazard map shows the dangerous area without any structural measures. Therefore, it is possible to remove the three areas of Berrinche, Reparto and Bambu except the landslide masses themselves from the hazard map after the completion of the structural measures.

The METROPLAN, which is in charge of the land use regulation of the city area, should make an appropriate land use plan referring to the hazard map prepared in the Study.

In this Study, the following are proposed on land use regulation:

- Rank A block of landslide risk area is to be set as “the disaster prevention green area” where no houses are allowed and vegetation is promoted.
- All slope failure risk area is to be set as “the disaster prevention green area” where no

houses are allowed and vegetation is promoted.

Based on this proposal, the future land use plan was prepared and shown in *Figure 4.26.* This map shows the idealistic situation where all the dangerous areas have converted to “the disaster green area” after all the houses in the dangerous areas are relocated.

4.3.7 FORECASTING/WARNING/EVACUATION

(1) Preparation of Evacuation Destination

COPECO is now making a detailed emergency plan to cope with natural disasters including evacuation plan. For their reference, rough evacuation plan from flood was prepared based on the inundation simulation in this Study. *Table 4.16* shows the evacuation destination from each Rank A landslide risk area.

Table 4.13 shows the names of the colonias and the number of endangered households numbers in each colonia. It is possible to identify the names of colonias with comparatively large number of endangered households and prioritize the colonias which should be warned during natural disasters.

(2) Preparation of Forecasting/Warning by Rainfall Amount

Basic information for forecasting of warning for landslide and slope failure area (1) symptoms (2) velocity of ground surface movement and (3) rainfall amount.

Symptom

In the case of landslide or slope failure, there are often some symptoms observed by the people living in the area before the large movement of earth and rock occurs. The following are such common phenomenon.

- Development of cracks or heaving of ground
- Development of cracks on the structures
- Sudden fall of well water or appearance of new springs
- Vibration of ground or earth sounds

It should be noted that slope failures could occur without any symptom as above.

A warning manual should be prepared based on the items described above.

Velocity of ground surface movement

Measurement of ground surface movement is a direct method and most reliable. Following are the measuring instruments of ground surface movement.

- extensometer
- ground inclinometer
- survey (ground survey, GPS survey)

An example of monitoring threshold values are as follows:

- 1mm/hr movement continues three hours or more: emergency preparation
- 4mm/hr or more: evacuation

Rainfall amount

It is considered that a warning system employing rainfall data is the most practical method. However, the threshold value of rainfall amount to be related with the movement of each land mass is not determined at this stage, as not enough information has been accumulated. Therefore, it is recommended to set up a rainfall observation system in the area and collect precise information which can relate the movement of the land and the amount of rainfall in the area. According to examples in Japan, the hourly rainfall amount of 10 to 20 mm or the total continuous rainfall amount of 50 mm is the common threshold value to dispatch alarm for evacuation. These values should be used as a reference because rainfall patterns are different from place to place.

As of now, there is no such system working and in this Master Plan, four rainfall gauging stations were proposed for landslide warning system. *Figure 4.32* shows the location of the observation stations together with the observation stations for flood warning system.

(3) Preparation of Warning Manual

In the case of landslide or slope failure, there are often some symptoms observed by the people living in the area before the large movement of earth and rock occurs. The following are such common phenomenon.

- Development of cracks or heaving of ground
- Development of cracks on the structures
- Sudden fall of well water or appearance of new springs
- Vibration of ground or earth sound

It should be noted that slope failures could occur without any symptom as above.

A warning manual should be prepared based on the items described above.

4.4 OTHER NON-STRUCTURAL MEASURES

4.4.1 EDUCATION/ENLIGHTENMENT AND TRAINING

The education/enlightenment and training plan was made aiming at two purposes, namely, capacity building of the related officials and public education on natural disasters. The capacity building will be enforced to the government officials, educational staffs/teachers and community leaders in charge of disaster prevention and the public education will be implemented to all residents.

The content of education/enlightenment/training is as follows

- education and enlightenment of disaster prevention administrators (capacity building)
- education and enlightenment of school teachers (systematic transfer of disaster knowledge)
- education and enlightenment of urban plan administrators (urban planning considering disaster prevention)
- education and enlightenment of public (knowledge on dangerous area and symptoms, emergency responses)

4.4.2 DISASTER MANAGEMENT INFORMATION SYSTEM

The bottleneck of the disaster prevention activities is the large number of organizations to be involved in decision making and implementation of the plan. As the first step to good coordination among the related agencies on the matter, it is essential to share identical information on disaster prevention.

Based on this idea, the disaster management information system was proposed as an information sharing system among the related agencies. The system comprises a combination of hardware and organization. The hardware is composed of devices to collect, process and share information such as rainfall gauging stations, water level gauging stations, telemeter system, computers, optical fibers and so on. The organization set-up is the one that runs the system.

Figure 4.33 shows the flow of information on disaster.

It is proposed that the system is to be managed by COPECO, which is administrating all information on disaster form all over the country. The organizations to be connected to the system are all counterpart organizations of the study (SOPTRAVI, SETCO, COPECO, SANAA, SERNA, and AMDC) , COHDEFOR, ENEE and others.

4.5 OPERATION AND MAINTENANCE PLAN

4.5.1 RIVER FACILITIES

As described above, it is not necessary to practice constant dredging of the riverbed in order to maintain the river profile. It is necessary to maintain the river structures such as revetments and dikes. Therefore, 0.5% of the construction cost of revetment and dike was included in the maintenance cost of the river facilities.

It is important to maintain the river flow of small tributaries by removing garbage from the river course. This will be done by the municipal office.

Maintenance of Anchor Works

The purpose of maintenance of anchor works is to confirm the planned function. It is necessary to repair when the function of anchor works is insufficient. In doing maintenance, it is necessary to arrange the anchoring record and keep it. Items of observation and measurement of anchoring are as follows.

- Load and displacement caused in anchor bar
- Displacement and movement of structure
- Movement and erosion condition of anchor head
- Groundwater level
- Others

The check, observation, and measurement for maintenance should be continued during anchoring.

4.5.2 LANDSLIDE PREVENTION FACILITIES

It is important to maintain the function of drainage for landslide prevention. Channels and ditches should be dredged constantly to keep the drainage capacity of the facilities. For the maintenance of the facilities, 0.5% of the construction cost was allocated for maintenance cost.

