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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

SUPPORTING REPORT

MAY 2002

PACIFIC CONSULTANTS INTERNATIONAL
NIKKEN CONSULTANTS, INC.

LIST OF SUPPORTING REPORT

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-	**SUPPORTING B**	**:**	**GEOLOGICAL SURVEY**
-	**SUPPORTING C**	**:**	**HYDROLOGICAL/HYDRAULIC ANALYSIS**
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SUPPORTING REPORT A

AERIAL PHOTO MAPPING/RIVER SURVEY/PLAN SURVEY

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AERIAL PHOTO MAPPING/RIVER SURVEY/PLAN SURVEY

1. INTRODUCTION

1.1 GENERAL

The aerial photo mapping was carried out as scheduled by the Study Team after contracted with **Aerocarta S.A**. during the Four (4) month from the middle of February to the middle of May 2001. The river survey was also carried out as scheduled after contracted with **Topografia de Honduras,** during the Two (2) month from the middle of February to the middle of April 2001. The plan survey by ground survey was carried out after contracted with **Topografia de Honduras,** during the approx. Forty-Five days (45) from the middle of September to the end of October 2001.

1.2 SCOPE OF WORKS

The scope of works for the aerial photo mapping, river survey and plan survey includes the following contents.

(Aerial Photo Mapping)

- Color aerial photography at a scale of 1:10,000: 157 km^2 (11 lines)
- Photo control survey (GPS): 16 points
- Ordinary leveling: 50 km
- Aerial triangulation: Approx. 136 models
- Ortho photo mapping at a scale of 1:10,000: 105 km^2
- Digital mapping at a scale of 1:5,000: 105 km^2

(River Survey)

- Horizontal control survey: 580 points
- Vertical control survey: 580 points
- Cross-section survey: 290 sections/29.00 km
- Drawing of cross-sections: 290 sections
- Drawing of Longitudinal profiles: 29.00 km

(Plan Survey)

- Horizontal/vertical control survey: 6 points
- Topographic survey: 635,000 m^2
- Drawing of topographic mapping at scale of 1:500: 635,000 m^2

1.3 DATUM OF SURVEY AND MAPPING

The following datum of survey and mapping was applied based on the coordinates and elevation of reference control points obtained from the Instituto Geografico National (IGN) in Honduras.

- Horizontal datum: NAD 1927 (North American Datum)
- Vertical datum: Mean sea level
- Ellipsoid: Clarke 1866 (a = 6,378,206.400 km, b = 6,356,583.800 km)
  Where, a: semi-major axis, b: semi-minor axis

- Projection: UTM (Universal Transverse Mercator), Zone16 (Central Meridian 87 °)

1.4 EXISTING SURVEY AND MAPPING DATA

The following main survey and mapping data was collected from the related organizations in Honduras.

Table A.1.1 Existing Survey and Mapping Data

Data	Scale	Contour interval	Descriptions
1) Digital map of Tegucigalpa (dwg/dxf format of Auto CAD)	1:5,000	1 m	Prepared by INGENIERIA GERENCIAL S.A. using the aerial photos shot in 1996
2) Topographic map of Tegucigalpa	1:10,000	4 m	Prepared by IGN using the aerial photos shot in 1985-6
3) Lidar data of Tegucigalpa (shp format of ArcView)			Prepareing Digital Elevation Model (DEM) by USGS using the Leser profile data flyed and observed on March 2000
4) Digital map of Berrinche aera (dwg/dxf format of Auto CAD)	1:2,000	5 m	Prepared by SERNA/USGS on May 2000
5) National base map of Tegucigalpa	1:50,000	20 m	Revised by IGN in 1981
6) Data of existing control points			Obtainrd the coordinates/elevation of national control points and elevataion of benchmarks from IGN

2. AERIAL PHOTO MAPPING

2.1 AERIAL PHOTOGRAPHY AND PHOTO SIGNALS

The permission of the aerial shooting was obtained officially from Air Force and Army of Honduras dated on February 15, 2001, after petitioned through the SOPTRAVI and IGN.

The aerial shooting was carried out in suitable weather condition on February 16, 2001. The roll of the developed negative film has been handed over to IGN in accordance with the regulation (Acuerdo Presidencial No.01176 de fecha 11 de Noviemble de 1985) of the Government of Honduras.

The photo signals to be installed on the photo control points and existing control points has been observed by using the four (4) GPS receivers before the aerial shooting.

The covering area by aerial photography, location of photo control points, mapping area and objective routes of river survey are shown in *Figure A.2.1*.

The main work quantities and specifications are as follows:

- Aerial photo signals: 21 signals
- Covering area by aerial photography: 157 km^2
- Aerial photo scale: 1:10,000
- Number of flight lines: 11 lines
- Flight altitude: Approx. 1,500 m above mean ground level

The equipments used by aerial photography are as below:

- Aircraft: Cessna 310
- Aerial camera: Zeiss LMK1000 (Serial No.NR266616B)
- Focal lens: 152.372 mm (Serial No. NR 7384528C)
- Negative film: Kodak SO 846

2.1.1 QUANTITY OF AERIAL PHOTOS

The color aerial photos covers the objective study area according to the specified 60 % for forward overlap and 30 % for lateral overlap as the following quantities:

Table A.2.1 Quantities of Aerial Photos

Line No.	Photo No.	Nos of photo	Remarks
Line-1	005 to 018	14	Flight from East to West
Line-2	050 to 065	16	Flight from East to West
Line-3	072 to 106	15	Flight from West to East
Line-4	112 to 126	15	Flight from East to West
Line-5	131 to 144	15	Flight from West to East
Line-6	150 to 164	14	Flight from East to West
Line-7	169 to 183	15	Flight from West to East
Line-8	186 to 200	15	Flight from East to West
Line-9	201 to 208	15	Flight from West to East
Line-10	201 to 208	8	Flight from East to West
Line-11	209 to 216	8	Flight from West to East
Total:	-----	150	

2.2 PHOTO CONTROL SURVEY

The photo control survey using GPS (Global Positioning System) has been carried out for the purpose to obtain the orientation elements of aerial triangulation. The position of photo control points necessary for the photogrammetric mapping are shown in *Figure A.2.1* Aerial Photo Mapping and River Survey.

The main work quantities of the photo control points are as below:

- Photo control points: 22 points (included 4 points of IGN's control points)

The equipments of GPS receivers used were 4 units of Trimble LS 4600.

The geographical coordinates (longitudinal/latitude) and height on ellipsoid (WGS 84: World Geodetic System) computed by the software (GPSurvey by Trimble) was not converted to the national coordinates system based on the horizontal datum (NAD 1927), since there is not available official transformation parameter between WGS 84 and NAD 1927 in Honduras defined by the IGN. Therefore, the following transformation parameters were adopted the computed data after compared with the coordinates of photo control points for the Digital Maps of Tegucigalpa prepared by the Ingenieria Gerencial.

- Transformation parameter from WGS84 to NAD 1927:

  dX = -0.532 m, dY = -101.370 m, dZ= -197.430 m

The fixed reference control points were selected as Two (2) points of **Angelita and Base Tegucigalpa** after identifying the relative precision of the Four (4) IGN's existing control points. The adjusted coordinates and elevation of the photo control points are as below:

Table A.2.2 Coordinates and Elevation of Photo Control Points

Photo Control Points	North (m)	East (m)	Elevation (m)	Remarks
ANGELITA	1555508.106	484356.452	1295.805	Reference control point
V01	1563251.400	483416.202	1411.09	
V02	1563646.578	479754.974	1009.13	
V03	1564123.246	477109.501	1004.30	
V04	1563983.313	471974.610	1398.76	
V05	1560359.147	484081.171	1074.991	(=PCF-F-202) Benchmark
V06	1560499.024	478899.179	1300.57	
V07	1560487.701	475910.385	1159.31	
V08	1560574.167	472567.164	1215.47	
V09	1556016.682	482859.500	1095.14	
V10	1555811.233	480022.085	986.663	(=PCF-E-38) Benchmark
V11 (Base Tegucigalpa)	1555752.750	478135.018	965.753	Reference control point
V12	1555507.807	476620.018	1006.48	
V13	1556091.695	472885.850	1260.04	
V14	1552381.139	483942.391	1240.63	
V15	1551787.052	481703.351	1104.43	
V16	1551108.049	477455.918	983.47	
V17 (Sauce)	1551155.956	475716.614	1181.483	
V18	1553329.032	472165.543	1086.46	
V19	1547932.520	479078.734	1203.99	
V20	1548245.407	476367.791	1085.19	
V21 (Olvidos)	1562186.352	471406.099	1368.827	

Note: The existing control points of ANGELITA, BASE TEGUCIGALPA, SAUCE and OLVIDOS are the National Geodesic Control Points installed by the IGN.

2.3 VERTICAL CONTROL SURVEY

The vertical control survey using the GPS receivers adopted the indirect method (GPS leveling) which can be computed based on the deferential height of the elevation and ellipsoid height of WGS84, for the purpose to maintain the accuracy of elevation. The location of vertical control points was selected as the certain topographical position to be identified on the aerial photos.

The main work quantities of the photo control points are as below:

- Vertical control points: 22 points (included 8 points of IGN's benchmarks)

The equipments of GPS receivers used were 4 units of Trimble LS 4600.

The elevation of vertical control points is as below:

Table A.2.3 Elevation of Vertical Control Points

Vertical Control Points	Ellipsoid height (m)	Elevation (m)	Remarks
PCF-L-10-2	988.014	982.934	Benchmark
PCF-B-202	991.594	986.265	Benchmark
PCF-E-182	1075.562	1070.529	Benchmark
PCF-B-182-1	1165.127	1159.158	Benchmark
PCF-P-10	989.196	984.010	Benchmark
PCF-E-192	1255.433	1250.06	Benchmark
PCF-F-202	1080.471	1074.991	Benchmark
PCF-E-38	991.857	986.663	Benchmark
PC-101	1398.933	1393.40	
PC-102	1168.951	1163.86	
PC-103	1005.793	1000.30	
PC-104	932.787	927.30	
PC-105	1067.146	1062.12	
PC-106	1062.352	1056.89	
PC-107	975.173	969.71	
PC-108	1024.705	1019.24	
PC-109	1082.960	1077.52	
PC-110	991.401	985.95	
PC-111	947,270	941.82	
PC-112	991.914	986.91	
PC-113	1027.438	1022.03	
PC-114	969.763	964.39	

2.4 AERIAL TRIANGULATION

The aerial triangulation was executed in one block in order to assure the accuracy and optimization of photo control points by using the following photogrammetric system and by covering the stereo models.

- Computation system: LH System Socet Set HATS (Helawa Automatic Triangulation System)
- Stereo models: 150 models to cover the objective study area

2.5 DIGITAL ORTHO PHOTO MAPPING

The digital ortho photo mapping at a scale of 1:10,000 was executed in accordance with the following specifications and photogrammetric system.

- Digital ortho photo mapping area: 156 km^2
- System/Software's: LH Systems Socet Set DTM, Orthomosaic, Dodger and Bently Microstation
- Grid mesh of DEM (Digital Elevation Model): 5 meters
- Interval of contour lines: Supplemental contour 2.5 meters, Intermediate contour 5 meters, Index contour 25 meters
- Resolution of digital data: 600 dpi
- Format of digital image data: TIFF
- Format of vector data: Microstation DGN

The contour lines was obtained from DEM data and adjusted with elevation data obtained from digital stereo plotting. The adjusted and/or modified areas are mainly in a flat area, an urban area and a dense vegetation area.

2.6 FIELD CLASSIFICATION

The field classification for the digital mapping was carried out in order to update the necessary land information (e.g. the name of main public buildings, roads, rivers and other topographical features) by using the enlarged photo images. The information collected in the field was classified in sequential order and codified according to the list of code and layer previously defined by the Study Team. All those information therefore composes the part of numeric information data of digital mapping as well as in GIS database of this Study.

2.7 DIGITAL MAPPING

The digital mapping at a scale of 1:5,000 was executed in accordance with the following specifications and photogrammetric system.

- Digital mapping area: 105 km^2
- System/Software's: LH Systems Stereo Socet, Core Socet and, Pro 600 and Bentley Microstation
- Interval of contour lines: Supplemental contour 2.5 meters, Intermediate contour 5 meters, Index contour 25 meters
- Mapping accuracy (standard deviation): Planimetry: 1.0 mm on the map
Spot height: 1/3 of contour interval
Contour line: 1/2 of contour interval
- Format of vector data: Microstation DGN

The land information collected from the said field classification has been plotted, and recorded in the files of respective code and layers. The digital file of name and boundary of "Colonias" collected by the Study Team has been provided to the Contractor in order to be indicated on digital maps. The position of uncertain boundary of "Colonias" has been edited in consideration with the topographical features observed by digital mapping.

3. RIVER SURVEY

3.1 QUANTITIES OF RIVER CROSS-SECTIONS

The main work quantities are as below:

- Horizontal and vertical control survey: 590 points
- Cross-section survey: 295 sections
- Drawings of cross-sections: 295 sections
- Drawings of longitudinal profiles: 30.962 km

The work quantities of cross-section survey executed along the objective rivers are as below:

Table A.3.1 Work Quantities of Objective Rivers

Objective rivers (code)	Nos. of sections	Length of profiles	Interval of section
1) Choluteca River (C)	202	20.875 km	Approx. 100 m
2) Guacerique River (G)	11	1.061 km	Approx. 100 m
3) Chiquite River (CH)	51	5.924 km	Approx. 100 m
4) Sapo River (S)	31	3.102 km	Approx. 100 m
Total:	295	30.962 km	

3.2 HORIZONTAL AND VERTICAL CONTROL SURVEY

Prior to the horizontal and vertical control survey, the locations of cross-section post were indicated by iron pegs per approx. 100 m intervals along the objective rivers. Horizontal control survey was carried out using the Two (2) GPS receivers for primary control points per approx. 500 m intervals on cross-section posts. The Total Stations (Leica TC 800 and Leica TCR 305) for secondary control points on the remained cross-section posts were used. The reference control point was selected from the existing point of **"Base Tegucigalpa"**. It is the GPS first order control point installed by IGN as below:

Table A.3.2 IGN's Control Point

Control point	North (m)	East (m)	Elevation (m)	Remarks
Base Tegucigalpa	1555752.750	478135.018	965.753	First order

Vertical control survey was carried out using the Auto Level in order to connect the elevation from the following IGN's benchmarks to the whole cross-section posts. The accuracy due to the closing error was within the specified allowance (20 mm √ km).

Table A.3.3 IGN's Benchmarks

Benchmarks	Elevation (m)	Remarks
E-10	1010.0619	First order
B-10	926.9188	First order
G-10	931.2587	First order
K-10	945.6280	First order
K-10-1	962.2043	First order
P-10	984.0104	First order
A-202	941.7505	First order

3.3 CROSS-SECTION SURVEY

The cross-section survey measured the topographical features by using the Total Stations (Leica TC 800 and Leica TCR 305) based on the elevation of the cross-section posts or horizontal/vertical control points, which was connected from the said IGN's benchmarks. The measured river width is average 100 m. The measured data was calculated using the Micro Soft Excel and edited using the Auto CAD software.

3.4 DRAWINGS OF CROSS-SECTIONS

The cross-sections has been drawn in accordance with the following specifications:

- Drawing scale of the Choluteca, Guacerique and Chiquito River

  Horizontal: 1:500, Vertical: 1:500
- Drawing scale of the Sapo River

Horizontal: 1:200, Vertical: 1:200
- Data format: DWG of Auto CAD

3.5 DRAWINGS OF LONGITUDINAL PROFILES

The longitudinal profiles has been drawn in accordance with the following specifications:

- Drawing scale: Horizontal 1:5,000, Vertical: 1:500
- Data format: DWG of Auto CAD

4. PLAN SURVEY

4.1 QUANTITIES OF PLAN SURVEY

The work quantities executed by ground survey and the mapping areas are as below:

- Horizontal/vertical control points: 6 points
- Topographic survey: 635,000 m^2
- Drawings of topographic maps: 635,000 m^2

Table A.4.1 Work Quantities of Control Points and Mapping Area

Location of objective area	Control points	Mapping area (m^2)
1) Choluteca River (Section between C40 and C65)	0	400,000
2) Pescado Lake (Outlet site)	2	1,000
3) Reparto (Landslide site)	2	173,000
4) Bambu (Landslide site)	2	61,000
Total:	6	635,000

The location of topographic mapping area is shown in *Figure A.4.1*.

