

## 4.2 Production of 1/10.000-scale Orthophoto Maps

### 4.2.1 Ground control point survey (in technical cooperation with IGN)

This work is carried out to obtain the XY coordinates and elevation values of control points to be used in the subsequent automatic aerial triangulation. The work specifications and required accuracy that were decided in the process of “Discussions on GIS/printed map specifications, about OJT scope and investigation of existing conditions” were adopted for this work.

For the basis of horizontal position and elevation, the following control points were placed.

- Control point : 25 points (plan=20 points)
- Pricking of existing triangulation point : 7 points (plan=10 points)
- GPS bench mark : 34 points (plan=25 points)
- Pricking of existing bench mark : 184 points (plan=175 points)

#### (1) Risk management

##### 1) Discussions with the Japanese embassy, JICA office, and related organizations

At the beginning of the field survey, the JICA office in Guatemala and Japanese embassy informed us of security problems in Guatemala. Therefore the study team raised safety as the first priority and also made IGN aware of this situation.

The study team prepared an emergency communication network for the members staying in Guatemala City. Also, the study team prepared a weekly fieldwork schedule of the members working outside of the city so that communications among the members were secured. This information was reported weekly to the JICA office in Guatemala and the Japanese embassy.

On February 14<sup>th</sup>, the JICA office requested the study team to enforce security control.

Hence the study team requested IGN to cooperate in changing survey points in (Totonicapan) and forming an advance mission.

##### 2) Formation of the advance mission

The role of the advance mission was to arrive to the survey area earlier than the survey group, check the local security, and escort the survey group members while they were surveying.

In fact, the advance mission interviewed local policemen, city hall, neighboring stores, gas stations, and local people so that the study team and IGN would be aware of the local

conditions.

### 3) Securing communication lines

In Guatemala, the mobile phone network is developed along the main roads. In order to conduct the GPS surveys, two mobile phones and two satellite telephones were supplied for communication. With these, survey teams could exchange with each other information about survey progress and transportation and also establish the emergency communication network with the study team office in Guatemala City. As a result, all the tasks were finished safely and efficiently.

## (2) Survey preparation

### 1) Adjustment of equipment

The followings are the equipment used for this survey. All equipment were examined, and adjustments made in Japan were reconfirmed before using.

- Trimble 4000SSE, Ssi GPS receiver (double frequency) : 4 sets
- Topcon Total Station GTS-3 : 1 set
- Nikon Autolevel AE-5 : 4 sets

### 2) Personnel assignment

The staff for the survey formed in technical cooperation of IGN is as follows:

- Survey supervisor ( JICA study team ) : 3 persons
- Survey engineer ( IGN ) : 8 persons

## (3) Survey

### 1) Control point survey (simplified static GPS survey)

At the request of IGN, the study team changed from photo control point survey to ground control point survey. Accordingly, the accuracy of the survey was increased.

The control point survey was conducted using GPS, including area triangulation, and 25 new control points were created. Eight existing control points in Guatemala were used as existing points. The survey was implemented by following the survey specifications decided in “Discussions on GIS specifications”. The control point survey plan is shown in Figure 4.2-1.

The results of analysis are as follows and are within the horizontal accuracy limit of 150mm and the vertical accuracy limit of 300mm.

Maximum error is:

Guatemala area:                    B(X)=24mm,        L(Y)=29mm,        H=200mm

Puerto Barrios area:                B(X)= 3mm,        L(Y)= 4mm,        H=18mm

To determine the elevation of each control point, an interpolation program was used. But if the evaluated point was near a standard line the elevation was determined by direct leveling. In this survey, the elevations of 13 points were determined by direct leveling and 12 points were by computation.

## 2) Pricking of existing bench marks

There are standard lines already set up throughout Guatemala, with approximately 700 km of the standard lines within the range of the 1/20,000 aerial photography. Benchmarks were pricked on these existing standard lines (184 points at approx. 4 km intervals). The prick points were selected in clear places on the aerial photos by the study team and IGN survey engineers and the difference in elevation measured from the benchmark by direct leveling.