The purposes of the maintenance of landslide-countermeasures facilities are to prevent decrease of function of the landslide-countermeasures facilities, against reactivation of the landslide.

Landslide-countermeasures facilities of Berrinche are water channel work, horizontal boring works, drainage well, and shaft works etc. In case something wrong of these facilities is founded, the function of facilities should be recovered by investigation and repairs.

In particular, drainage function of strainer of catchment boring hole of drainage well decrease in several years after construction, because strainer is clogged with soil. In this case, the strainer should be washed. And, the horizontal drainpipes from the drainage well also regularly should be checked.

4.5.3 OBSERVATION FACILITIES

Maintenance of rainfall gauging stations, water level gauging stations with telemeters are being maintained by SERNA presently. SERNA is also maintaining the inclinometer and the piezometer at Berrinche. After completion of the installation of the monitoring equipment proposed in the Study, it is proposed that the related agencies have discussion and combine the maintenance operation.

The maintenance of monitoring facilities is composed of protection from vandalism/daily inspection and periodical professional inspection and measurement of the facilities. The first part of the work can be entrusted to the representative of the residents and the last part of the work can be done by professional engineers of the relevant governmental agencies.

(1) Rainfall Gauging Station

Maintenance of rainfall gauging station is important to obtain precise value of the rainfall. The station should be located without any interruption of rainfall catch by trees. The trees and bushes around the stations should be cut and removed constantly. The measurement device and transmission device are to be checked periodically so that there is no error of measurement and transmission of data.

(2) Water Level Gauging Station

Water level gauging station often employs an automatic pore pressure meter. It is necessary to check the installation condition of the meter to maintain an accurate water level reading. Constant cross section survey and periodical measurement of discharge are essential to obtain an accurate relationship between water level and discharge. The existing rainfall observation stations in the system are maintained by SERNA and it is recommended all the observation stations are to be maintained by a single organization in order to standardize the maintenance level.

(3) Landslide Observation Instruments

The observation instrument of landslide is inclinometers and pore pressure meters. SERNA is now in charge of the devices installed by the U.S. Corp of Engineers in Berrinche. The observation instruments installed in this Study are to be maintained and observed by SOPTRAVI. The observation data obtained by various organizations should be shared by the agencies concerned with proposed disaster management information system, which will be discussed later.

4.6 ORGANIZATIONAL PLAN

4.6.1 ORGANIZATIONAL PLAN FOR DISASTER PREVENTION

Generally, an integrated disaster prevention master plan is composed of “disaster preparation plan," "emergency action plan" and "rehabilitation plan." This Master Plan is a "disaster preparation plan" basically.

However, in the organizational plan of the study, the organization for the emergency action plan and the organization for the rehabilitation plan were also studied. The discussion was made in the participatory workshop with the counterpart team, and some examples of integrated disaster prevention master plan of municipalities in Japan were also taken up.

Tables 4.17 to *4.19* show the organizational plan for each stage of "the disaster preparation plan," " the emergency action plan" and "the rehabilitation plan."

In order to make the above mentioned set-up to work as planned, it is necessary to agree upon the coordination plan among the agencies involved. The coordination plan for each of the above stage is shown in *Figure 4.34*.

4.6.2 ORGANIZATIONAL PLAN FOR IMPLEMENTATION OF THE MASTER PLAN

All the disaster related activities should be planned according to the proposed organizational set-up described in **4.6.1**. Accordingly, the organization for the implementation of this Master Plan is as follows:

(1) Overall Coordination

As this is an inter-ministerial project, one entity in charge of the overall coordination is necessary. CODEM-DC is proposed as the most appropriate inter-institutional organization for disaster mitigation in Metropolitan area. The steering committee of the Study commented on this proposal in the draft final report, stating that a new steering committee composed of all the counterpart agencies should be formed for this overall coordination task. The organizational set up for the implementation of the project should be discussed further among Honduran side from now on.

(2) Flood Control Structural Measures

This part of the Plan is to be proceeded with by AMDC as organizer with cooperation of other related organizations, especially SOPTRAVI, which have a long history of experience in such river improvement works throughout the country. They have enough technical staff and equipment for implementation of the projects. Presently, SOPTRAVI is in charge of the same kind of project, such as rehabilitation/reconstruction of flood control and landslide prevention structures damaged by Hurricane Mitch, under the On-going National Reconstruction Plan.

(3) Landslide Prevention Structural Measures

This part of the Plan is to be proceeded with by AMDC as organizer with cooperation of other related organizations, especially SERNA as they have been working on the Berrinche landslide problem since the beginning of its occurrence during Hurricane Mitch. As they lack experience of large-scale civil works, it is necessary that they collaborate with SOPTRAVI in implementation of projects.

(4) Watershed Management

Watershed management is to be proceeded with by AMDC with cooperation of other related organizations, especially SANAA, SERNA and COHDEFOR.

(5) Land Use Plan (including Land Use Regulation, Resettlement and Structural Codes)

Land use plan should be dealt with by AMDC with the collaboration of COPECO/CODEM-DC.

(6) Preparation and Publication of Risk Map

Preparation and publication of risk map should be dealt with by CODEM-DC with the collaboration of COPECO, SOPTRAVI and SERNA.

(7) Education/Enlightenment

Education/Enlightenment of people should be dealt with by CODEM-DC as they have been preparing the education/enlightenment and training program, with the cooperation of COPECO.

(8) Forecasting/Warning/Evacuation

Forecasting, warning and evacuation of the people should be dealt with by COPECO and the CODEM-DC as a regional organization of COPECO with the collaboration of SERNA and National Meteorological Service (SMN). In this Master Plan, more significant role of CODEM is proposed.

4.7 COST ESTIMATE

4.7.1 CONSTRUCTION COSTS

The construction cost of the civil works was estimated through work volume calculation and unit price calculation of each work item. The result of the cost estimate is shown in *Table 4.20.*

4.7.2 OPERATION AND MAINTENANCE COST

The operation and maintenance cost of the Master Plan Project was estimated proportionally to the construction cost of each item considering the nature of the project. Annual maintenance cost for river works except dredging is allocated 0.5% of construction cost.

As for the river structures, replacement cost of revetment and dike was considered as taking 10% of the construction cost once per 15 years.

The maintenance cost for warning system and disaster management information system was included in the plan taking 0.5% of the installation cost and replacement cost once per 10 years.

4.8 IMPLEMENTATION PROGRAM

Implementation program for the Master Plan Project was prepared in order to realize all the program by the target year 2015. The implementation program is shown in *Table 4.21*. The detailed implementation program is shown in Supporting K.