4.2 HORIZONTAL/VERTICAL CONTROL SURVEY

Horizontal control survey was carried out using the Two (2) GPS receivers based on the reference control point of **"Base Tegucigalpa".** It is the GPS first order control point installed by IGN. The elevation of vertical control was done by the method of GPS leveling to adopt the ECHAT software (Leica). For the Choluteca River, horizontal/vertical control survey has not been done in period of this topographic mapping, because it was already installed and surveyed during the period of river survey. The coordinates and elevation of the horizontal/vertical control points are as below:

Table A.4.2 Horizontal /vertical Control Points

Control points	North (m)	East (m)	Elevation (m)	Remarks (Location)
P-1	1545439.152	477076.097	1107.952	Pescado Lake
P-2	1545412.300	477052.162	1105.506	Pescado Lake
R-1	1560084.583	479620.912	1014.042	Reparto
R-2	1560070.319	479597.237	1015.061	Reparto
BA-1	1559830.220	478423.190	1031.350	Bambu
BA-2	1559866.593	478449.778	1037.841	Bambu

4.3 TOPOGRAPHIC SURVEY

The topographic survey was performed for the topographical features, buildings, roads and other existing structures by the radiation method using the Total Stations (Leica TC 800 and Leica TCR 305) based on the traverse points or horizontal/vertical control points. The N, E coordinates and elevation on the topographic map was calculated using the ECHAT software (Leica) and Micro Soft Excel.

4.4 DRAWINGS OF TOPOGRAPHIC MAPPING

The drawings of contour lines were supported by the data of the Software of Digital Elevation Model (DEM). The drawings has been prepared in accordance with the following specifications:

- Drawing scale: 1:500
- Interval of contour line: 1 m
- Data format: DWG of Auto CAD

5. FINAL PRODUCTS

5.1 AERIAL PHOTO MAPPING

The Study Team received the following final products from the Contractor (Aerocarta) on May 20, 2001 after checked by the Study Team.

Table A.5.1 Final Products of Aerial Photo Mapping

Final Products	Quantity	Remarks
Aerial photography		
1) Negative films:	1 set	Handed over to IGN on April 30, 2001
2) Photo contact prints:	1 sets	This is 1 set of preliminary contact prints (192 pcs).
	2 sets	These are 2 sets annotated photo information.
3) Positive films (CD-ROM)	1 set	Received CD-ROM (50 pcs) for the changed products
4) Photo index (1:50,000)	3 sets	
Photo control survey		
5) Field survey data:	1 set	Stored by the Contrator
6) Computation data:	1 set	Included in final report
7) Descriptions of photo control points	1 set	Included in final report
Digital color orthophotos		
8) Data file of orthophoto with descriptions	1 set	Included in final report
9) Digital color orthophotos (1:10,000) 13 sheets	2 sets	There are 2 types of orthophoto. One present the image file separated from contour files. The other present composed the image and contour files.
10) Softcopies of digital data (CD-ROM):	1 set	
Digital maps (DM)		
11) Digital maps (1:5,000) 13 sheets	2 sets	
12) Reduced digital maps (1:10,000) 13 sheets	2 sets	
13) Softcopies of digital data (CD-ROM)	1 set	
14) Code list of digital data	1 set	Included in final report
Reporting		
15) Final report	3 sets	

5.2 RIVER SURVEY

The Study Team received the following final products from the Contractor (Topografica de Honduras) by the end of April 2001 after checked by the Study Team.

Table A.5.2 Final Products of River Survey

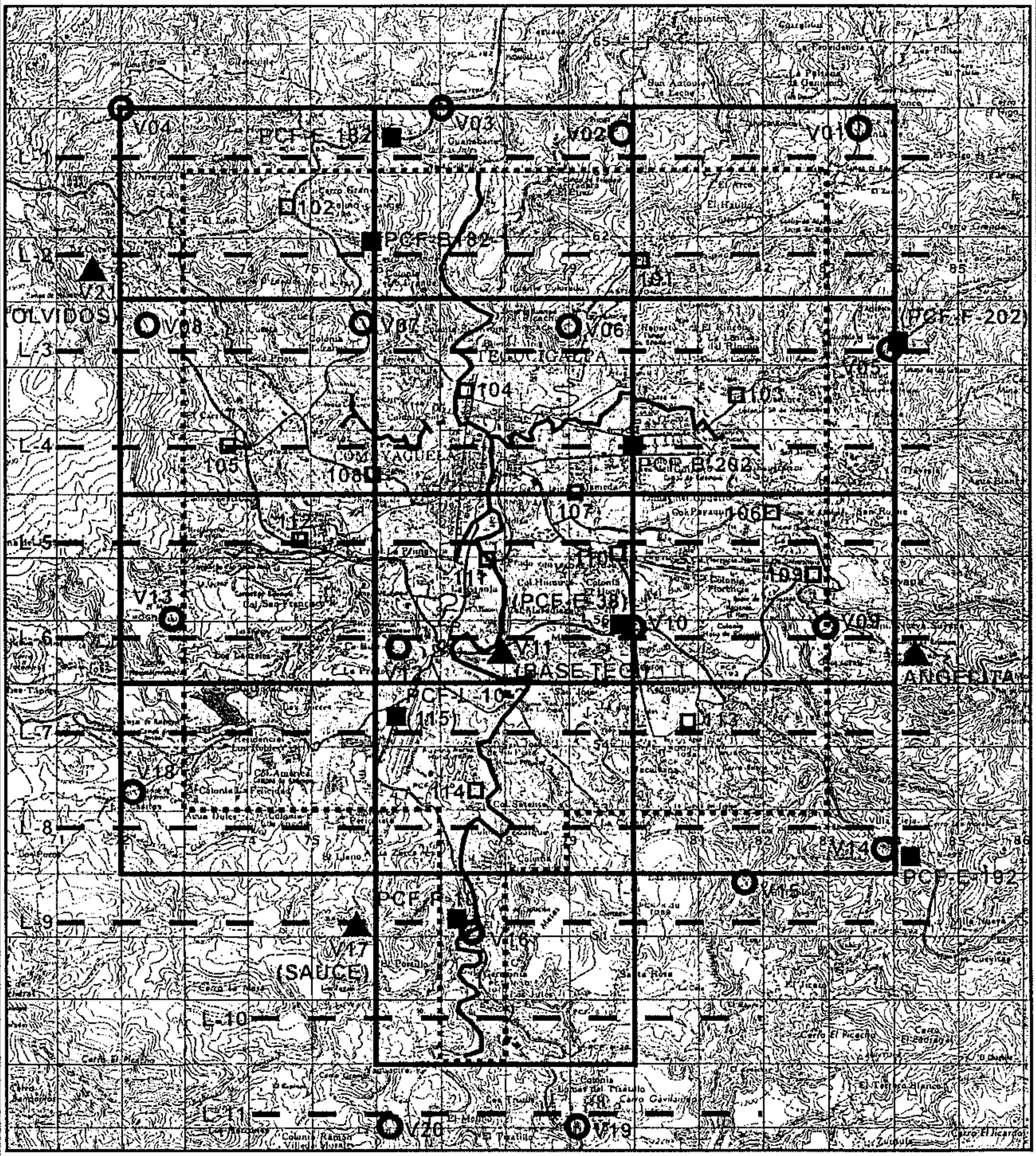
Final Products	Quantity	Remarks
1) Cross-sections	1 set	
2) Location map of cross-sections	3 sets	Scale: 1:10,000
3) Longitudinal profiles	1set	
4) Reduced products of the above 1),2),3)	2 sets	A-3 size
5) Soft copy of digital data (CD-ROM)	2 sets	
6) Measuring and computation data (CD-ROM)	1 set	
7) Field data book a) Measuring record b) Elevation and distance data list of cross-sections and longitudinal profiles	1 set	Stored the measuring record by the Contractor
8) Final report	3 sets	

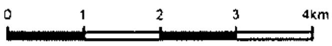
5.3 PLAN SURVEY

The Study Team received the following final products from the Contractor (Topografica de Honduras) by the end of October 2001 after checked by the Study Team.

Table A.5.3 Final Products of Topographic Mapping

Final Products	Quantity	Remarks
1) Topographic map (Scale: 1:500)	1 set	- Choluteca River: 12 sheets - Pescado Lake: 1 sheet - Reparto: 5 sheets - Bambu: 2 sheets
2) Reduced products (A-3 size) of the above 1)	2 sets	
3) Soft copy of digital data (CD-ROM)	1set	
4) Measuring and computation data (CD-ROM)	1 set	
5) Field data book	1 set	Stored the measuring record by the Contractor
6) Final report	2 sets	





Legend		
Covering Area of Photo Shooting	157 km²	
Flight lines	11 lines	- - -
Digital Orthophoto Mapping Area (1:10,000)	156 km²	▭
Digital Mapping Area (1:5,000)	105 km²	
Existing Control Points	4 points	▲
Photo Control Points Installed Photo Signals	18 points	○
Existing Benchmarks	8 points	■
Vertical Control Points	14 points	□
River Survey	30.962 km	

Figure A.2.1	Aerial Photo Mapping/River Survey

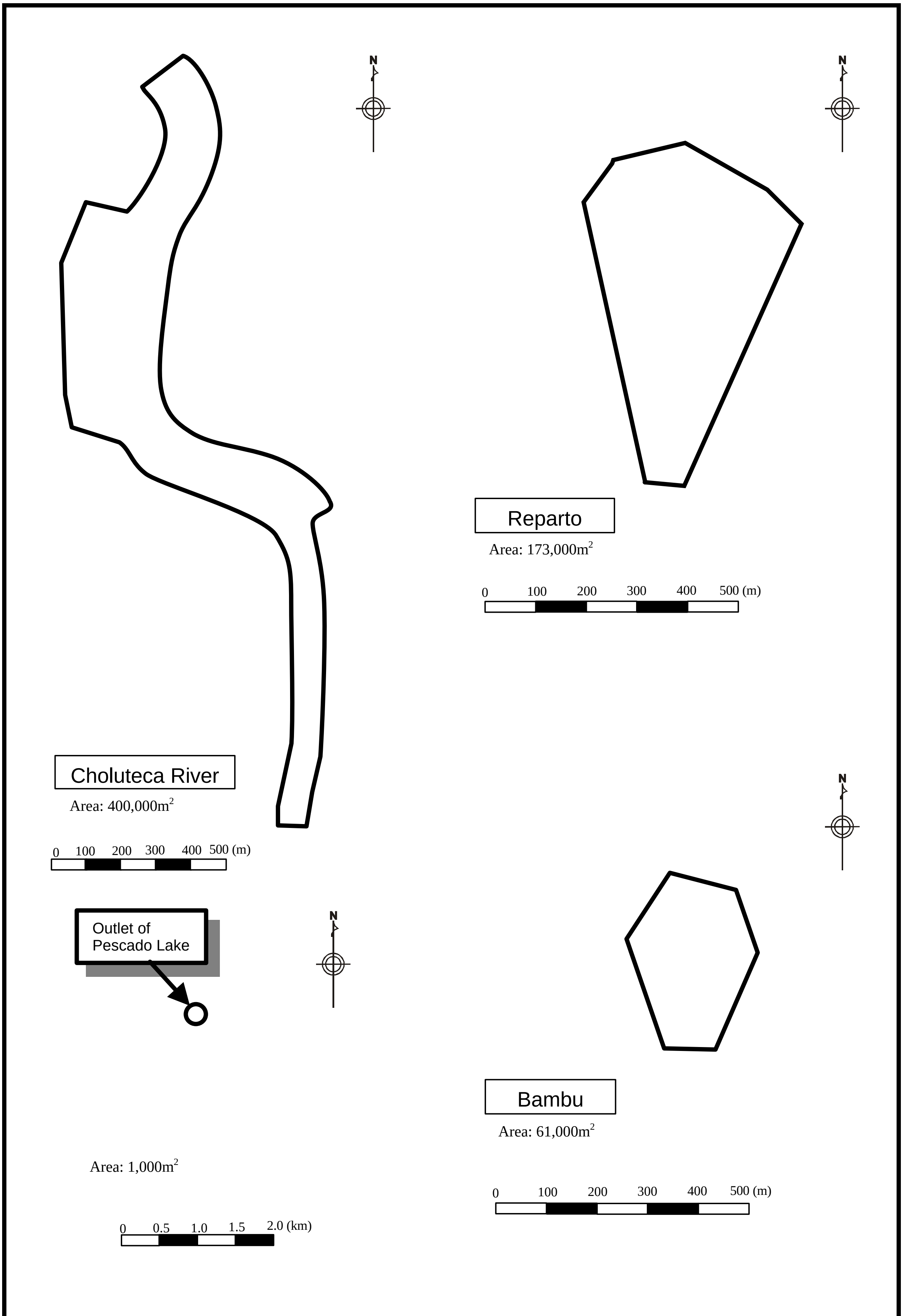


Figure A.4.1 **Location of Plan Survey Area**

SUPPORTING REPORT B

GEOLOGICAL SURVEY

SUPPORTING B : GEOLOGICAL SURVEY

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GEOLOGICAL SURVEY

1. INTRODUCTION

1.1 GENERAL

In the geological survey, the hazard map of landslides and slope failures were created. These hazard maps are used to formulate the disaster prevention master plan by structural and non-structural measures.

The geological survey was carried out in the following manner;

1. Creation of the geologic map of the scales 1/10,000 based on field surveys
2. Present condition investigation of a slope disaster
3. An interpretation of the hazard area of landslides and slope failures, and creation of the hazard map of scales 1/10,000
4. Influence study by the slope disaster expected
5. Data creation for warning and evacuation

In order to make landslide and slope failure hazard map in a scale of 1/10,000, it is necessary to create an accurate geological map with the scale of 1/10,000 as the existing geological maps are in the scale of 1/25,000 and 1/50,000 and they are not accurate enough.

The natural disaster caused by the movement of earth and rock is classified into three categories in Japan, namely "landslide", "slope failure" and "debris flow". In the case of disaster in Tegucigalpa by the Hurricane Mitch, "landslide" and "slope failure" are the main problems and there was few cases of "debris flow". Therefore, in the Study only "landslide" and "slope failure" are dealt with. "Landslide" and "slope failure" are defined as shown in *Table B.1.1*.

Table B.1.1 Definition of Landslide and Slope Failure

	Landslide	Slope Failure
Scale	large	small
Slope Gradient	mild	steep
Movement	slow	rapid

The landslide study included the topographic interpretation of the aerial photograph, observation of the aerial photograph showing the actual landslides caused by the Hurricane Mitch and the field geological survey.

The slope failure study included the observation of the aerial photograph showing the actual slope failures caused by the Hurricane Mitch and the geological survey. Slope analysis for each geological classification was also made.

The hazard map was prepared in the scale of 1/10,000 containing all the information of risky area in terms of both landslide and slope failure. The map shows not only the landslide blocks and dangerous slopes but also the affected areas by the occurrence of landslide and slope failure.

After making the hazard map of landslide and slope failure, evacuation destinations were studied for each Rank A (most dangerous) landslide blocks.

1.2 THE GEOGRAPHICAL FEATURE AND THE GEOLOGICAL -POSITION

The Republic of Honduras is located to the south of Yucatan Peninsula in Central America. The width of the land at the narrowest place is 300-500km, and it has the Pacific Ocean in the south and the Caribbean Sea in the north.

As shown in *Figure B.1.1*, this area is located in the position where the North American plate, the Caribbean plate, and the Cocos plate in geological structure, and Honduras serves as the form where it rides on the Caribbean plate. Since the Cocos plate sinks into a Caribbean plate, earthquakes are generated along the Pacific coast where it hits the plate boundary. *Figure B. 1.2* shows the hypocenter distribution from 1898 through 1986. Hypocenters mostly distribute along the Pacific coast in a Fonseca bay and El Salvador, and Nicaragua, and it turns out that there is almost no distribution of a hypocenter near Tegucigalpa which is the Study Area.

Tegucigalpa is located with north latitude 13-14 degrees and near the east longitude of 87 degrees, and it is on the plateau with the altitude of 1000m.