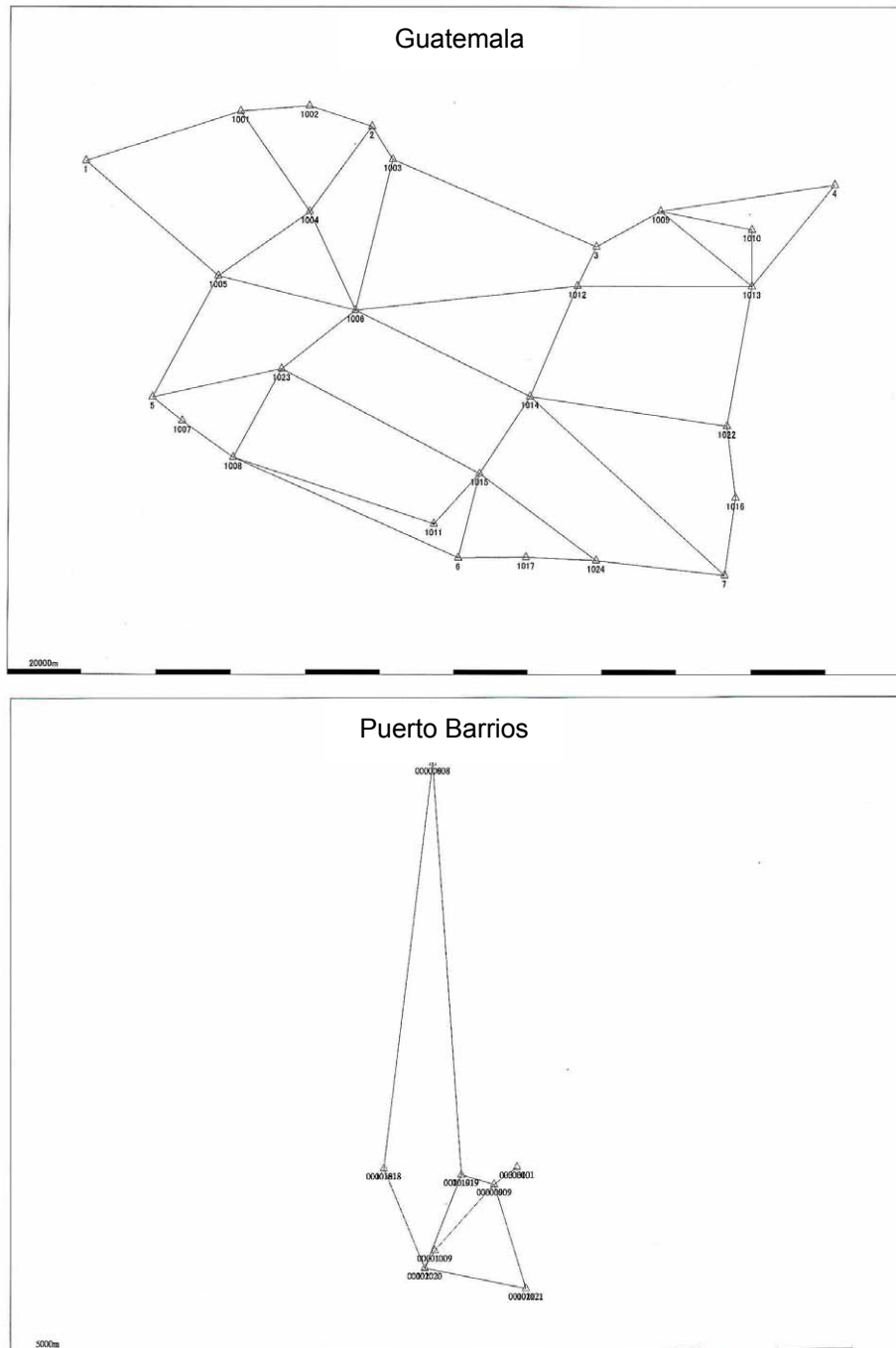


Figure 4.2-1 Control point survey

### 3) GPS leveling (simplified static GPS observation)

GPS leveling was carried out over a distance of about 100 km along a road with no fixed benchmarks at intervals of about 4 km. Using GPS, it was leveled by forming traverse routes and setting 34 GPS leveling points. Control points, with accurate elevations derived from direct leveling, were used as existing points. Surveys followed the survey specifications determined in "Discussions on GIS specifications".

## **4.2.2 Production of orthophoto maps**

### **(1) Negative film scanning of aerial photos**

The data was acquired with a resolution of 20µm per pixel and in 256 monochrome gradation levels, and the original image data acquired was stored as an archive in a universal TIFF format separately from the work data file.

### **(2) Automatic aerial triangulation**

Automatic aerial triangulation can yield stable results using a number of tie points. 649 photos for the west area, 1,070 photos for the central area and 18 photos for the east area were subjected to automatic aerial triangulation using the bundle adjustment method. In this process, batch processing and automatic processing were used extensively to ensure higher work efficiency.

### **(3) Creation of DEM**

Automatic DEM extraction is the work of searching for and determining stereo pair points. The DEM interval was set to 40m, equivalent to 4mm on a 1/10,000-scale map, and it was confirmed that this value was appropriate for topographic representation at this scale, the generation of contour lines and the creation of orthophotos.

### **(4) Generation of Contour Lines**

As for contour lines, it became apparent that if intermediate contours of 5m and index contours of 25m were drawn as originally planned, the intervals between the contours in mountainous terrain became particularly narrow, hiding the image data in the background. The Study Team therefore held discussions with their counterparts in both IGN and INSIVUMEH and determined that the interval would be 50m for index contours and 10m for intermediate contours. However, it was determined that the supplementary contours would be drawn at intervals of 5m on flat terrain.

### **(5) Contour Data Plotting**

To draw the contour lines, the method of creating TIN models to generate contours based on the DEMs at 40m intervals created in the above-mentioned work was used in conjunction with the method of acquiring some contour lines through stereoscopic viewing by the operator on the digital plotter.

For forest areas in which the error between the contour lines based on DEMs and the plotted contour lines exceeded 2.5m, the operator extracted the area and performed the plotting

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manually. The forest areas occupied approximately 40% of the Study Area, so it was more desirable and efficient to acquire the contour data by direct plotting than to perform processing to lower the DEM for each forest area by the tree height.

**(6) Creation of Final DEMs**

A TIN model was created based on the contour data acquired in direct plotting. DEMs at 40m intervals were created from the TIN model in this area and matched with the DEMs acquired in the above automatic processing, until the DEMs at 40m intervals were completed for the entire area.

**(7) Checking and Correction**

For the contour data that was created, accuracy control of the following items for each model was conducted to correct any errors:

- Technique (automatic generation method and contour line drawing method)
- Number of major errors (mismatching) only in automatic generation
- Number of features (trees, houses, etc.) requiring manual correction only in automatic generation
- Number of points joining adjacent models to be corrected

Accuracy control of the following items when creating DEM data (per model) was conducted to correct any errors:

- Data sequence
- Format errors
- Number of points

**(8) Plotting of Planimetric Data**

Planimetric features were plotted using a digital plotter. The main items plotted are shown in Table 4.2-1. As a rule, data was acquired and compiled in 3 dimensions.

**Table 4.2-1** Items for plotting planimetric features

	Point	Line	Poligon	Annotation
Center line of roads				
Center line of railways				
Center line of rivers				
Lakes and marshes				
Center line of road tunnels				
Center line of road bridges				
Center line of railway tunnels				
Center line of railway bridges				
Points of altitude				
Contour lines				
Values of altitude				

### (9) Horizontal/Vertical Sectioning of Rivers

For analyzing river floods, the horizontal/vertical section map of a river selected in “Discussions about hazard map production plan” was prepared through navigational measurement. The horizontal section survey lines were generated at a pitch of 2km from the vertex of the fan-shaped land and a width of 500m (250m on one side). The vertical section map was made at a scale of 1/10,000 on the horizontal axis (distance) and 1/100 on the vertical axis (height), while the horizontal section map was made at a scale of 1/1,000 on the horizontal axis (distance) and 1/100 on the vertical axis (height).

