in the three areas. In other words, it is difficult to clarify the threshold that causes landslides and slope collapses. After the earthquake in 1976, many researchers including Edwin L.Harp, Gerald F. Wieczorek, and Raymond C. Wilson (1981) conducted investigations.

According to Edwin L.Harp, Gerald F. Wieczorek, and Raymond C. Wilson (1981), the landslides and slope collapses occurred frequently in the IX area as defined in the Modified Mercalli's intensity scale (MMI) and occurred selectively in evidently fragile locations in terms of topographic and geological features in the VIII and VII areas. Incidentally, landslides in San Salvador and Santa Tecla due to the El Salvador Earthquake that struck on January 13, 2001 also occurred in the MMI VII area.

Based on these past cases of landslides and slope collapses, we may be able to determine the threshold of ground motion that triggers them. The Modified Mercalli Intensity (MMI) establishes that landslides are produced at intensities of VII (small ones) and more than X (large ones). Thus, the correspondence of this rule with the known data of previous earthquakes (1976-2-4´s in Motagua Fault) must be established. For the case of the 1976-2-4's earthquake, in Figure 2.3.8-45 the distribution of seismic intensities and landslides is shown for the affected area.

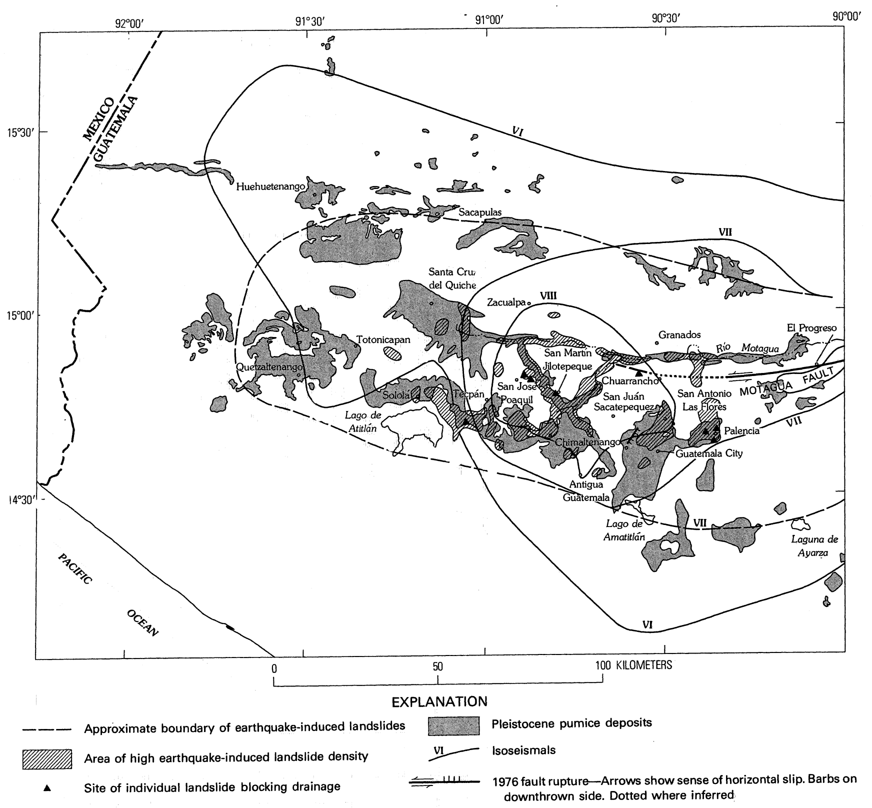

Figure 2.3.8-45 Southwestern Guatemala, showing areas of high density of earthquake-induced landslides, distribution of Pleistocene pumice deposits (Bonis and others, 1970; Koch and McLean, 1975), isoseismals (Espinosa and others, 1976), fault rupture (Plafker and others, 1976), and approximate limits of landslide-affected area. (After E.L. Harp, et al, 1981).

It is known that topographic amplification of ground motion depends on the angle of incidence of the incoming waves, on their frequency and on the geometry of the reflecting surface. Greatest amplifications are produced in nearly horizontal waves with wavelengths equal to or smaller than the canyon dimensions (separating walls).

According to the inventory of landslides at INSIVUMEH, rainfalls caused 73% of the landslides and slope collapses that occurred in the central and southern departments of Guatemala in 1881 to 1991. In the case of Hurricane Mitch, a rainfall of about 200 mm in a day or about 300 mm in two days in Guatemala City caused many slope collapses. In the disaster of Ciudad Vieja on June 13, 2002, a rainfall of 70 mm in a day caused a debris flow. At this time, there was an estimated rainfall of 70 mm in about two hours.

Since INSIVUMEH does not observe hourly rainfalls in all study areas, the amount of hourly rainfall that influences the occurrence of landslides and slope collapses in the study areas cannot be identified in detail. However, it is assumed that slope collapses occur if there is a daily rainfall of about 100 mm and much of the rain falls in a short time and that more slope collapses occur following a precipitation of a few hundred millimeters for several days. Figure 2.3.8-46 shows the relationship between slope collapse disasters and rainfalls in a certain area of Japan. While the antecedent precipitation specifies the underground moisture content, daily or short-time rainfalls can constitute triggers. Thus, the occurrence of slope collapses due to rain should be estimated according to these two indexes.

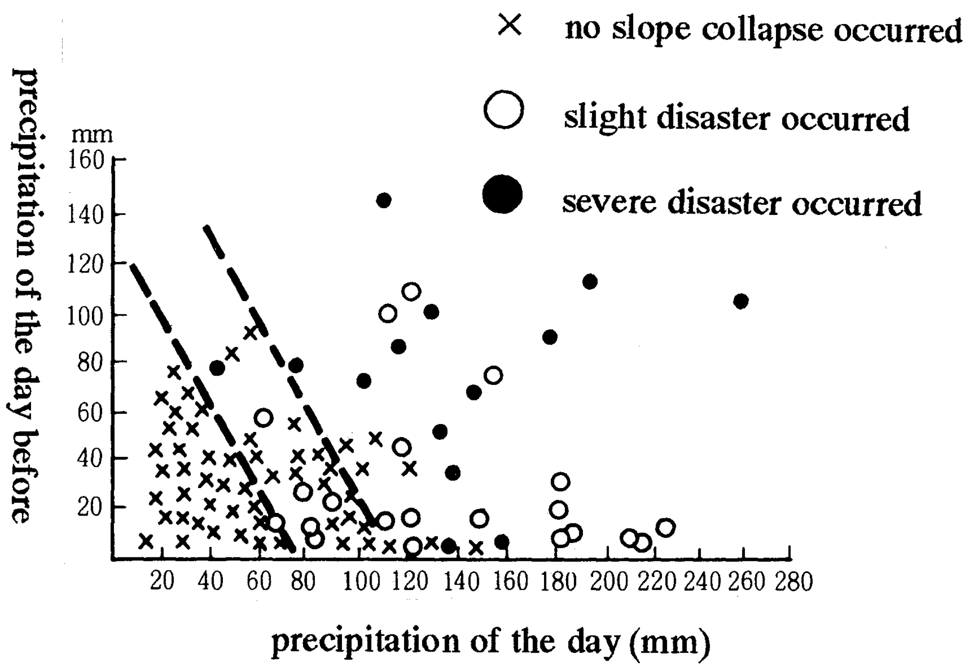

Figure 2.3.8-46 Relationship between antecedent precipitation and daily rainfall (Japan Aomori Meteorological Observatory, 1986)

Summary of Conditions under Which Landslides and Slope Collapses Occur:

Earthquakes: In the MMI IX or higher areas, extensive landslides occur and, on many slopes, slope collapses and rock falls frequently occur.
In the MMI VIII and VII areas, landslides sporadically occur and, locally, slope collapses and rock falls frequently occur.
In the MMI VI area, slope collapses and rock falls sporadically occur.

Rainfalls: With a daily rainfall of 200 mm or more, slope collapses and debris flows frequently occur and landslides and rock falls sporadically take place.
With a daily rainfall of 100 to 200 mm which concentrates in a few hours, slope collapses and debris flows frequently occur and landslides and rock falls sporadically take place.
With a daily rainfall of 100 to 200 mm during many hours, slope collapses, debris flows, and landslides sporadically occur.
With a daily rainfall of 70 to 100 mm which concentrates in one or two hours, slope collapses and debris flows sporadically occur.

Note: Landslides due to rain are likely to occur only if the underground moisture content has increased.

e) Definition of hazard ranks

In hazard rank evaluation of slope collapses and landslides, three elements including inclinations, landform classifications, and geological features were evaluated comprehensively. We assigned Hazard Rank A (the most dangerous) , Hazard Rank B (fairly dangerous), Hazard Rank C (a little dangerous) and Hazard Rank D (safe) ,based on the definitions in Table 2.3.8-15 to Table 2.3.8-17.

Table 2.3.8-15 Score of hazard rank evaluation of slope collapses in Guatemala City Area

		Slope angle					
		0-10°	10-20°	20-30°	30-40°	40-50°	50° -
Geology	Qp	0	1	3	5	5	3
	Tv	0	1	3	5	3	3
Slope collapse	Existing	5					
	Not Existing	0					

Qp : Quaternary Pumice, Tv : Tertiary Volcanic Rocks

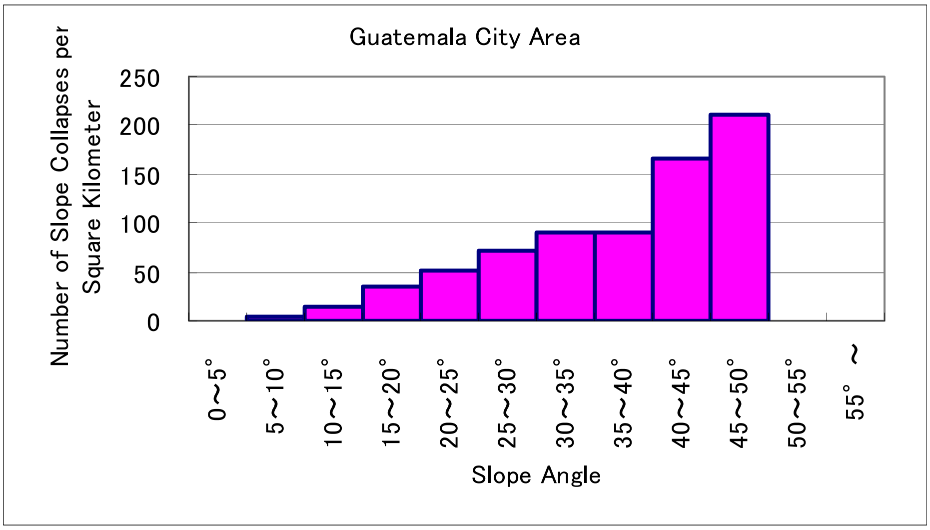

Figure 2.3.8-47 Number of slope collapses by slopes angles per Square Kilometer in Guatemala city area

Table 2.3.8-16 Score of hazard rank evaluation of slope collapses in Quetzaltenango Area

		Slope angle					
		0-10°	10-20°	20-30°	30-40°	40-50°	50° -
Geology	Qp	0	1	3	1	1	1
	Qv	0	0	1	3	3	3
	Tv	0	1	1	3	5	5
Caldera wall and crater wall		0	0	3	1	1	1
Slope collapse	Existing	5					
	Not Existing	0					

Qp: Quaternary Pumice, Qv: Quaternary Volcanic Rocks, Tv: Tertiary Volcanic Rocks

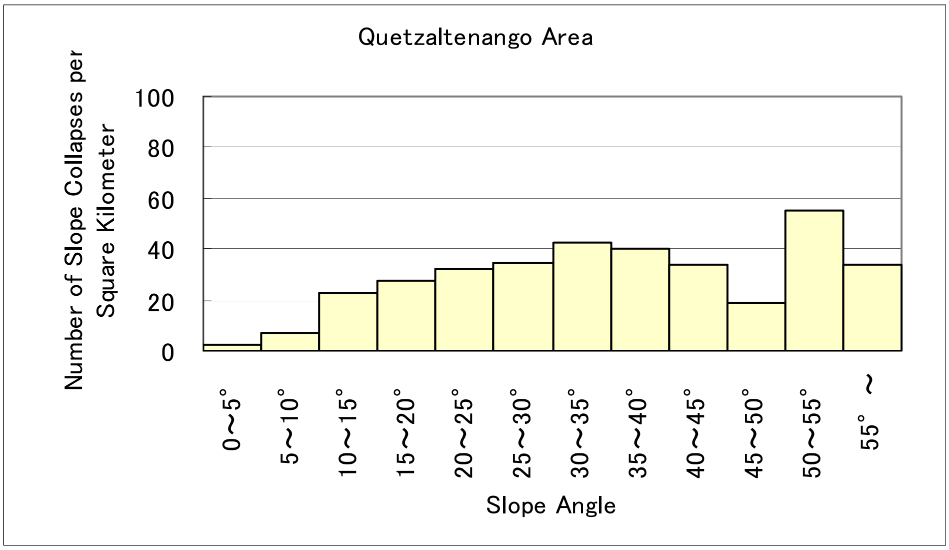

Figure 2.3.8-48 Number of slope collapses by slopes angles per Square Kilometer in Quetzaltenango area

Table 2.3.8-17 Score of hazard rank evaluation of slope collapses in Antigua Area

		Slope angle					
		0-15°	15-30°	30-35°	35-45°	45-55°	55° -
Geology	Qv	0	3	1	1	1	1
	Tv	0	1	1	3	5	3
Slope collapse	Existing	5					
	Not Existing	0					

Qv: Quaternary Volcanic Rock, Tv: Tertiary Volcanic Rocks

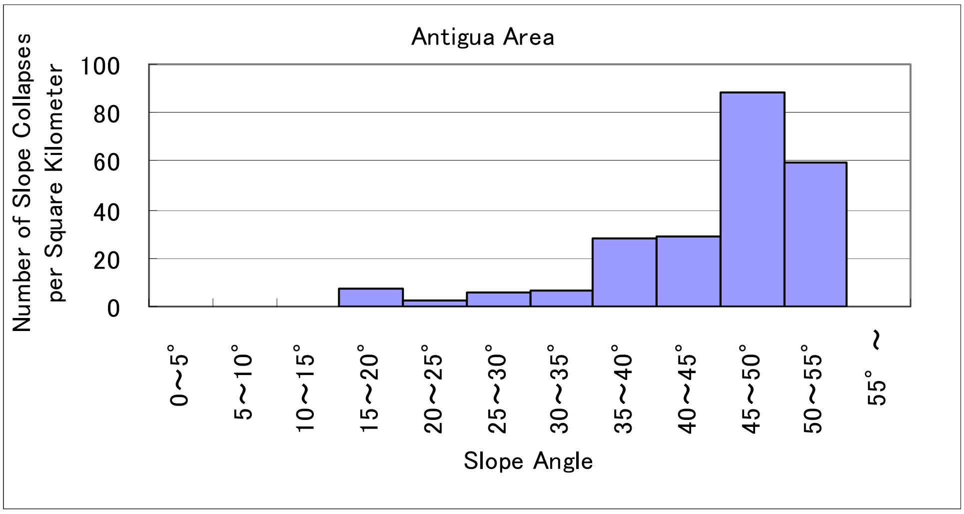

Figure 2.3.8-49 Number of slope collapses by slopes angles per Square Kilometer in Antigua area

Table 2.3.8-18 Classification of ranks of slope collapse hazard

Hazard rank	Definition	Restriction on land use, etc.
A (score:5)	Areas in which the Guatemala Earthquake or subsequent rainfalls caused slope collapses or there are existing evident slope collapses which may reactivate in the future	The land use should be restricted because the slope collapses may damage buildings and structures.
B (score:3)	Areas around the Rank A areas with similar topographic and geological conditions as the Rank A areas	It is advisable to avoid land use for residences because new slope collapses may occur.
C (score:1)	Areas with slopes where no slope collapse has occurred and no slope collapse is likely to occur because of geological conditions	There is no problem in land use as long as an attention is paid to embankment, cutting, and drainage on the slopes, if the area has enough distance from slope.
D (score:0)	Areas with gentle slopes or plain where no slope collapse will occur	No attention should be paid to landslides, if the area has enough distance from slope.

Table 2.3.8-19 Criteria for hazard rank evaluation of landslides

Evaluation item	Angles	Geomorphological type	Geology
Data precision	Grid	Polygons	Polygons
Comments		Only landforms where a landslide had occurred were evaluated. No other landforms were considered.	Geology where landslides had frequently occurred were picked up and evaluated. Regarding the ages, many landslides occurred in metamorphic and sedimentary rocks.

f) Presumption of debris spread area

Even a house in flatland where no landslide or slope collapses can occur may be damaged by landslide or slope collapse on a slope behind it. A house or building located in a valley plain or under upland consisting of pumice may be in danger depending on the distance between it and a slope. If people's lives are the priority, it is more important to consider how a slope collapse may affect houses and roads.