4.9 SELECTION OF PRIORITY PROJECTS

4.9.1 GENERAL

Among the Master Plan Projects, Priority Projects have been selected for the Feasibility Study. The selection of the Priority Projects was made based on the pre-set criteria and the discussion among the counterpart team members as well as the steering committee of the Honduran side.

As a result, a part of the flood damage mitigation structural measures, all of the landslide damage mitigation structural measures and a part of the non-structural measures were selected as the Priority Projects.

4.9.2 SELECTION CRITERIA FOR PRIORITY PROJECT(S)

The selection criteria for the Priority Projects are as follows:

- Significance
- Urgency
- Immediate Consequence
- Economy

4.9.3 FLOOD DAMAGE MITIGATION STRUCTURAL MEASURES

In terms of flood damage prevention, the main causes of the problem is the bottleneck of the main channel at the location of Berrinche and the large amount of sediment caused by the bottleneck. Therefore, the widening of the Choluteca River adjacent to Berrinche landslide is the most significant project. The next significant project is the removal of the large amount of sediment with the combination of revetment and dike construction. Reconstruction of Mallol Bridge is less significant in terms of the effect to the river discharge capacity. Improvement of the Pescado Lake is also significant considering its large impact to the flood downstream.

In terms of urgency, excavation of the Choluteca River has the first priority, as the mal-capacity of the Choluteca River at the center of the city is lowering the safety factor against flood of the capital. Excavation of the river is also critical in order to solve the problem of inundation along the Sapo River happening almost every year. Other projects are less urgent compared to this.

Immediate consequence for the problems will be attained by all the structural measures except the reconstruction of Mallol Bridge where a long-term discussion is needed. Mallol Bridge reconstruction is excluded from the Priority Projects as they are less significant and will take a long time to clear the environmental issues.

The economic justification is to be made by considering the area to be saved from the inundation after the completion of the projects.

Therefore, as the Priority Projects, “river widening at Berrinche”, “river excavation”, “a part of revetment/dike construction” and “Pescado Lake outlet improvement” were selected. In order to determine the extent of the revetment/dike construction, the inundation area along the Choluteca River by a flood with the scale of once in 15 years. *Figure 4.35* shows the inundation area. According to the figure, the area between C40 and C60 is the inundation area where the population density is high. Therefore, C40-C60 was selected as the priority project for revetment/dike construction. The other river reaches with river bed excavation and without revetment area are to be protected by gabion mattresses temporarily.

<u>Choluteca River Improvement</u>

- River widening at Berrinche L＝ 200 m
- A part of riverbed excavation V＝ C23-C93; 750,000m^3
- A part of revetment construction L＝ 3 km

- A part of dike construction L＝ 1 km

Other Projects

- Pescado Lake Outlet Improvement

4.9.4 LANDSLIDE DAMAGE MITIGATION STRUCTURAL MEASURES

In terms of landslide disaster prevention, the most significant component of the Master Plan is non-structural measures as most of the landslide masses or steep slope area where a huge number of people live cannot be coped with by structural measures.

However, the most effective non-structural measure, namely, resettlement, is not attained promptly; therefore, it is necessary to cope with the problem with structural measures. Three landslide blocks in the Master Plan are all urgent because their risk is large. The structural measures proposed in the Master Plan are prompt in the sense that there is little need of house resettlement.

The economic justification is to be made by counting the number of houses saved from the danger of landslide by accomplishing the structural measures.

The locations for the Priority Projects proposed are as follows:

- Berrinche
- Reparto
- Bambu

4.9.5 NON-STRUCTURAL MEASURES

The non-structural measures in the Master Plan are composed of watershed management, land use regulation, structural code application, forecasting/warning/evacuation, education and disaster management information system.

Non-structural measures which give an immediate consequence are forecasting, warning and evacuation. Watershed management, land use regulation and structural code application will not give prompt solution to the inundation problems or landslide problems. They should be regarded as long-term solutions. The forecasting/warning/evacuation measure is the most significant projects which deal with a large number of households in danger.

Education and disaster management information system are urgent parts of the solution to be initiated as soon as possible.

Therefore, following projects were selected as Priority Projects:

- Forecasting/warning/evacuation
- Education/Enlightenment/Training
- Disaster management information system

Chapter 5

Evaluation of the Master Plan

CHAPTER 5
EVALUATION OF THE MASTER PLAN

5.1 GENERAL

The proposed Master Plan was evaluated from the economic, financial, managerial, technical, environmental and social aspects. The overall evaluation of the Master Plan was made integrating all the aspects of evaluation.

5.2 ECONOMIC ASPECT

5.2.1 ECONOMIC BENEFIT

Benefit of the disaster prevention project is generally defined as an economic difference of damage between “with-project” and “without-project” situation.

There are two kinds of benefit, namely, tangible benefit and intangible benefit. Further, tangible benefit would be classified into direct benefit and indirect benefit.

The direct/tangible benefit of the project is estimated as a reduction in damage to assets such as buildings, household effects, livestock, crops, infrastructure and other facilities. And indirect/tangible benefit also would be estimated as a reduction in damage, which would be derived secondary from the direct damage of the project. Because of the difficulty of estimating the intangible benefit appropriately, the amount of intangible benefit would not be included in the economic evaluation of this Study.

The calculation method of damage reduction is as follows:

(1) Flood Damage Reduction

Inundation simulation was made by the established hydraulic model and the inundation area was identified for floods with the return periods of 5, 10, 50 and Hurricane Mitch scale flood. The simulation was made for both with-projects case and without-projects case.

The inundation area was overlaid on the base map of GIS having the distribution of households in the area. The values of the households composed of structures and furniture were estimated based on the damage survey conducted in the Study. The damage was calculated integrating all the damage caused by each flood with-projects and without-projects. The reduction of damage was calculated as the difference of damage between with-projects and without-projects.

(2) Landslide Damage Reduction

The Master Plan contains landslide structural measures for three landslide masses, namely, Berrinche, Reparto and Bambu. The structural measures were planned targeting a Hurricane Mitch class storm,. Therefore, it is considered that with-projects those three blocks will be able to withstand a storm with a return period of 500 years. On the other hand, if the projects are not implemented, these three blocks will slide, inflicting damage in the estimated dangerous areas.