### (10) Automatic Creation of Orthophotos

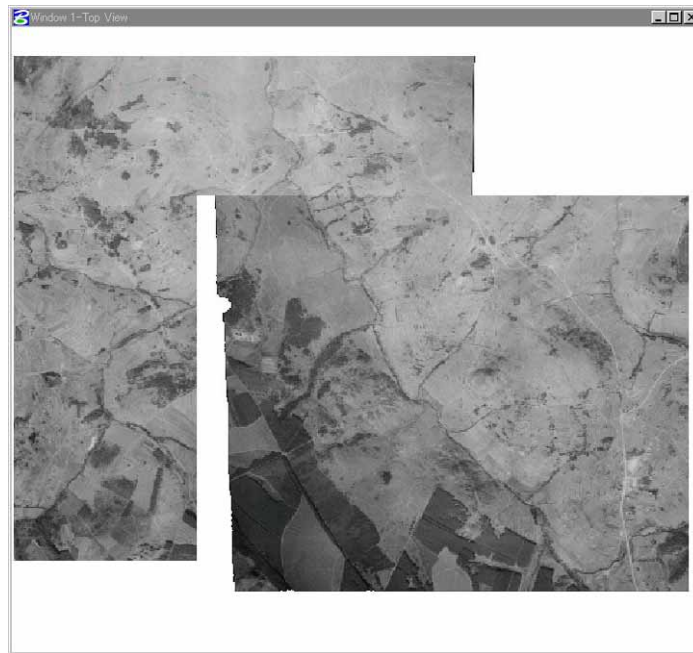
The orthophotos were produced by automatic processing using the created DEMs and the digitized aerial photo data. This process defined which photo of a stereo pair, left or right, was used, and the tie line was roughly drawn.

### (11) Mosaic Processing

The Study Team selected the joining line of the created orthophoto with the adjacent photo within the overlap range to set a tie line manually and create a mosaic image. The mosaic image was then subjected to cut-out processing for each 1/10,000 map sheet.

The specifications of the neat line files were as follows:

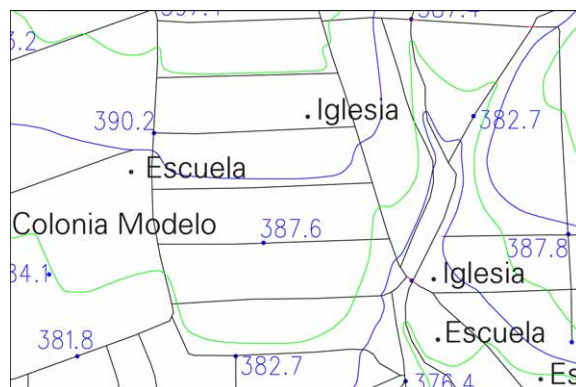
- Resolution : 600 dpi
- Gradation : 256 monochrome gradation levels
- Format : TIFF



**Figure 4.2-2 Mosaic Processing**

**(12) Checking of administrative boundaries and names**

As they were prepared based on the 1:50,000-scale annotations, not all of the 1:10,000-scale maps have the administrative names entered in them. Thus, it was necessary to rearrange each 1:10,000-scale orthophoto map so that the administrative names would be entered. It was decided through consultation with IGN that where a map showed no administrative boundary, one administrative name would be positioned at the centre of the map. Where a map did show administrative boundaries, one administrative name would be arranged at the centre of each administrative district.



**Figure 4.2-3 Compilation of annotation data by MicroStation**



**Figure 4.2-4 Merger of annotation data and orthophoto**



### (13) Supplementary field survey

#### 1) Checking of annotation positions

The positions of annotations that were unclear and picked out in the preliminary observation work were checked.

#### 2) Rectification of arrangement density

The names of new villages picked out in the preliminary observation work were investigated directly in the field. The input annotations were stored separately in an Excel file by IGN in order to prevent spelling errors.

#### 3) Checking of necessary public and other facilities

The positions of schools, churches, hospitals, police stations, military bases and public offices were checked accurately in the field. These facilities are public and medical institutions that at time of disaster would be designated as rescue and relief facilities and places of refuge.

These facilities were not entered as symbols, but as annotations such as “Escuela”, “Iglesia”, “Hospital”, “Policia”, “Militar” and “Municipalidad”, and the buildings were marked.



Photo 4.2-1 Field survey and OJT

### (14) Data entry of annotations/administrative boundaries

As a rule for the annotations on orthophoto maps the data created in preparing the 1:50,000-scale national base maps were input at reduced size. This means that some objects indicated by the annotations were unclear, but their positions were rectified on the basis of survey results (see Figure 4.2-5.).

Something that caused problems during the work of annotation input was notations unique to the Spanish language. When Spanish words are input into MicroStation, if the operating system and MicroStation are non-English versions, characters become garbled and do not show up correctly.



Figure 4.2-5 Input of schools and churches

Although the study equipment provided to Guatemala had English-language versions of both the operating system and the software, on

the equipment that the Study Team used both were Japanese-language versions. Therefore, as a temporary measure the Study Team replaced accents and other marks with other characters

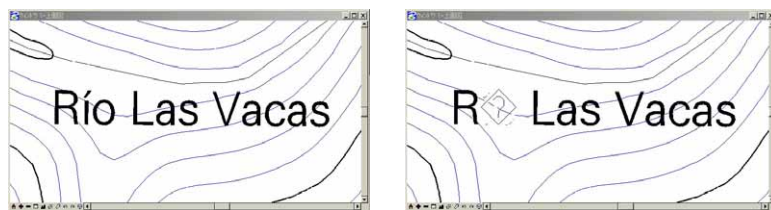


Figure 4.2-6 Normal and garbled character lines

when editing the annotations. When all the work was completed, the Study Team carried out a batch conversion of the annotations in Microstation on the study equipment, to reproduce the correct representations.