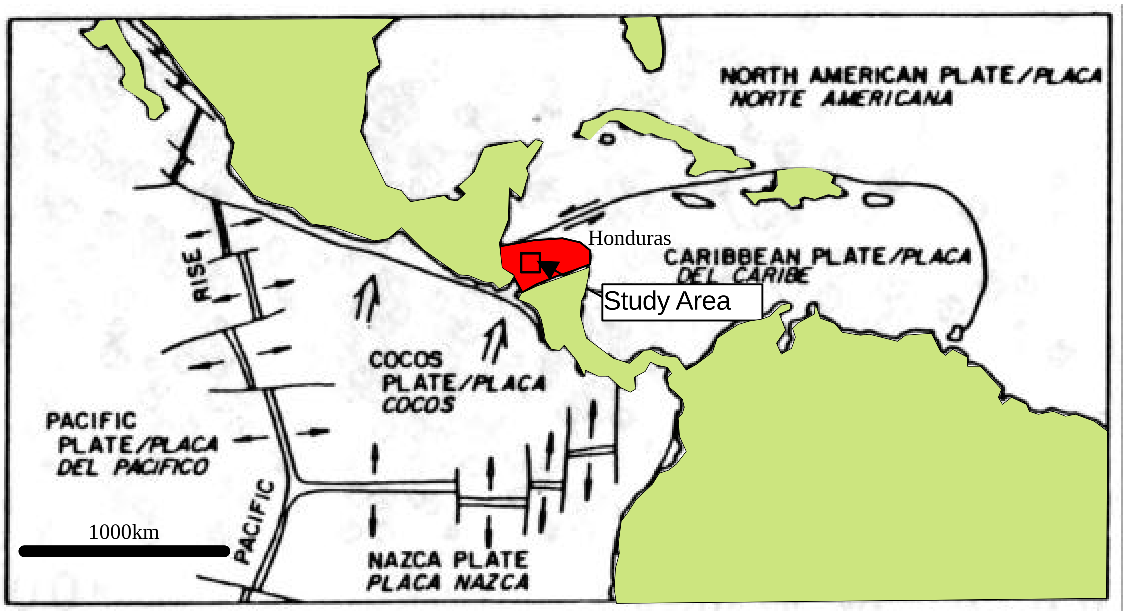

Figure B.1.1 The Geological Structural Position of Honduras

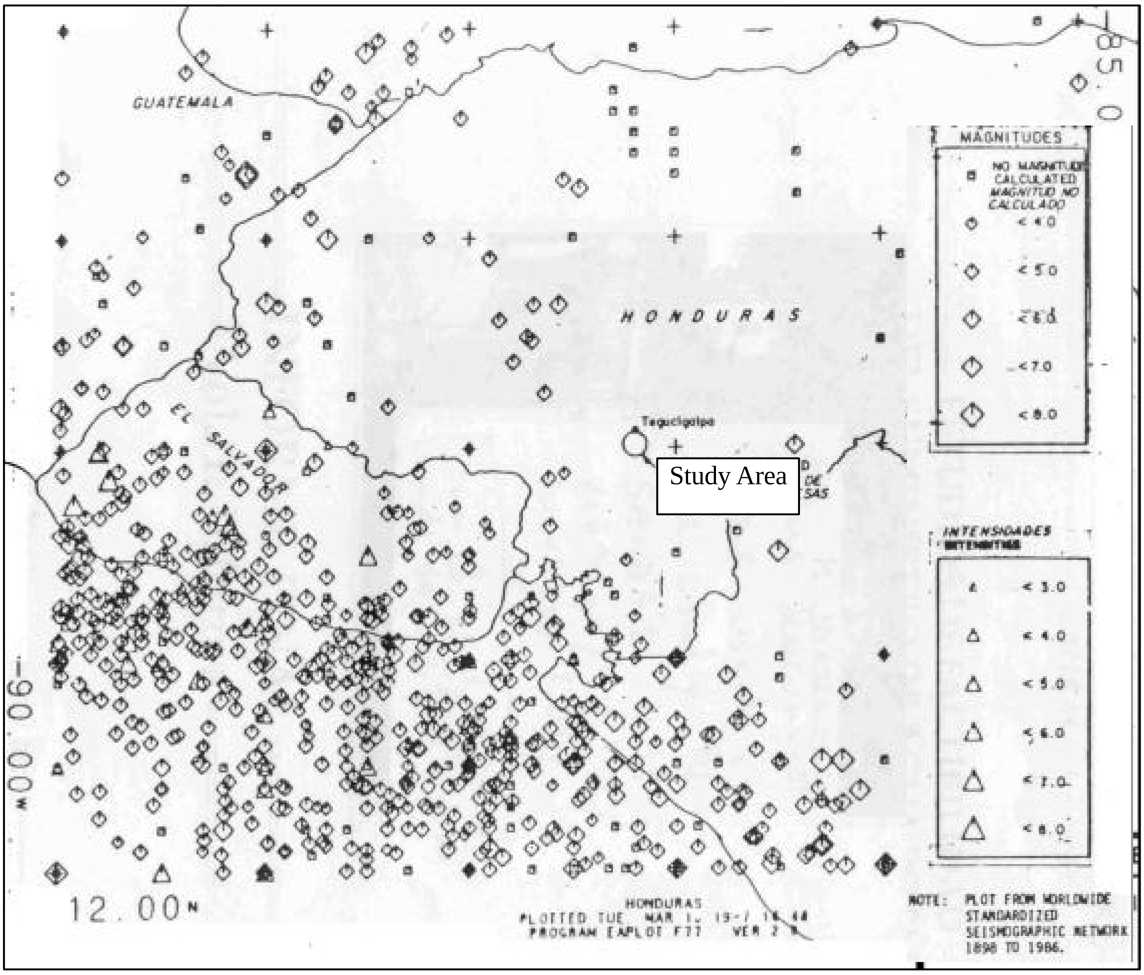

Figure B.1.2 Distribution of Earthquakes Around Honduras

2. LITERATURE REVIEW

The main references for the geological survey and landslide investigation used for examining the geographical feature and the geological-rock features in the Study Area was shown in *TableB.2.1*.

Table B.2.1 Bibliography

Issue years	Author	Paper name and issue origin
1993	SANAA, British Geological Survey	Geological Map of Honduras Tegucigalpa, Lepaterique, and San Vuenabentura S=1/50,000 (IGN)
1987	SANAA, Italian Technical Cooperation	Master plan for Tegucigalpa D.C project “Under ground water and Chile mountain in Tegucigalpa” Geological map S=1/25,000
July, 1999	Ryuichi Hara	The Republic of Honduras The Hurricane Mitch disaster support project 「Landslide preventive measures・Technical instruction about maintenance of the warning-evacuation method」 Report

3. GEOLOGICAL OUTLINE OF THE STUDY AREA

Table B.3.1 and *Figure B.3.1* shows the existing geological map and stratigraphy around the Study Area.

Geology in and around the Study Area is roughly divided into three categories, namely Padre Miguel Group, Matagalpa Formation in Tertiary Period, and Valle de Angeles Group in Cretaceous Period. The other basement rocks of Cacaguapa Schist, Honduras Group, and Yojoa Group are not distributed in the Study Area.

Basalt lava covers Padre Miguel Group and Matagalpa Formation in early Quaternary period. These consolidated basement rocks are covered by terrace deposit, talus deposit, and river deposit in Quaternary period.

Table B.3.1 Geology in and Around the Study Area by Previous Study

Era	Period	Epoch	Sym-bol	Name Formation	Litho logy
Cenozoic	0 Quaternary 2	Holocene | Pleistocene	Qal	River, flood plain dt.	sand and gravel with clay
			Qb	Basalt	basalt (lava flow)
	Tertiary	Miocene	Padre Miguel Group		
			Tpm	young volcanics	rhyolitic ignimbrite
				Periodista Member (Tep)	tuffaceous sandstone with gravel
				Tenampua Mem.	local deposit, ash fall
				ignimbrite	Vitric rhyolitic ignimbrite
				Nueva Aldea Mem.	well sorted tuff with locally pumice
				Puerta de Golpe Mem.	tuffaceous shale , calcareous shale, limestone
			Tc	Cerro Grande Mem. (Tcg)	ignimbrite
			Matagalpa Formation		
	65	Oligocene	Tm		andesite with hydrothermal alteration
Mesozoic	Cretaceous	Upper	Valle de Angeles Group		
			Krc	Rio Chiquito Form.	reddish-brown sandstone, siltstone, mudstone with lens of limestone
			Kvac		Limestone layer in Krc
		143	Kvn	Villa Nueva Form.	conglomerate
		Lower	*Ky*	Yojoa Group	*limestone, mudstone*
	Jurassic 247*		*Jkhg*	*Honduras Group*	*shale and sandstone with volcanic rocks*
Paleozoic			*Pzm*	*Cacaguapa Schist*	*mica-schist, quartzite with marble, meta-diabese*

Source: Geological map of Tegucigalpa, Lepaterique, and San Vuenabentura (1/50,000)

Note: *Italic groups and formations are not distributed in the Study Area.*

247*: geologic age (x 10^6 years ago)

4. TOPOGRAPHY OF TARGET AREA

The target area for disaster prevention is Tegucigalpa urban area, as shown in *Figure B.4.1, Figure B.4.2,* the total area of which is 105 km^2. The elevation of the urban area 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 B.4.1* shows the topography of the Target Area for Disaster Prevention.

Figure B.4.2 shows the elevation map of the area. There observed 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 the flat area, there exist mountain ranges with the elevation higher than 1040 m, where the density of inhabitants is scarce.

Figure B.4.3 shows the slope angle distribution of the area. The area of a steep slope with the slope angle larger than 30 degree occupies 8% of the total area. The area with steep slope distribute along the main trunk and along the tributaries of the Choluteca River.

5. GEOLOGY OF TARGET AREA

5.1 GEOLOGICAL SURVEY

The geological survey was performed from April 2001 through July 2001.

For the field survey, the topographical map of the scales 1/10,000 and scale 1/5,000 created in this project was used. The scope of the work was limited to 105km^2 in the target area of this project. However, the periphery of the target area was also investigated if needed for the sake of the convenience to create a geological map. In the field, the out crops which appear in the road cut, cliffs along a river, river bed, the construction site, etc. were observed. And the category of a geological rock, the strike and dip of stratum and fracture, the thickness of a weathered layer, the covering of topsoil, etc. were scrutinized. Moreover, the distribution of landslides and slope failures were also studied.

The result of the geological survey is summarized as a geological map of scales 1/10,000. Based on this, the geological section of scales 1/10,000 were drawn. *Figure B.5.1* shows the geological map and *Figure B.5.2* shows the geological sections.

5.2 STRATIGRAPHY

The stratigraphy in the Study Area is shown in *Table B.5.1*.

The rocks in the Target Area (105km^2) is shown in *Figure B.5.3*. It turns out that the Rio Chiquito formation (Krc), the Cerro Grande member (Tcg), and the Ignimbritic sequence (Tpm) occupy a large area.

FigureB.5.4 shows the distribution of the rocks by their formation age. The stratum (Kvn+Krc) of the Cretaceo accounts for 25% of the Target Area. Tm member which makes the Ignimbritic sequence of the Neogene occupies 43%. Qe member which makes terrace deposits of Quaternary accounts for 15%.

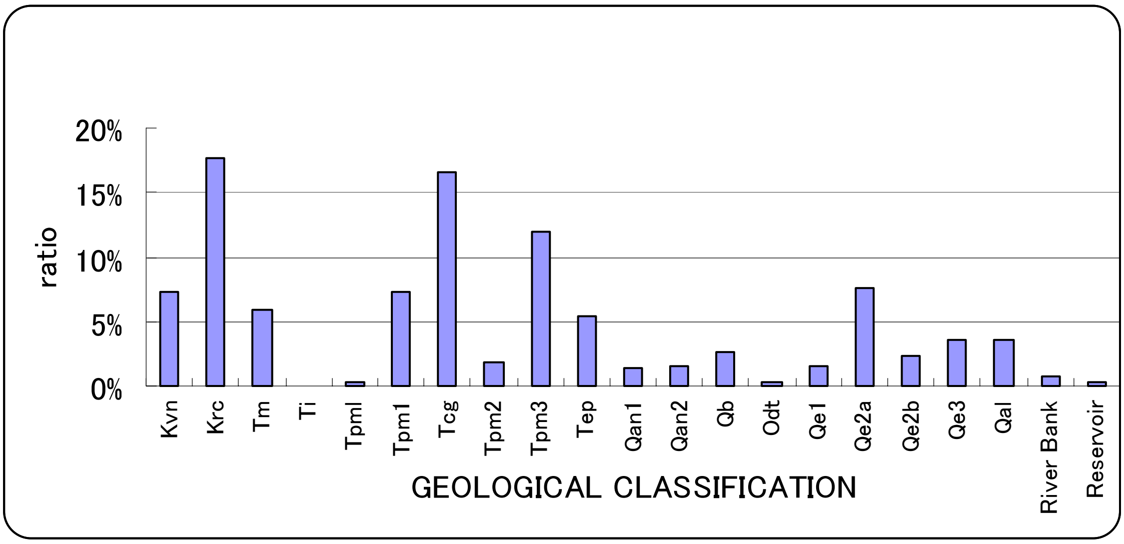

Figure B.5.3 Distribution of Geological Classification

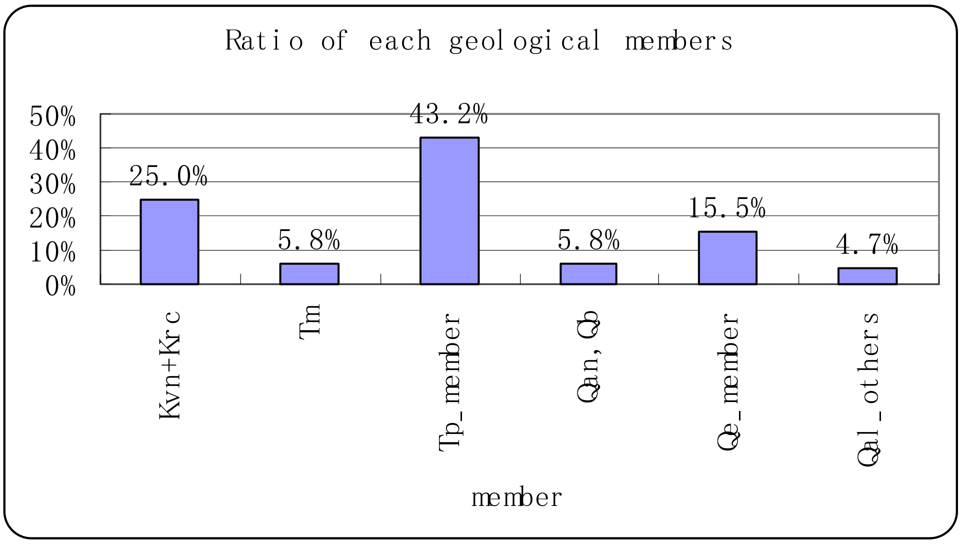

Figure B.5.4 Distribution of Geological Members

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 Formation. The best representation of this formation is along the first kilometer from Tegucigalpa along the road to Danli close to Villa Nueva and other important outcrops are found in the south of Tegucigalpa along the road to Yaguasire. These rocks are exposed at the south of Kennedy and Residential Plaza, where they are folded and inclined in various directions.

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 fine layer was observed mainly close to the contact surface with Rio Chiquito Formation.

The colors of these layers vary from red in finest part to purple in coarse staff. At Villa Nueva these rocks underlies Rhyolitic tuffs of Padre Miguel Group with unconformity. In the neighborhood of La Peña, it underlies banded tuffs of Padre Miguel Group with unconformity.

The thickness of these layers vary from 10 cm to 2 m. 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 folding structures. Sedimentary structure is with normal grading and plain lamination. The materials of this layer are solid in general but the boundaries of layers are fragile and become potential slip-surfaces of landslide.

Rio Chiquito Formation (Krc)

These rocks overlie Villa Nueva Formation layers with conformity. They are distinguished from Kvn due to the fine grain**.** These are sandstones, sillstones and mudstone of red color which are well represented along the road to Valle de Angeles and the lowest part of El Hatillo and along Rio Chiquito. Other important outcrops are located at Juan A Lanes hill overlaid by Tertiary tuffs and Loma Linda, El Hogar and 3 de Mayo those are overlaid by tertiary tuffs. A good representation of this Chiquito formation is at Residential El Molino close to the road to Valle de Angeles.

These rocks are inclined and folded in various directions. The deformation of this layer makes it very soft and easy to be eroded, and many landslides occur in areas where this layer exists. The thickness of this layer varies from 2 cm to 20 or 30 cm, and sometimes more. The age of this layer identified by pollen is Upper Cretaceous. Sedimentary structure is with plain lamination and normal grading. The top of this layer is overlaid with unconformity by Rhyolitic tuffs in Padre Miguel Group. These rocks are susceptible to weathering and to become fragile. A lot of landslides are recognized in these rocks.

The boundary between Krc and Padre Miguel Group is particularly unstable, and some water springs are found close to this contact and many landslides are observed in it. Sometimes the erosion causes the fall of a hard and fractured volcanic rock of Padre Miguel that overlies on it.