Thus, it is assumed that without projects all the households in the area of three landslide blocks are destroyed by a 500-year storm, while all the households in the same area of three landslide blocks are safe against a 500-year storm with the projects.

(3) Damage Reduction Amount

Reduction of flood and landslide damage is calculated as shown in *Table 5.1*.

Table 5.1 Reduction of Flood/Landslide Damage

Return Period (year)	Damage Reduction (US$ million)
5	14.30
10	20.58
15	23.60
50	36.08
Mitch (500)	139.19

5.2.2 ECONOMIC COSTS

The following preconditions and assumptions are applied for calculation of the economic costs in this Study:

- The inflation factor is not included.
- Transfer payment factors such as taxes and duties are applied to goods and services procured locally with following rates:
  Value added tax (VAT) : 12%
  Income tax : 10%
  Import tax : 10% (average)
- Standard conversion factor of 0.9634 is applied as the shadow price for all the costs except imported goods based on the Honduran external trade statistics and the value used for other studies.
- Adjustment factor for personal costs of unskilled laborers was not applied.
- The real exchange rate is assumed to be fixed because so far the government has not introduced any special protective measure for trade and its currency.

Under the preconditions and assumptions mentioned above, the economic costs of the project are estimated from the project costs provided in Chapter 4.

5.2.3 COST BENEFIT ANALYSIS

The project life is economically taken as 50 years after commencement of the project. The benefits together with the OM cost are assumed to accrue throughout the period of project life after completion of the construction works. The partial benefit and OM cost under the construction period would be considered in this analysis.

The estimated EIRR of Master Plan indicates 10.49 % and it can be said that the project is economically feasible, from the viewpoint of the opportunity cost of capital (OCC) in Honduras.

Table 5.2 shows the Net Present Value (NPV) and Cost Benefit Ratio (B/C) of the Project.

Table 5.2 NPV and B/C for the Master Plan Project

Discount Rate	NPV (US$ million)	B/C
4 % (Real yield of the Honduran state bond)	47.40	2.11
8 %	9.30	1.28

5.3 INTANGIBLE SOCIO-ECONOMIC IMPACT OF THE PROJECT

As it is confirmed in the previous section, the proposed projects would produce direct economic effects, and the conclusion is that these projects are economically feasible. Furthermore, it is expected that the projects would have various intangible effects of reducing the socio-economic damage as follows:

Spread of Infectious Disasters

Natural disasters may frequently cause a spread of infectious diseases by destroying the water supply and drainage facilities.

Shortage of Goods

Natural disasters would cause shortage of goods in and around the area affected due to damage to products and manufacturing factories, standstill of distribution system of commodities and cutting of road network, and increase in demand of equipment and materials caused by damage to buildings, household effects and public facilities.

Steep Rise in Prices

The shortage of goods and standstill of traffic and distribution system of commodities would cause a steep rise in prices in and around the area. Further there is the possibility that such a steep rise in prices expands in the whole country.

Lowering of Administrative and Educational Activities

Administrative and educational activities in the affected area would drop due to the damages to public offices and schools.

Decline in Communication

Communications between the affected areas and other areas would decline due to damage to telecommunication facilities and standstill of traffic.

Decline in the Standard of Living

Inhabitants in the areas affected would inevitably experience a decline in their standard of living due to damage to their assets and public facilities, shortage of goods, steep rise in prices, lowering of administrative and educational activities, etc.

Time Lag of Social and Economic Development

Various negative factors mentioned above would cause a delay of social and economic developments in and around the areas affected by natural disasters. Further there is the possibility that the delay would expand in the country as a whole, because the area has the highest socio-economic potential in the country.

5.4 FINANCIAL ASPECT

5.4.1 RAISING OF THE PROJECT FUND

In order to examine the financial viability of the project, consideration would be given on raising the construction fund in this section.

The project cost excluding O/M cost for the Master Plan Project is estimated at US$ 63.05 million in total. It is assumed that the fund for the project will be raised from two sources of local-fund and external debt, under following conditions:

- The external debt will cover the whole project cost except government administration and land acquisition cost. The government administration cost and land acquisition cost would be prepared from local-fund.
- The following loan conditions were assumed based on the actual conditions of IDB loan for Honduras.
  - Repayment period : 40 years
  - Grace period : 10 years (only for principal repayment)
  - Interest rate : 1% for the first 10 years and 2% afterward
- During the grace period, only interest is paid, and repayment of the debt with the interest is made after the grace period.
- Disbursement will be done in the beginning year of the Priority Project and the remaining of Master Plan Project respectively.
- Repayment of principal was calculated based on an equal installment repayment method.

According to the repayment schedule prepared in the Study, the maximum disbursement of US$ 37.46 million will be accrued in 2006, which is the beginning year of the project, and the maximum repayment of US$ 2.91 million in2027.

5.4.2 REPAYMENT OF EXTERNAL DEBT

According to the repayment statistics of the external debt of Honduras, the average annual repayment amount for multilateral loan is approximately US$ 240 million for the past 8 years.

The annual maximum repayment amount of US$ 2.91 million in 2027 for this project will be 1% of the total annual repayment of Honduras. The total amount of the project cost is US$ 64 million and small compared to the damage in Tegucigalpa during Hurricane Mitch (around US$ 500 million). The total project cost is equivalent to the annual budget of Tegucigalpa Municipality (around US$ 50 million).

It can be judged that the raising of the project fund from external loan seems to be possible, from the viewpoint of the amount of maximum repayment.

5.5 MANAGERIAL ASPECT

The Master Plan is composed of structural measures and non-structural measures. The structural measures consist of flood control projects and landslide prevention projects. The non-structural measures are composed of inter-ministerial projects such as forecasting/ warning/evacuation. Therefore, the management of the implementation of Master Plan Projects is rather complex and difficult. However, it is inevitable to face this managerial problem in solving the disaster prevention problem and it should be challenged.

The organization plan and the coordination plan was proposed in Chapter 4 and if the overall coordination is accomplished as planned, the management of the project will be handled by placing the Municipal government and CODEM in charge.

(1) Implementation Ability of the Organization

As the proposed organization is a joint team composed of national as well as local organizations. This combination will facilitate the organization in mobilization of experienced engineers in large scale civil works and local government officials who are familiar with the local residents and local conditions. Therefore, the implementation ability of the proposed organization is good enough if the coordination of all the parties proposed goes well.