### (15) Digital compilation/structuralization

The data on topographic and planimetric features, annotations and administrative boundaries for which digital compilation was completed were subjected to structuralizing compilation in order to promote the effective use of GIS in the future. Specifically, the centre-line elements of roads, railways, rivers, etc., that form a network were inspected for data directivity and continuity, and corrected. In particular, the line elements between map margins where continuity is easily lost (see Figure 4.2-7) were inspected and corrected carefully.

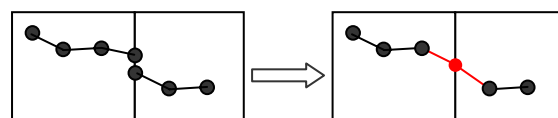


Figure 4.2-7 Connection between map margins

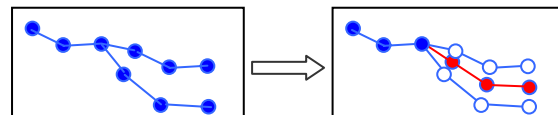


Figure 4.2-8 Generation of river centre line

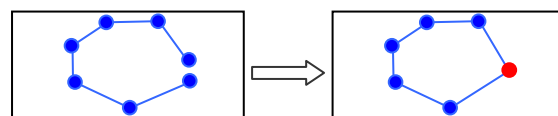


Figure 4.2-9 Closed figure for lake or swamp

For double-line rivers, the same processing was done after centre lines had been generated

separately. (See Figure 4.2-8)

It was confirmed that the shorelines of lakes and swamps were represented as closed figures. (See Figure 4.2-9)

#### **(16) Accuracy control**

The Study Team carried out an inspection on rough discrepancies for each neat line and on the height of the entire study area, continuity of data and layer architecture, and prepared an accuracy control table on the inspection results.

#### **(17) Production of output maps and CD-ROMs**

The orthophoto maps were produced by overlaying various types of hazard information on the orthophotos produced using the digital photogrammetry system.

The total number of 1:10,000 scale orthophoto maps produced was 401 sheets, and it is expected that their handling and data management will be complicated. Considering the original purpose of the hazard maps, the Study Team and the counterparts decided that there was no need to output the 1:10,000 scale orthophoto maps. Thus, it was decided to divide the area for the production of hazard maps into 6 blocks and to output them at a scale of 1/25,000.

As the orthophoto data is set by latitude and longitude, the map margin lines were moved. On the orthophoto images the pixels of the oblique parts touching the map margins were set to white, so that if things were left in this state there would be gaps between adjacent orthophoto images. This problem was solved by using graphic software to remove the white color.

Each type of hazard map was overlaid on this image data, then all the map sheets were given marginal information and output. Separately from the output maps, the ortho image data and graphic data for all the map sheets were stored on CD-ROMs.

## 4.3 Hazard mapping

### 4.3.1 Outline of hazard mapping study

#### (1) Purpose of hazard mapping

The Republic of Guatemala suffered from severe damages caused by Hurricane Mitch in 1998. The country being prone to disasters from earthquakes and volcanoes, it is extremely important to create hazard maps, define hazard areas, and promote evacuation measures and safe use of land for minimizing losses due to disasters.

The hazard mapping project undertaken in cooperation by the JICA Study Team and Guatemalan government agencies, particularly INSIVUMEH, was aimed at creating hazard maps to improve the disaster prevention in Guatemala. It would also promote the transfer of technologies in creating hazard maps as well as proposing methods for use.