Matagalpa Formation (TM)

This formation is composed of basaltic and andesitic lavas and some layers of basic tuffs. These rocks are widely altered by weathering and hydrothermal alteration. Most of the outcrops have green color and some are reddish. Feldspar has been altered to white clay (argilized) and amphibol and pyroxene has been altered to chlorite and epidote. This formation is identified by the light gray soils developing on it. The top of this formation is overlaid with unconformity by rocks in Padre Miguel Group. The bottom boundary with Valle de Angeles group is unknown. Outcrops of this formation appear at north west corner of the survey area along the road to El Lolo and on the old northern road where it always underlies below Tcg member of PM Group. To the north along old road to Olancho higher above Cadeca chicken farm, this rock appears underlie below Tpm3 member of Padre Miguel Group.

In the east of Sagastume camping in front of road to Cadeca chicken farm on the west riverbank, there is an landsite outcrop with clear lava flow structures and with a dike of andesite. Other small outcrops appear along the road from El Chile to Cerro Grande. This outcrop underlies Tcg. The age of this formation is estimated as Oligocene (Fred Mac Dowell-Texas univ.) because it is between Upper Cretaceous of Krc and Miocene of Padre Miguel Group. These rocks are susceptible to weathering and to become fragile. So a lot of landslides are recognized in these rocks and at boundaries with upper layers.

Padre Miguel Group

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

Tpm member:

There is a volcaniclastic outcrop at the 1.5 Km from Tegucigalpa along the Valle de Angeles road with a length of 200 m. This member is a sedimentary chaotic deposit of yellow color. No sedimentary structures were 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 exists 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 of 2-4 cm.

The deposit is filled with fine and medium sands matrix. This outcrop is extended to the south of the road where it is overlaid by Tpm (1 or 3). The north of the contact between this unit and Krc is made by a fault with 80 degree W and 85 degree dip to the south. This member is defined not as lahars but as high viscosity mud flow, because clast is not mainly contemporaneous with a volcanic eruption. This is a yellow sedimentary deposit which appears in the outcrops at 1.5 Km from Tegucigalpa on the road to Valle de Angeles.

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 are found and dacitic/andesitic tuffs are found, too. Sometimes it looks like a sandy pumice tuff. Color varies between white, pale yellow and green or pale pink.

The bottom of this member overlies with unconformity on Valle de Angeles group and the top is overlaid by a red layer which separates it from Tpm2. This red layer is an altered surface probably due to the contact with very hot Tpm2 tuff.

In this member, mainly rhyolitic pumice tuffs are found and dacitic/andesitic tuffs are found, too. Color varies between white, pale yellow and green or pale pink. It is well represented at the lower areas of outcrops at Las Brisas pass over, close to Suyapa church, where the red top layer is visible. These are massive tuffs whose thickness reaches 15 of 20 meters in some outcrops. The pumice fragments are 0.5 to 3.0 cm thick in average, and few lithification was found.

At Las Brisas pass-over, a yellowish white sandy tuff was found just below the red layer. As the differentiated erosion is easy to be seen, and this layer is apparently softer than Tpm2.

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

Tpm-2:

This is the middle member of the ignimbritic sequence, this member overlies with conformity on Tpm1 and the contact is characterized by the presence of the red layer, probably caused by the heat of Tpm2 on Tpm1.

These layers are relatively soft and banded tuff that appears in many areas of Tegucigalpa. The thickness of this layer varies from 1 meter to 20 m approximately. These are silty white-banded tuff that appears in many places of Tegucigalpa. Main outcrop location is at Las Brisas pass-over, close to Suyapa church on the road to Colonia Nueva Suyapa.

Banded layers in these rocks are susceptible to slip. Several landslides occurred on those banded layers.

Tcg:

Rhyolitic lavas characterize this member and dacitic welded tuffs. It is the hardest member of Padre Miguel group and is easy to be recognized by the vertical fractures that it presents. The Rhyolitic lava flows included in this member are characterized by the prevalence of flow structures. Location of main out crops is Cerro Grande and La Primavera (high area).

These rocks form high crops and extremely steep slopes. So a lot of slope failures occur in those landforms. And the bottom boundary is susceptible to become slip-surface.

Tep:

This is a volcanic member of Padre Miguel Group. This member overlies on Tcg with conformity and in many places overlies Tpm with conformity, too. This member is characterized by the presence of sedimentary structures, such as paleo-channels, lamination, normal graduation imbrication in clasts, cross lamination and others. The layers are characterized by the well selection of clasts.

Best outcrops are at the southern area of Tegucigalpa around Anillo Periferico and close to Colonia Satelite and at Colonia El Periodista where these formations takes its name.

These layers are approximately stable.

Tpm-3 :

This layer is litho logically similar to Tpm-1 and is defined like the pumice tuffs that overlies on Tep. This layer overlies on Tep and Tcg.

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

Intrusive rock :Ti

Rhyolitic intrusive rock is found in Vallu de Angeles Group, Generally along with a dislocation, it is distributed between the intrusive rock and the base rock deterioration is given to Vallu de Angeles Group, and it is easy to become the cause of a slope failure.

The formation age of this geology is unknown.

Quaternary

Qan :

This formation is marked by the presence of andesitic lava (Qan2) and andesitic tuffs and some rhyolitic tuffs(Qan1), too. Main locations of this unit are at Colonia Cerro Grande at the top of

Estacado hill and, Colonia Centro America (top of the water tank hill), where this formation overlies Tcg Member with conformity.

Qan1: Andesitic tuffs have different colors from pale yellow and yellow to reddish brown. This layer is underlaid by andesitic lava. This layer is well layered and banded structures are founded in it.

Qan2: This andesitic lava has 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 grain. The rock is very hard and brakes in sharp pieces.

This rock is easy to be weathered and deteriorated. Tuff material is mainly pumice and fine ash. The interval of the banded planes are approximately 30 cm. The thickness of this formation is estimated approximately between 50 to 100 m. There are several big landslides in this layer.

Qb :

This formation consists of Basaltic lava flows with small crystals and some pyroclastics scoria. They are located mainly at Colonia San Francisco and from here to the west covering all this flat area. This is porphyritic to aphanitic basaltic rock, without alteration.

Terrace deposits:

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

The distribution height of each deposit is as follows;

Qe1; El 1050 m to 1075 m
Qe2a; El 930 m to 980 m and 1060 m
Qe2b: EL 1000 m to El 1011 m
Qe3; Elevation 920 m to 940 m

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.

6. LANDSLIDE AND SLOPE FAILURE

The disaster caused by movement of earth and sand is classified into three, a "landslide", a "slope failure", and a "debris flow", in Japan. This classification was adopted in this Study. Generally, a "landslide" moves slowly (the speed is less than cm/minutes), and its move period is long, or the movement is repeated over again. On the other hand, the move speed of a "slope failure" is more than 1 m/second, and its move period is less than 1 hour. Their occurrence scale and slope angle of occurrence spot are also different.

Vanes (1978) categorized slope movement into five types namely "Topple", "Slide", "Spread", "Fall", and "Flow" as shown in *Figure B.6.1*. Japanese classification is based on the grade of the damage caused by the scale and speed of a moving object. Although Japanese classification can’t necessarily correspond to Vanes’ one, "Landslide" in this Study approximately corresponds to the "Slide" in the category of Vanes. "Slope failure" nearly corresponds to "Fall" and the small scale of "Slide" in the category of Vanes.

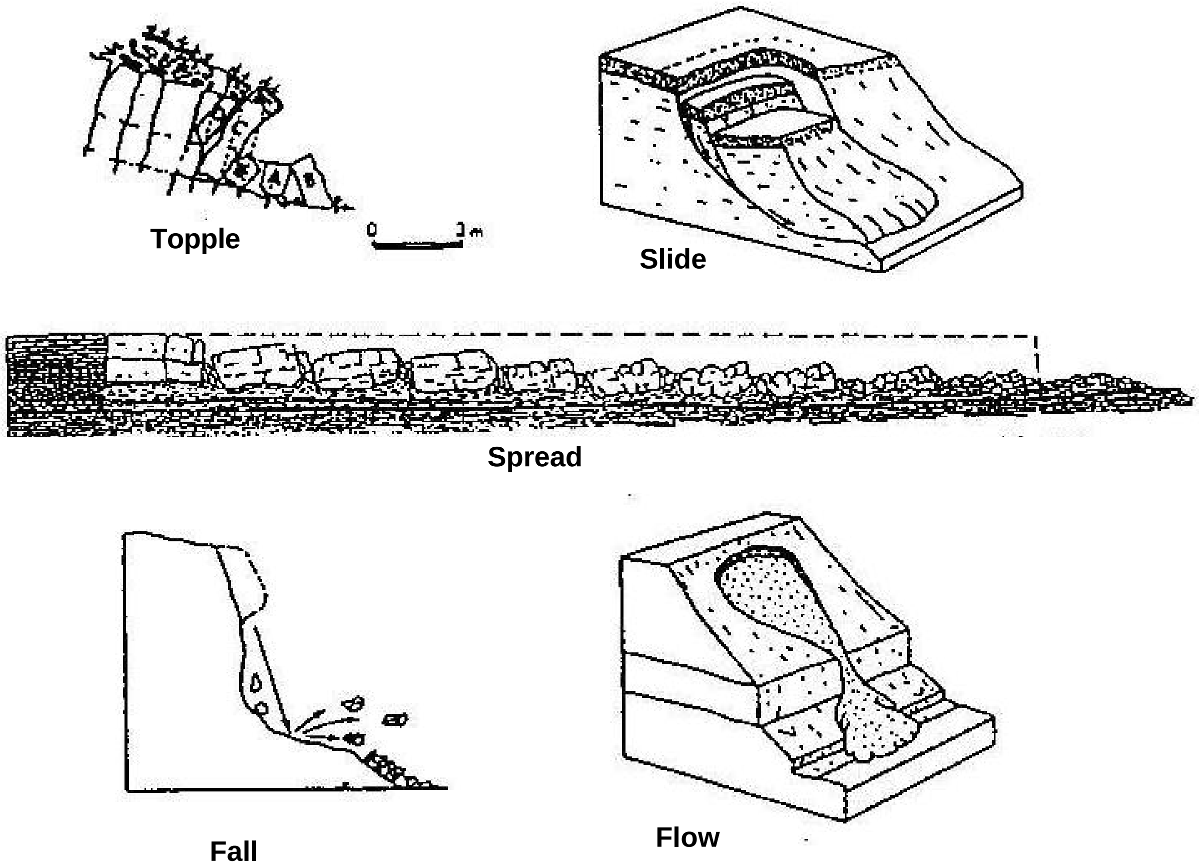

Figure B.6.1 The Classification of a Slope Movement by Vanes(1978)

6.1 LANDSLIDE

The interpretation of a landslide area was performed by the use of the aerial photo (scales 1/10,000) and an ortho-photo (scales 1/10,000) created in the Study.

(1) Landslide pattern

Figure B.6.2 shows several geological structures of landslide in the area. Those structures are classified as follows;

Pattern① A banded layer is underlaid by hard welded tuffs. Those banded surfaces are susceptible to become slip-surfaces.

Pattern② 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 to induce landslide.

Pattern③ Comparatively hard and light tuff layer (Tpm-3)overlays Chiquito formation (Krc) which is prone to be weathered. When the dip slope structure is formed 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 prone to be weathered and weak. In this case, andesite of Quartery with high density overlies the layer of Matagalpa Formation(TM) which is prone to be weathered. Also the lower layer has become impermeable and raises the groundwater level in the mass and triggers a large scale landslide.

(2) Classification of the Degree of Landslide Danger

The degree of landslide danger is classified 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 assessed by observing the deformation of existing structures and micro topography of the area. It is also necessary to do hearing from the residents was also carried out. In this Study, the micro topography of the area and the record of movement were collected and judged accordingly.

The degree of danger was classified into three categories, namely A, B and C. *Table B.6.1* shows classification of the degree of landslide danger.

Table B.6.1 Degree of Danger of Landslides

Rank of danger degree	Topographic Characteristics and Observation
A	There are evidences of present or recent movement of the landslide mass. The landslide blocks which moved during Hurricane Mitch or those which are judged as having moved in these ten years. The slip scarp is not covered by any vegetation and where outcrop reveals. Cracks are observed at the boundaries and misalignment of artificial structures are observed. The bottom part of the landmass is swelling out or small slope failure of tongue shape is observed.
B	Although the typical landslide topographic features are observed, it is judged that there are no movement in recent years. (slip scarp or side cracks are covered by vegetation). Without any typical landslide topographic features, following observations are made; there are examples of recent landslides with a similar geological formation in the neighborhood the structure of the land mass is composed of clay or colluvial deposit and it is weak
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. There observed a swelling shape at the bottom but no new collapse or deformation of structures around. There is no symptom of landslide from the hearing of the residents.

(3) Distribution of Landslides

Figure B.6.3 shows the distribution of landslide masses with danger ranks.

In the figure, it is observed that many landslide masses distribute in the north of the area. *Figure B.6.4* shows the northern part of the area in a larger scale 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 and it is observed that faults and fractured zone are triggering landslides.

(4) Affected Area by a Landslide

When a complete hazard map is to be made, it is necessary to take into account all the affected area by the landslide, where the earth or the rock fractures are brought into and may cause damage on houses and public facilities.

It is generally difficult to predict the affected area of a landslide because the range of landslide varies with conditions, such as the scale of a landslide, the geological features of the base rock and the landslide mass. Here the method used in Japan to estimate the affected area is applied.

An example of estimating the affected area is shown in *Figure B.6.5*. Here the length of the affected area is assumed to be the same as that of the landslide mass itself. The width of the affected area is also the same as that of the landslide mass. This method holds when the toe of the landslide mass is a horizontal plane.

If the toe of the landslide is not a horizontal plane, the method of estimation is different as follows;

(1) The toe of the landslide lies at the bottom of the valley and the landslide is overriding on the valley.

The affected area is assumed by filling up the valley by the maximum depth of the landslide mass. The maximum depth of the landslide is estimated from the surrounding topography. When that estimation is difficult, the maximum depth can be assumed to be the one seventh of the width of the landslide.

(2) The toe of the landslide lies on the middle of a slope in the same direction.

There is a possibility of the occurrence of a debris flow and it should be considered. The affected area by this debris flow is up to the valley bottom and the flat area on the opposite side of the valley with the height from the bottom less than a few meters.

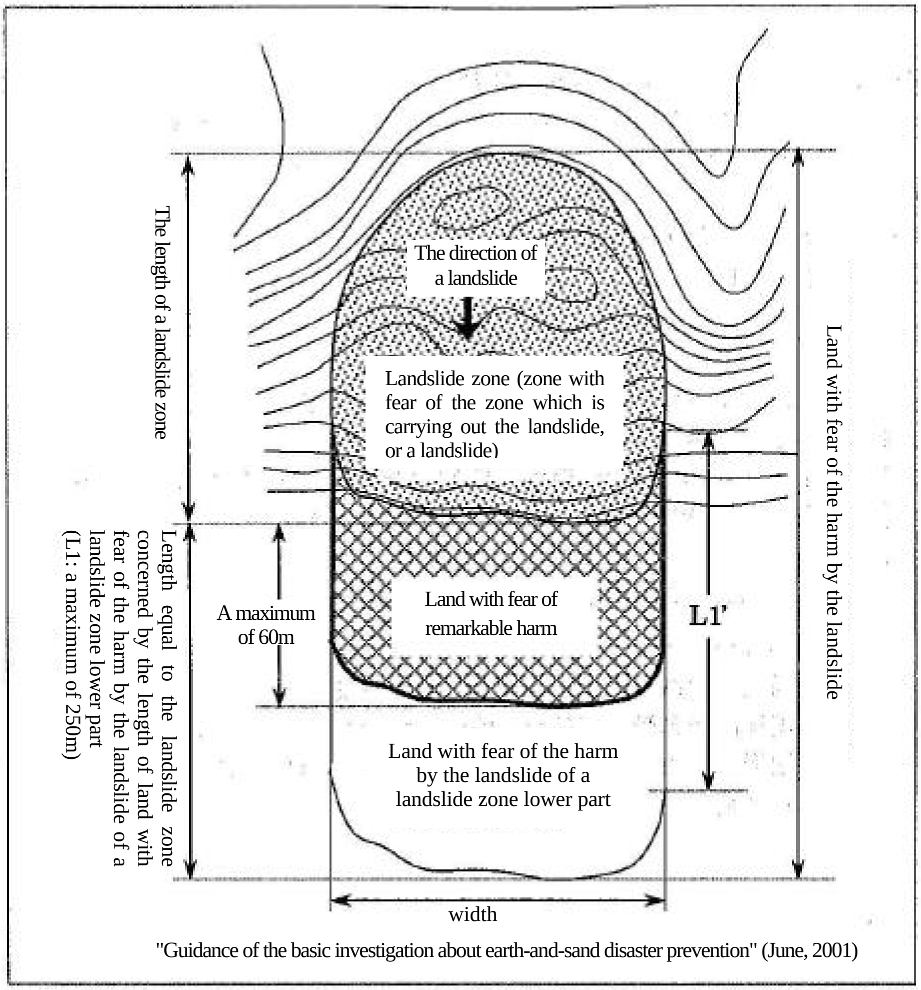

Figure B.6.5 Example of Estimation of Affected Area by Landslide

6.2 SLOPE FAILURE

Based on the geographical feature of the existing slope failures, the dangerous slopes was selected. In an extraction of the dangerous slopes, the occurrence factor of a slope failures is mainly closely related to the gradient of geographical feature, and a slope failure is possible to occur also in the part where the signs of a slope failure have not appeared at present in the future. In this study, the area where a slope failure may occur in the future was predicted from the geographical feature and geological-rock-feature. A large amount of work is required in order to perform this analysis over the whole Target Area. For this reason, the geographic information system (GIS) was used for analysis. The details of the hazard map creation using GIS are shown in Supporting-H.