(2) Independence and Sustainability of the Organization

Among the proposed organizations in the master plan, COPECO and CODEM are comparatively new organization. However, they have been receiving strong supports from international organizations such as IBD and World Bank. USAID is also joining the series of projects for empowerment of COPECO and CODEM.

Therefore, it is expected that CODEM will be empowered by those supporting projects of BID, World Bank and USAID as a central organization for disaster prevention in Tegucigalpa City and the proposed organization is sustainable and independent.

(3) Feasibility of the Institution Proposed

In the institutional proposal of the master plan, the practicability of them were taken into account. No new legislation was proposed but the application or strengthening of existing laws and regulations was proposed. No new organization was proposed but the strengthening or coordination of existing organizations was proposed.

For example, the concept of “the river reserve area” was introduced in 1992 and the effectiveness of the idea has been appreciated. This master plan has given the engineering meaning into the concept of the river reserve area from the view point of flood damage mitigation. Considering the fact that METROPLAN has been successful in land use regulation for the land in Comayguela area along the Choluteca River, it is possible to impose this concept more strictly as a part of the land use regulation for disaster prevention.

Thus, the institution proposed in the plan is realistic and feasible.

5.6 TECHNICAL ASPECT

Most of the civil works included in the Master Plan are a combination of simple works although the volume of each work is huge. The process of excavation, hauling and disposal of sediment is a simple but repetitious operation. Revetment and dike construction work need structural excavation and concreting work in river course and require coffering and dewatering. This coffering and dewatering operation should be limited during dry season so that it will not bring about difficult technical problems.

Bridge reconstruction is being done at present in the city and gives no difficult technical problems.

It is observed that Honduras has no experience in concrete shaft building, drainage well construction and horizontal drainage boring. It requires technical assistance by foreign consultants and contractors and import of materials but it is possible to be carried out in

Tegucigalpa. The horizontal drainage boring is not common in Honduras but there are some foreign boring companies in Tegucigalpa that have such experience. Therefore, it is possible to introduce some foreign boring companies to do the operation.

Overall, it is necessary to get technical assistance and cooperation of foreign consultants and foreign contractors to implement the Master Plan Projects.

5.7 ENVIRONMENTAL ASPECT

According to the literature review and from the local environmental expert, there is no endangered or threatened species of flora or fauna in the Master Plan Projects area.

As there was a fear of inclusion of heavy metal in the river sediment from the urban discharge, investigation was made in the Feasibility Study stage. As a result, no heavy metal was detected with an amount larger than the regulation and the problem was eliminated.

As a whole, there is no significant environmental problem in the Master Plan Project area. *Tables 5.3 and 5.4* show the screening and the scoping of the environmental issues for the Master Plan Projects respectively.

5.8 SOCIAL ASPECT

(1) Land Acquisition/Resettlement

The land to be acquired for the civil works is as shown below.

Table 5.5 Land Acquisition and Resettlement

Project	Land to be acquired (m^2)	Number of houses To be resettled
River widening at Berrinche	12,000	0
Pescado Lake Outlet Improvement	1,000	0
Reparto Landslide Prevention	3,000	10
Total	16,000	10

The land for river widening at Berrinche, 12,000 m^2 was designated as a river area in 1999 by the Planning Department of Tegucigalpa Municipal Office and there is no problem of land acquisition. The outlet of Pescado Lake is privately owned and the land is to be acquired or to be leased temporarily. The landowner of the place is cooperative toward the project according to initial talks with the Study Team. In Reparto landslide, approximately 10 houses are to be relocated in order to construct a surface drainage channel. The homeowners have not been contacted, but they have to be relocated to a safer place anyway. It is considered possible to relocate them by proper compensation.

Thus, overall, there exist problems but the land acquisition and the resettlement related to the Master Plan Projects can be solved by prudent approach to the landowners.

(2) Preservation of Historical Landscape

In April 1994, the Municipal Mayor's Office of the Central District and the Honduran Institute of Anthropology and History signed an agreement for the "Conservation of the Historical Area of Tegucigalpa/Comayaguela and Neighboring Areas."

The project related to this matter is the reconstruction of Mallol Bridge. As stated in Chapter 4, the reconstruction of the bridge was basically agreed upon. The type of the new bridge will be discussed further in the feasibility stage of the project in future.

(3) Social Acceptability of the Organization, Institution and System Proposed

As stated before, the proposed organization/institution/system are combination and strengthening of existing ones and the acceptability is rather high. The idea of hazard area has been accepted by the citizens who experienced severe damage of Hurricane Mitch.

(4) Benefit to Poverty Group

A larger portion of the people who live in the dangerous areas belongs to poverty groups as they migrated to the lands where wealthy people had not used because of the danger of the area. Therefore, implementation of the master plan will give a great benefit to the poverty groups in the area.

(5) Negative Impact to Residents

No negative impact to the residents is expected as the land acquisition and resettlement problems by civil works is minimum.

5.9 OVERALL EVALUATION

According to each aspect of the evaluation, the Master Plan Projects proposed are feasible. The implementation of the projects will definitely give great benefit to Tegucigalpa City. As the technical, environmental and social problems are not significant as a whole, the most crucial matter is the project management. The strong leadership of the central as well as the local government will realize the good coordination of this complex and difficult task.

Chapter 6

Feasibility Study of Priority Projects

CHAPTER 6
FEASIBILITY STUDY OF PRIORITY PROJECTS

6.1 GENERAL

The Priority Projects selected for the Feasibility Study are as shown in *Table 6.1*.

Table 6.1 Priority Projects

	Flood Damage Mitigation	Landslide Damage Mitigation	Common
Structural Measures	- Choluteca River Improvement - Pescado Lake Outlet Improvement	- Berrinche Landslide - Reparto Landslide - Bambu Landslide	-
Non-structural Measures	- Forecasting/Warning/ Evacuation	-Forecasting/Warning/Evacuation	-Education/Enlightenment/Training -Disaster Management Information System

Figure 6.1 shows the location map of the structural part of the Priority Projects.

In the Feasibility Study of the Priority Projects, additional topographic survey was done to cover all the project site with the scale of 1/500. (Supporting A) Geological boring was performed for the sites of Berrinche and Reparto to plan the structural measures for flood damage mitigation and landslide damage mitigation. The environmental impact assessment was made for all the structural measures in the Priority Projects to assess the impact of the project.

Alternative study was made for structural measures after more detailed site investigation including the topographic survey and geological survey. The benefit and the cost of the projects were calculated with higher accuracy and utilized for economic evaluation of the projects.