#### (2) Overall flow of hazard mapping study

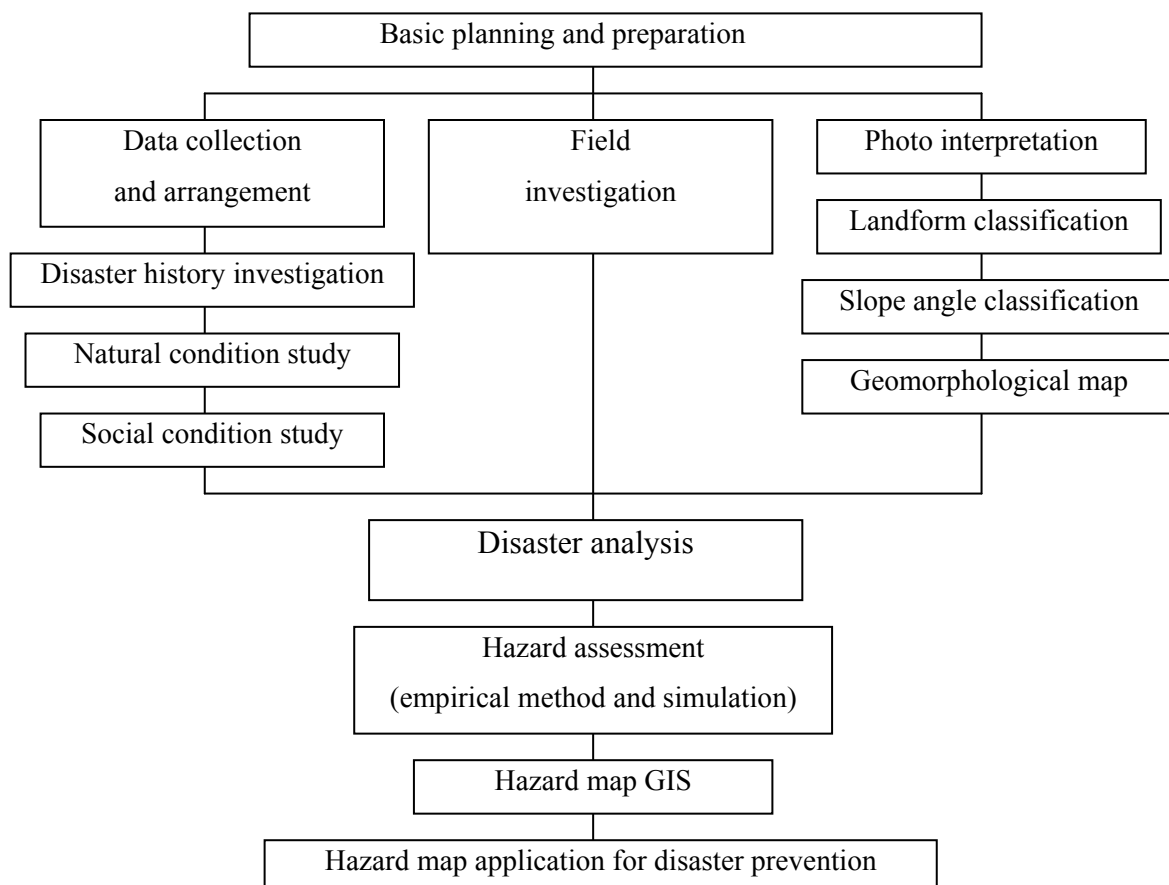


Figure 4.3-1 Overall flow of hazard mapping study

**List of work items in FY2000**

- ◆ Basic planning and preparation
- ◆ Discussion on implementing policies (objectives, processes, work systems, products, etc.)
- ◆ Investigation of present conditions for creating hazard maps
- ◆ Data collection and arrangement
- ◆ Field investigation (understanding the general conditions of disaster environment in each area)

**List of work items in FY2001**

- ◆ Discussion on implementing policies (processes, work systems, and technology transfer)
- ◆ Disaster history investigation
- ◆ Investigation of natural conditions (geological, seismological, volcanic, and hydrological conditions)
- ◆ Investigation of social conditions (population, buildings, national and regional disaster prevention systems)
- ◆ Interpretation of aerial photographs
- ◆ Geomorphological investigation and slope angle classification
- ◆ Field investigation (examination of disaster causes)
- ◆ Analysis of disaster causes (discussion on methods for creating hazard maps)

**List of work items in FY2002**

- ◆ Discussion on implementing policies (processes, work systems, and technology transfer)
- ◆ Creation of geomorphological maps and slope angle classification maps
- ◆ Field investigation (examination of disaster causes)
- ◆ Disaster estimation operation (such as simulation)
- ◆ GIS technology transfer

**List of work items in FY2003**

- ◆ Discussion of implementing policies (processes, work systems, and technology transfer)
  - ◆ Discussion of disaster estimation results (such as the simulation techniques)
  - ◆ Creation of products
  - ◆ Hazard map GIS technology transfer
  - ◆ Proposals and discussion of utilization of hazard maps
  - ◆ Preparation for and holding of seminars
-

◆ Submission of products

Table 4.3-1 shows the list of created hazard maps.

**Table 4.3-1 Created hazard maps**

Type of Hazard	Study Areas	Number of Sheets		
		1:50000	1:25000	1:10000
Seismic Hazard	Guatemala City		5	
	Quetzaltenango			1
	Mazatenango			1
	Escuintla			(combined)
	Puerto Barrios			1
Volcanic Hazard	Tacana	1		
	Santiaguito		5	
	Cerro Quemado		4	
	Pacaya		4	
Landslides	Guatemala City		4	
	Quetzaltenango		3	
	Antigua		1	
	North-west Region	14		
	Central Region	5		
Floods	Samala River		5	
	Acome • Achiguate • Maria Linda River		12	

A number of 13 sets of output maps are available only for the Takana volcano, while for others, 100 sets of printed maps are available.

### 4.3.2 Hazard map creation environment

#### (1) Guatemalan government agencies involved in disaster prevention

The counterpart organization concerning hazard maps for the Project is INSIVUMEH (Instituto Nacional de Sisimologia, Vulcanologia, Meteorologia, e Hidrologia: National Institute of Seismology, Volcanology, Meteorology, and Hydrology). INSIVUMEH, mainly in charge of observation, recording, and forecasting of natural phenomena, and other operations, also cooperated with researchers and donor organizations from other countries in creating their hazard maps. The observation equipment, most of which were damaged during the Civil War and Hurricane Mitch, are being repaired gradually, thanks to the assistance by USGS and other organizations. However, their budgets are currently reduced and the staff for observation and research could hardly be increased and technological improvements are late in coming.

CONRED (Cordinadora Nacional para la Reducción de Desasteres: National Coordinator for the Disaster Reduction) became, after Hurricane Mitch, an organization with full powers for disaster prevention and is receiving the assistance from several countries. The equipment (such as transportation devices and information collection systems and devices) required for handling emergencies are being steadily introduced. While getting the existing hazard map information from INSIVUMEH, CONRED is providing disaster prevention training and guidance using GIS to the local governments.

**Table 4.3-2 Major organizations for disaster prevention**

Organization name	Organization name (English)	Major operations	Relationship with hazard maps
INSIVUMEH (Instituto Nacional de Sisimologia, Vulcanologia, Meteorologia, e Hidrologia)	National Institute of Seismology, Volcanology, Meteorology, and Hydrology	Seismological, volcanic, meteorological and climatological, and hydrological observation, observation record management, weather forecast, and disaster survey	An counterpart organization in the Project, which was also involved in the creation of hazard maps in the past
CONRED (Cordinadora Nacional para la Reduccion de Desasteres)	National Coordinator for the Reduction of Disasters (directly controlled by the President)	Emergency handling, coordination of disaster prevention organizations, establishment of disaster prevention plans, and supply of guidance to local governments	An organization that utilizes hazard maps

**(2) Existing hazard map**

The creation of hazard maps started before Hurricane Mitch (Table 4.3-3). Small-scale hazard maps that cover the entire country were created around 2000. Many of the detailed hazard maps concerning volcanoes were created around 1986. Hazard maps for landslides, slope collapses, and debris flows were created by USGS in the Motagua river basin after Hurricane Mitch. The hazard maps created in the JICA project are the most detailed for earthquakes and floods because there are few others.