Figure 2.3.8-50 Influence of Slope Collapse on Houses under Cliff (Home page of Ministry of Land, Infrastructure and Transport of Japan)

Table 2.3.8-20 shows the statistical data of about 2,000 slope collapses that occurred in Japan. According to these data, the distance at which a slope collapse spreads debris significantly ranges from 1% of the height of collapsing land to about 13 times as long. Average slope height is 52% and the most is approximately 30%. For this survey, we set the spreading distance to 50% of the slope height although it varies according to the moisture content of debris or the inclination immediately under the collapsing land. Incidentally, landslides at Santa Tecla in San Salvador due to the El Salvador Earthquake that struck on January 13, 2001 caused debris to flow down to a distance about five times as long as the slope heights.

Table 2.3.8-20 Statistics of slope collapses in Japan

	Height H:m	Width W:m	Depth D:m	Volume V:m^3	Ratio of spread (Length/Height)
Average	16.6	17.6	1.6	335	0.52
Most frequent	10-20	10-20	1-1.5	100>	0.2-0.39
Min. to Max.	1.3-200	2-120	0.25-8	1-15000	0.01-12.9

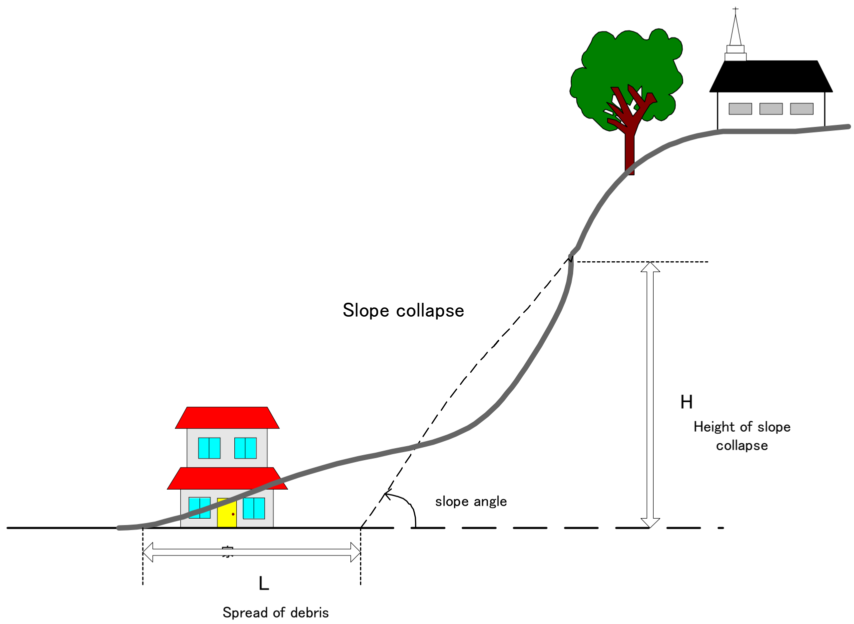

Figure 2.3.8-51 Schematic profile of slope collapse

Summary of distance to which debris reaches in landslides and slope collapses

◎ Debris may spread up to a distance 50% as long as the slope height.
◎ A larger landslide or slope collapse may spread debris to a longer distance.
◎ A slope collapse by heavy rain tends spread debris to a longer distance than a slope collapse due to an earthquake

4) Wide study areas (North-West Region and Central Region)

a) Identification of areas with concentrated landslides, slope collapses, gullies and major roads vulnerable to slope disasters

The maps indicating the distribution of areas with concentrated landslides, slope collapses, and gullies are shown in Figure 2.3.8-52 and Figure 2.3.8-53. These maps are based on the interpretation of aerial photographs, supplementary field survey, and information supplied by Mr. Manuel Mota.

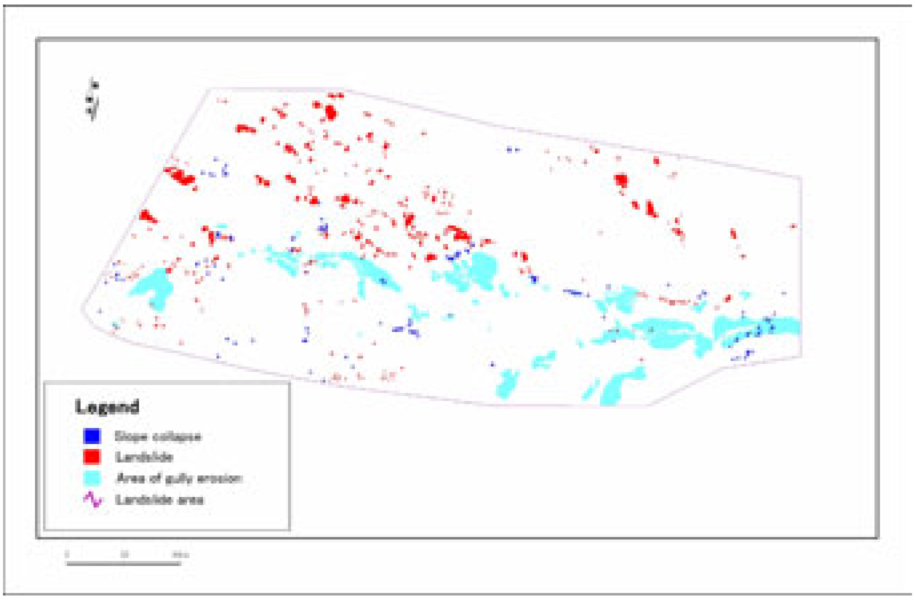

Figure 2.3.8-52 Areas with concentrated landslides, slope collapses, and gullies in North-West Region

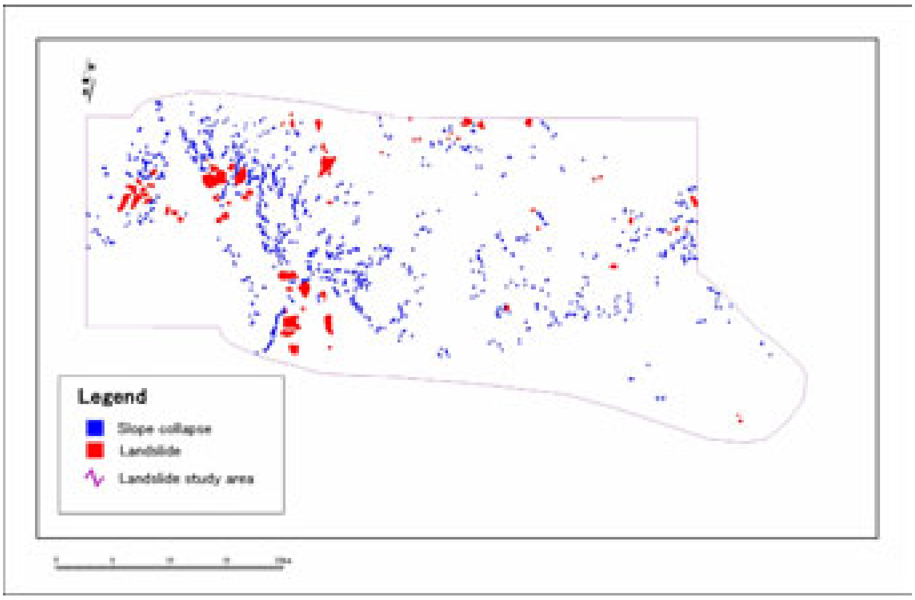

Figure 2.3.8-53 Areas with concentrated landslides, slope collapses, and gullies in Central Region

b) Slope classification and mapping

A slope classification map was created in the North-West and Central Regions. Figure 2.3.8-54 and Figure 2.3.8-55 show those two slope classification maps.

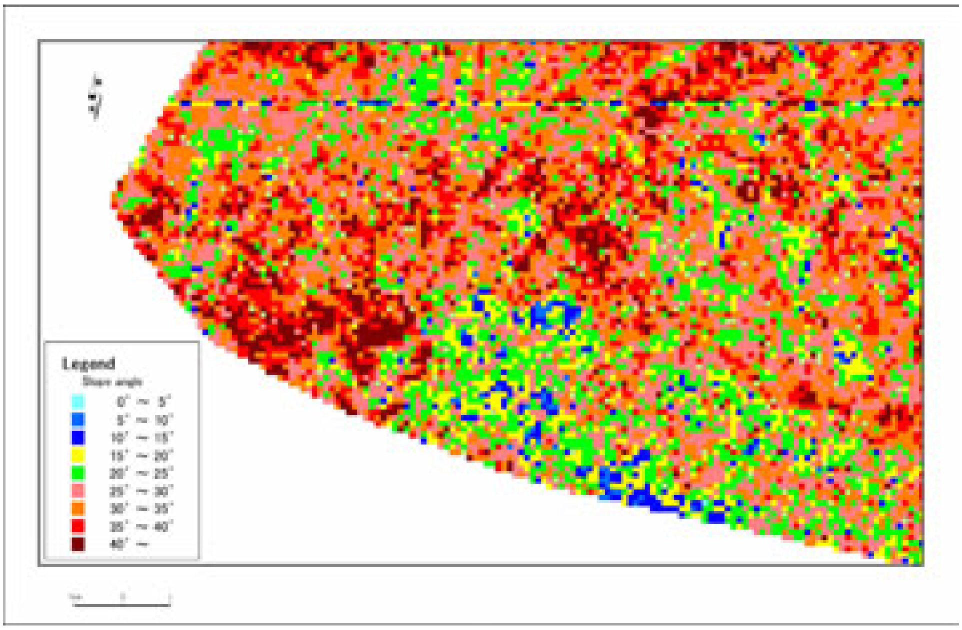

Figure 2.3.8-54 Slope classification map in North-West Region

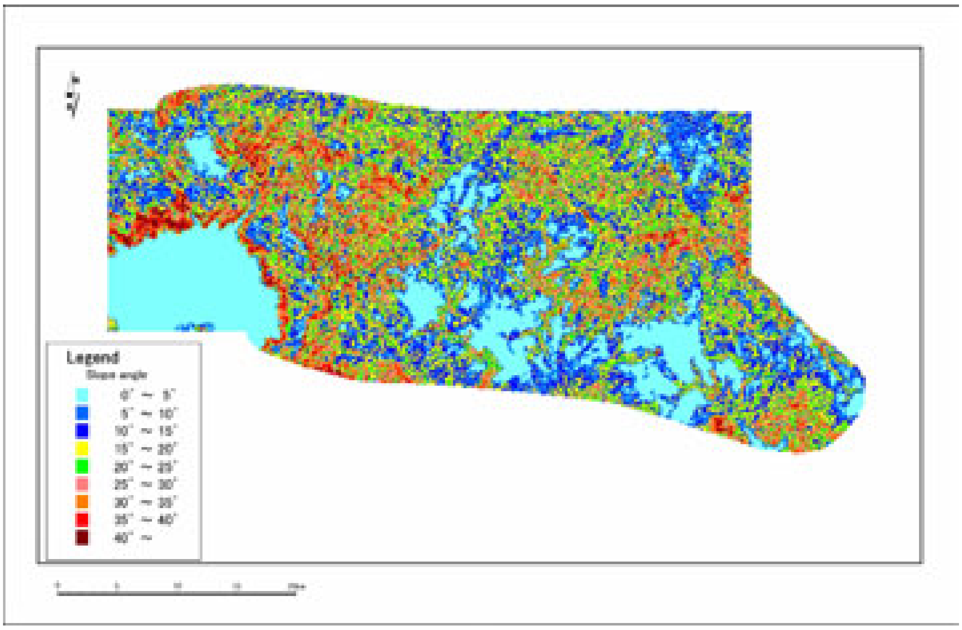

Figure 2.3.8-55 Slope classification map in Central Region

c) Relationship between landslides and slope angles

The distribution of these landslides, etc. was superimposed over the slope classification map to understand the relationship between landslides and slope angles. The relationship between landslides and slope angles in the two areas is shown in Figure 2.3.8-56 and Figure 2.3.8-57.

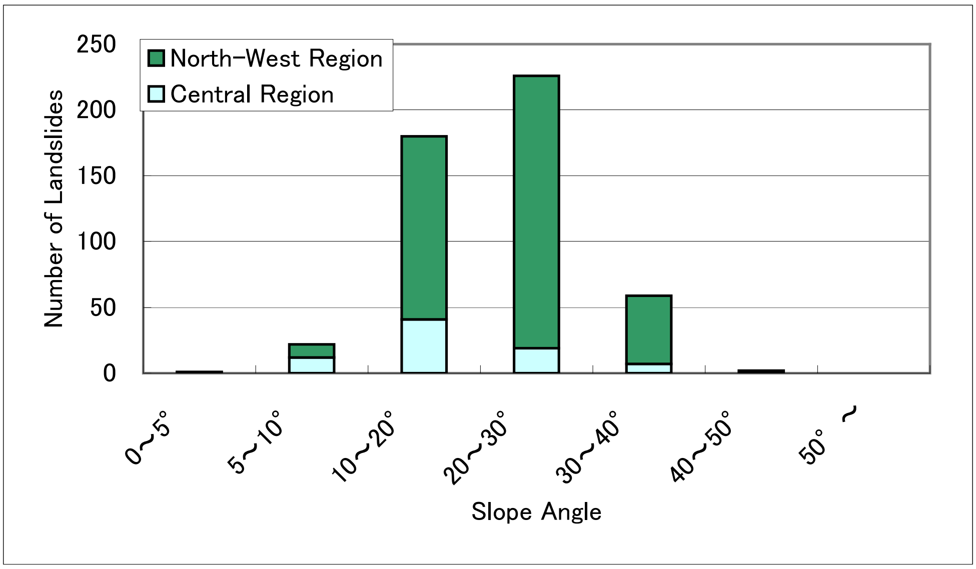

Figure 2.3.8-56 Number of landslides and slope collapses by slopes angles (All)

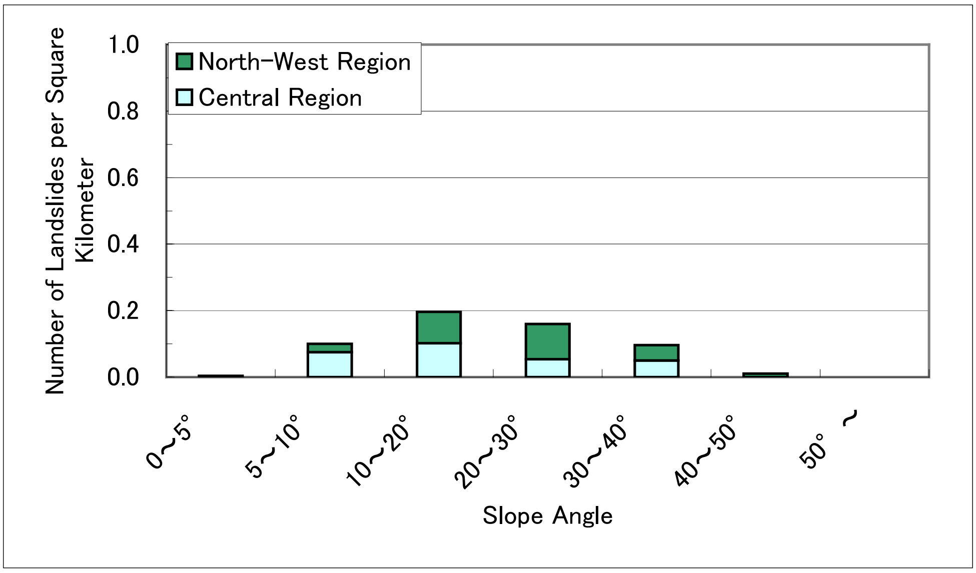

Figure 2.3.8-57 Number of landslides and slope collapses by slope angles per square kilometer

d) Relationship between landslides and geology

The distribution of landslides in the two areas was superimposed over the geological data with an accuracy corresponding to a scale of 1:250,000 provided by MAGA to understand the relationship between landslides and geological features (Figure 2.3.8-58 and Figure 2.3.8-59).