USGS has analyzed the actual landslides caused by Hurricane Mitch based on the aerial photo taken in March 1999. There are rather accurate data as the photo was taken with little time after the disaster and when the scars were still fresh. Identification of slope failure was done by combining the field survey result with this aerial photo data. The data of USGS includes not only slope failures but also the big scale landslide, for example Berrinche and Reparto. Those landslides were excluded in slope failure analysis. The location map of landslide during Hurricane Mitch is shown in *Figure B.6.6.*

(1) Features of Slope-failures

In this Study, the altitude data in the Target Area sere generated as digitized data of each square of 10 m times 10 m from the digital elevation model (DEM) of the area. The slope of ground surface was calculated for each square.

Figure B.6.7 shows the frequency distribution of the slope of all the slope-failures during the Hurricane Mitch. The X-axis shows the slope gradient of their original topography and the Y-axis shows the number of slope failures. The number of cases of slope failure is large when the slope gradient is between 20 degrees and 40 degrees. According to the figure, 80 % of the cases has the slope gradient less than 40 degrees.

Figure B.6.8 shows the geological classification of slope failures. The figure shows that the number of cases with Tcg and Tpm is large. It is observed that it is wise to analyze the case according to the geological classification of the slopes.

Accordingly, the slope failure cases were analyzed with the two parameters, namely the gradient of the original slope and its geological classification.

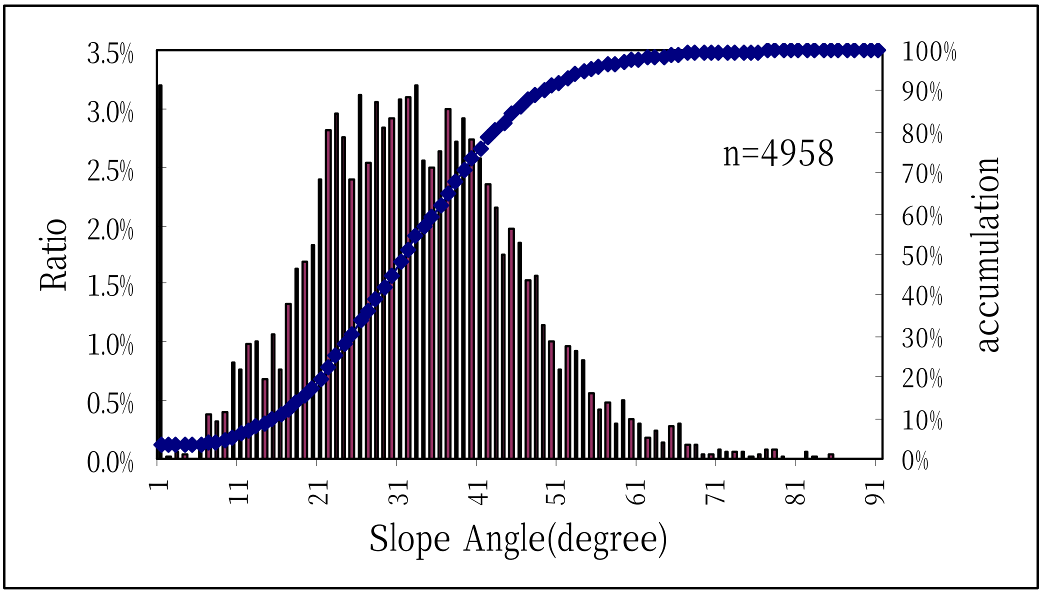

Figure B.6.7 Slope Gradient of Slope Failures

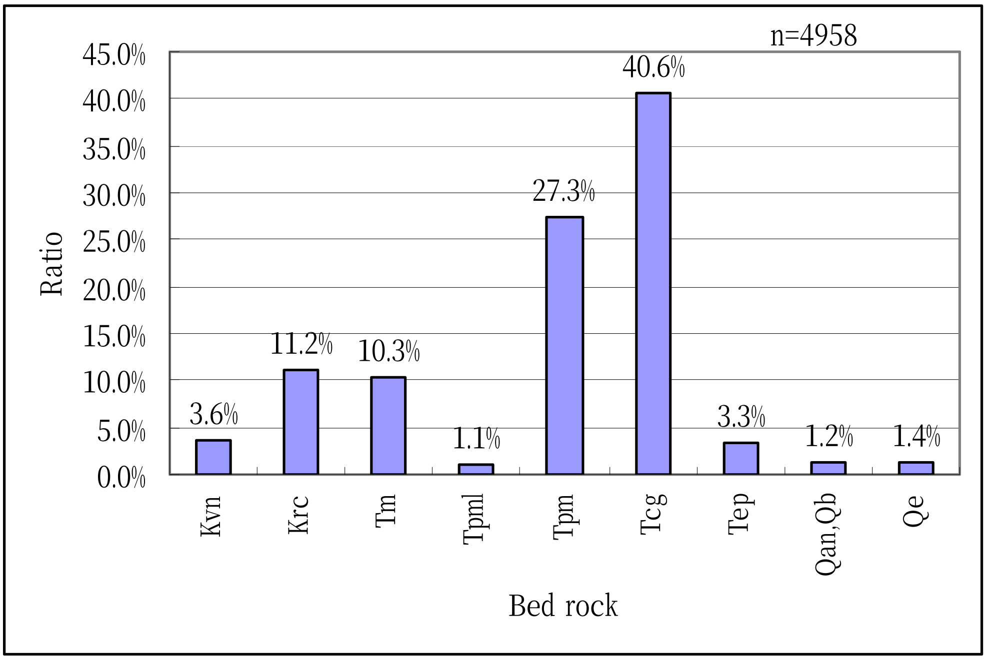

Figure B.6.8 Geological Classification of Slope Failure

(2) Gradient Analysis by Geological Classification

As mentioned above, it is estimated that the danger of a slope failure can be presumed by the gradient of the slope and its geological classification. The slope failure cases were categorized according to their geological classification and the examination of their original gradient of the slope was made.

The concept of the topographic analysis of a slope failure case is shown in *FigureB.6.9*. In the figure, the H is the height of the slope failure, θ is the gradient of the original slope, L is the length of the affected area.

Among the 691 cases (4,958 cells) of slope failures in the Target Area, 173 apparent cases were selected for above analysis. The result of the topographic analysis was classified according to the geological classification of the slopes.

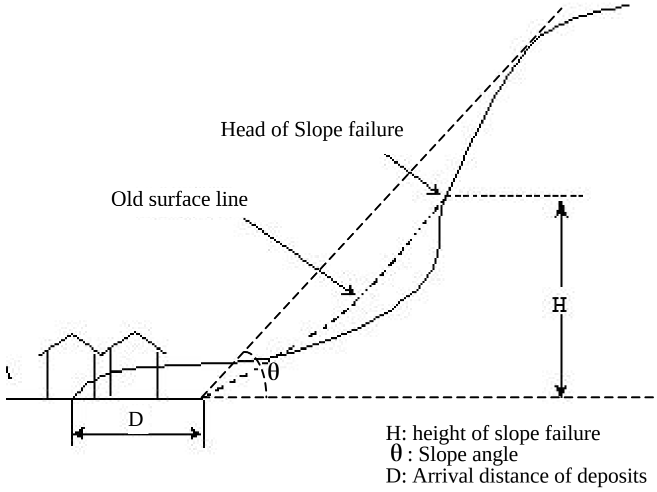

Figure B.6.9 Topography of Slope Failure

Table B.6.2 shows the result of the analysis. *Figure B.6.10* shows the frequency distribution of all 173 cases according to the gradient. The minimum gradient is 18 degrees while the maximum value is 70 degrees making the average value 38.4 degrees.

Table B.6.2 Collecting Slope Angle of Each Bed Rocks Unit: degree

	Kvn	Krc	Tm	Tpm	Tcg	Tep	Qb_an	Qe	ls	dt	*total*
max	41	56	44	67	62	49	50	59	40	38	*70*
minmam	28	18	18	19	25	30	27	20	20	20	*18*
average	35.8	34.6	29.6	40.4	44.5	39.7	35.2	34.1	30.4	31.4	*38.4*
count	10	21	10	30	50	10	10	10	11	10	*173*

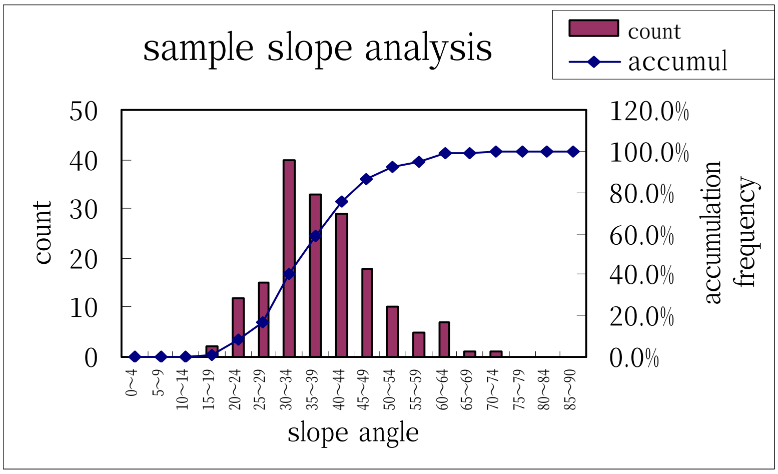

Figure B.6.10 Frequency Distribution of Slop Failure

Table B.6.3 and *Figure B.6.11* show the gradient of the slopes according to the geological classification. There is a difference in the range of gradient from one geological classification to another. *Figure B.6.12* summarizes the relation between the gradient (theta) and height (H) according to the geological classification. It shows a positive correlation between the slope gradient and the slope height.

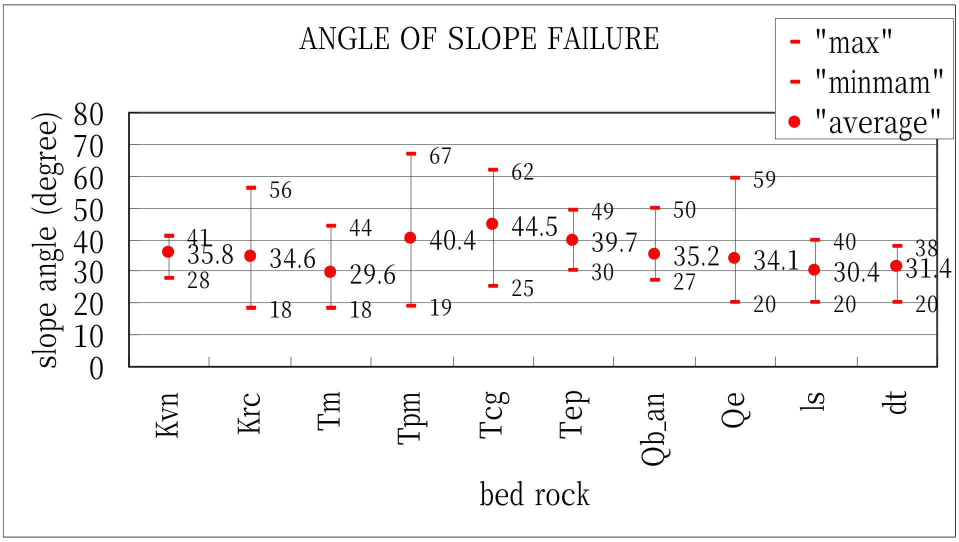

Figure B.6.11 Collecting Slope Angle of Each Bed Rocks

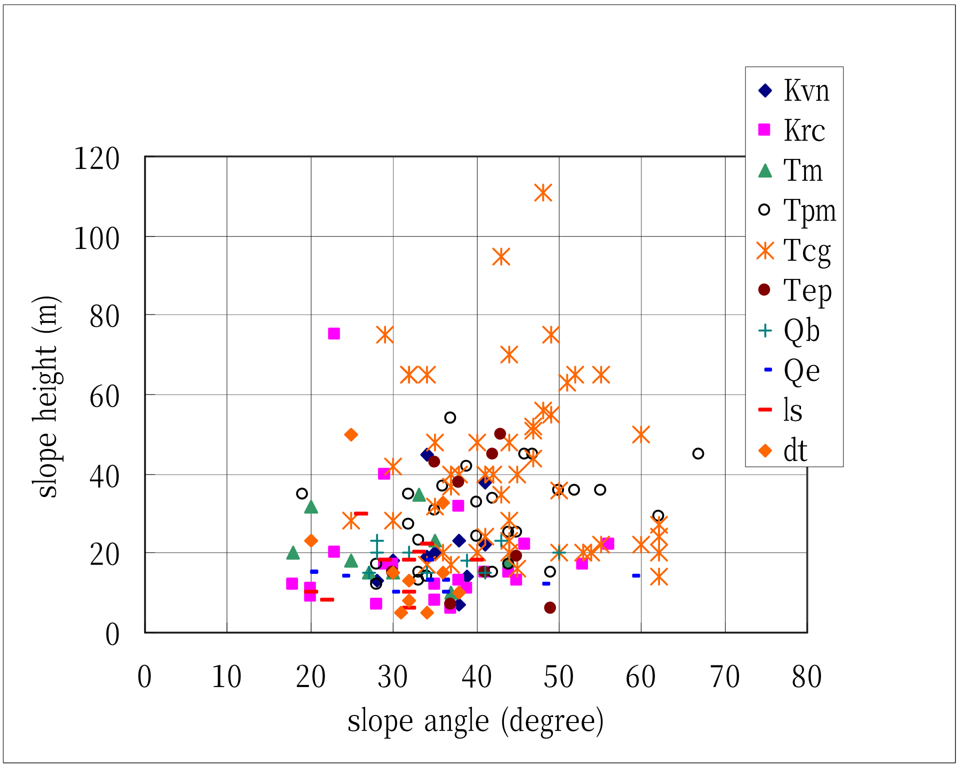

Figure B.6.12 Relationship Between Height and Angle of Slope Failure

(3) Estimation of Slope Failure Danger Area

The minimum, the maximum and the average values of the slope gradient classified by the geological classification are shown in *Table B.6.2* and *Figure B.6.11*.

There is an idea to take the minimum values of *Table B.6.2* for the threshold values to create a hazard map. However, there is a high possibility of being too conservative in it as there are some cases of extraordinary conditions such as a local surface run-off of storm water or very weak top soil failed there. Therefore, the estimation of the danger area in terms of slope failures were made as follows;

1. The gradients values were arranged by an ascending order for each geological classification.
2. The slope gradient corresponding to 10% was designated as the threshold value for "a dangerous slope".
3. The slope gradient corresponding to 50% was designated as the threshold value for “a very dangerous slope”.

Table B.6.4 and *Figure B.6.13* show the example of Tcg. According to the table and the figure, the threshold value for “a very dangerous slope” is 44 degrees and that for “a dangerous slope” is 32 degrees.