**Table 4.3-3 Hazard maps published in Guatemala**

Hazard	Object	Year	Scale	Title	Disaster factor	Creator
Earth-quake	All country	2000	1:250,000 1:2,000,000	Catálogo de Mapas República de Guatemala - Amenazas de Sismos -	Scale of intensity	MAGA
Volcano	Tacaná	1986	1:50,000	Mapa preliminar de zonas de riesgo potencial de flujos de lava y depositos de nubes de cenizas de futuras erupciones del Volcan Tacana.	Lava flows Ash cloud	INSIVUMEH
				Mapa preliminary de areas de riesgo potencial de futuros flujos piroclasticos, flujos de lodo e inundaciones y explosions laterals del Volcan Tacana, Guatemala	Pyroclastic flows, Mud flows, Floods, Lateral blasts, Dome extrusion, Lava flows, Avalanches	
	Santiaguito	1988	1:50,000 1:500,000	Mapa preliminar de riesgos volcanicos del domo de Santiaguito, Guatemala	Pyroclastic flows, Lahars, Floods, Surge, Crater collapse, Lateral blast, Inundations	INSIVUMEH
				Mapa preliminar de zonas de riesgo potencial de depositos de nubes de ceniza de futuras erupciones del domo de Santiaguito, Guatemala	Ballistic bomb Ash fall	
	Cerro Quemado	1989	1:50,000	Areas de peligro potenciales para flujos de lavas, flujos piroclasticos y nube de cenizas-asociados en Cerro Quemado, Guatemala	Lava flows Pyroclastic flows Ash clouds	INSIVUMEH
				Area de peligros potenciales para explosiones laterals, avalanches, flujos de lodo, lahars y tephra en Cerro Quemado	Lateral blasts Ash fall Debris avalanche Debris flows	
	Fuego	1987		Preliminary ashfall hazard map for Fuego volcano, Guatemala.	Ash fall	INSIVUMEH
				Mapa preliminar de riesgo volcanico del volcan de Fuego	Ballistic bomb Debris flow Debris avalanche Lava flow	
	Feugo and Acatenango	2001	1:50,000	Riesgos volcanicos en Los Volcanes Fuego y Acatenango, Guatemala	Pyroclastic and lava flow Debris avalanche Lahar	J.W. Vallance, S.P. Schilling O.Matias W.I.Rose M.W.Howell



Hazard	Object	Year	Scale	Title	Disaster factor	Creator
	Pacaya		1:55,000	Mapa que muestra las areas de riesgo de avalanches de debris y colapso del volcan de Pacaya	Collapse Debris avalanche	INSIVUMEH
				Mapa que muestra las areas de riesgo de base surge y otros flujos piroclasticos del volcan de Pacaya	Base surge Pyroclastic flow	
				Mapa que muestra las areas de riesgo de flujos de lava del volcan de Pacaya	Lava flow	
				Mapa que muestra las riesgo de flujos de lodo del volcan de Pacaya	Mud flow	
				Mapa que muestra las areas de riesgo de caida de bloques de lava del volcan de Pacaya	Ballistic blocks Ash fall	
Land-slides	All country	2000	1:250,000 1:2,000,000	Catálogo de Mapas República de Guatemala - Zonas susceptibles a Deslizamientos –	Landslide, Collapse, Debris flow	MAGA
	Motagua river and Polochic river basin	2002	1:50,000	Mapa de Amenaza	Landslide, Collapse, Debris flow	USGS
Floods	All country	2000	1:250,000 1:2,000,000	Catálogo de Mapas República de Guatemala - Zonas susceptibles a Inundaciones -	Principal river, Problem of drainage	MAGA

### (3) Past disasters in Guatemala

The disaster records in Guatemala are not well organized. In the Study, we collected and organized various documents and records and created a chronological table of disasters from Mayan times to the present (from 1469 to 2003). We identified as many as 230 incidents in the 534 years but the records for some of them may not be very reliable. Table 4.3-4 shows the major disasters.

**Table 4.3-4 Large disasters in history**

Date	Outline of damage
1541	<b>Ciudad Vieja Earthquake.</b> , the old Capital City of Guatemala was destroyed.
1773-7-29	City of Antigua Guatemala was destroyed by the <b>earthquakes of Santa Marta</b> . Max IM=IX, Ms=6.5
1862-12-19	<b>Earthquake of Santa Catarina Ixtahuacán</b> , Tecpán. The area of intensity of VIII and VII was 29,444 km <sup>2</sup> , and that of VI was about 54,000 km <sup>2</sup> . Max IM=VIII, Ms=7.24, D=30 km
1902-10-24/25	<b>Eruption of Santa María Volcano</b> . About 6,000 deaths. It is called the Twentieth Century's eruption (probably at world level).
1929-9-15	<b>Hurricane</b> . Heavy rainfall at the whole country, damages in 24% area of the country. Destruction of the railroad of Los Altos (Quetzaltenango-San Marcos Area). Affected road sections: 33, bridges: 24, towns: 18
1929	<b>Eruption of Santiaguito volcano</b> . Killed about 2,500 persons.

### 4.3 Hazard mapping

Date	Outline of damage
1933-9-11	<b>Tropical storm.</b> Deaths: 59 persons. Affected road sections: 47, bridges: 50, railroads: 9, inundated towns: 64, tumbled houses: at least 110, settlements and crackings: 9, affected public facilities: 21. Damages in 37% area of the country,
1942-8-6	<b>The biggest earthquake</b> up to now, in terms of energy liberation. Main damages were recorded at Guatemala, Sacatepequez, Chimaltenango, San Marcos, Totonicapán, EL Quiché, Escuintla and Huehuetenango. MR=8.3, D=60 km.
1949-9-28	<b>Tropical storm.</b> Total duration: Sept. 27-Oct. 6 <sup>th</sup> . Economic losses: US\$ 13.6 million.
1969-9-3	<b>Hurricane Francelia.</b> About 500 deaths. Economic losses: US\$ 6.5 million
1974-9/14-19	<b>Hurricane Fifi.</b> About 8,000-10,000 deaths. Economic losses: US\$ 30 million.
1976-2-4	<b>Guatemala Earthquake.</b> Most deadliest earthquake. 22,778 deaths and 76,465 injured. Economic losses: US\$1,250 million. Max IM=IX, MR= 7.5, D=5 km.
1998-10-27/30	<b>Hurricane Mitch.</b> 202 deaths. Economic losses: US\$748 million.