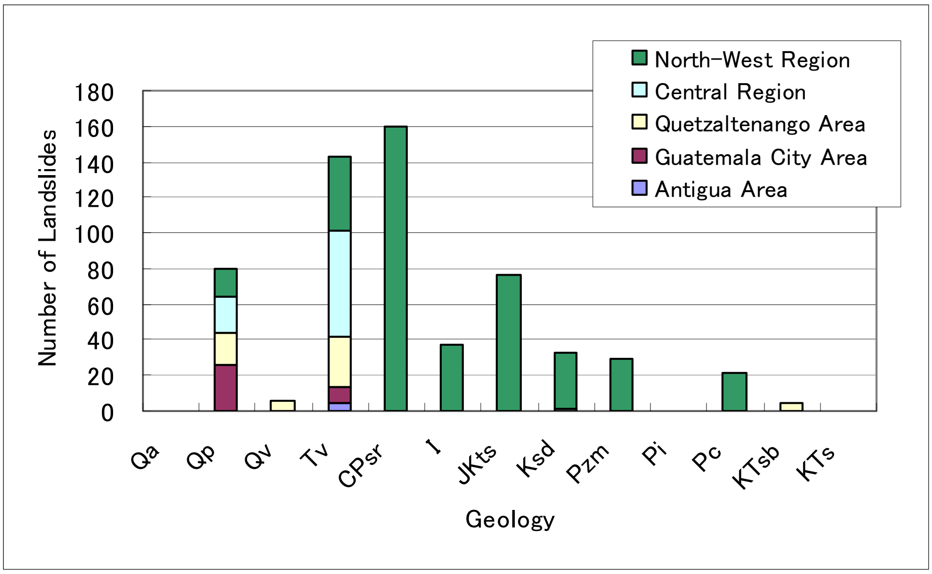

Figure 2.3.8-58 Number of landslides and slope collapses by geological features (All)

Abbreviation of geological type are same as Figure 2.3.8-39.

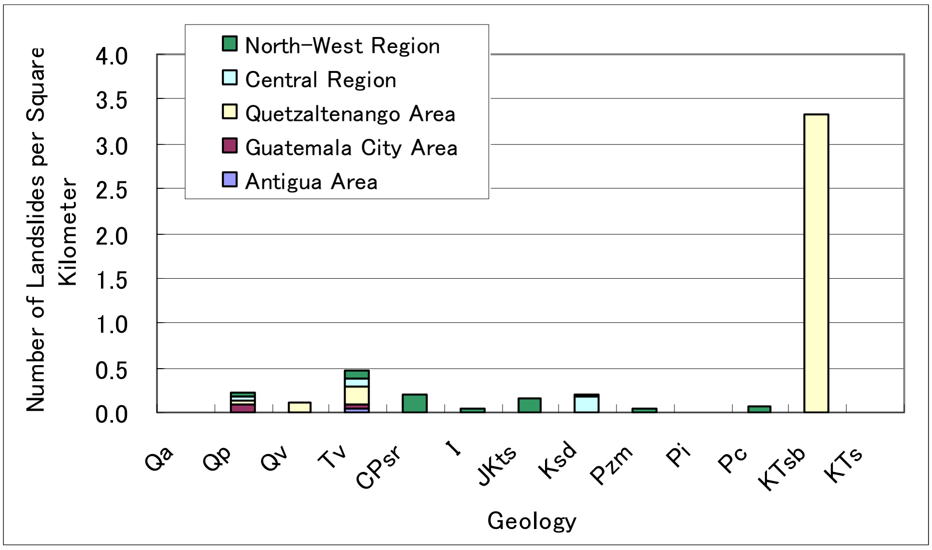

Figure 2.3.8-59 Number of landslides and slope collapses by geological features per square kilometer

Abbreviation of geological type are same as Figure 2.3.8-39.

e) Overlaying landslides over the slope maps

For the north-western and central areas, we decided not to create any landslide hazard map but to superimpose the slope classification map over the map showing the distribution of landslides, etc. in order to evaluate the probability of landslides, etc. These maps are not hazard maps indicating the risks of landslides but only one type of data used to examine the risks of landslides.

(5) Floods

1) Outline of simulation

There are four rivers for which flood hazard maps were made: the María Linda, Achiguate, Acomé, and Samalá.

Flood hazard maps were created in the following method and workflow (Figure 2.3.8-60 and Table 2.3.8-21). For the Samalá River, a hazard map was created through flood simulation. For the remaining three rivers, hazard maps were created through landform classification and disaster history analysis

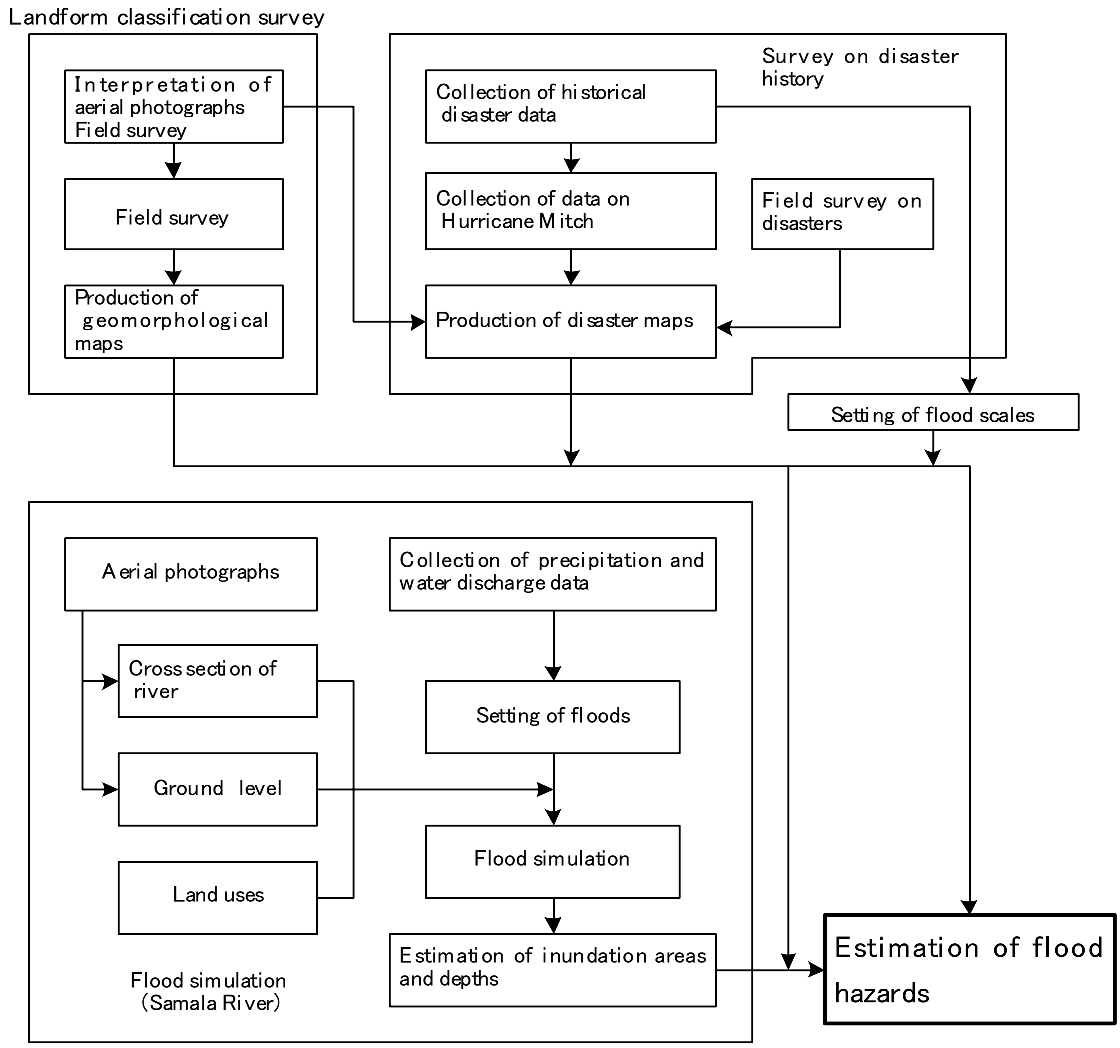

Figure 2.3.8-60 Flow of flood hazard map production

Table 2.3.8-21 Method for creating floods hazard maps

River	Hazard map production method
María Linda	Geomorphlogical classification, aerial photograph interpretation, and disaster history (Hurricane Mitch and other historical disasters)
Achiguate	
Acomé	
Samalá	Other methods plus flood simulation

2) Magnitude of target floods

The following three expected flood scales were used in the hazard maps (Table 2.3.8-22).

However, these flood scales are not based on such data as probable rainfall but are qualitatively assumed based on the situations in which floods occurred and the experiences of INSIVUMEH staff.

Table 2.3.8-22 Expected flood levels

Hazard level	Flood frequency	Comments
A	Flood that occurs about once every five years	Flood that frequently occurs due to torrential rain and inundates lowland areas along rivers
B	Flood that occurs about once every ten to fifteen years	Flood that occurs due to a hurricane, etc. smaller in scale than Hurricane Mitch. Flood that mainly inundates lowland areas along rivers and coastal areas.
C	Flood that occurs about once every twenty to thirty years	Flood as large as or larger than the one that occurred due to Hurricane Mitch

3) Method of flood simulation

a) Overall workflow

The flood simulation on the Samalá river was run as shown below.

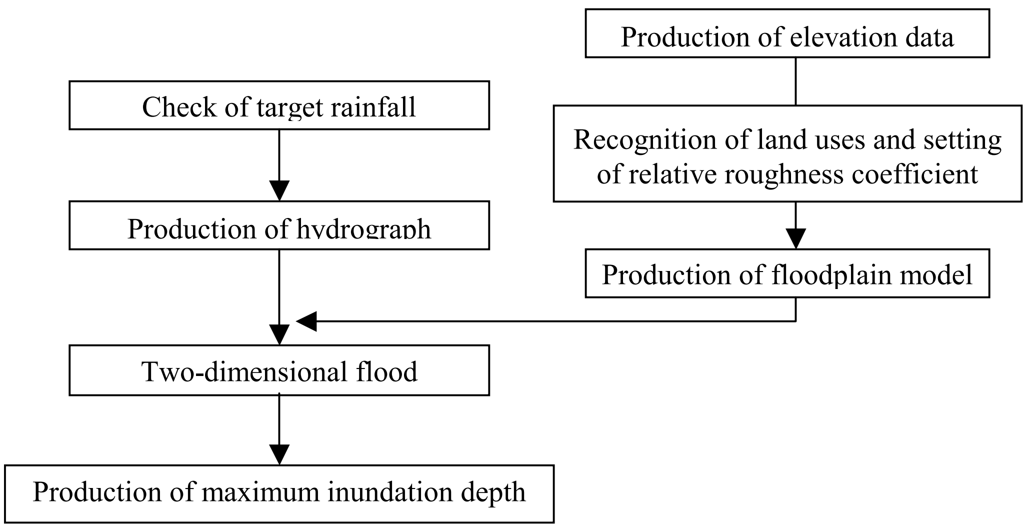

Figure 2.3.8-61 Flood simulation method

b) Production of elevation data

Based on DEM data at 40m vertical and horizontal intervals in an orthophotomap with a scale of , sixteen elevation values included in a calculation grid were averaged to be used as the average soil height of the calculation grid.

c) Recognition of land uses and setting of relative roughness coefficient

Based on aerial photographs and field survey, the characteristics of land in a grid were evaluated and a relative roughness coefficient was given to the grid.

d) Production of hydrograph (setting of flood)

INSIVUMEH measures the water level of the Samalá river at Candelaria. The observation result from September 20 to 22, 1974, during which the highest water level in the past was recorded, was used to create a hydrograph. We set Flood Level A as the record-high flood scale in 1974, Level C as the largest water discharge that occurs every 50 years based on the calculation by INSIVUMEH i.e., $1084m^3/s$, and Level B as the value in-between.

e) Two-dimensional flood simulation

The following two-dimensional unsteady-flow model was used to calculate the trace of flood flow.

- Continuity equation

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0$$

- Equation of motion (x direction)

$$\frac{\partial M}{\partial t}+\frac{\partial (uM)}{\partial x}+\frac{\partial (vM)}{\partial y}=-gh\frac{\partial H}{\partial x}-\frac{\tau_{bx}}{\rho}$$

- Equation of motion (y direction)

$$\frac{\partial N}{\partial t}+\frac{\partial (uN)}{\partial x}+\frac{\partial (vN)}{\partial y}=-gh\frac{\partial H}{\partial y}-\frac{\tau_{by}}{\rho}$$

Here, $M=uh$, $N=vh$, H : Water level, h : Water depth, g : Gravitational acceleration, ρ : Water density, u : Current velocity in x direction, v : Current velocity in y direction, τ_{bx} : Bottom frictional force in x direction that works on flowing water, and τ_{by} : Bottom frictional force in y direction that works on flowing water. Bottom frictional forces τ_{bx} and τ_{by} can be expressed as shown below using Manning's equation.

$$\tau_{bx} = \rho g n^2 \sqrt{(u^2 + v^2)} \cdot u / h^{1/3}$$
$$\tau_{by} = \rho g n^2 \sqrt{(u^2 + v^2)} \cdot v / h^{1/3}$$

Differences between the above equations (continuity equation, equations of motions, and bottom frictional forces) were taken. Next, a staggered scheme that defines water depth h in the middle of a grid and water discharge fluxes M, N and current velocity u, v in the sides of the grid was used. Then, a solution was obtained through digital calculation.

Table 2.3.8-23 Setting of conditions

Setting item	Condition
Grid size	120m grid
Land use	Relative roughness coefficient: River course mainly covered with gravels n=0.033 River course mainly covered with sand n=0.027 Floodplain n=0.060
Srudy area	Castillo Armas bridge to estuary
Flood scale	A: Record-high flood that occurred from September 20 to 22, 1974 (Maximum water discharge of 218.7m^3/s) B: Flood with an intermediate scale between A and C (Maximum water discharge of 542m^3/s) C: Flood that comes once every 50 years (Maximum water discharge of 1084 m^3/s) as defined by INSIVUMEH
Flood model	Two-dimensional unsteady-flow model

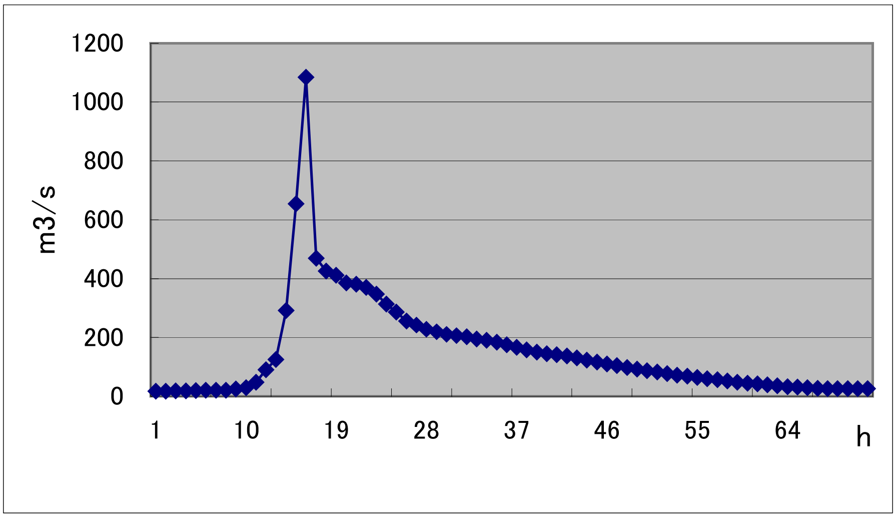

Figure 2.3.8-62 Hydrograph (Flood level C)

4) Evaluation by geomorphological method

Since a river landform is originally formed by frequent inundations and sediment outflow on the river, it is possible to identify a factor, i.e., disaster that has formed the landform, through interpretation of aerial photographs and field survey.

We made hazard evaluation on the María Linda, Achiguate, and Acomé rivers by making geomorphological analysis based on geomorphological maps and disaster history based on the interpretation of aerial photographs. For the Samalá, on the other hand, we used geomorphological maps during the process of estimating the inundation area from the digital data obtained through flood simulation so that the digital data and the landform situations were correctly reflected.

In general, the landform classifications based on the aerial photograph interpretation and the flood hazard levels have the following relationship. However, the rivers have different relationships between landforms and flood hazard levels depending on the vertical difference between the water surface and the landform surface, its distance from the rivers, the flow direction of the rivers, and the existence of embankments.

On the costa sur in particular, the zone from the mountains to the coast is a floodplain with little vertical differences. Such a landform has characteristics of encountering such phenomena as inflow of flood currents in the outward direction of curves of rivers, i.e., into diverging rivers and irrigation canals as well as overflow streams at confluence of rivers. Based on the landform classifications, we comprehensively evaluated the flood hazard ranks of study areas through field confirmation, disaster history, and interviews of residents.