Table B.6.4 The Grade List of the Slope Failures in a Tcg Distribution Region

No	slope angle (degree)	accumulation
1	25	2.0%
2	29	4.0%
3	30	6.0%
4	30	8.0%
5	32	10.0%
6	32	12.0%
7	34	14.0%
8	34	16.0%
9	35	18.0%
10	35	20.0%
11	36	22.0%
12	37	24.0%
13	37	26.0%
14	37	28.0%
15	38	30.0%
16	40	32.0%
17	40	34.0%
18	41	36.0%
19	41	38.0%
20	42	40.0%
21	43	42.0%
22	43	44.0%
23	44	46.0%
24	44	48.0%
25	44	50.0%

No	slope angle (degree)	accumulation
26	44	52.0%
27	44	54.0%
28	45	56.0%
29	45	58.0%
30	47	60.0%
31	47	62.0%
32	47	64.0%
33	48	66.0%
34	48	68.0%
35	49	70.0%
36	49	72.0%
37	50	74.0%
38	50	76.0%
39	51	78.0%
40	52	80.0%
41	53	82.0%
42	54	84.0%
43	55	86.0%
44	55	88.0%
45	60	90.0%
46	60	92.0%
47	62	94.0%
48	62	96.0%
49	62	98.0%
50	62	100.0%

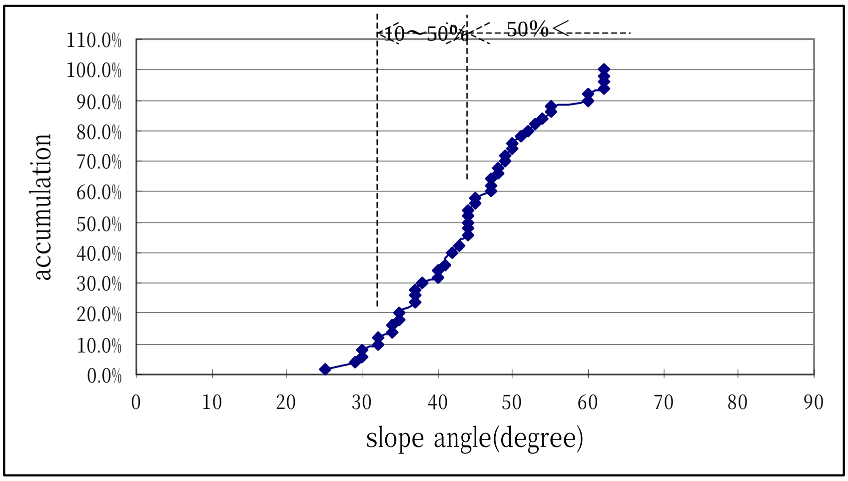

Figure B.6.13 The Relationship Between Slope angle and Occurrence Ratio of Slope Failures in Tcg Area

The same analysis was made for all the geological classifications. The threshold values of each geological classification analyzed are shown in *Table B.6.5*.

Note; A dangerous slope and A very dangerous slope are mere grade of danger which decided based on the gradient data of slope failures occurred in Mitch, and these are not determined in consideration of all the slope-failure factors. For this reason, judgment work at a spot will be required about each extracted slope in future.

(4) Affected Area by a Slope Failure

Figure B.6.14 shows the distribution of the lengths of the affected area (the value of D in *Figure B.6.9*). There are 47 cases. *Figure B.6.15* shows the correlation between the slope height (H) and the length of the affected area (D).

According to *Figure B.6.15*, the correlation between D and H is weak, although it is observed that all the cases fall above the line D=2H. *Figure B.6.14* shows that 80 % of all the cases have the values of D less than 20 meters.

In this Study, in creating the hazard map, the length of the affected area for all slope failure dangerous area was assumed to be 20 meters. It is recommended that more information to be collected to analyze the relationship between the length of the affected area and the height of the slope.

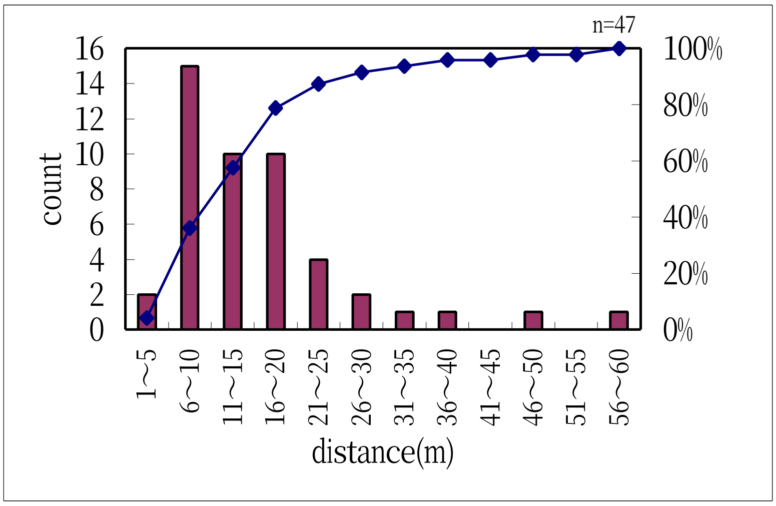

Figure B.6.14 Length of Affected Area

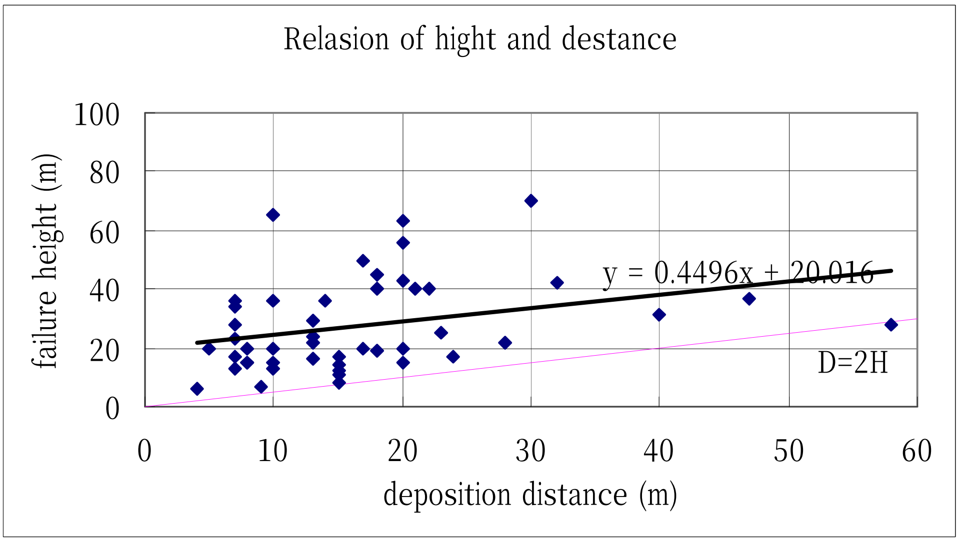

Figure B.6.15 Correlation Between Slope Height and Length of Affected Area

(5) Hazard Map of Slope Failure

Based on the above study, the slope failure analysis map was created for the Target Area as shown in *Figure B.6.16.*

The categories indicated in the map are as follows;

***Actual slope failures*：**The actual slope failures by the Hurricane Mitch selected by USGS and supplemented by this Study.

***Very dangerous slopes*：** The slopes with high possibility of failure.

***Dangerous slopes*：** The slopes with possibility of failure.

***Affected Areas*：** The dangerous area by the failure of the slope near by. It lies within 20 meters from the toe of “the very dangerous slope” or “the dangerous slope”.

All above area are in danger when a very heavy rainfall with the scale of the Hurricane Mitch. The areas of the above four categorized zones are shown in *Table B.6.6*. According to the table, 25 % of the whole Target Area.

Note; The hazard area shown in this map has judged danger only from two factors, the gradient of slopes, and bed rocks. The other dangerous factors of a slope are the concentration of surface water, the weathering grade of a natural ground, the thickness of topsoil, and the distribution of geological fracture zone etc. Moreover, since 5m mesh GIS is used for geographical feature analysis, it is with error. From these things, there may be another dangerous areas apart form dangerous slopes shown here. Therefore, it is appropriate that this map shows the minimum hazard-area range. Especially, the area along the valley where surface water concentrates is dangerous, even if it is not chosen as dangerous slope. The area requires cautions.

Table B.6.6 Slope Failure Danger Areas

	Very Dangerous Slope	Dangerous Slope	Affected Area	Other Actual Slope Failure during the Hurricane Mitch	Total
Area (m^2)	2,604,200	10,606,400	12,712,825	95,600	26,019,025
Ratio to The target area	2.5%	10.1%	12.1%	0.1%	24.8%

6.3 CREATION OF HAZARD MAP OF LANDSLIDES AND SLOPE FAILURES

The hazard map of landslides and slope failures combined is shown in *Figure B.6.17*.

It is necessary to plan some counter measures for the Rank A landslide blocks and the two categories of slope failures dangerous areas. As for the Rank B and Rank C landslide blocks are stable at present but it is necessary to watch them so that any future development of the area will not destabilize the blocks.

6.4 DESCRIPTION OF RANK A LANDSLIDE BLOCKS

The location of the Rank A landslides is shown in *Figure B.6.18*. The detail map of each block is shown in *Figures B.6.19* to *B.6.33*. *Table B.6.7* shows the number of houses located in each Rank A block and its affected area. The total area occupied by these 17 Rank A landslide blocks is 1,100,000 and 1 % of the whole Target Area. The number of houses is 1,540 among which Reparto has 450 houses and Berrinche has 360 houses.

In Table B.6.8, detail description of each Rank A landslide block was made together with the appropriate evacuation area considering the whole hazard map.

7. SELECTION OF MITIGATION MEASURES

Based on the hazard map created in the Study, the mitigation measures were selected.

As the dangerous area covers a large proportion of the whole Target Area (the Rank A landslide dangerous area is 1 % and the slope failure dangerous area is 25 %), it is impossible to solve the problem only by structural measures. The main focus must be non-structural measures.

Especially for the slope failure problems, the structural measures to stop them are comparatively costly considering the amount of efforts to be paid and the area saved by the efforts. This is because slope failures occur in rather steep area and the sliding energy is comparatively larger.

Dangerous slopes selected in this Study were extracted by GIS based on a geological rock and a gradient of a slope, a detailed field survey about each dangerous slope must be performed and the check of danger and the priority of a measure must be examined in future.

Therefore, to cope with the slope failure problems, it is not wise to select structural measures in this area. In stead, non-structural measures such as resettlement promotion and forecasting /warning/evacuation are proposed.

In the case of landslide, selection of structural measures and non-structural measures were studied for each 17 Rank A block. The focus of the study was on the danger of a slope, influence of the landslide and the number of houses to be relocated for the implementation of the structural measures. The study result is tabulated in *Table B.7.1*.

According to *Table B.7.1*, the blocks with high priority are Reparto, Berrinche, Bambu, Bosque, San Martin, Zapote Centro and Nueva Esperanza.

Among these block, Reparto, Berinche and Bambu were selected to be dealt with by the structural measures mainly because of the easiness of the resettlement problem. In the case of Berrinche the structural measures is a must considering the effect of the block to the closure of the Choluteca River and the inundation of the central area of the city.

Although other blocks were planed for the non-structural measures, the two blocks namely Zapote Centro and Nueva Esperanza were selected as the blocks for pilot project of resettlement in the Master Plan. This is because these two blocks are at high risk and houses on the blocks are in a very dangerous conditions.

TableB.7.1 Mitigation Measures for Landslide Blocks

Number	Block Name	Affected Houses	Resettlement for Structural Measures	Instability	Application of Structural Measures
1	Canaan	113			
2	Reparto	452		X	X
3	Bambu	42		X	X
4	Bosque	196			
5	Buena Vista	7		X	
6	Berrinche	361		X	X
7	Campo Cielo	25		X	
8	San Martin	74		X	
9	Flor 1	21			X
10	Zapote Centro	126		X	
11	Zapote Norte	4		X	
12	Villa Union	5			X
13	Brasilia	61			
14	Centro America	6			X
15	Nueva Esperanza	16		X	
16	Las Torres Este	19		X	
17	Las Torres Oeste	15		X	

8. NON-STRUCTURAL MEASURES

8.1 GENERAL

When non-structural measures were studied, it is necessary to classify the landslide hazard area into two categories as follows;

(1) The dangerous area where people live presently

It is necessary to remove or minimize the risk of the residents by the permanent resettlement from the area or the emergency evacuation in disaster. For the permanent resettlement, education and enlightening of the residents by various ways should be employed. For the emergency evacuation, the forecasting/warning/evacuation plan is to be made as described in the following section.

(2) The dangerous area where people do not live presently

All the effort should be made so that no people will come to live there. This is the policy of land use regulation and described in Supporting J.

8.2 LANDSLIDE WARNING SYSTEM

As the method of predicting occurrence of a landslide and a slope failure in advance, and preventing a disaster, it is considered two kinds of method. One is the method of paying attention to rain fall. Another is the method of paying attention to the surface changes.

In the method of paying attention to rainfall, the rainfall situation to be warned is determined from parameter of rainfall intensity and rainfall amount, and then the warning condition to be evacuated is determined. However, there are few cases that those data is well related though a certain amount of data is collected by this method. Moreover, since rainfall pattern is greatly influenced by geographical feature conditions, it is necessary to have many observation stations in place and establish the system to judge the real time observation. In Japan, there are many cases that the rough standard rainfall for alert was determined and alert system is prepared.

On the other hand, there are the following two cases for the method of paying attention to the surface changes of the field. When local residents discover the surface changes occurred on the local slope, such as a crack and a gush of groundwater, they take refuge independently. Or local residents get in contact with appropriate agency, the engineer checks the field, and urges refuge.

In Honduras, it is appropriate to combine the above two methods, which firstly determine the standard rainfall amount and in case of the observed rainfall beyond it check the surface changes in dangerous slope.

8.2.1 WARNING BY RAINFALL AMOUNT

Together with the rainfall observation stations for flood forecasting/warning, new rainfall observation stations for landslide forecasting/warning are proposed as shown in *Figure B.8.1*.

The new stations are Reparto, Nueva Esperanza, Suyapa and Villa Franca. All the rainfall data are to be transmitted to CODEM and COPECO for the analysis and determination of landslide alert. The warning should be dispatched from CODEM to the Colonia concerned.

Table B.8.1 shows an example of warning criteria according to the total rainfall amount by the storm.

Table B.8.1 Planned Landslide Warning Level

Warning Level	Data to be used for Warning	Warning Level
1	Cumulative Rainfall and Intensity	Preparation for evacuation
2	Cumulative Rainfall and Intensity	Evacuation to the designated places

The threshold values for the warning should be determined by the accumulation of data in future. 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 a reference, the example of the method for setting threshold values in Japan is shown as follows.

Reference; The method for setting the standard rainfall

The stability of landslide is influenced by the comparative long-term rain, but slope failure is affected by short term rainfall intensity. Thus, it is thought that the slope disaster occurs in relation to cumulative precipitation and short-term rainfall intensity. In setting up the standard rainfall for warning/evacuation, it is necessary to grasp these both rainfall values.

As a technique of setting up the standard rainfall, various methods are proposed now. But there is no established method. The following three techniques are mainly in use in Japan presently.

1) Continuation rainfall and hourly rainfall intensity method

2) Execution rainfall method

3) Soil rainfall method

Among them, as for the method of 1) and 2), standard rainfall is decided from the relation between accumulated rainfall and rainfall intensity. The basic concept is as follows;

1. Firstly, the target area is classified into the several area (block), where the conditions of sediment-disasters occurring, such as geographical feature and a geological rock are considered to be the same.
2. In the each area, the rainfall value at the time of sediment-disasters occurring and un-occurring is plotted by using two index, a short-term rainfall index (1-hour rainfall etc.) in vertical axis and long term rainfall index in horizontal axis.
3. A Critical line (sediment-disasters occurring dangerous base line: CL) is defined for partition of occurring rain and non-occurring rain as shown in *Figure B.8.2*. In case that rainfall exceed this line, it is afraid that sediment disaster occur. This is able to use as one of the judgment indices of a warning/evacuation.

It is desired to collect observation data from now on in new observation stations proposed in this Study, and determine the standard rainfall for warning/evacuation by the technique shown above.