Nomenclature:

IM=Intensity Mercalli, MR=Magnitude Richter, Ms=Magnitude of Surface Wave, MI=Local Magnitude, Mag=Magnitude (no specification), SS= Seismic Source, EP= Epicenter, D=Depth, E=Earthquake, V=Volcanic Eruption, H= Hurricane, L=Landslides

The recent major disasters include Hurricane Mitch that hit Central America from late October to early November 1998 (202 dead in Guatemala), Guatemalan Earthquake that struck on February 4, 1976 (22,778 dead), Hurricane Fifi in September 1974 (about 10,000 dead), the eruption of the Santiaguito volcano in 1929 (about 2,500 dead), and the eruption of the Santa Maria volcano in 1902 (about 6,000 dead).

Based on the field survey of 2001, the interpretation of aerial photographs, and data provided by various organizations, the disaster maps showing damages due to Hurricane Mitch were created. The backgrounds of the disaster maps are 1:50,000 topographical maps (digital data). The maps cover the four river basins, Guatemala City, and Puerto Barrios, which are the flood study areas in the Project.

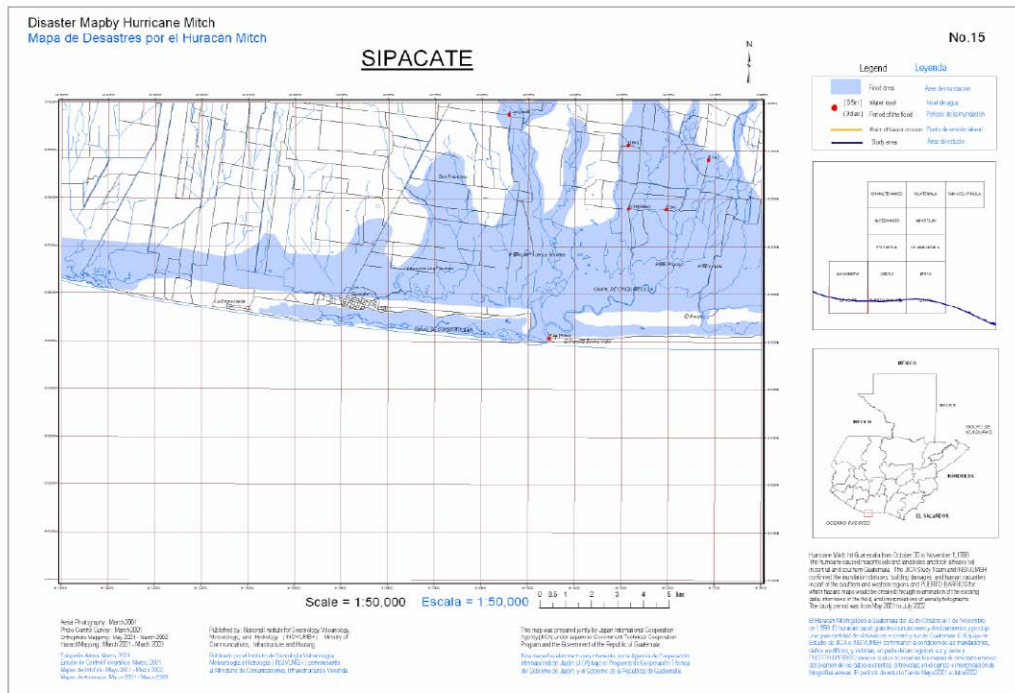


Figure 4.3-2 Sample disaster map

**(4) Natural environment**

The Republic of Guatemala, located in a geographical position where the Caribbean, Pacific, and North American plates encounter (Figure 4.3-3), is frequently hit by earthquakes and volcanic eruptions. In the surrounding ocean area, there brew many hurricanes, one or two of which hit Guatemala every year on the average. The central and southern departments of this country, surrounded by steep mountains and generally covered with pyroclastic flow deposits, are prone to sediment disasters including landslides, collapses, and debris flows when they are hit by earthquakes and torrential rains.