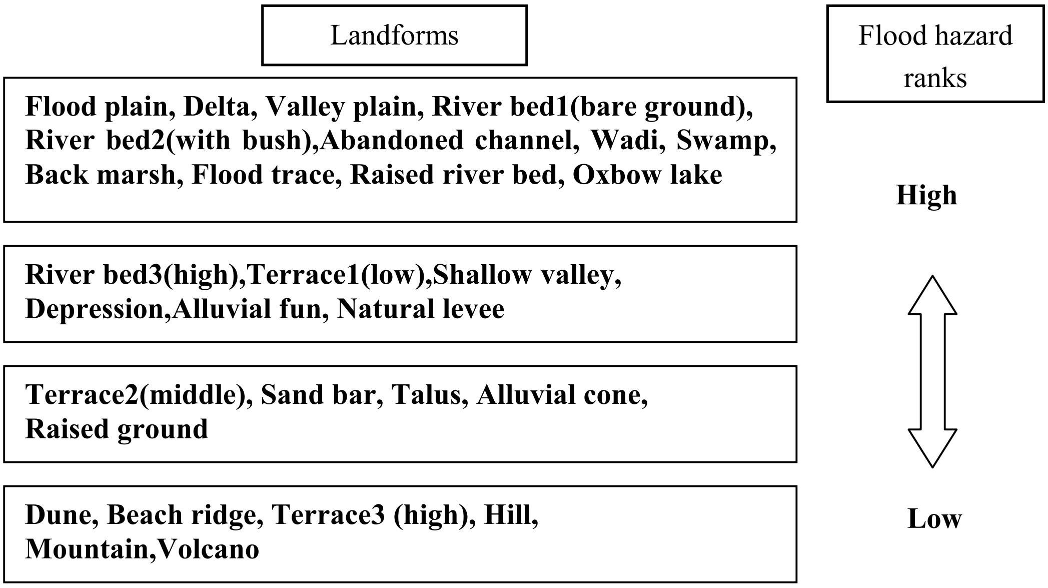

Figure 2.3.8-63 Relationship between landforms and flood hazard ranks

For the Samalá, we carried out lengthwise and crosswise survey using aerial photographs of the river and created 150 cross and logitudinal sectional views every 0.5km from the estuary to the 68.0km point.

On the Samalá, there is little vertical difference between the riverbed and the surrounding land downstream from near the 54km point (near San Sebastián). When rising, the river starts to flood such locations from the river course to the surrounding land.

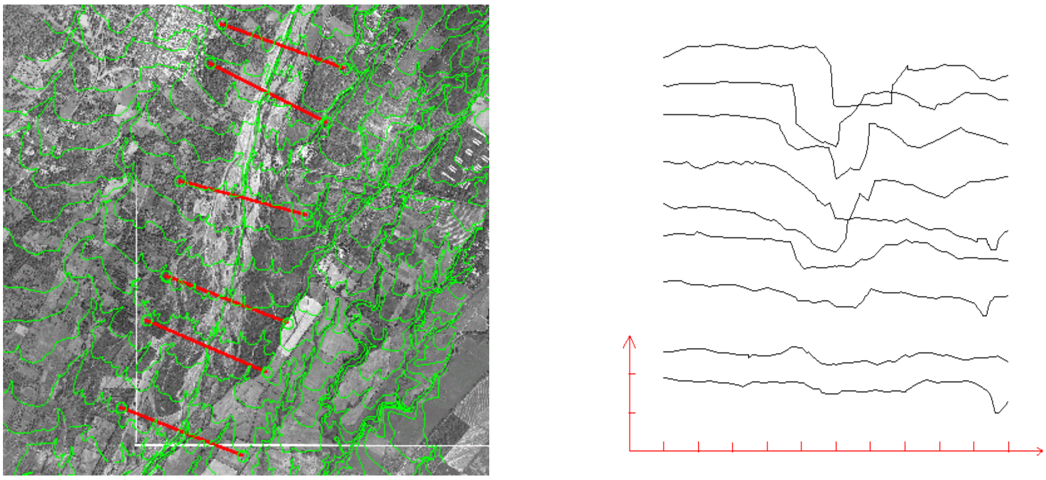

Figure 2.3.8-64 Cross sectional view of the Samalá River

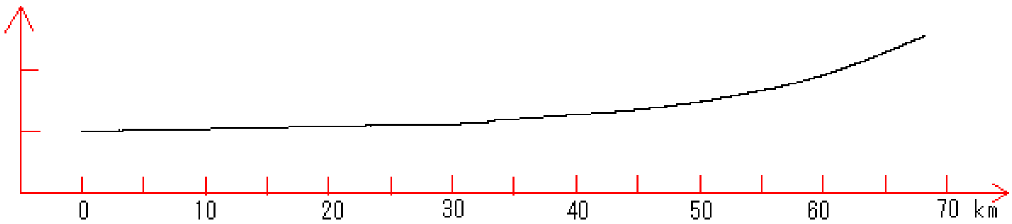

Figure 2.3.8-65 Longitudinal sectional view of the Samalá River

2.3.9 Results of hazard mapping

(1) List of hazard maps

Through the discussions with the Guatemala government organizations, mainly with INSIVUMEH, hazard maps were improved to be more user-friendly and easier to understand. Table 2.3.9-1 shows the list of hazard maps created by November 2003.

Table 2.3.9-1 Created hazard maps

Type of Hazard	Study Areas	Number of Sheets		
		1:50000	1:25000	1:20000
Seismic Hazard	Guatemala City	5		
	Quetzaltenango			1
	Mazatenango			1 (combined)
	Escuintla			
	Puerto Barríos			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	

(2) Seismic hazards study areas

1) Guatemala City

a) Results of estimations for hazard of ground motion and liquefaction

The seismic hazards are estimated for the following target source faults and earthquakes:

(a) Mixco fault

(b) Sta. Catarina Pinula fault

(c) Jalpatagua fault west segment

(d) Chixoy-Polochic fault central segment

(e) Motagua fault west segment

(f) Motagua fault central segment

(g) Subduction shallow segment

(h) Subduction deep segment

(a) Mixco fault

It is expected that the Guatemala City area would have a seismic intensity of Level VII or VIII. The seismic intensity is especially strong in the area extending from the west of the study area, close to the fault, to the central area. In the hill and mountain region, the seismic intensity would be of Level VI. The maximum acceleration would reach approximately 150 to 1020 cm/s2 and the maximum velocity, about 7 to 58 cm/s. The hazard of liquefaction would reach high level in the lowlands along Pinula, Las Minas, and Las Vacas Rivers.

(b) Sta. Catarina Pinula fault

It is expected that the Guatemala City area would suffer a strong shake with a seismic intensity of Level VIII. The seismic intensity is high especially at the center of the study area close to the fault. In other areas, the seismic intensity would be of Level VII. In the hill and mountain region, the seismic intensity would be of Level VI. The maximum acceleration would reach approximately 170 to 1020 cm/ s^2 and the maximum velocity, about 8 to 57 cm/s. The hazard of liquefaction would reach high level in the lowlands along Pinula, Las Minas, and Las Vacas Rivers.

(c) Jalpatagua fault west segment

It is expected that the Guatemala City area would have a seismic intensity of Level VII. The seismic intensity is high at Level VIII, especially in the southern part of the study area, close to the fault. In the hill and mountain region, the seismic intensity would be of Level VI. The maximum acceleration would reach approximately 120 to 930 cm/ s^2 and the maximum velocity, about 6 to 52 cm/s. The hazard of liquefaction is possible in the lowlands along Pinula, Las Minas, and Las Vacas Rivers. In the lowlands along Pinula and Las Minas Rivers in the southern part of the study area, close to the fault, the hazard of liquefaction would reach high level.

(d) Chixoy-Polochic fault central segment

It is expected that the Guatemala City area would have a seismic intensity of Level VI or VII. The seismic intensity is high in the lowlands along Pinula, Las Minas, and Las Vacas Rivers. The seismic intensity for the hill and mountain region would be of Level V. The maximum acceleration would reach approximately 80 to 270 cm/ s^2 and the maximum velocity, about 5 to 19 cm/s. It is expected that there is no hazard of liquefaction in this case.

(e) Motagua fault west segment

It is expected that the Guatemala City area would have a seismic intensity of Level VII or VIII. The seismic intensity is high especially in the northern part of the study area, close to the fault, and the lowlands along Pinula, Las Minas, and Las Vacas Rivers. In the hill and mountain region, the seismic intensity would reach Level VII in the northern part of the study area, close to the fault, and level VI in other areas. The maximum acceleration would reach approximately 180 to 910 cm/ s^2 and the maximum velocity, about 10 to 56 cm/s. The hazard of liquefaction is possible in the lowlands along Pinula, Las Minas, and Las Vacas Rivers with high or low level of hazard.

(f) Motagua fault central segment

It is expected that the Guatemala City area would have a seismic intensity of Level VII. The seismic intensity of the north-eastern part of the study area, close to the fault, and that of the lowlands along Las Vacas River would be of Level VIII. In the hill and mountain region, the seismic intensity would reach Level VII in the north-eastern part of the study area, close to the epicenter, and Level VI in other areas. The maximum acceleration would reach approximately 150 to 740 cm/ s^2 and the maximum velocity, about 8 to 49 cm/s. The hazard of liquefaction is possible in the lowlands along Pinula, Las Minas, and Las Vacas Rivers with high or low level of hazard.

(g) Subduction shallow segment

It is expected that the Guatemala City area would have a seismic intensity of Level VI. The seismic intensity in the hill and mountain region would reach Level V. The maximum acceleration would reach approximately 70 to 270 cm/ s^2 and the maximum velocity, about 4 to 16 cm/s. The hazard of liquefaction is possible in the lowlands along Pinula, Las Minas, and Las Vacas Rivers with low level of hazard.

(h) Subduction deep segment

It is expected that the Guatemala City area would have a seismic intensity of Level VI. The seismic intensity of the hill and mountain region would reach Level V. The maximum acceleration would reach approximately 80 to 270 cm/ s^2 and the maximum velocity, about 4 to 16 cm/s. The hazard of liquefaction is possible in the lowlands along Pinula, Las Minas, and Las Vacas Rivers with low level of hazard.

In general, the surface soil of Guatemala City can be classified into the hill and mountain region, the basin with thick accumulation of pyroclastic flow deposits, and the lowlands along rivers, which constitute a dissected valley. From the results of the estimation for ground motion, the ground motion would be stronger in the basins and the lowlands along rivers compared with the hill and mountain region. Especially in the target earthquake with its source fault in the shallow earth crust near Guatemala City such as (a) Mixco fault, (b) Sta. Catarina Pinula fault, (c) Jalpatagua fault west segment, (e) Motagua fault west segment, and (f) Motagua fault central segment, a seismic intensity of Level VIII is estimated including the city area. Therefore, considerable damages are expected mainly for poorly built or badly designed buildings. The possibility of liquefaction is limited to the lowlands mainly along Pinula, Las Minas, and Las Vacas Rivers. It is necessary to consider the disasters caused by liquefaction around Petapa Guatemala, in which the city area is formed along the river. If liquefaction occurs, disasters such as the settlement or inclination of structures, damages of underground installations, or cracks or bumps on road surface may occur.

b) Possibility of surface movement accompanying earthquakes

Guatemala City area constitutes a large graben. As the graben continuously formed even after the accumulation of Los Chocoyos pumice flow, surface movement may occur through tectonic movement each time there is a large earthquake with its epicenter near Guatemala City. In addition to the ground motion, surface bump or crack may be generated. A faults and raptures zone was established based on the occurrence state of bumps and cracks at the Guatemala earthquake in 1976, on the landforms related to the active faults recognized by aerial photographs, and on the faults indicated on the geological maps. As there is a Mixco fault zone in the west central area of Guatemala Basin, bumps and cracks in the direction of north-northeast to south-southwest may be generated easily. The bumps are usually low on the east side, but there are fault zones that are low on the west side near Villa Nueva.

In the east part of Guatemala Basin, there is a Santa Catarina fault zone where the bumps and cracks in the direction of north-northeast to south-southwest are generated easily. Although this fault zone is low on the west side, not many bumps and cracks were recognized at the time of Guatemala earthquake in 1976. Compared with the Mixco fault zone, the Santa Catarina fault zone may not be very active.

2) Quetzaltenango

The seismic hazards are estimated for Chixoy-Polochic fault west segment, Subduction shallow segment, and Subduction deep segment.

a) Chixoy-Polochic fault west segment

It is expected that the Quetzaltenango City area and the area located north of the city area would have the seismic intensity of Level VII. The seismic intensity of other areas would reach Level VI. The maximum acceleration would reach approximately 130 to 420 cm/ s^2 and the maximum velocity, about 7 to 25 cm/s. It is expected that there is no hazard of liquefaction.

b) Subduction Shallow Segment and Subduction Deep Segment

In both cases, the Quetzaltenango City area and the area located north of the city area would reach the seismic intensity of Level VII. The seismic intensity of the area southwest of the city area would reach Level VI and that of volcanic region south of the city area would reach Level V. The maximum acceleration would reach approximately 110 to 360 cm/ s^2 and the maximum speed, about 6 to 18 cm/s. It is expected that there is no hazard of liquefaction.

With regard to the earthquake caused by subduction, the result shows that the ground motion is larger in Quentzaltanango than in Mazatenango and Escuintia although the former are located farther from the fault. This result is caused by the difference of depths of basements or of sediments. The latter in which shallow gravel layers are distributed over a shallow basement has better ground conditions than the former in which pyroclastic flow deposits are distributed thick over a deep basement.

3) Mazatenango

The seismic hazards are estimated for Subduction Shallow Segment and Subduction Deep Segment. The closest distance from each fault to the center of the study area is 61 and 62 km, respectively.

In both cases, it is expected that the entire area would reach the seismic intensity of Level VI, a maximum acceleration of approximately 270 to 330 cm/ s^2, and a maximum velocity of about 12 to 13 cm/s. It is expected that there is no hazard of liquefaction.

4) Escuintla

The seismic hazard are estimated for Subduction Shallow Segment and Subduction Deep Segment. The closest distance from each fault to the center of the study area is 64km in both cases.

In both cases, it is expected that the entire area would reach the seismic intensity of Level VI, a maximum acceleration of approximately 110 to 260 cm/ s^2, and a maximum velocity of about 6 to 12 cm/s. It is expected that there is no hazard of liquefaction.

5) Puerto Barrios

The seismic hazards are estimated for Chixoy-Polochic fault east segment and Motagua fault east segment. The closest distance from each fault to the center of the study area is 14 and 18 km, respectively.

a) Chixoy-Polochic fault east segment

It is expected that the seismic intensities of the coastal plain extending from the city area including the airport to Puerto Santo Tomás de Castilla and the lowlands along Pichilingo, Escondido, and Cacao Rivers would reach Level VIII. The seismic intensity of other areas would reach Level VII. The maximum acceleration would reach approximately 290 to 810 cm/ s^2, and the maximum velocity, about 16 to 42 cm/s. The hazard of liquefaction would reach very high level for the coastal plain and high level for the area near the airport and the lowlands along rivers.

b) Motagua fault east segment

It is expected that the seismic intensity of the coastal plain extending from the area near Cacao River mouth to Puerto Santo Tomás de Castilla would reach Level VIII. The seismic intensity of other areas would reach Level VII. The maximum acceleration would reach approximately 280 to 660 cm/ s^2, and the maximum velocity, about 15 to 33 cm/s. The hazard of liquefaction would reach very high level for the coastal plain and high level for the lowlands along rivers.

In both cases, both the hazards of ground motion and liquefaction tend to be higher in the coastal plain extending from the city area near the airport to Puerto Santo Tomás de Castilla, due to the fact that soft grounds are distributed in the coastal plain. This area may suffer larger earthquake disasters due to a concentration of the population and capitals. In the areas where liquefaction occurs, disasters such as sedimentation and inclination of harbor facilities and structures caused by lateral flow and those of underground installation caused by floating up or sedimentation are expected. As the cracks or bumps may be generated on the road surface because of liquefaction, the influence to the airport must be given due consideration.

The estimation for very high hazard of liquefaction does not mean that the liquefaction will occur in the entire area. It must be understood that there is a high possibility of liquefaction in this case.