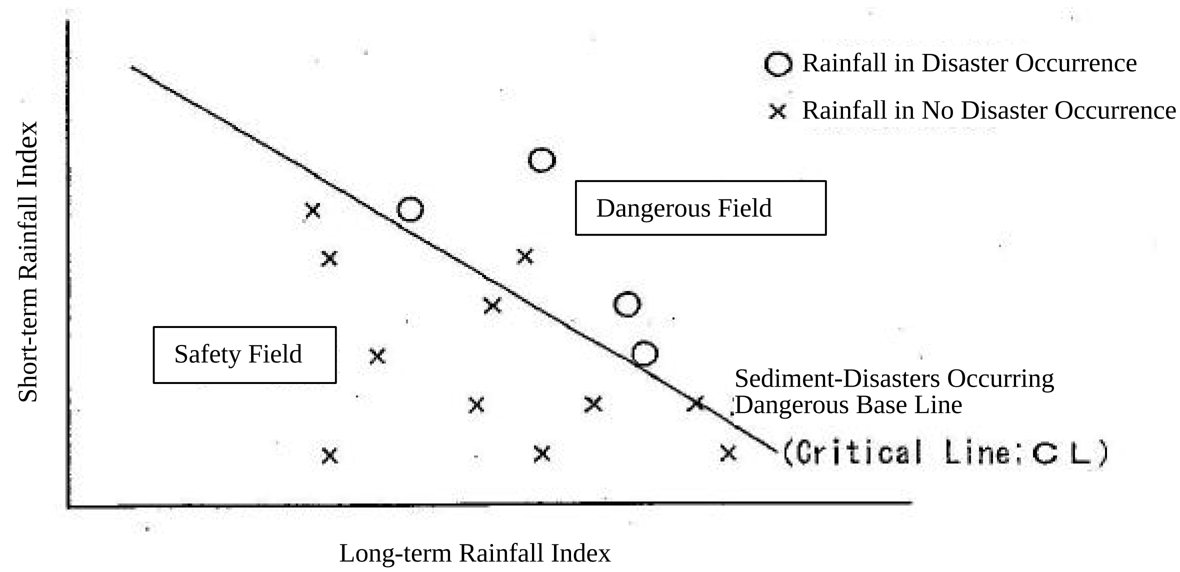

Figure B.8.2 Concept of Setting Standard Rainfall for Warning/Evacuation of Sediment-Disasters

8.2.2 WARNING BY THE SURFACE CHANGES AND SIMPLE MEASUREMENT OF THE FIELD

The new system is required, which in case that the signs of a landslide shown below are observed, information should be promptly transmitted to appropriate agency, detailed measurement should be performed by the technique as shown in 8.2.2(2), and refuge or no-refuge should be judged.

(1) The Signs of a Landslide

1) The Phenomenon about the Surface Changes

- Occurrence of a crack; The surface changes in a slope first appears in a upside tension crack. A slope failure is promoted when rainwater etc. goes into this crack. A crack is first produced as an open crack, a level difference is produced gradually, and a compression crack appears in the lower part further. When the place which the crack produced cannot be identified the upper part or the lower part of a landslide, if it is in the situation that the opening fracture has arisen and the foundation of the point was lengthened, it may be concluded that the place is in the upper part of a landslide.
- The pregnant shape of a slope; It is better to think that the pregnant shape has arisen, when the portion curved on the convex is discovered to see from the side of a slope.
- The pregnant shape of a stone wall and a slope failure
- Occurrence of the opening crack to the drainage canal and runout of water in drainage canal due to crack
- Cutting of the water pipe, suspension of water supply, and unusual turbidity of the tap water caused by changes of the foundation

2) The Phenomenon about the State of a Sewer

- Hot running water stops suddenly, or it becomes muddy.
- Stream water stops suddenly or becomes muddy.
- Well water falls suddenly or dries up.
- A new spring water spot appears or ground water level goes up. Muddy soil pushes out to along a mountain stream.

3) The Phenomenon about Change of a Ground Surface and an Unusual Sound; The following phenomena appear just before a slope failure.

- The foundation shakes dully.
- Underground rumbling carries out.
- There is a sound in which a standing tree splits.
- The branch and leaf of trees make a rustling sound by rubbing against each other without a wind.
- The electric wire is shaking.
- The creaking sound of a building makes it a continuation target.

(2) The Method of the Slope Measurement at the Time of Confirming the Surface Changes

There are following two methods for briefly grasping the situation of landslide movement.

1) Method by Installation of a Displacement Board

As shown in *Figure B.8.3*, woody files are put at the both side of surface cracks and the displacement board which passed the sideways board to woody piles is installed. Next, a break is put into this sideways board. The displacement of a crack is simply investigated by measuring expansion, reduction, etc. of this break.

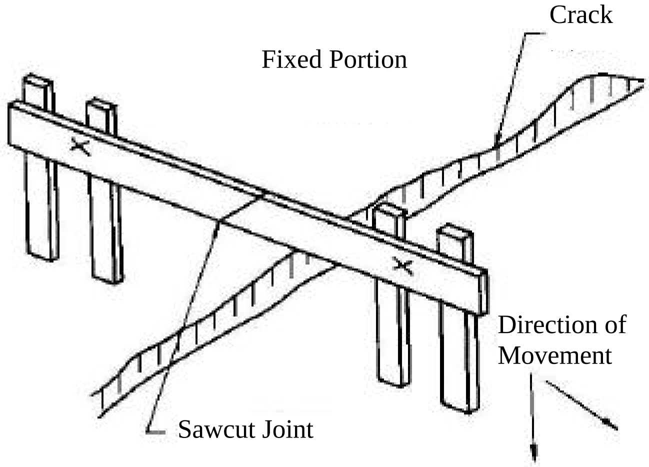

Figure B.8.3　Typical Observation by the Displacement Board

2)　Method by Displacement Stakes

Displacement stakes are installed on a sighting line in the inside of the landslide ground and the exterior (fixed natural ground) across the landslide as shown in *Figure B.8.4.* The amount of movements of the stakes is measured. As for the measurement, it is desirable to measure the movement amount in landslide direction, transversal direction, and perpendicular direction.

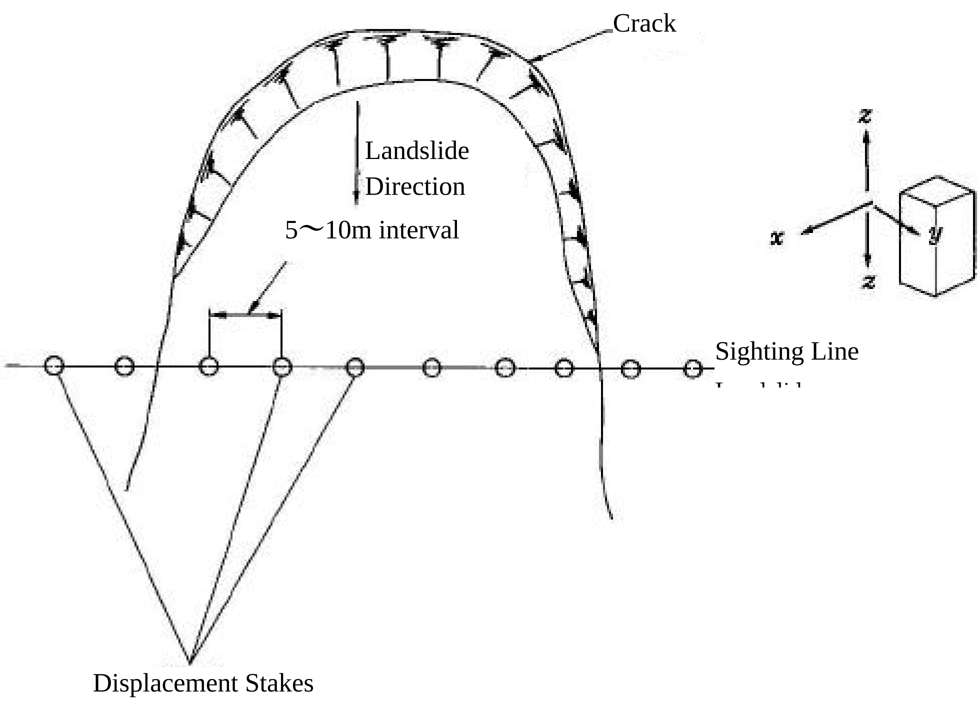

Figure B.8.4　Layout of Displacement Stakes

(3)　Warning Standard by Displacement Measurement

Movement characteristic of landslide is dependent on each area's characteristic such as a geological rock, groundwater conditions, etc. Therefore, it is not desirable that the warning standard based on the displacement measurement is uniformly determined for every area. It is necessary to accumulate the data in future using proposed observation attitude, and to determine the warning standard in each area.

Here, the warning standard generally applied in Japan is shown in *Table B.8.2* as a reference.

Table B.8.2 Warning Standard by a Simple Displacement Measurement

Classification	Displacement Speed	Displacement Continuation Time	Solution
Fluctuation A	1mm/day	More than 3 days	Landslide administrator takes a state of caution. Strengthening of measurement Local patrol once a day
Fluctuation B	1mm/hour	More than 3 hours	Landslide administrator takes a state of alert. Full-time field surveillance Installing measurement meters (displacement board etc.) at crack generated points
Fluctuation C	2mm/hour	More than 2 hours	Advice of evacuation preparation to residents
Fluctuation D	4mm/hour		The official announcement of evacuation order

Table B.5.1 Stratigraphy in Target Area

Era	Period	Epoch	Symbols	Features
Cenozoic	Quaternary	alluvial	**dt**	Detritus sediment (based on a landslide, a slope failure, etc.). It consists of debris and earth and sand.
			Qal	The latest alluvial sediment. It consists of clay , sand and boulders.
			Qe3	Lower terrace sediment : Fan of Sands and cobbles
		pleistocene	**Qe2b**	Terrace sediment of middle rank : It consists of sand and stones. A matrix is not solid. An old fan or the sediment on the bottom of a river. It mainly consists of volcanic rock after the Tertiary. The color is from dark gray to gray.
			Qe2a	Terrace sediment of middle rank : It consists of sand, stones, and silt.Tightness is good although a matrix is not solid. An old fan or bottom of river, and the sediment of a lake. It mainly consists of rock of Valle de Angeles group, and volcanic rock after the Tertiary. The color is from dark brown to blackish brown.
			Qe1	Higher terrace sediment : It mainly consists of sand and stones, and tuff layer is inserted. By oldest terrace deposits, the matrix is consolidated weakly.
			Qb	Lava of basalt (olivine slanting feldspar and scoria)
			Qan2	It is distributed on the hill of Cerro Grande. It consists of andesite lava. Although the rock itself is precise hard, joint progresses and it is easy to dissociate massive ly. In the border part of a range, this stratum serves as cap rock and tends to cause a landslide.
			Qan1	It is distributed over the low rank of Qan2. It consists of andesitic and rhyolitic tuff. Banded structure progresses. It is weak in weathering and easily to deteriorate in it. It becomes the cause of a landslide rarely.
			Odt	It is mainly distributed near a Villa Nueva area. It consists of debris of the stones which made the subject rhyolite with a diameter of 20cm - 3m, and has a Vallu de Angeles Group origin. Half a matrix is solid, tightness is good.
	Tertiary	miocene(Padre Miguel Group)	**Tpm3**	Ignimbritic sequence, upside member: Tuff of rhyolite of many colors.Some sedimentary rocks equipped with volcanic debris, tuff of quartz andesite nature, and tuff that andesitic tuff. This rock itself is massive and it is solid. When a stratum with weak intensity is distributed over the low rank of this stratum, it is easy to generate a landslide.
			Tep	It consists of rhyolitic tuff and conglomerate, sandstone, and siltstone. It deposits in underwater environments, such as a river. Stratified structure progresses almost horizontally. It is easy to dissociate from a stratum side, and may become the cause of a landslide in the part where the stratum inclines.
			Tcg	Cerro Grande member: Ignimbrite and rhyolite lava equipped with the matrix of crystals of the glassy quartz and crystal feldspar of a violet color. The rock itself is very hard, it is strong in weathering, and tends to form a steep cliff. Logic progresses and it is easy to dissociate. When this rock is distributed on a layer with weak intensity, this rock serves as cap rock and it is easy to generate a landslide. The deterioration action is received locally, and in the portion, intensity is falling remarkably and it is easy to generate a slope failure.
			Tpm2	Ignimbritic sequence middle member: Tuff by which quartz andesite nature was divided by class by style rhyolite. Banded structure progresses and it becomes the cause of a layer slide.
			Tpm1	Member of an Ignimbritic sequence low rank: Tuff of rhyolite of many colors. Some sedimentary rocks equipped with volcanic debris, tuff of quartz andesite nature, and andesitic tuff.
			Tpml	Lahars (debris flow tuff) with clast of tertiary volcanic rocks and cretaceous sediments. It consists of debris and consolidated sandstone. It is hardly the cause of a landslide by massive and hard ones.
		oligocene (Matagalpa F)	**Ti**	Rhyolitic intrusive rock which is intrusive in Vallu de Angeles Group: Generally along with a dislocation, it is distributed, deterioration is given to Vallu de Angeles Group, and it is easy to become the cause of a slope failure.
			Tm	Matagalpa formation: It consists of tuff, tuff breccia, and the andesite lava which presents a green color as it's base. It is easy to weather and changes in the shape of clay easily near the surface of the earth. For this reason, it is easy to become the cause of a landslide.
Mesozoic	Cretaceous (Valle de Angeles Group)		**Krc**	Rio Chiquito formation: It consists of mudstone, siltstone, sandstone, thin conglomerate layer, and thin limestone layer. Stratified structure is made. It's colors are blackish brown. It is easy to weather and changes simply to earth and sand. It is the stratum which is easy to generate a landslide and a slope failure.
			Kvn	Villa Nueva formation: Conglomeratic siliciclastic layers (with clast of metamorphic and volcanic rock and limestone). Brown to light red sandstone and some volcanic tuff. Stratified structure progresses partially. It's colors are thin red to dark purple. Although it is strong compared with Krc, the landslide is generated locally.

Table B.6.3 Description of Geology and Slope Topography of Slope Failures

No	bed rock	slope angle (degree)	failure height (m)	Deposition distance (m)
1	Tm	18	20	10
2	Tcg	25	28	58
3	Tcg	44	70	30
4	Tcg	37	40	18
5	Qan 2	34	15	
6	Tcg	47	52	
7	Qan 1	27	15	
8	Tm	35	23	
9	Tcg	35	32	
10	Tcg	51	63	20
11	Tcg	29	75	
12	Tcg	43	95	
13	Tcg	32	65	
14	Tcg	32	65	
15	Tcg	43	35	
16	Tcg	40	48	
17	Tcg	48	56	20
18	Tcg	47	51	
19	Tcg	54	20	
20	Tcg	48	111	
21	Tcg	30	42	
22	Tcg	49	55	
23	Tcg	55	65	10
24	Krc	29	17	
25	Krc	35	8	15
26	Tcg	49	75	
27	Tcg	45	40	
28	Tcg	36	20	
29	Tpm 3	19	35	
30	Krc	45	13	7
31	Krc	38	13	10
32	Krc	44	15	8
33	Krc	23	75	
34	Krc	29	40	
35	Krc	35	12	15
36	Krc	46	22	13
37	Krc	37	6	4
38	Krc	53	17	7
39	Tpml	32	33	
40	Tcg	41	24	
41	Tcg	44	20	
42	Tcg	50	20	17
43	Tcg	55	22	28
44	Tm	20	32	
45	Tcg	30	28	
46	Tcg	40	20	20
47	Tcg	45	16	13
48	Tcg	34	17	
49	Tcg	62	24	
50	Tcg	62	20	5
51	Tcg	44	23	
52	Tcg	53	20	
53	Tcg	44	48	
54	Tcg	60	50	17
55	Tcg	34	65	
56	Tcg	37	37	47
57	Tcg	62	14	15
58	Tcg	62	27	
59	Tcg	37	17	24
60	Tcg	42	40	22
61	Tcg	44	28	7
62	Tcg	41	40	21
63	Tcg	60	22	
64	Tcg	38	40	
65	Tcg	50	36	10
66	Tcg	52	65	
67	Tpm 1	35	31	40
68	Tpm 1	34	14	
69	Krc	41	15	
70	Krc	56	22	
71	Krc	30	17	
72	Krc	38	32	
73	Tpm 1	42	15	
74	Tpm 1	44	17	
75	Tpm 1	28	12	
76	Tpm 1	33	13	
77	Tpm 1	47	45	
78	Tpm 1	30	15	
79	Tpm 1	44	25	
80	Tpm 1	33	15	8
81	Krc	18	12	
82	Krc	20	11	
83	Krc	20	9	
84	Tpm 1	46	45	
85	Kvn	41	22	
86	Kvn	41	38	
87	Krc	39	11	15
88	Krc	23	20	
89	Krc	28	7	
90	Tpm 1	39	42	32
91	Tpm 1	40	24	13
92	Tpm 1	40	33	
93	Tpm 1	52	36	7
94	Tpm 1	36	37	
95	Tpm 1	32	35	
96	Tpm 1	49	15	10
97	Tpm 1	42	34	7
98	Tpm 1	38	38	
99	Tpm 1	32	27	
100	Tpm 1	33	23	7
101	Tcg	35	48	
102	Tcg	47	44	
103	Tpm 1	28	17	15
104	Tpm 1	55	36	
105	Tpm 1	62	29	13
106	Tpm 1	45	25	23
107	Tep	42	45	18
108	Tep	35	43	20
109	Kvn	34	19	18
110	Kvn	35	20	8
111	Kvn	39	14	
112	Tep	30	15	20
113	Kvn	38	23	
114	Tep	43	50	
115	Tep	37	7	9
116	Tpm 1	37	54	
117	Kvn	34	45	
118	Tpm 1	50	36	14
119	Tep	38	38	
120	Tep	45	19	
121	Qb	50	20	
122	Tpm 1	67	45	
123	Tm	25	18	
124	Tm	30	15	
125	Tm	33	35	
126	Qan 1	28	20	
127	Qan 2	32	20	
128	ls	34	22	
129	Tm	44	18	
130	Tm	27	15	
131	Qan 1	30	15	
132	dt	32	8	
133	dt	31	5	
134	Qan 1	41	15	
135	Tm	27	15	
136	Tm	37	10	
137	dt	30	15	
138	ls	29	18	
139	dt	32	13	
140	dt	25	50	
141	dt	38	10	
142	ls	22	8	
143	ls	33	20	
144	ls	40	18	
145	Qe	36	10	
146	dt	36	33	
147	ls	32	18	
148	dt	36	15	
149	dt	20	23	
150	ls	26	30	
151	dt	34	5	
152	Qe	34	18	
153	Qe	48	12	
154	Qe	30	10	
155	Qe	36	13	
156	Qe	20	15	
157	Qe	24	14	
158	Qe	20	15	
159	Qb	43	23	
160	Qb	28	23	
161	Qb	39	18	
162	Qe	34	13	
163	Qe	59	14	
164	Tep	37	7	
165	Tep	49	6	
166	ls	32	6	
167	Tep	41	15	
168	ls	32	10	
169	ls	20	10	
170	ls	34	22	
171	Kvn	28	13	
172	Kvn	30	18	
173	Kvn	38	7	