Project evaluation was made from the economic aspect, the financial aspect, the environmental aspect and the social aspect and it was concluded that the Priority Projects were feasible economically and financially as well as from the environmental and social aspects.

6.2 TOPOGRAPHIC SURVEY

Topographic survey with the scale of 1/500 was done for the area of the Priority Projects. The topographic map was utilized to make more detailed plan for the Priority Projects.

6.3 GEOLOGICAL INVESTIGATION

Boring investigations were conducted in the sites of Berrinche and Reparto. Detailed field reconnaissance was carried out for Berrinche, Reparto, Bambu and the Pescado Lake outlet for landslide prevention plan. The location and the amount of boring investigation are shown in *Table 6.2* and *Figure 6.2* respectively.

The summary of the geological investigation is given below. Detailed result of the geological survey is described in Supporting G.

6.3.1 BERRINCHE

(1) Topography and Geology

Berrinche landslide is a landslide with an area of 320,000 m^2, a width of 400m and a length of 800m. The top of the landslide mass is around EL 1,060 m and the toe of the mass is at EL 920 m at the bottom elevation of the Choluteca River.

Geological survey revealed that at the east ridge of Barrio El Chile and Colonia El Porvenir, limonite, silt and mudstone of Rio Chiquito Formation of Mesozoic era are exposed below an elevation of 1,015 m, and Tertiary tuff is seen above 1,015 m. On the steep cliff located from Colonia Cielo to Barrio El Berrinche and Colonia El Porvenir, volcanic rocks of Ignimbrites are seen underlain by tuff. Tuff is outcropped to the west of Block C and D. Rio Chiquito Formation is outcropped to the east.

The area can be divided into several landslide sub-blocks as shown in *Figure 6.3* according to the landslide mechanism study.

(2) Boring Result

In the area, the U.S. Corp of Engineers had performed boring investigation in 2000. The sites of the boring investigation are shown in *Figure 6.2(1)*. In this Study, additional boring was made to study the geology of the site further. *Figure 6.2(1)* shows where the additional boring was performed.

The boring result is summarized in *Figure 6.4*. By observing the boring core, the slip surface of the landslide during Hurricane Mitch was identified. The identified slip surface of profile B-4 in particular is described in *Figure 6.6*.

(3) Monitoring Result of Inclinometer and Piezometer

SERNA has been monitoring the behavior of the land mass by using inclinometers and piezometers since 2001. The observation points are shown in *Figure 6.2(3).* The measurement of the inclinometer shows a movement at BS-4 by the amount of 2mm/month at a depth of around 38 m. At the other locations no apparent movement has been detected.

The seasonal variation of groundwater level is large at the mountain side at BS-3, BS-4 and BS-7 while that at the river side at BS-1, BS-2, BS-5 and BS-6 is small.

In the Study, three piezometers and eight inclinometers were installed and observation was made for two month. No movement of the land mass was observed in the period as it was in dry season. The measuring instruments were hand over to SOPTRAVI for continuous monitoring of the movement of the land mass. The obtained data are shown in the Data Book.

(4) Landslide Mechanism

- Water collected from the scarf zone of the landslide and up-hill areas flowed into tension zone of the landslide (upper most zone) and has been pressurized into artesian conditions within the shear zone of Formation Chiquito.
- Judged from the movements of the land together with displacement of the ground surface, the slide surface is considered to be closed-end type and stepped shape type.

Based on the geological investigation, monitoring result and field reconnaissance, the mechanism of landslide in Berrinche during Hurricane Mitch is interpreted as follows:

- Block A1 started to slide because of rising groundwater after heavy rainfall
- Block A1 pushed Block B and formed a compression topography
- Block A1 pushed Block A2 and Block A3 started to slide
- The end of Block A3 intruded into the Choluteca River forming a barrier
- Block A1 pushed Block B and Block B started to slide
- The end of Block B intruded into the Choluteca River and closed it
- Blocks C and D moved down with the movement of Block A1

Thus, it is interpreted that Block A started to slide first and it pushed down the block at the lower elevation into the Choluteca River and closed it.

6.3.2 REPARTO

(1) Topography and Geology

The Reparto landslide is a landslide with an area of 30,000 m^2, 200 m long and 150 m wide. The top elevation of the land mass is EL 1,130m and the toe elevation is EL 1,070m. The western parts of steep slopes downward from western high land area of El Picacho changes to gently undulating hills at a road to El Picacho, and steep cliffs lie further east with streams. The geology along the road is tuff and the area lower than the road is covered with old landslide materials. The Reparto landslide is interpreted as one block of soil mass.

At the downstream of the landslide, slopes were formed with the earth delivered by debris flow.

(2) Boring Result

In the Study, 6 new boring were made to investigate the geology of the area. The location map of the boring is shown in *Figure 6.2(2)*. The boring result as boring log is shown in *Figure 6.7*. The slip surface during Hurricane Mitch was assumed from the boring result as shown in *Figure 6.8*.

(3) Monitoring of Inclinometer and Piezometer

In the Study, three piezometers and three inclinometers were installed and observation was made for two month. No movement of the land mass was observed in the period as it was in dry season. The measuring instruments were hand over to SOPTRAVI for continuous monitoring of the movement of the land mass. The obtained data are shown in the Data Book.

(4) Landslide Mechanism

According to the boring result and the field reconnaissance, the landslide mechanism of Reparto is as follows:

- The stream on east side that drained the groundwater had been blocked by the construction of the road at the toe of the landslide mass and new ponds had been created.
- During Hurricane Mitch, heavy rainfall caused a large flow of surface water on the landslide mass together with the water coming from the road to El Picacho.
- Surface water raised the groundwater level of the mass causing the movement of the block.
- The damage became a second disaster because debris flows from the landslide blocks were spread over wide areas.

6.3.3 BAMBU

(1) Topography and Geology

This landslide mass presents typical old age landslide topography composed of small fractured landslide masses broken up through long period of movements. The landslide mass exists in an open valley with the slope of 25 to 35 degree. It is 180 m wide and 250 m long. The thickness is 5 to 15 m. The geology of the mass is Rio Chiquito Formation (Krc), which overlies on Tpm (light tuff). The landslide mass sits on the top of the valley and it is horseshoe shape with a narrow bottle neck. The slip scarp is 5 to 10 m and new. The sliding mass is extremely weak as it is a weathered light tuff, which is becoming sandy clay.