(3) Volcanic hazards study areas

1) Tacaná Volcano

a) Ash fall

If there is a blowout of volcanic ashes similar to the one caused by the eruption of Santa María Volcano in 1902, volcanic ashes are expected to accumulate more than 2 m in the leeward side of the crater in the study area. If the wind blows strong, there will be almost no ash fall on the windward side. However, if the wind is weak, ashes may accumulate more than 10 cm even in the windward side.

b) Ejected rocks

If a block with a diameter of 1.5 m is ejected from a position near the crest of a mountain with the initial speed of 250 m/s, it may drop on the area within approximately 3.9 km from the crater. This area includes Vega Del Volcán, San Rafael, La Hacienda, and Tonimá. As the blocks with smaller diameters are carried to the leeward side, the affected area may increase.

c) Pyroclastic flow

The dangerous area in which the pyroclastic flow may reach is estimated by the energy cone model. A pyroclastic flow with low mobility and of the scale that occurred in Santiaguito in 1922 may reach the canyon along Suchiate river on the southeast side and the canyon along Coatán river on the north. However, it will not cross the ridge line near Cerro Checambá on the northeast to the east side. If a pyroclastic flow of large scale should occur, the dangerous area will expand and even Sibinal will be included in the dangerous area on the east side.

d) Lava flow

If lava flows out from a position near the crest, it may flow down towards the Mexican side in most cases. However, if a crater opens on the Guatemala side, the lava may flow down in the direction of Tojcul or Vega del Volcán. If the lava flows out from the hillside, it may flow down along the valley immediately below the crater and reach Las Majadas or La Laja river.

e) Lahar

The place where lahar is generated varies depending on the accumulation state of volcanic ashes or the precipitation. However, there is a possibility that lahar is generated in the area classified as the valley plain on the geomorphological map. From December to April, when the wind high up in the air of north to east direction is dominant, there is a high possibility that volcanic ashes accumulate on the Guatemala side. Afterwards lahar may be generated frequently in the rainy season. Most of the dangerous areas are the valleys where houses are sparsely located. However, towns such as Vega del Volcán and Sibinal are found in the dangerous area.

f) Edifice collapse

If a volcanic edifice collapses, the debris avalanche may flow down to the Mexican side from the topographical reason. If the volcanic edifice collapses towards the Guatemala side, the area in which even small-scale debris avalanches may reach extends to the canyon of Suchiate river on the southeast side, the canyon of Coatán river on the north side, and Sibinal on the east side. However, on the northeastern side, the area is limited to the west of ridge line near Cerro Checambá. If the collapse is large-scale, the affected area will increase further and the debris avalanche may possibly reach wide area excluding Montaña Los Madrones and Sierra Madre highlands.

g) Volcanic gas

As the volcanic gas is heavier than the air, the volcanic gas gushing out from the crater easily flows down along the valley topography. With regard to Tacaná Volcano, the valley to which the volcanic gas from the crest may flow down is limited to the northern slope. However, the influence is deemed small because this area is located far from villages. If a side crater is generated, the villages along the valley may possibly affected by the volcanic ash.

2) Santiaguito Volcano

a) Ash fall

If there is a blowout of volcanic ash similar to the one from the eruption of Santa María Volcano in 1902, volcanic ashes would accumulate more than 2 m in the leeward side of the crater in the study area. If the wind blows strong, there will be almost no ash fall on the windward side. However, when the wind is weak, ashes may accumulate more than 10 cm even in the windward side. According to the wind direction, ashes may accumulate more than 2 m in the cities like Quetzaltenango and Retalhuleu and serious human damages are anticipated.

b) Ejected rocks

If a block with a diameter of 1.5 m is ejected from a position near the crest with the initial speed of 250 m/s, it may drop on places within approximately 3.6 km from the crater and would not reach the villages. As the blocks with smaller grain diameters are carried to the leeward side, the affected area may increase.

c) Pyroclastic flow

If a pyroclastic flow with a scale similar to the one in 1922, the dangerous areas are considered as follows. If a pyroclastic flow is generated near Caliente crater, it will flow down along Nimá I and Nimá II rivers. If a pyroclastic flow is generated near El Brujo crater, it will flow down along Tambor river. The pyroclastic flow will flow into Samalá river and further flow down to near Finca San Luis or San Martín Zapotitlán, but the ash cloud blast accompanying the pyroclastic flow may possibility affect all the villages along the valley or San Sebastián in the downstream area.

d) Lava flow

If lava flows out from near Caliente crater, which is active now, it will flow down along Nimá I and Nimá II rivers. If the center of the eruption activity moves towards the west side, the lava would flow down along Tambor river. With the repeated gushing out of lava, the upstream topography and the flow route of lava may change. The lava would not reach the villages, but with the progress of sediment supply, lahar may be generated.

e) Lahar

The hazard of lahar is evaluated for Nimá I and Nimá II rivers through numerical estimation. Nimá I river may flood in Finca San Marta or El Palmar. In the downstream of the confluence of Samalá and Nimá II rivers, the river may overflow and the nearby farmlands and roads may suffer damages. From the hazard evaluation based on topography, all mountain streams on the southern foothill have the possibility of lahar generation. In the upstream of Llano del Pinal Valley in the northern foothill of Santa María Volcano, there is a hazard of lahar.

f) Edifice collapse

If Santiaguito Dome collapses, debris avalanche will reach Finca El Faro and Finca La Florida even if the scale of avalanche is small. If a collapse of large-scale occurs, the debris avalanche may reach Retalhuleu. If Santa María Volcano collapses, the debris avalanche is considered to reach near San Felipe even if the scale of collapse is small.

g) Volcanic gas

As the volcanic gas is heavier than the air, the volcanic gas gushing out from the crater easily flows down along the valley topography. With regard to Santiaguito Volcano, the volcanic gas easily flows down towards the south side. However, the distance from the crater to the village is long, the influence is considered to be small.

3) Cerro Quemado Volcano

a) Ash fall

If there is a blowout of volcanic ashes similar to the one from the eruption of Santa María Volcano in 1902, volcanic ashes may accumulate more than 2 m in the leeward side of the crater in the study area. If the wind blows strong, there will be almost no ash fall on the windward side. However, when the wind is weak, ashes may accumulate more than 10 cm even on the windward side. According to the wind direction, ashes may accumulate more than 2 m in the cities like Quetzaltenango and Retalhuleu and, physical and human damages are anticipated.

b) Ejected rocks

If a block with a diameter of 1.5 m is ejected from a position near the crest of a mountain with the initial speed of 250 m/s, it may drop on places within approximately 3.6 km from the crater, which include south end of Quezaltenango, Almolonga, Llano del Pinal, Chicavioc, Las Majadas, El Chorro, and La Calera. As the blocks with smaller diameters are carried to the leeward side, there is a possibility that the affected area may increase.

c) Pyroclastic flow

If a pyroclastic flow is generated near the present crest, it may possibly flow down Llano del Pinal Valley and reach the western part of Quetzaltenango. If it flows down to the east side, the pyroclastic flow may affect the city areas of Quetzaltenango and Almolonga with high probability. Furthermore, the pyroclastic flow is accompanied by ash cloud blast, which will affect wider areas near and downstream of the one where the pyroclastic flow flows down.

d) Lava flow

If lava flows out from a position near the present crest, it may reach the roads and houses in Llano del Pinal Valley on the west side. As the lava flew out in 1818 is blocking, the new lava flow is difficult to reach Chicuá on the east side. If lava flows out from the west hillside, the lava flow may reach the wide area of Lalano del Pinal Valley. The lava gushed out from the east hillside may reach national road 9S, Almolonga and Samalá rivers.

e) Lahar

As Cerro Quemado volcano is covered by lava, the hazards of lahar are low. However, lahar may be generated on the foothill of Siete Orejas Volcano or Santa María Volcano. Also with these dangerous areas being close to Santiaguito, lahar may be generated due to the rainfall after the accumulation of volcanic ashes from Santiaguito. There is a hazard of lahar even on the national road along Almolonga and Samalá rivers.

f) Edifice collapse

If a volcanic edifice collapses and debris avalanche flows down to the west or the north side, it will reach almost entire area of Llano del Pinal Valley and the southern part of Quetzaltenango City even if the avalanche is of small-scale. If the debris avalanche flows down to the east side, it will reach Almolonga. Furthermore, it has the hazards of reaching near La Estancia de la Cruz along Samalá river. If a debris avalanche of large-scale is generated, it has a risk to reach the entire area of Quetzaltenango City.

g) Volcanic gas

As the volcanic gas is heavier than the air, the volcanic gas gushing out from the crater easily flows down along the valley topography. With regard to Cerro Quemado Volcano, the volcanic gas may flow down to the villages in Xetuj, Llano del Pinal, Candelaria Xecac, and Las Canoas depending on the place where the crater appears.

4) Pacaya Volcano

a) Ash fall

If there is a blowout of volcanic ashes similar to the one on May 20, 1998, in the leeward side of the wind up in the air, volcanic ashes will accumulate more than 10 cm in the area within 5 km from the crater, more than 5 cm in the area within 7.5 km from the crater, and more than 1 cm in the area within 15 km from the crater. According to the wind direction, volcanic ashes may accumulate about 0.1 to 0.5 mm even in Guatemala City. From December to March when the south wind is dominant, ashes may fall in

Guatemala City if a large-scale eruption occurs during this period. In the area within 5 km from the crater, there are villages such as San Vincente Pacaya, El Patrocinio, El Cedro, Mesillas Bajas, etc.

b) Ejected rocks

If a block field with a diameter of 1.5 m is ejected from a position near the crest of a mountain with the initial speed of 150 m/s, it may drop on places within approximately 1.6 km from the crater. Therefore the ejected rocks will not reach the villages. However, as Cerro Chino and the mountain trail are included in this area, damages may occur to the antenna and the maintenance facility. As the block fields with smaller grain diameters are carried to the leeward side, there is a possibility that the affected area may increase.

c) Lava flow

As the north and the east sides are blocked by the caldera limb, the lava flow will flow down from the west to the south. If it flows down to the southwest side, it will expand laterally at the foothill, making the distance to flow down shorter. Therefore, the lava flow will not reach the road connecting El Patrocinio and Los Pocitos, but may cross the road if the lava flows down to the south side or north side.

d) Lahar

The valleys along the road on the south bank of Amatitlán Lake may suffer from lahar. Colonia Loma del Rito, Finca el Embeleso, Granja el Rincón, and Finca el Llano are located at the exits of valleys and may be easily affected by lahar. The west foothill of Pacaya Volcano is covered by lava flow where lahar may not occur easily. However, in the past, lahar caused damages to Los Ríos and El Patrocinio and they may still receive damages in the future. Valleys are much dissected near El Cedro, which may become a source for lahar.

e) Edifice collapse

If a volcanic edifice collapses, debris avalanche would flow down to the southwest side. However, it will flow down near Finca Berlín, Finca El Tulillo, and Finca Santa Fe along Metapa river even if the scale is small.

f) Volcanic gas

As the volcanic gas is heavier than air, the volcanic gas gushing out from the crater easily flows down along the valley topography. With regard to Pacaya Volcano, the volcanic gas easily flows down to the west and the south sides because there is a caldera limb on the east and the north sides. On the south slope, there usually exist withered and dead trees affected by volcanic gas

(4) Landslides study area

1) Guatemala City

In Guatemala City area, there are dissected slopes of pumice flow upland and the slopes in the east and west mountain region occupied by tertiary volcanic rocks. The hazard of landslide is higher on the pumice slopes. The slopes having Hazard Rank A are found mostly in the northern part of the study area. The slopes in Zona 6, 17, 18 along Rio Las Vacas, the slopes in Zona 2 and 7 in Rio El Zapote and Rio La Barranca catchment areas, and the slopes in Vio Saraya catchment area are ranked A for hazard. During times of heavy rains, water collects from the flat area, which is the city area, and the surface water collects from the shallow valley to the ravine head, where a deep hole is forming. On the side slopes of valleys where there are knick points, the hazard of landslide starting from that area is highly possible. There are not many houses under the knick points because the slopes are too steep, but the houses right above the knick points have the possibility to be affected by a landslide.

In Chinautia located north of Guatemala City area, large landslides occurred frequently and the pumice layer easily calliopes in large scale with the corrosion of rivers.

In the valleys of Rio Villalobos and Rio Molino catchment areas located south of Guatemala City area, the ravine slopes exposed of pumice layer are ranked A for hazard. The slopes in Zona 14 along Rio Pinula and the slopes in Zona 13 and 21 in Rio Guadron catchment area are also ranked A for hazard.

The mountain regions east and west sides of Guatemala Basin have Hazard Rank A and B for slope collapse hazard. However, on the cutting slope face of the road, the hazard of rock falls is high because weathered tertiary volcanic rocks constitute the pumice stones.

At the time of the Guatemala earthquake in 1976, not many people were said to be living on the slopes or in the area close to the slopes. However many people, mostly poor people, have come to live on the slopes with a gradient of less than 20 degree. Therefore the anticipated disaster can be much larger than expected.

2) Quetzaltenango

Quetzaltenango is located in the Quetzaltenango Valley, an inter-mountain basin in the volcanic highlands. This basin is filled with pumice deposits that have provided a relatively flat area for the development of the city.

There are not many collapsed lands in Quetzaltenango City and the areas with Hazard Rank A for collapse are limited in number. On the dissected slope of pumice flow upland extending from San Christobal Totonicapan to Totonicapan in the northern part of the study area, there are slopes ranked A for slope collapse disaster. However, the landslides occurring on these slopes were mostly small-scale ones wherein only the surface course was peeled off. There are rather steep slopes having Hazard Rank A and B along the valley from upstream of Rio Siguila to Olintepeque and Cajola consisting of pumice layer,

La Pedrera, meaning "quarry" in Spanish, is located in a part of lava flow from Cerro Quemado Volcano or right under the lava dome. Cracked lava blocks are exposed on the slopes. There were rock falls during earthquakes or rainfalls. The hazard is permanent due to fractured rocks at the top of the cliff. There are about forty houses of the Barrio Santa Ana in danger of damages by rock falls.

Because the slope continuing from Siete Orejas is covered by grain volcanic ashes from the eruption of Cerro Quemado and Santa Maria Volcanoes, surface water does not generate easily and the slopes do not collapse easily also. There are many steep slopes in Rio Ocosito catchment area of Siete Orejas Caldera, which are ranked A and B for hazard. However, since there are not many places occupied by people, it causes no problem.

3) Antigua

Despite landslide study area, no evidence of large landslides was found in this area. Mountain slopes are steep enough to collapse, but only small rock falls occurred on the cutting slopes of CA-1 and National Road 10. One of the reasons may be, since the area is covered by air fallen pumice, the large infiltration capacity of the materials does not allow surface runoff during heavy rains, and there is no susceptibility to landslides because of the lightweight and tight adhesion of pumice grains.

In Antigua area, the slopes having Hazard Rank A are limited to eastern mountains and the face of slope of road. It cannot be said whether there is no possibility of landslide on the sliding surface of clayey volcanic ashes, but the hazard of it is very low.

4) North-west region

The north-west region is the alpine area with the altitude of 1000 to 3700 m. As the geology is complicated and weak reflected tectonic movement and there are many steep slopes, the danger of landslide is high.

The region extending from Cuilco to Tacana consists of deeply weathered granite and landslides that occurred many times on the upper hillside and the gentle slopes near the top of the mountain. Wide ranges of slopes are used as farmlands (corn fields) and houses are dotted, and yet outflow of soil from surface layer occurs easily. In the transverse valley located south to north along Cuilco River, there are scattered large landslides.

In the area near Huehuetenango, valleys are filled with pyroclastic flow deposits from Los Chocoyos that form pumice flow upland and valleys are being dissected. On the slopes that are used as farmlands, there are many gullies and the possibility of continuous generation of large amount of sands and earth is high. The pumice flow upland is being corroded by the lateral invasion accompanying the zigzag flow of rivers.

On the slopes along the roads west of Aguacatan, collapses are found in the weathered schists or near the boundary of the strata. Collapses occurred on the upper and lower slopes of roads and the collapse of lower slopes may fall down to the roads. The road between Aguacatan and Chiantia may be blocked.

On the northern slopes of Sacapulas, weathered Phyllites are distributed and the hazard of landslide is high. In addition, on the southern slopes of town, there are mountain streams having debris flow hazard.

A tectonic line runs in the study area from east to west and a fracture zone accompanying the tectonic line also emerges. Landslides may occur along the tectonic line.

5) Central region

In the central region, there still remains the topographic features caused by the Guatemala earthquake in 1976. There are many glide type landslides that collapsed from the top of slope with the difference of elevation of 150 to 200 m. Landslide and collapse may occur easily at the time of strong earthquake or rainfall in the future. It is difficult to expect the places where large-scale landslide may occur. However the grand slopes invaded by rivers, having uneven geology, sandwiching a clayey layer, and having faults can be said to have the hazard of landslides. In Rio Teculchaya, Rio Coloya, and Rio Los Chocoyos catchment areas, large-scale landslides may occur easily.

On the other hand, on the steep slopes with a gradient of more than 50 degrees, many collapsed areas are observed in which the surface layer of pumice flow deposits have collapsed as thin layers. The amount of collapsed earth is not much, but the collapse will occur frequently at the time of slight rain or small earthquake.