Table B.6.5 Threshold Values for Slope Failure Danger for Each Geology

Bed rock	Dangerous Slope		Very Dangerous Slope		notes
	Slope Gradient (degree)	Area (m2)	Slope Gradient (degree)	Area (m2)	
Kvn	30	533,500	38	111,800	
Krc	20	2,893,600	35	288,900	
Tm	20	882,300	30	228,000	
Ti	32	200	44	0	The value of "Tcg" is adopted.
Tpml	32	17,700	44	1,200	The value of "Tcg" is adopted.
Tpm1	28	866,800	40	325,900	Tpm1, Tpm2, and Tpm3 are united and examined.
Tpm2	28	100,300	40	40,200	Tpm1, Tpm2, and Tpm4 are united and examined.
Tcg	32	1,511,200	44	386,100	
Tep	35	148,200	41	151,600	
Tpm3	28	1,546,100	40	412,500	Tpm1, Tpm2, and Tpm4 are united and examined.
Odt	28	10,100	34	4,200	Odt, Qan1, Qan2, and Qb are united and examined.
Qan1	28	195,300	34	70,100	Odt, Qan1, Qan3, and Qb are united and examined.
Qan2	28	176,500	34	95,700	Odt, Qan1, Qan4, and Qb are united and examined.
Qb	28	128,600	34	89,100	Odt, Qan1, Qan5, and Qb are united and examined.
Qe1	20	102,600	34	13,100	Qe1, Qe2a, Qe2b, and Qe3 are united and examined.
Qe2a	20	292,500	34	27,700	Qe1, Qe2a, Qe2b, and Qe4 are united and examined.
Qe2b	20	64,500	34	14,700	Qe1, Qe2a, Qe2b, and Qe5 are united and examined.
Qe3	20	76,900	34	12,200	Qe1, Qe2a, Qe2b, and Qe6 are united and examined.
dt	25	0	32	187,900	
ls	22	564,000	32	143,300	
total area(m2)		10,110,900		2,604,200	—
The rate to whole area		9.6%		2.5%	—

Table B.6.7 Rank A Landslide Blocks

No.	Block Name	Address	Area (block area + affected area) (m2)	Numbers of influence houses
1	Canaan	COL.CANAAN	147,467	113
2	Reparto	BARRIO EL REPARTO	276,929	452
3	Bambu	BARRIO LA CABANA ,BARRIO EL EDEN No.1, BARRIO LA RONDA,COL.ALTOS de LA CABANA	46,801	42
4	Bosque	BARRIO ALTOS DEL BOSQUE o 13 de FEBRERO, BARRIO LA ESTRELLA	49,709	196
5	Buena Vista	BARRIO.BUENA VISTA	10,220	7
6	Berrinche	COL.SOTO	382,494	361
7	Campo Cielo	COL.CAMPO CIELO	6,460	25
8	San Martin	COL.AYESTAS	25,717	74
9	Flor 1	COL.LA FLOR No.1	16,112	21
10	Zapote Centro	CO.ZAPOTE CENTRO , CO.BRISAS DE OLANCHO	29,902	126
11	Zapote Norte	CO.ZAPOTE NORTE	5,355	4
12	Villa Union	CO. VILLAUNION	6,067	5
13	Brasilia	CO. BRASILIA C0. SAN JUAN DEL NORTE No.2	43,768	61
14	Centro America	RE. CENTRO AMERICA CO. 1DE DICIEMBRE	6,930	6
15	Nueva Esperanza	CO. NUEVA ESPERANZA	30,907	16
16	Las Torres Este	CO. LAS TORRES	6,881	19
17	Las Torres Oeste	CO. LAS TORRES	5,580	15
Add			***1,097,299***	***1,543***

Table B.6.8 Situation of Landslide Rank A (1/5)

number	Name	Landslide features						Affected area	Proposed evacuation site
		Width (m)	Length (m)	Estimated volume (m^3)	Slope gradient (degree)	Landslide pattern (FigB.6.1)	Symptom		
1	Canaan	100~200	300	700,000	15~20	③	A slope failure occurred at the landslide block border during the Hurricane Mitch . Erosion from a stream below is progressing.	The valley 300m below the landslide. Debris flow could be generated.	The ridges on the east and the west side are appropriate. COL.CANAAN
2	Reparto	240	530	1,200,000	10~15	③	300,000m^3 of soil and sand collapsed during the Hurricane Mitch, and these are distributed in an unstable situation. The block in the back was unstabilized by this slope failure A spring is observed.	A debris flow may occur in the valley by a rapid movement of a landslide soil block. It is presumed that influence reaches even the point 900 m downstream where the slope becomes mild.	The ridge in the east is appropriate. COL. GUILLEN
3	Bambu	180	250	150,000	12	③	Streams are distributed at the central part, and erosion along these streams are generating many small collapses. During the Hurricane Fifi in 1974, a large debris flow occurred along the streams, and the colluviums has reached even the movie theater 400m below.	The earth and sand may reach 400m below along the valley.	The western ridge is appropriate. Bo.EL EDEN No.1, Co.ALTOS de LA CABANA

Table B.6.8 Situation of Landslide Rank A (2/5)

number	Name	Landslide features						Affected area	Proposed evacuation site
		Width (m)	Length (m)	Estimated volume (m^3)	Slope gradient (degree)	Landslide pattern (FigB.6.1)	Symptom		
4	Bosque	100	180	74,000	10	⑤	It forms a clear circular landslide configuration. Although no symptom appears in houses or the structures, It is judged that the block is unstable. Because, a slope failure is progressing at the toe of the block, the landslide mass consists of detritus, and the topographically the groundwater tends to concentrate there. Two blocks in the southwest have high danger of landslide or slope failure	Earth and sand may reach the length of a landslide (100m) along the direction of a landslide (west-southeast). .	The south flat plane is appropriate. Bo. EL BOSQUE
5	Buena Vista	80	110	15,000	40	③	A slope failure which originated in a landslide occurred during the Hurricane Mitch. New cracks are developing behind the slip cliff, and the landslide area may be expanding.	The influence may reach the Choluteca River bed. At the top of the landslide mass, the border may expand by 10m.	The north flat plane is appropriate. Bo. BUENA VISTA
6	Berrinche	330	800	5,000,000	10~20	②	It moved by a large distance during the Hurricane Mitch and blocked the Choluteca River. According to the observation by SERNA, a displacement is observed at the upper central part of the block. At the toe of the block, a landslide 60 m wide occurred after Mitch.	It may be moving at a deep position presently, the river bed may be blockaded by the landslide mass with the thickness of 10-30m. The area on the opposite side of the river with the altitude of 930m or less may be covered by earth and sand. The width of the influence is 200m in maximum.	Both upper and lower side of the Choluteca River on the left bank is dangerous. The hill in the direction to the Centro, or Cerro Grande hill is appropriate Bo.LA CHIVERA

Table B.6.8 Situation of Landslide Rank A (3/5)

number	Name	Landslide features						Affected area	Proposed evacuation site
		Width (m)	Length (m)	Estimated volume (m^3)	Slope gradient (degree)	Landslide pattern (FigB.6.1)	Symptom		
7	Canpo Ciero	35	100	13,000	27	②	It moved in a large scale during the Hurricane Mitch, and dozens of houses were destroyed. The sliding mass is still in an unstable condition.	There is a possibility of the earth flowing out with the width 40m and the length 100m.	Neighbor areas are hazard areas, and an evacuation area is restricted. The north or the west ridge is comparatively stable, and can be chosen as an evacuation area. Co.CAMPO CIELO, Co.SAN MARTIN
8	San Martin	60	200	50,000	12	②	It moved in a large scale during the Mitch, and dozens of houses were destroyed.. The landslide mass is in the unstable state and at the toe of the block, a retaining wall is pushed by the landslide and many fractures are developing.	The landslide mass is in the middle of a slope. If it once moves, it will influence the range of width 200m and length 80m.	Neighboring areas are all hazard areas, and selection of an evacuation area is difficult. The plateau on the south can be chosen as a safe place. Co.SAN MARTIN
9	Flor 1	70	190	50,000	20	②	It moved by a large distance during the Hurricane Mitch. Slipping cliff is observed at the top of the slope.	The soil mass may reach the valley downstream.	The gentle slope above a northeast slope is appropriate. Co.LA FLOR No.1
10	Zapote centro	200	120	90,000	28	②	Horseshoe-shaped topography is observed. It is a steep slope, and the outflow of earth and sand is progressing and few vegetation is growing. It is possible that the landslide is being unstabilized by erosion	Influence may reach 70m from the toe of the slope.	The northwest upper part is safer than the flat plane a the toe of the slope. Co.FUERZAS ARMADAS

Table B.6.8 Situation of Landslide Rank A (4/5)

number	Name	Landslide features						Affected area	Proposed evacuation site
		Width (m)	Length (m)	Estimated volume (m^3)	Slope gradient (degree)	Landslide pattern (FigB.6.1)	Symptom		
11	Zapote norte	80	60	10,000	38	②	It is a steep slope and erosion is progressing. A slope failure of 5 m thick may occur.	The earth and sand may reach at the valley floor.	It is better to avoid refuge along the stream. The top of the southern slope is safe.. Co.3de MAYO
12	Villa Union	60	90	20,000	15～25	①	The landslide has occurred during the Hurricane Mitch. According to the local people, the mass is still moving.	The earth and sand may reach at the valley floor.	All the surrounding slopes are hazard areas. The top of the ridge 300m away in the directions of southeast is suitable. Co.FLOR No.1
13	Brasilia	170	180	130,000	15～35	①	It moved by heavy rainfall 10 years ago. A new 1~2m high scarp is observed.	It may reach the same distance as the length of the landslide mass(180 m).	The lower southern land with a mild slope. Co.EL CARRIZAL
14	Centro America	60	80	16,000	20	④	It moved during the Hurricane Mitch. The slope id falling gradually and the new main scarp is developing. The gabion being constructed will not be enough to stop the movement..	It may reach the same distance as the length of the landslide mass(100 m).	Many flat lands are available in the neighborhood. Re.CENTRO AMERICA

Table B.6.8 Situation of Landslide Rank A (5/5)

number	Name	Landslide features						Affected area	Proposed evacuation site
		Width (m)	Length (m)	Estimated volume (m^3)	Slope gradient (degree)	Landslide pattern (FigB.6.1)	Symptom		
15	Nueva Esperanza	260	100	170,000	37	①	During the Hurricane Mitch, a large-scale slope failure (presumed volume 40,000m^3) occurred, and many houses were destroyed.. The slope failure occurred at the end of a landslide block. New cracks are developing and it is in an unstable state.	The earth and sand will accumulate on the river bed.	The upper gentle slope is suitable. Co.NUEVA ESPERANZA, Co.NUEVA ESPERANZA Ⅲ ETAPA
16	Los Torres este	100	40	14,000	50	①	The slope failure has occurred during the Hurricane Mitch. Large scale slope failures occurred a few times after Mitch. The toe of the steep slope is being eroded by river current and it is unstabilizing the cliff	The earth and sand will accumulated on the river bed. There is a possibility of landslide expansion by 10 m at the top of the slope.	The plateau 50m away from the cliff. Co.INESTROZA
17	Los Torres oeste	70	60	17,000	25	①	The slope failure occurred during the Hurricane Mitch. A landslide of a width 100m is a the back, and the sliding block is its division block. It is in an unstable condition.	the earth and sand will accumulate on the river bed.	The southern plateau is appropriate. Co.INESTROZA

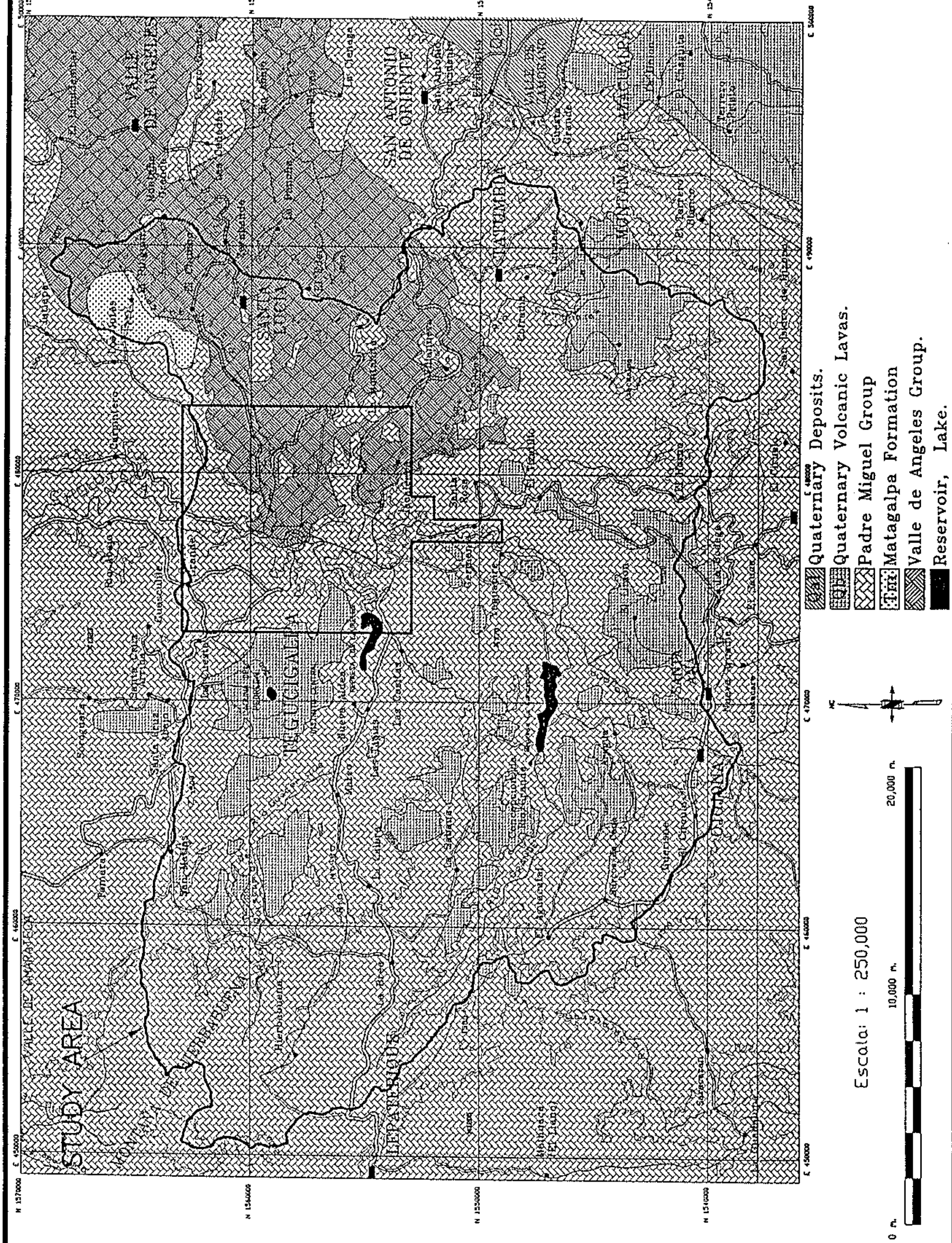

Figure B.3.1	Geological Map of the Study Area