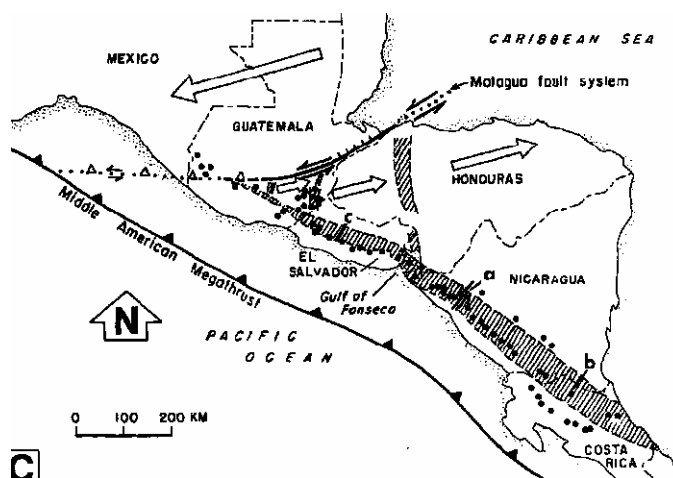
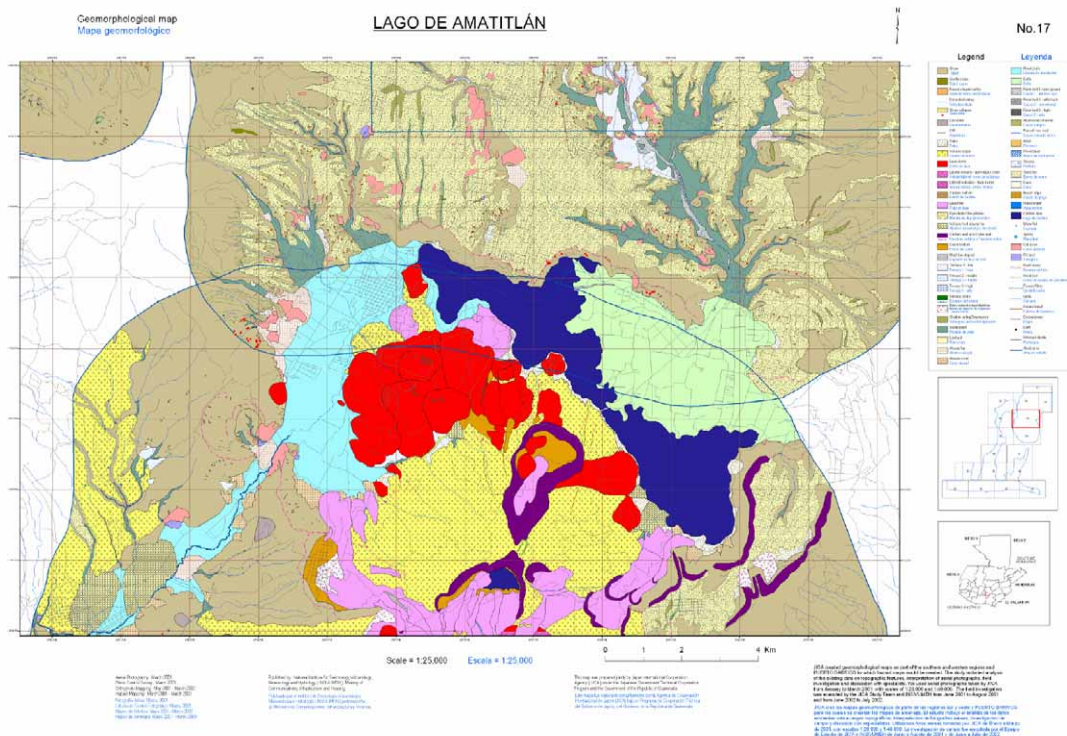


Figure 4.3-3 Movement of plates around Guatemala (G. Plafker, 1978)

**(5) Creation of geomorphological maps and slope angle classification maps**

For an appropriate understanding of disaster environment and creating hazard maps, we produced geomorphological maps through the interpretation of photographs and field survey. The geomorphological maps were once converted to 1:10,000 orthophoto maps, which were then digitized into 1:25,000 digital maps.

For the northwestern and central areas in the landslide study area, we created slope angle classification maps as one of the elements of landslide evaluation. Furthermore, we identified through the interpretation of photographs and supplementary field survey, then digitized the areas with concentrated landslides, slope collapses, and gullies and major roads vulnerable to sediment disasters.



**Figure 4.3-4** Sample geomorphological map

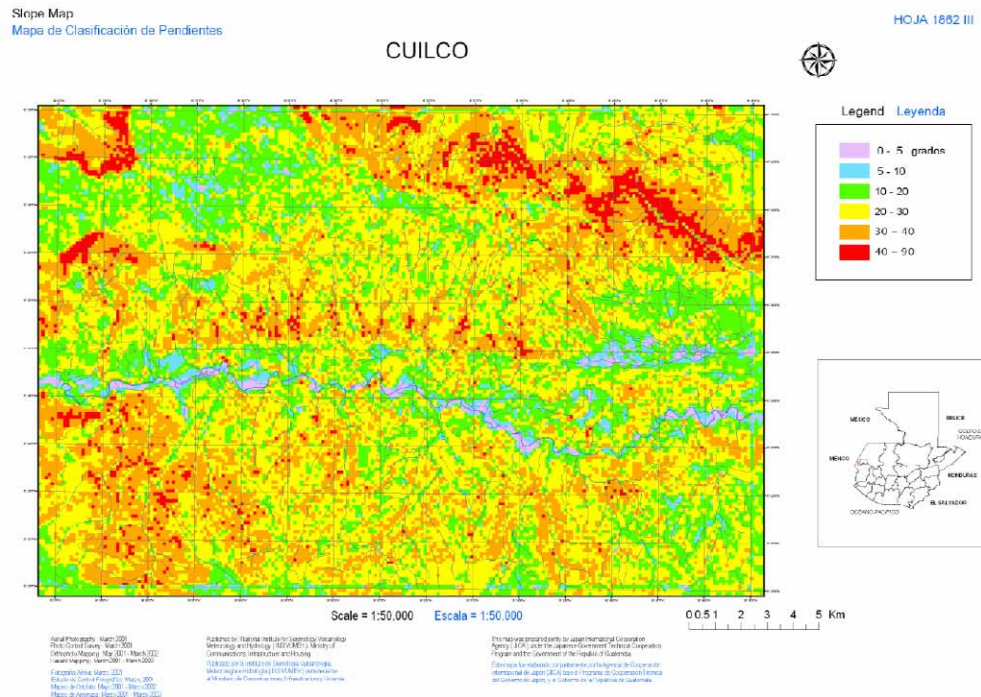


Figure 4.3-5 Sample slope angle classification map

## (6) Social vulnerability

In view of the social conditions, the vulnerability in terms of the social aspects such as poverty, lack of disaster cultures, and absence of visions for land policies is closely related to the occurrence of disasters. Poverty deprives people of choices of land, forcing them to live on land that is not appropriate for living such as steep slopes and lowland area along rivers. Furthermore, people and communities living in such land do not have sufficient disaster prevention facilities such as communication devices and evacuation routes. They often get disaster information through television or radio and escape on their own decision. There are not yet sufficient evacuation centers or escape routes that allow people to go up slopes to safe plateaus.

Moreover, the information on past disasters is not communicated properly because the migration of people is intense and there are many new residents.

Furthermore, the government has not yet put restrictions on residence or land use in dangerous areas in order to develop a community immune or resistant to disasters. Although the governmental agencies have been tackling disaster prevention after Hurricane Mitch, the main problem in disaster prevention that many people live in disaster hazard areas has not been solved yet.

It can be said from the field survey that roads and river structures are repaired only on a first-aid basis or apparently mostly left unattended. Regarding the mountain roads, even major