In the earthquake of more than MMI IX, large-scale landslides will occur easily on the grand slopes consisting of pumice flow deposits. In the areas having the earthquake of MMI VIII to VII, landslides will occur occasionally and frequent collapses of slopes and rock falls will occur locally. As for the rainfall, when the amount of daily rainfall reaches more than 100 m, slopes will collapse and debris flow will occur frequently.

The road connecting Solola and Panajachel passes through a sharp cliff. On the middle of a slope, cracked rocks are exposed and the block fields once fell down remain as the pumice stones. At the time of earthquake, rock falls will occur easily and there will be a high possibility of road blockage. At the time of rain, rocks remaining as the floating stones will become more unstable because the soils are carried away, which will further cause rock falls.

(5) Flood study areas

1) Samalá River Basin

a) Results of simulation

Simulations were made on three types of floods, and results were obtained on the maximum flooded area, the depth of flood, and the arriving time of flood for each type of flood. Hazard maps were created from the results of simulation, the landform classification, and the history of disasters.

b) Area near Retalhuleu

The area upstream of Castillo Armas Bridge (CA-2) situated on terrace. As the terrace surface stands 5 to 6 m higher than the riverbed, it will not be flooded. In the area near Castillo Armas Bridge, the river width is narrowed. According to INSIVUMEH, when this bridge was designed, it stood 20 m above the riverbed. At present, the river channel is secured with the dredging of sediments. However, if the riverbed rises more than the present height, both banks may become flooded.

In the area downstream of Castillo Armas Bridge, the terrace lowers down gradually. Therefore the national road (CA-2) is highly possible to be flooded with Hazard Rank A. San Sebastián town is located far from the river and will not be flooded at present. However, it may be flooded if the riverbed rises in the future. In the area downstream of San Sebastián, the riverbed is widespread and has no difference of height from the terrace surfaces on both banks. For this reason, flood will easily spread. The flood flow will run into the area upstream of Ixpatz River and Maricón River even at a small-scale flood. Therefore, the valley is ranked A for hazard and the areas around the valley are ranked B and C.

c) rea near the middle stream

The mainstream of flood flows down the present river channel and flows into shallow valleys towards Ixpatz River such as at the bend of the river. This area has terrace. However if the riverbed of the mainstream rises further, this area may be flooded also.

Therefore, the area near the river channel is ranked A for hazard and the terraces around the river channel is ranked B and C.

In the area downstream of La Lolita, the center of flood stream runs into Oc River and the water level rises by 2 to 5 m. The flood will not reach the terrace surface on the left bank. However, on the right bank, as a large flood plain spreads towards Ixpatz River, it is highly possible to be flooded. In this flood plain, small-scale flood will run down the old river channel of Samala River, but the large-scale flood will spread to the entire flood plain. However, as most of the floods run down the present riverbed or old river channel, they are considered to be shallow and spread widely.

On the other hand, the flood flow running down Ixpatz River does not spread from the present river channel if the flood is small-scale. However, at times of large-scale flood, lowlands or depressions along the river may be flooded, especially Nueva Candelaria Village.

d) Area downstream of river

The flood flow runs down Oc River towards the old river channel of Samalá River. During the course of running, it flows into shallow valleys such as Zanjón Cordoncillo on the terrace on the left bank. Many flood flows run into the shallow valleys continued to Laguna Madre Vieja on the left banks of Oc and Samala Rivers. If the future floods deposit sand and earth, the flood plain may expand to these shallow valleys in ten or more years. In the area further downstream of the river, most flood flows will run into Laguna Güiscoyol.

On the other hand, Samalá River merged with Ixpatz River runs into the shallow valley on the right bank before the merging point with Oc River. This shallow valley passes through Agrario Las Victorias, but the entire village will not be flooded.

e) Area near the river mouth

At the river mouth, the dunes or sandbanks along the seashore disturb the flow. For this reason, the flood flow spreads along the coastline and runs into marshes and lagoons inside the dune line.

2) Acomé River Basin

a) Area near La Gomera

The area near La Gomera will not be flooded widely because the catchment basin is small. Therefore, terrace l, about 1 m higher than the riverbed, is ranked A for hazard, and terrace 2, located higher than terrace 1, is ranked B. La Gomera town is located in the flood plain, but is ranked C for hazard because it is located higher than the above mentioned areas.

b) Flood plain from La Gomera to the seashore

The area extending to the seashore is a flat flood plain. There is no clear topographic division to divide the flood levels, but the marshes along the river and flood plain are ranked A, and the areas outside them are ranked B. The bend of the river has a characteristic to flood in the direction of the undercut slope. Furthermore, as the river runs downwards, it gets more easily flooded because the difference of heights between river and flood plain is lost. The flood plain located far from Acome River has low hazard of flooding by the Acomé River. However as it has a hazard of being flooded by the small river and the rivers separated from Achiguate River, it is ranked C. This flood plain is highly affected by flooding of the rivers separated from Achiguate River under heavy rains such as at the time of Hurricane Mitch.

c) Area near the river mouth

As the dunes are formed in two lines along the coastline, drainage to the sea is not sufficient and floods are generated behind the dunes. For this reason, the area behind the dune, the marshes between dunes, and the flood plain are ranked A for hazard. Dunes have low possibility to be flooded because they are located higher than the flood plain by more than 4 m. The artificial alteration land (salt pan) is ranked B because it is enclosed by a dike.

d) Area near Sipacate town

As Sipacate town is located on the dune, it will not be flooded. The marshes around the town are located low and have the topography that can easily collect water, therefore they are ranked A. As the road to La Gomera is banked, it is less possible to be flooded.

3) Achiguate River Basin

a) Area near Antigua Guatemala

As Guacalate River near Antigua Guatemala has small area to collect water and the highland covered by volcanic ashes have high permeability, it has low possibility of being flooded in large scale. There are shallow depressions on both sides of the river. As this kind of topography is most easily flooded, it is ranked A for hazard. Around this area, there are areas ranked B or C, but the outside areas about 200 to 300 m from the river have low possibility of being flooded. Pensativo River, which is the branch river of Guacalate River, is frequently flooded. Flood occurs at the exit of valley and submerges the areas along the river. In Antigua Guatemala city area, flood in which water runs onto roads may occur, but there will be no flood flow that will submerge the entire city area.

b) Area near Ciudad Vieja

This area is narrow being sandwiched by the mountain region on the left bank and the lava of Agua Volcano on the right bank. If Guacalate River is dammed up by the debris flow from Agua Volcano because of heavy rain, a lagoon may be formed in the upstream area. Therefore the upstream area is ranked B or C for hazard. Under the frequent heavy rains, only the lowlands along the river are ranked A. In the rivers running from the foot of Agua volcano, the river bed will rise caused by fixed river channel. Therefore the hazard of debris flow or mud flow by the squall is high, and these rivers are ranked A.

The flood of Guacalate River does not affect northern lowland of San Miguel Duenas. However as water may become temporarily stagnant and forms a lagoon, it is ranked B or C.

c) Area from Alotenango to Escuintla

This area is sandwiched by Agua, Acatenango, and Fuego Volcanoes and forms a deep valley. For this reason, it has no hazard of flood. In the downstream area, terraces are formed on both banks. These and the riverbeds have a difference of heights. From this difference of riverbed heights, riverbeds 1 and 2 are ranked A, riverbed 3 and Terrace 1 are ranked B for hazard. Flood will not reach the higher terraces 2 and 3.

d) Area near Escuintla

In the area near Escuintla, the river becomes slightly wider. From the difference of heights of geomorphologic units, river beds 1 and 2 having the lowest level are ranked A for hazard, river bed 3 is ranked B, and terrace 1 is ranked C. Near the CA-2 bridge, as the level of right bank is slightly lower, the river may be flooded by the large-scale flood and run into Provincias River. The further downstream area will be easily flooded because the difference of heights of riverbed and flood plain is small. The flood may submerge finca Los Cerritos from the separated Tulito River. On the other hand, as Escuintla City area is located on the terrace and the hill (deposit of rock debris), the flooded Guacalate River will not endanger it. However, both banks of Limoncillo River, formed shallow valley, may be flooded.

e) Area near Masagua

From the difference of heights of various geomorphologic units, riverbeds 1 and 2 are ranked A for hazard and river bed 3 and lower area along the river are ranked B and C. Masagua has not been flooded because it is located 5 m higher than the riverbed.

f) Area near the merging point of Guacalate and Achiguate rivers

Flood will spread in a wide range of area from the merging point of two rivers caused by the small difference of heights between the riverbed and the surrounding lands and overlapping of two flood flows. Especially as the riverbed of Achiguate River is wide and dilapidated, many outflows are supplied from the south slope of Fuego Volcano at the time of heavy rain.

Riverbeds 1 and 2, having the lowest levels, are ranked A for hazard. Riverbed 3, which is approximately 3 m higher than riverbeds 1 and 2 and the flood plain along the river, are ranked B. The flooded area of flood plain depends on the discharge of the flood, the subtle height of land, and the existence of roads, trees, and houses, but is assumed to be approximately 500 m on both sides of the river. With a large-scale flood, the entire flood plain may be widely flooded.

g) Flood plain extending from the merging point to the seashore

In this area, many rivers are separated from Achiguate River and there is no clear mainstream. When the discharge increases, flood runs into these separate rivers and expands. Especially this occurs remarkably on the left bank. With the running in of flood to Dolores wadi and Limón Rivers, the area to be flooded expands. Furthermore, between Achiguate River and these rivers, there is no geomorphologic characteristic that obstructs the flood, and even a small-scale flood may invade Limón River. On the other hand, Achiguate River is separated into Quebrada del Pilar or many wadis on the right bank, but tends to flow towards the left bank. Therefore the flood does not expand easily.

h) Area around the river mouth

As the river mouth has a geomorphologic characteristic that is obstructed by a dune, flood expands easily in the marsh or the flood plain at the back of the dune. Therefore, the marsh at the back of the dune is ranked A for hazard, and the area outside the marsh is ranked B. There are wadis and traces of flood in some places, which are considered to become the center of flow at the time of flood.

i) Area near Puerto San José

As the marshes around Puerto San José and the area along Zanjón Chilate are located at the same height as the water surface, they are ranked A for hazard. Puerto San José town is ranked B because small rivers flood sometimes. The dunes along the seashore and Puerto Quetzal in the artificial alteration lands are located higher than the surrounding flood plains. However as they were flooded at the time of Hurricane Mitch, they are ranked C. The dunes located at the high level in Puerto San José have no danger of being flooded.

4) María Linda River Basin

a) Mountain region

As Maria Linda River flows along the valley in the mountain region, only the riverbed is ranked A, B, and C for hazard. In the slightly downstream area where the valley is widened, terrace 3 is ranked B and terrace 2 is ranked C because of the difference of heights from the riverbeds.

b) Area near Las Flores

Along María Linda River, as the difference of heights between the riverbed and the terrace is 2 to 3 m, the area will not be flooded by a small-scale flood. The bending portion of the river is easily flooded because the flow becomes slow at this point. Furthermore, as the terrace surface of this area is slightly lower than the surrounding area, it is ranked B for hazard. Other terraces near the river are ranked C. At the time of Hurricane Mitch, Las Flores village was actually flooded to 1 m deep.

The area near Brito is also ranked B because the bending portion of river is easily flooded. Terrace 2 where a village exists is ranked C. The downstream flood plain is ranked C because its height is same as that of the riverbed. On the other hand, terrace 3 between Asuchillo and Mityatoya Rivers and the debris avalanche deposit plateau on the right bank of Mityatoya River have no hazard of flood because they have enough height differences from the riverbed.

c) Area near the merging point of Maria Linda, Asuchillo, and Mityatoya Rivers

As there is no slope on the riverbed and even the merging point is not clear, the flood flow does not run downstream smoothly. For this reason, the flood plain along the river is ranked A for hazard, and the area outside the flood plain is ranked B. As the flood plain extending from this area to the seashore is flat and has no clear topography to stop the flood, the entire area is ranked C. The points where channels are separated are ranked B because the river may flood towards the direction of the channel. The extent of flood depends on the slight difference of heights and the existence of roads and channels.

d) Flood plain

The area near the river and the marsh along the river are ranked A for hazard, and the area around them is ranked B. Especially the bending portion of river has a characteristic that the river floods towards the undercut slope. As the marshes near the merging point with Naranjo River have no clear boundary from the river, even small-scale flood will spread widely and become shallow. Along the river, there are banked dikes at some places. These dikes have temporary effect to stop the small-scale flood and can temporarily change the direction of flood, but cannot withstand a flood exceeding the small-scale or water swelling for long hours.

e) Area near Iztapa

As there are two lines of dunes along the coastline, the water flow of the river is slack and the river floods easily at the back of dunes. For this reason, the area at the back of dune, the marsh between dunes, and the flood plain are ranked A for hazard. Furthermore, the dune in the second line having lower level is ranked B.

Some of the dunes in Iztapa and Puerto Viejo have generally low possibility to be flooded. However as the river mouth of María Linda River has narrow drain port like the bottle mouth and has wide catchment area, a large amount of flood flow can be collected and the water level rises easily compared with Acomé River. Therefore, the dunes near the river mouth are ranked C and the degree of hazard lowers as the distance from the river mouth increases.

2.3.10 Hazard map GIS

JICA study team created various maps related to hazard maps in the Study. Furthermore, we collected several maps owned by the concerned organizations including INSIVUMEH. Whereas the maps were managed as paper-based ones previously, the computers and GIS software provided by JICA allow much of the map information to be managed now using GIS. We created Hazard Map GIS to organize the maps and allow INSIVUMEH to manage geographic information related to disaster information with ease. This system, intended to facilitate accumulation of disaster data in the future and management of hazard maps, will hopefully contribute to enhance the efficiency of operations of INSIVUMEH and, consequently, improve the disaster resistance of Guatemala. Furthermore, the engineers of INSIVUMEH participated in training of GIS as part of the Study Team's technology transfer training and could improve their technological skills for GIS. It is recommended that, in the future, INSIVUMEH manages various map data including the existing one on this system.

The following figure shows the structure of Hazard Map GIS in INSIVUMEH.