The slip surface lies on the boundary of Krc and Tpm and the movement of the mass created the present valley topography. After the rainwater had penetrated and the rock had been weathered to become sandy clay.

(2) Landslide Mechanism

During Hurricane Mitch, heavy rainfall concentrated in the center of the block and a part of the landslide mass collapsed and washed down. It is considered that the debris flow from the part of the landslide mass destroyed some houses and closed the stream of Bambu and caused inundation in the lower area.

6.3.4 PESCADO LAKE OUTLET

(1) Topography and Geology

The geology around the outlet of the lake consists of lava of Ignimbritas and tuff. Although the rock on the right bank appears to be basic rock formation, it is a large piece of rock that slipped down from the up-hill gradually for a very long period of several tens of thousands of years. On the left bank, the lava of Ignimbritas is distributed along the ridge and talus material deposits on the downstream side. The talus material seems to include the material from the right bank in addition to the talus material from the left bank. This observation suggests that the outlet has been subjected to frequent blocking by the collapse of the right bank. *Figure 6.9* shows the geological sketch of the site.

(2) Flash Flood Mechanism

According to the detailed field reconnaissance, the mechanism of flash flood during Hurricane Mitch was estimated as follows:

- Before Hurricane Mitch, the crest elevation of the outlet was higher than the present ground level by 4.5 m protected by a concrete structure 0.5 m wide.
- During Hurricane Mitch a large amount of logs cascaded from the upper reach and accumulated at the outlet.
- A part of the right bank collapsed and together with the logs raised the crest elevation of the outlet by another 3.5 m and a large amount of water accumulated in the lake.
- The water level rose higher than the crest level and washed away all the collapsed soil mass, the logs, the concrete structure and the riverbed material causing flash flood down stream.

6.4 ENVIRONMENTAL IMPACT ASSESSMENT

The impact on environment by the Priority Projects was studied. Detailed result is described in Supporting Report E.

The main points of the EIA are as follows:

- Possibility of contamination of the riverbed material by heavy metals
- Resettlement problems caused by structural measures of the projects

6.5 FLOOD DAMAGE MITIGATION PROJECTS

6.5.1 RIVER WIDENING AT BERRINCHE

In the river widening at Berrinche, landslide prevention measure was planned in order not to affect the Berrinche landslide mass. The prevention measures were planned assuming the slip surface at the toes of Blocks B1, B3 and Block E. The slip surface considered is the one which is being observed presently as shown in *Figure 6.6*.

The measures were planned so that the safety factor after the project becomes Fs=1.2 from the present safety facto Fs=1.0. Concrete shafts, steel piles and counterweight fill were compared. *Table 6.3* shows the comparison. The counter weight fill was employed in Block E as it is the most reliable method and the location of the slide against the river course. As for Blocks B and A3, counter fill is impossible because of its topography and concrete shafts and steel piles were compared. The geology at the site makes the construction of steel pile very difficult and the concrete shaft was selected finally. In Blocks B and A3, horizontal drainage boring (K=50m) was planned to lower the groundwater level.

Table 6.3 Comparison of Landslide Prevention Measures for River Widening

Block Name	Geology	Type of Structures			
		RC-shaft	Steel Piles	Counterweight fill	Earth Anchor
E	Riverbed deposit, Chiquito layor and sliding soil	-	-	X	-
A3	Sliding soil and debris	X	-	-	-
B	Sliding soil and gravel	X	-	-	-

The diameter of the concrete shaft was selected after comparing some cases. Based on the comparison of cost and construction planning, the diameter of 4.0 m was adopted. On the right bank, earth anchor system was proposed to reduce the land acquisition. (*Figures 6.10* and *6.11*)

6.5.2 RIVERBED EXCAVATION

River excavation volume of Priority Project is about 475,000m^3 between C40 and C65. The excavation will be done with a backhoe with the capacity and be hauled to the spoil bank downstream (C0-C10). The hauling will be done by using 10 t dump trucks and 20 t dump trucks depending upon the location of the excavation site. If the excavation site is downstream from the Carias Bridge, it is possible to use 20 t trucks as there is no hindrance of traffic. But if the site is upstream from the bridge only 10 t trucks will be used for hauling.

The effect of the spoil bank to the water level both at the exact location and upstream was studied. It was found that the water level at the spoil bank location will not rise so much but it was planned to protect the private land at the opposite side of the river where a chicken farm is located.

6.5.3 REVETMENT AND DIKE

The location of the revetment and the dikes were studied in detail based on the topography along the river. *Figures 6.12* to *6.15* shows the exact location of the revetment. Between C52 and C56, the channel section was modified to accommodate the newly planned bus terminal on the left side of the river.

6.5.4 IMPROVEMENT OF THE PESCADO LAKE OUTLET

Following countermeasures are planned in order to prevent the closure of the outlet of the Pescado Lake.

- Placing of gabion mattress, which is 15 m wide, 60 m long and 0.5 m thick, at outlet.
- Placing of gabion wall, which is 2 m wide, 3 m high and 60 m long, at left and right slope toe.
- Cutting of slope, which is in danger of collapse at the right side of slope.

6.5.5 FORECASTING/WARNING

The hardware for the flood forecasting/warning system was studied in detail and the cost was estimated. Examples of rainfall gauge, water level gauge and telemeter system is shown in *Table 6.4*.

Table 6.4 Flood Forecasting/Warning System

Item	Specification	Number
Rainfall gauge	0.2 mm unit	3
Water level gauge	Water pressure type	3
Telemeter		3

Note: The installation of the system was included in the cost of the projects.

6.6 LANDSLIDE DAMAGE MITIGATION PROJECTS

6.6.1 BERRINCHE

The structural measures planned are as follows:

- removal of top of the landslide mass
- surface drainage channel
- sub-surface drainage channel
- drainage well

The location of the structures is shown in *Figure 4.29. Figures 6.16* and *6.17* show each of the structure planned. The removed soil will be hauled to the same spoil bank as the riverbed excavation.

The surface drainage channel was designed to accommodate the design rainfall amount of 20 mm/hour, which is equivalent to the maximum hourly rainfall during Hurricane Mitch. The design catchment area for the surface drain system covers a part of the Cero Grande plateau.

6.6.2 REPARTO

The best defense measure is to quickly and smoothly drain surface water and groundwater that jeopardize the slope stability to outside the slope. To stabilize the slope, blocks of the earth at the head of the presently extremely unstable slope will be removed and the earth will be placed at the toe of the slope as counter weight. Replacement of soft portion at the toe of the slope may be necessary before placing the counter weight.