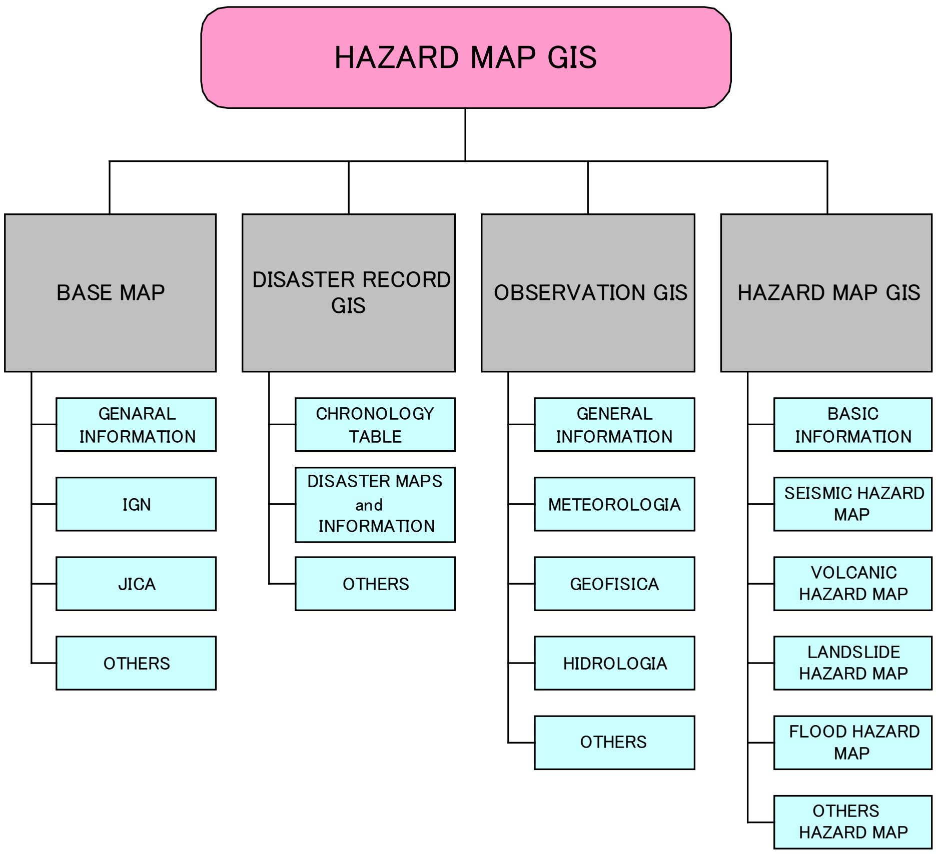

Figure 2.3.10-1 Outline of hazard map GIS

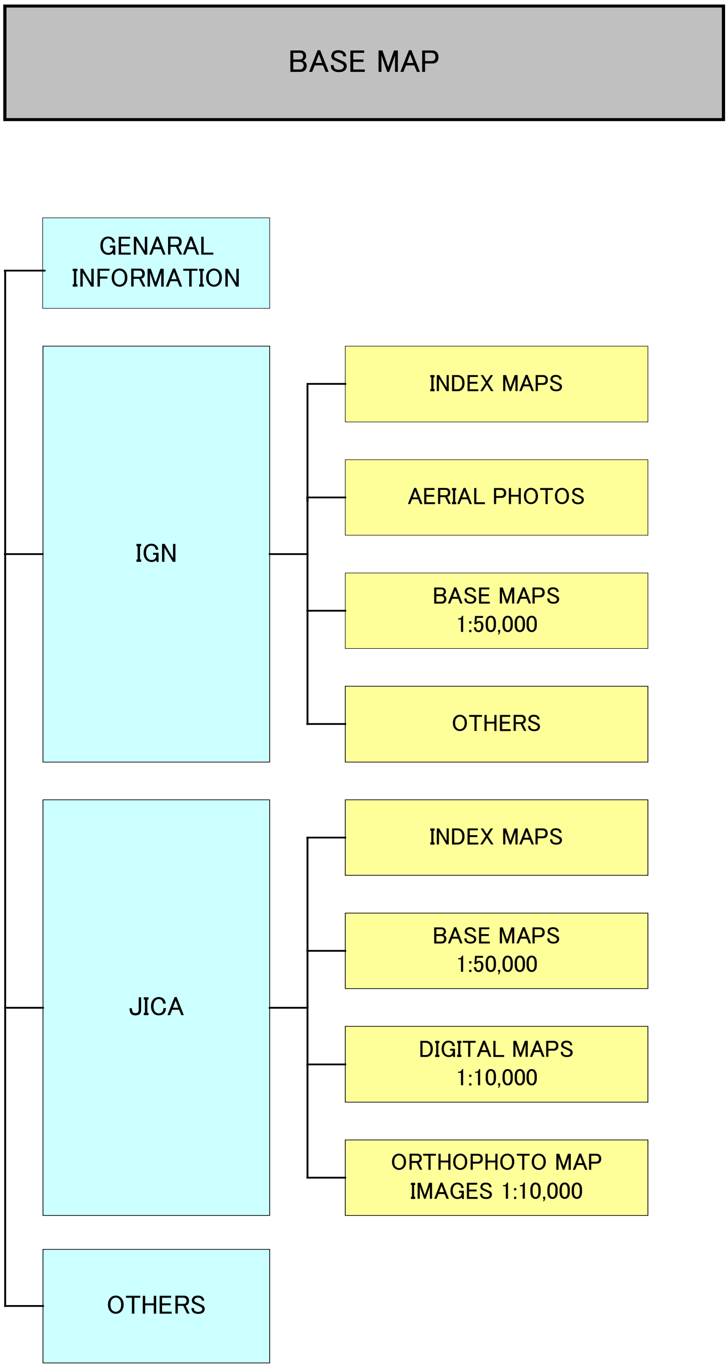

Figure 2.3.10-2 Structure of base map database

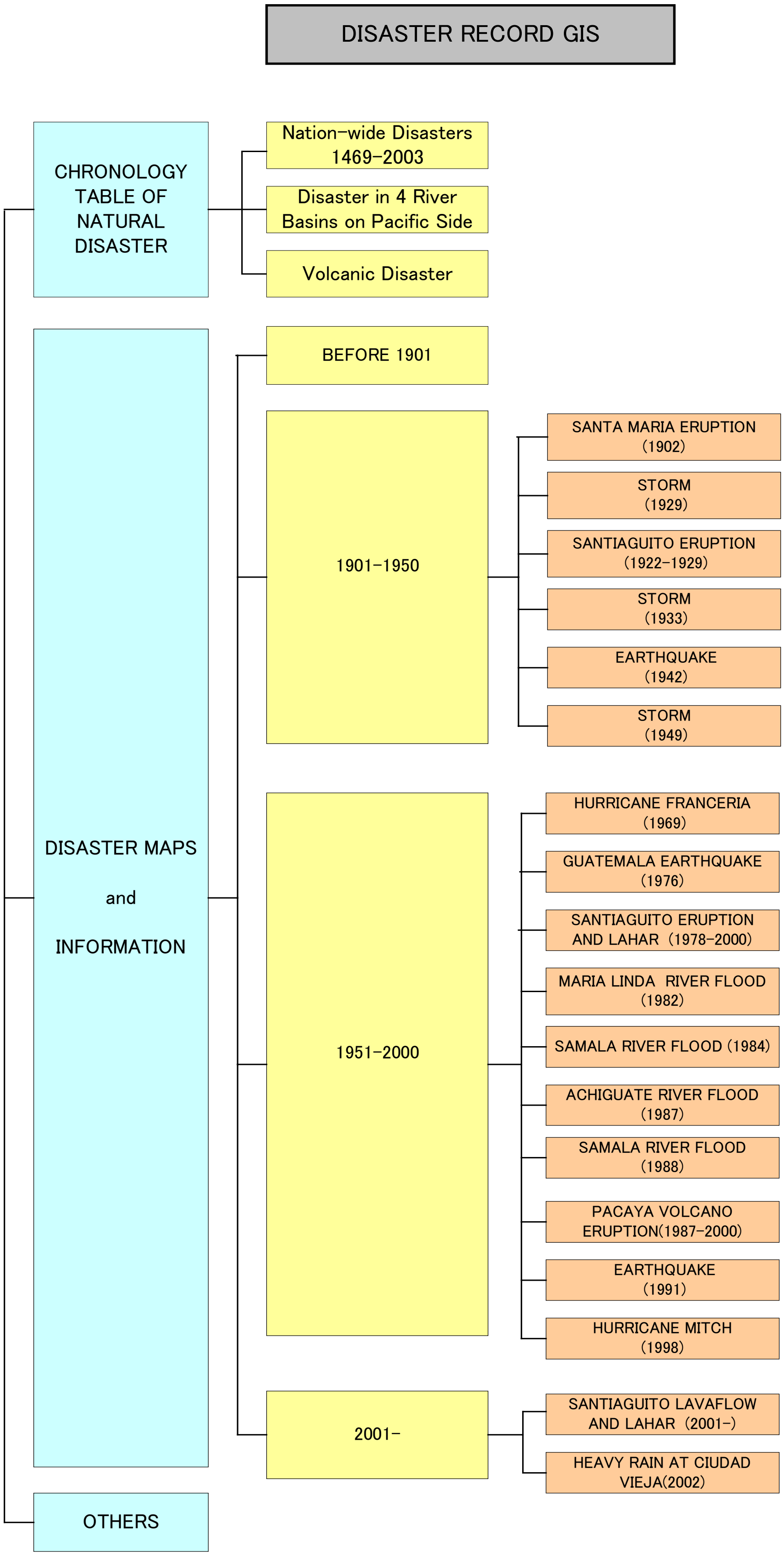

Figure 2.3.10-3 Structure of disaster record GIS

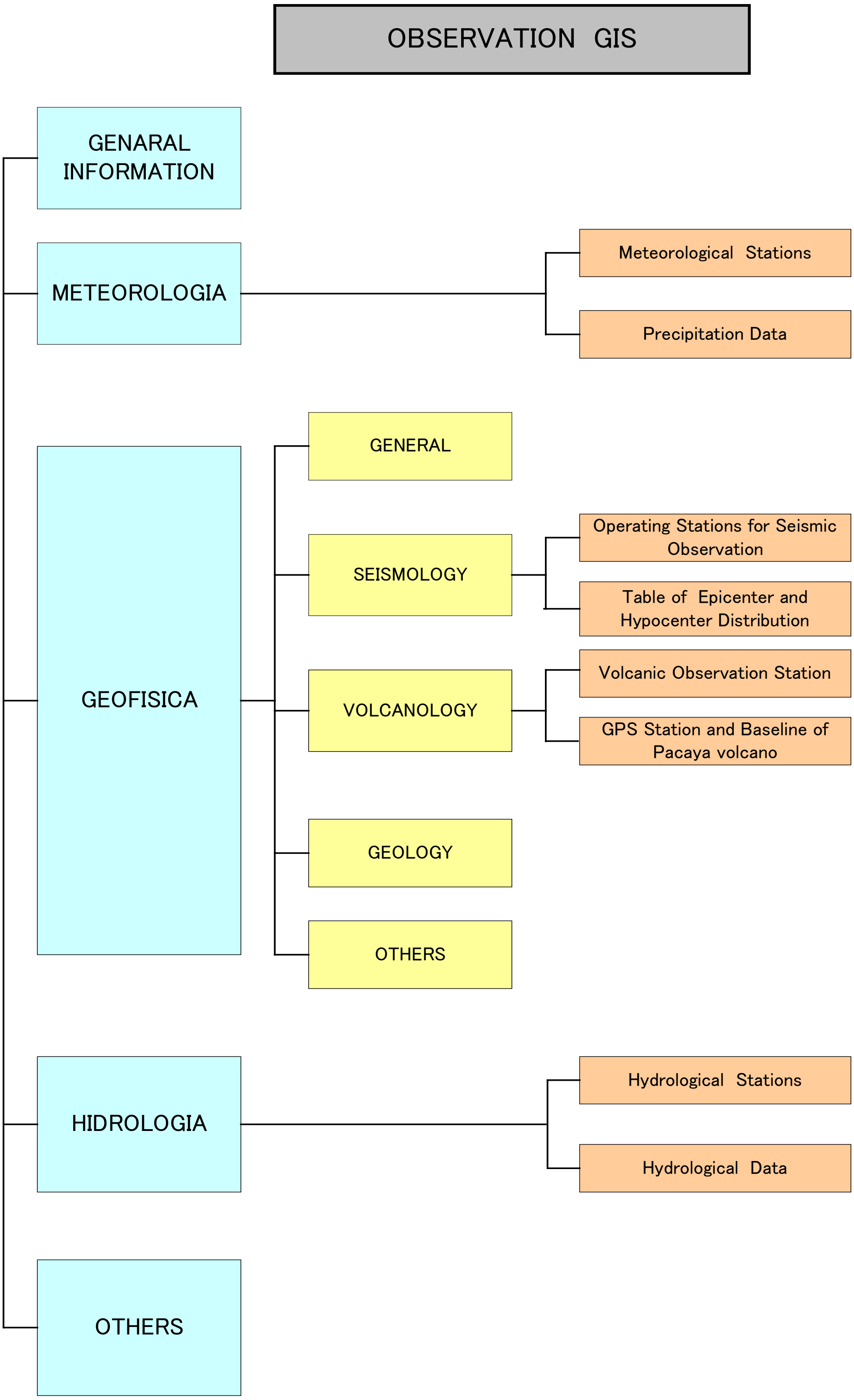

Figure 2.3.10-4 Structure of observation GIS

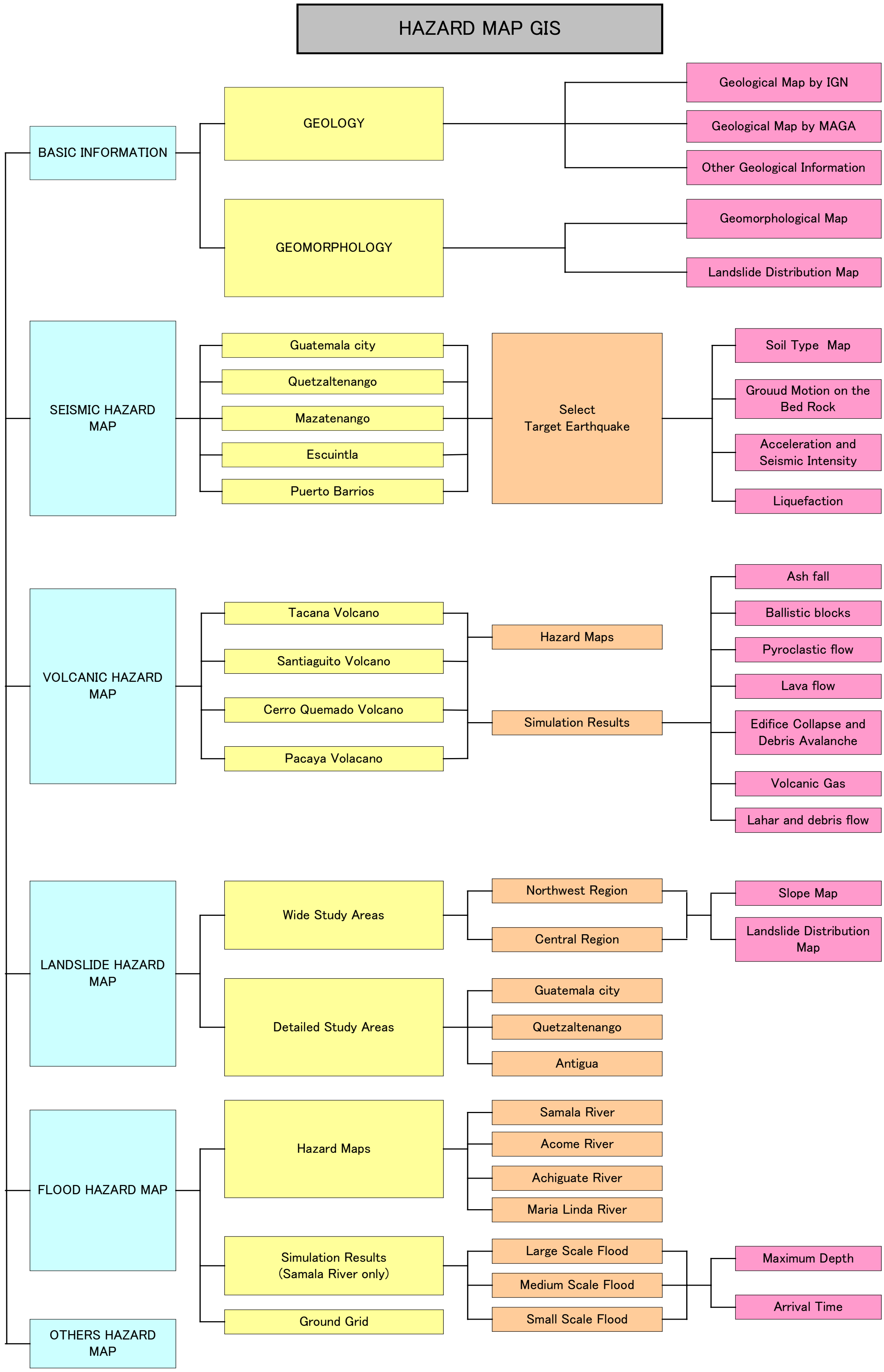

Figure 2.3.10-5 Structure of hazard map GIS

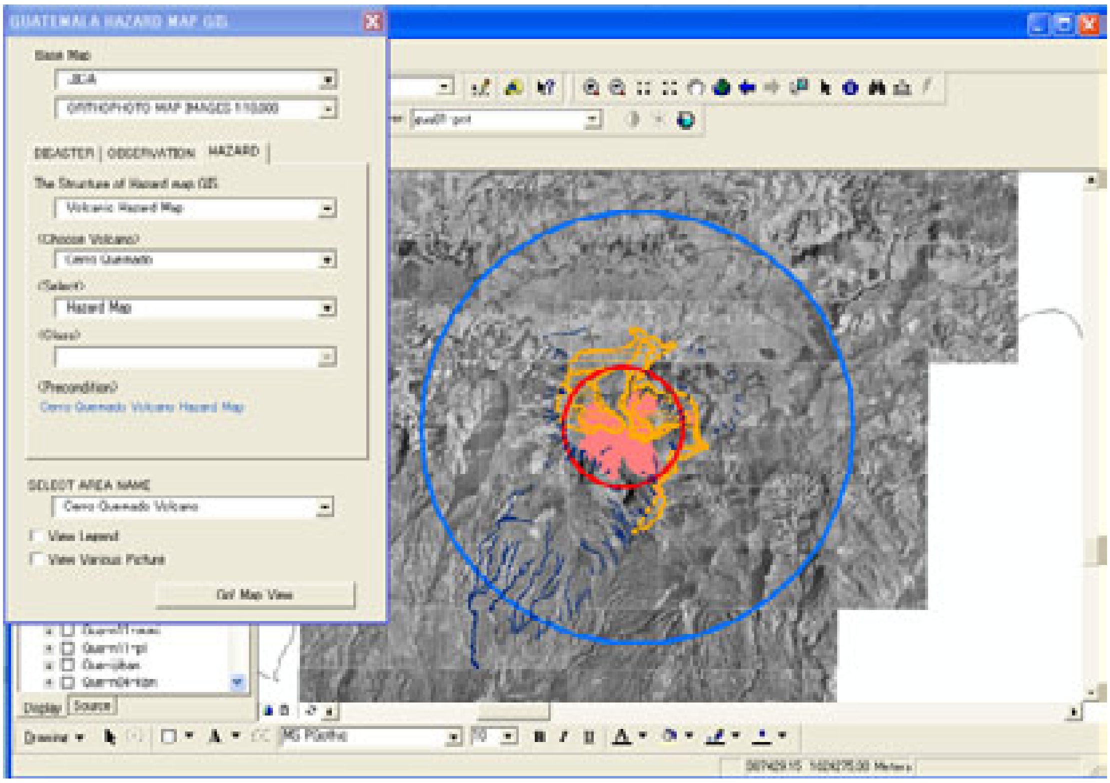

Figure 2.3.10-6 Example of hazard map GIS screen image

2.4 Transfer of Technology

2.4.1 Discussions about the scope of OJT

The scope of OJT was discussed and arranged in terms of items, content, trainees and number of trainees, by the study team and the Government of Guatemala. OJT will be carried out using hardware and software to be provided as equipment for the study. With regard to the digitizing of the 1/50,000 maps and production of orthophoto maps, IGN will work on 2 sheets for each of those processes for OJT. The scope of the work to be implemented was discussed and determined by the study team and IGN.

2.4.2 GPS precise survey

(1) Baseline Observation for Pacaya Volcano Crustal Movement Survey with GPS Survey Equipment

In this Study, two GPS units included in the equipment and materials provided by JICA were used for the technology transfer.

The contents of the technology transfer were the "national control point network survey" using GPS units, that was indispensable for IGN's work of redevelopment of the national control point network and "GPS baseline observation for monitoring crustal movement" that was important for INSIVUMEH to acquire the basic data for evaluating an activity of Pacaya Volcano.

Photo 2.4-1 Confirmation of GPS Observation Method (Jointly by IGN and INSIVUMEH)

In the technology transfer at the end of July 2001 before the GPS observation of Pacaya Volcano, a total of five new durable stone monuments were installed, which of four around the volcano and one near the crater as the control points (temporary) for future fixed baseline observation.

Photo 2.4-2 Baseline observation for Pacaya Volcano crustal movement survey

The first observation of Pacaya Volcano was jointly conducted by the Study Team, IGN and INSIVUMEH in the middle of August 2001 before installation of the survey equipment, using three Ashtech GPS units owned by MAGA, two rented Trimble GPS units, and one Trimble GPS unit installed on the rooftop of the IGN building for 24-hour observation.

Photo 2.4-3 Explanation of baseline observation for the survey of crustal deformation

The second observation was carried out using three GPS units, two new Trimble units provided as survey equipments by JICA's Guatemala Office and one unit at the permanent observation point on the rooftop of the IGN building.

The survey results are described below, but this observation survey was carried out with a combination of GPS units of different manufacturers, Ashtech and Trimble, so the measured values might be inaccurate. The errors and reliability of the measured values have to be verified and improved in a future survey. However, the observation and analysis methods will be examined in more detail and will no doubt be referred to in joint with data accumulation work by IGN and INSIVUMEH in future.

In addition, the Study Team gave a lecture on the importance, principles and methods of observation, analysis and assessment in the "crustal movement survey" to IGN and INSIVUMEH. This lecture was undoubtedly useful and will be a milestone for the future study including the technology transfer. The contents of the lecture are described below.

Table 2.4-1 Survey Result of Baselines for Monitoring Volcanic Activity

Point No.	Point Name	B・L (GMS)	X・Y (m)	H (Ell)
0001	IGN	+14-35-25.448370 -90-31-12.640230	1,613,346.3103 497,826.2223	1,521.6840
1001	Mesillas Bajas	+14-24-49.668589 -90-33-52.671534	1,593,810.7725 493,031.7244	1,563.7703
1002	San Vicente	+14-25-13.927675 -90-38-02.163974	1,594,559.4319 485,560.1047	1,523.7484
1003	El Rabon	+14-21-30.158310 -90-37-22.854587	1,587,682.7782 486,733.6791	1,336.6805
1004	Los Llanos	+14-21-44.782578 -90-34-14.768813	1,588,129.7889 492,368.1894	1,363.1510
1005	Cerro Chino	+14-23-20.507821 -90-36-36.271437	1,591,072.8937 488,130.7605	2,147.2429

WGS-84 and GTM

1) Baseline Observation for Monitoring Volcanic Activity of Pacaya Volcano

a) Significance of Observation

- Comprehensive understanding of volcanic activity serves to improve the technology of forecasting future eruptions.
- Improving eruption forecasting is important to make effective use of the hazard maps prepared in this Study in the event of disaster.
- INSIVUMEH is carrying out seismic observation and geo-thermal observation of Pacaya Volcano. Other important items of observation are crustal movement, and geophysical and geo-electromagnetic observations.
- Of these, crustal movement observation as well as seismic observation are basic observations.
- The GPS observation network installed in this Study is used to roughly monitor the conditions and features of Pacaya Volcano crustal movement.
- The control points installed are not final and it is necessary to change their positions based on analysis of repeatedly measured data.
- The observation results do not make it possible to forecast any eruption immediately.
- Observation of various items regarding volcanoes is conducted in Japan, but only once was an eruption forecast immediately beforehand.
- Volcanoes show different features in their eruptive process.
- It is essential to monitor the features of each volcano as early as possible, but it is very difficult to do this even with the latest technology.
- The Study Team attempted to analyze relation between the change in length of baselines and distortion of volcano’s body in each step of its activity.

b) Present GPS Observation Network of Pacaya Volcano

Network with two types of observation points

♦ Five points close to the volcano

- Expansion and contraction of the mountain are monitored from changes in the distance between the points (extension and contraction).
- This monitoring method provides general information, but it is highly accurate because the distance between the points is short.

♦ Three points on the outer circumference

- The positions are considered not to change by volcanic activity.
- Movement of the 5 points close to the volcano can be monitored from these 3 fixed

points.

- Of these 3 points, the observation point on the rooftop of the IGN building is particularly important.
  - * Constant observation (24 hours a day, 365 days a year) is performed.
  - * The observation points are connected to the international GPS observation network, thereby guaranteeing operational reliability.

c) Recommendations for Future Activities

- It is important to accumulate observation data and it is necessary to make repeated observations on a regular and irregular basis.
  * Observations should be continued after the end of this Study.
  (It is not guaranteed that any volcanic movement can be monitored during the period of this Study.)
- There are possible observation plans as shown in Figure 2.4-1, Figure 2.4-2, and Figure 2.4-3 that would be desirable to be implemented before the start of the field survey in the next fiscal year. These plans will largely depend upon the personnel, budget and equipment available from INSIVUMEH and IGN. Therefore, B and C are considered realistic plans.

A General observation

Upper center : Constant observation point on IGN building

Lower left : Existing triangular point

Lower right : Existing triangular point

①-⑤ : Observation points at the volcano

(Total: 8 observation points)

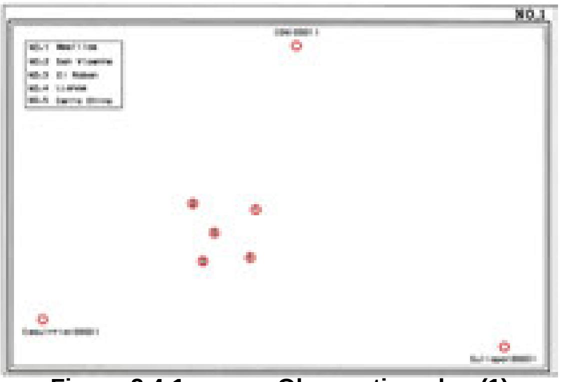

Figure 2.4-1 Observation plan (1)

B Observation at IGN + 5 volcanic points

Upper center : Constant observation point on IGN building

①-⑤ : Observation points at the volcano

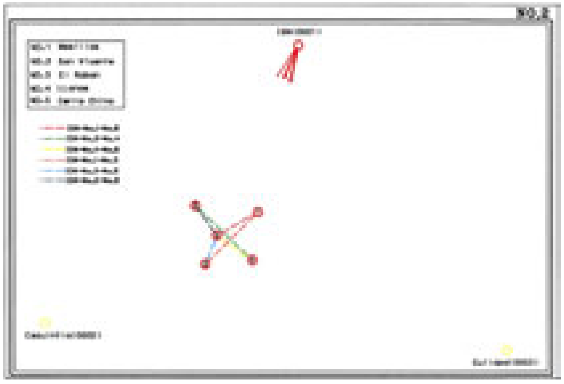

Figure 2.4-2 Observation plan (2)

C Observation at IGN + 4 volcanic points

Upper center : Constant observation point on IGN building

①−④ : Observation points at the volcano

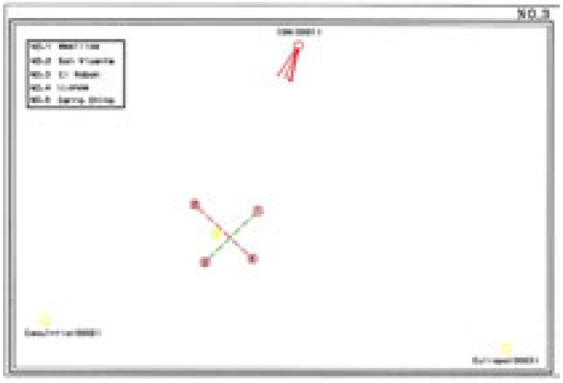

Figure 2.4-3 Observation plan (3)

＊ In each observation plan, it is important to use the data from the constant observation point installed on the rooftop of the IGN building.

(2) Recommendations for Future Observation Activities

1) Observation equipment

It is desirable to conduct future observations using the two Trimble GPS units included in the survey equipment procured by JICA and the one Trimble GPS unit installed on the rooftop of the IGN building. As it was made clear at the time of the first observation, it may lower the reliability of the observed data if different types of equipment, such as Ashtech, are combined in the GPS network.

2) Comparison of observed results

- Coordinates of observation points for the volcano obtained on the basis of the observation coordinate on the rooftop of the IGN building as the fixed point.
- Slant distance
- Horizontal distance
- Elevation

  * The results of observation and analysis of the above items should be accumulated to observe any sign of volcanic activity.
  * Differences in the data of the observation points closer to Pacaya Volcano should be observed carefully.

3) Maintenance of perfect accuracy

- Accurate installation of the antenna center (centering)

  * If observation is performed using the control points installed in July, a tripod must

be used to install the GPS antennas. In this case, it is necessary to estimate an installation accuracy of ± several mm.

* On the other hand, if installing the GPS antennas with no tripod, it is preferable to reconstruct the control points with a concrete high-pole structure in order to minimize installation error to the smallest degree.

- It is appropriate to measure crustal movement with more stress on accuracy than on efficiency and to repeat long-time observations frequently at the points very close to the volcano rather than to measure many sides for a short time.
- In a normal control point survey, the shape of the observation network largely affects the accuracy, but in this baseline observation, it is more important to measure each side with high accuracy rather than to consider the network shape.
- It is important to use the data from the GPS point for constant observation on the rooftop of the IGN building and to conduct the work of observation and analysis of the data by joint cooperation between IGN and INSIVUMEH.

2.4.3 Digital plotting/data compilation

The transfer of technology in new plotting techniques using a digital plotter was also started during the third work in Guatemala.

Almost everyone in the IGN Photogrammetry Division and some engineers from the Cartography Division participated in this technology transfer program.

Until now, plotting work at IGN relied solely on the craftsman's skills using a conventional analogue plotter. Computer-controlled, semi-automatic plotting was introduced for the first time using the digital plotter brought in for this Study. This system allows the creation of not only simple line maps but also orthophoto maps, and it has spread rapidly throughout the world in recent years. Its high processing performance is expected to lead to the fast and inexpensive production of maps.

Photo 2.4-4 A technology transfer

(1) Transfer of technology for aerial triangulation, DEMs, and contouring

1) Introduction

In the first technology transfer program, the aim was for the IGN staff to acquire the chain of techniques related to orthophoto mapping.

The digital photogrammetry system "VirtuoZo" was transported from Japan as part of the study equipment and was installed at the office of the IGN Photogrammetry Division in June 2002.

Photo 2.4-5 Equipment brought from Japan

This system features the capability for the smooth and continuous execution of the chain of processes from inner orientation to the preparation of the finished orthophoto maps.

The sheer volume of technology relating to orthophoto mapping and topographic mapping using this system was considerable, and it was impractical to explain the individual processes one by one. Thus, the third field survey was limited to the preparation of orthophoto maps, and it was decided to implement the transfer of technology relating to 1:50,000-scale national base mapping during the fourth field survey.

The content of the technology transfer carried out in this study was the theory of all aspects of digital photogrammetry, including aerial triangulation, preparation of DEM and orthophotos, digital plotting and digital compilation, using the digital photogrammetry system.

Photo 2.4-6 Assembling of equipment

In this process, a variety of software was used, including “Photoshop” for image processing, the digital photogrammetry systems “VirtuoZo” and “VirtuoZoAAT”, the adjustment computation software “PATB”, digital compilation CAD “MicroStationJ”, and “MicroStationDescartes” for handling image data.

2) Outline of technology transfer

The technology transfer for each process was carried out in accordance with the flowchart for actual orthophoto map preparation (Figure 2.4-4). For this purpose, the small Puerto Barrios area was selected as a sample for plotting (Figure 2.4-5). The reason for this choice was that in other areas the ground control points were set out with the intention of doing aerial triangulation of a large area, and taking a specific part of one of these areas as a sample was not considered appropriate for the aerial triangulation of a small area.

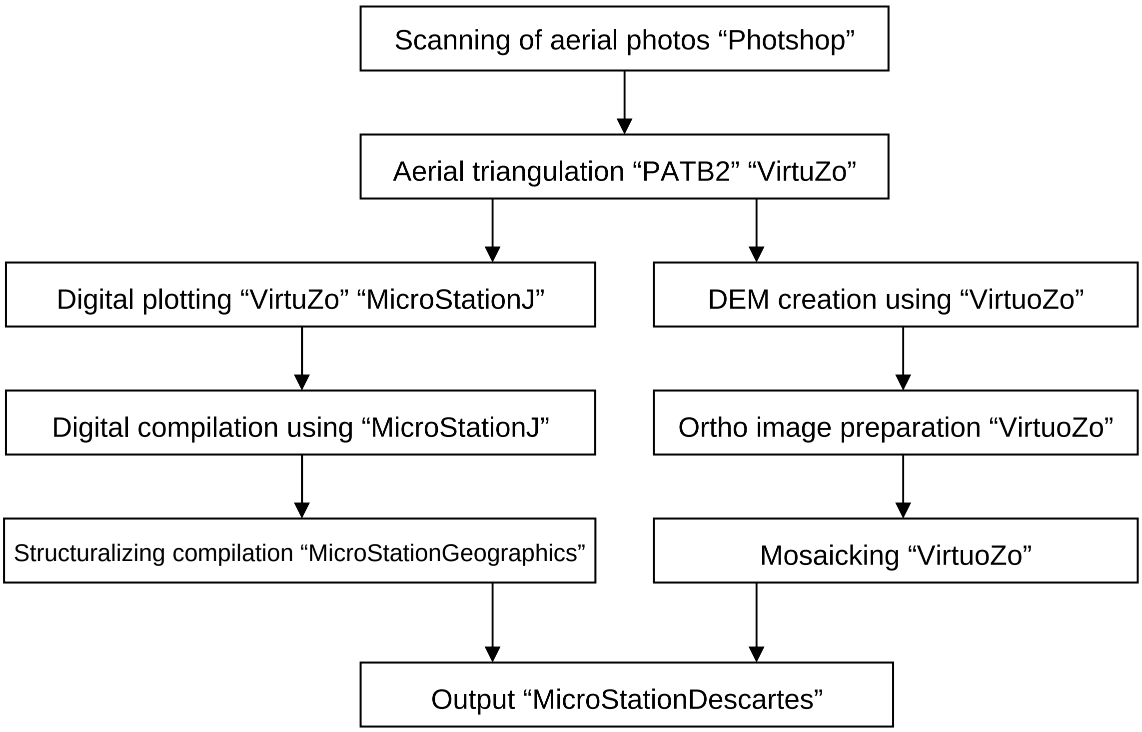

Figure 2.4-4 Flow of orthophoto map creation