The structural measures planned are as follows:

- removal of top of the landslide mass
- surface drainage channel
- sub-surface drainage channel
- drainage well

The location of the structures is shown in *Figure 4.30*. The removed soil will be hauled to the same spoil bank as the riverbed excavation.

The surface drainage channel was designed to accommodate the design rainfall amount of 20 mm/hour, which is equivalent to the maximum hourly rainfall during Hurricane Mitch. The design catchment area for the surface drain system covers the slope above the road to Picacho.

6.6.3 BAMBU

The structures planned are as follows:

- surface drainage channel
- gabion mattress

Figure 4.31 shows the location of the structures and *Figure 6.18* depicts the concept of the structures.

6.6.4 FORECASTING/WARNING

The hardware for the landslide forecasting/warning system was studied and the cost was estimated. Examples of rainfall gauge and telemeter system are shown in *Table 6.5*.

Table 6.5 Landslide Forecasting/Warning System

Item	Specification	Number
Rainfall gauge	0.2 mm unit	4
Telemeter		4

Note: The installation of the system was included in the cost of the projects.

6.7 OTHER NON-STRUCTURAL PROJECTS

6.7.1 EDUCATION/ENLIGHTENMENT/TRAINING

The education/enlightenment/training program was prepared targeting both the government officials in charge of disaster prevention and the school teachers.

(1) Education/Enlightenment/Training for Government Officials and School Teachers

A training was proposed for the capacity building of CODEM officials. The content of the training should be basic knowledge for disaster prevention, collection/processing/transmission of data on disaster. It was also proposed to train the officials in the planning department of the municipality on the land use planning and the land use regulation based on the risk map.

A training program was proposed for disaster prevention education targeting the school teachers. As the school education is the main part of the disaster prevention education, raising of the knowledge level of the school teachers was proposed as the first step.

(2) Education/Enlightenment/Training for the Public

It was proposed to perform public education through school education and community education. One purpose of school education is the transfer of memory of disasters to the next generation through the education of past disasters. Another purpose is scientific understanding of disaster mechanism.

In community enlightenment, it was proposed to conduct a basic level education on the relationship between rainfall and flood/landslide, on the activity of the municipality for forecasting/warning/evacuation and on the method of self-protection through the knowledge of landslide disaster symptom. It was proposed to enlighten the public so that they will move out from dangerous areas and will not build new houses in dangerous areas.

6.7.2 DISASTER MANAGEMENT INFORMATION SYSTEM

In the course of the Study, the following two problems are highlighted in disaster prevention in Tegucigalpa.

- The coordination of all the related agencies in disaster prevention is not well done because of the lack of common basic information on disaster. For example, the inundation map in the city area was created by SOPTRAVI, SERNA and AMDC separately. The monitoring data of Berrinche landslide obtained by SERNA are not shared with other agencies.
- There is a fear that the GIS hazard map created in the Study will not be utilized well, as GIS instruments are possessed by only a fraction of all the related agencies of disaster management.

In order to cope with this situation and to succeed in technology transfer of the result of the Study, construction of a disaster management information system shared by the related agencies was proposed. This system is composed of the following sub-systems:

- Information Collection and Transmission System
- Database System
- Information Processing System
- Decision-support System
- Information Distribution System

Disaster-related information are started from flood/landslide forecasting/warning as stated before, including disaster information in an emergency. The GIS base map utilized to create the hazard map in the Study would be applied as the base map of this Disaster Management Information System.

All the governmental agencies related to disaster prevention would be connected with each other through an optical fiber network. Therefore, it is possible for them to exchange information in an emergency and to implement coordinated disaster prevention policies based on a common database.

6.8 OPERATION AND MAINTENANCE

Operation and maintenance plan for the Priority Projects are the same as that of the Master Plan Projects.

6.9 COST ESTIMATE

Detailed cost estimates were carried out for the Priority Projects. The result of the cost estimate is shown in *Table 6.6*.

6.10 IMPLEMENTATION PROGRAM

The implementation program for the Priority Projects was prepared and is shown in *Table 6.7*. The projects were assumed to commence in the year 2002 for the detailed design and finance preparation. According to this schedule, all the Priority Project will be completed by the year 2007.

6.11 PROJECT EVALUATION

(1) Economic Aspect

The economic evaluation was done only for the Priority Projects. The evaluation method is the same as the Master Plan Projects'. *Table 6.8* shows the result of economic evaluation.

Table 6.8 Flood/Landslide Damage Reduction

Return Period (year)	Damage Reduction (million US$)
5	14.30
10	13.56
15	22.33
50	36.08
Hurricane Mitch (500)	139.19

The economic internal rate of return (EIRR) was calculated at 13.44%. *Table 6.9* shows the Net Present Value (NPV) and Cost Benefit Ratio (B/C) of the Project.

Table 6.9 NPV and B/C for the Priority Project

Discount Rate	NPV (US$ million)	B/C
4% (Real yield of the Honduran state bond)	55.73	2.94
8%	16.91	1.71

(2) Financial Aspect

The total project cost of the Priority Projects is 37million US$ and it is small enough compared to the total damage in Tegucigalpa by Hurricane Mitch – approximately 500 million US$. It is also small compared to the average annual repayment (approximately 90 million US$) and it is considered that the financial problem is small to implement the projects by foreign loans.

(3) Natural Environmental and Social Aspects

According to the EIA by local consultants, the results of analysis of problems on the above two aspects are as follows:

1) Heavy Metal

The heavy metals checked in the Study are Cr (chromium), Ni (nickel), Cu (copper), Zn (zinc), Cd (cadmium), Hg (mercury), Pb (lead) and As (arsenic). The quantity of heavy metal contained in the riverbed material is small enough compared to the standard of EPA and there is no problem of excavation, hauling and depositing of the riverbed material in the project.

2) Resettlement

According to the detailed plan of structural measures, the lone place where the resettlement of people is needed is Reparto and the number of houses affected is 10. Although there was no direct interview with the relevant residents, the community leader of Reparto said that the residents were well aware of the danger of the area and many of them desired to move out from the area to a safer place if possible. Therefore, it is possible to solve the resettlement problem by seriously considering the resettlement destination and the base line of the new settlement area with enough amount of compensation.

Thus, it is considered that the adverse effect of the Priority Projects on the natural and social environment is small.