Table 2.3.2-3 Seismic stations

Station		Approximate Distance from the Capital City (Km)
Name	Code	
GUATEMALA	CGC	0
PACAYA	PCG	60
TERRANOVA	TER	88
EL JATO	JAT	260
SANTIAGUITO 3	STG3	230
FUEGO 3	FG3	75
FUEGO 6	FG6	70
FUEGO 7	FG7	120
LAS NUBES	NBG	70
MARMOL	MRL	175
IXPACO	IXG	78

The seismic data are received at the central station through analog telemetry and processed. There are 3 basic types of data, Short Period, Long Period, and Strong Motion. The latter is sub divided into high and low gain and uses 6 channels. These data are first digitized with SEISLOG software, then processed with SEISAN software. The data (waveform, phase, data) are then stored in a database to update the catalog and publishing at a later date.

The data are stored within INSIVUMEH and also at the Central America Seismological Center (CASC) located in Costa Rica. Data are sent to CASC periodically and can be accessed through internet, and are also accessible by request from INSIVUMEH. INSIVUMEH also has a web site where the seismic data is uploaded and available to the public but is updated only once per day.

2) Seismic data

The Seismology Section at INSIVUMEH has been largely responsible for collecting, processing, and cataloging local seismic data since 1977. These data, stored as a catalog, were obtained from the Seismology Section as computer files. The data are formatted to international standards (USGS) which includes precise time and location as well as depth, magnitudes, and other details. Although the seismic stations are located within Guatemala, earthquakes strong enough to be recorded from neighboring countries are included in the catalog. These data are periodically uploaded to the Central American and global data centers.

CASC collects data from the entire Central American region, compiles it and makes it available in several formats. The sources of the data are from national agencies and institutions responsible for collection and processing data in each country’s territory. The data are compiled into the standard international format and made available to the public. These data were obtained for analyses at the regional level.

The USGS is a well known source of seismic data internationally. They collect data from a global network of stations, including one in Guatemala. The data from INSIVUMEH and CASC are not included in the USGS catalog, but the USGS does record seismic activity in the area. These data are formatted to the international standards and made available to the public. These data were obtained for regional analyses and to verify and compare to the locally collected data.

Other catalogs and reports have been compiled and created based on historical reports and data. These data are from various sources and with various descriptions. The data had to be interpreted to convert to the current magnitude system and fix the location as best as possible. Therefore, the reliability and quality of the data are relative to the ages of the events. These data were obtained to use for a conceptual view of the overall historical record of seismicity.

(6) Volcanologocal information

1) Volcanic observation

Seismic observation stations around the periphery of the volcanos total 10 stations: 2 for Tacana Volcano, 1 for Santiaguito, 4 for Fuego, 2 for Pacaya, and 1 for Tecuamburro（Figure 2.3.2-7）.

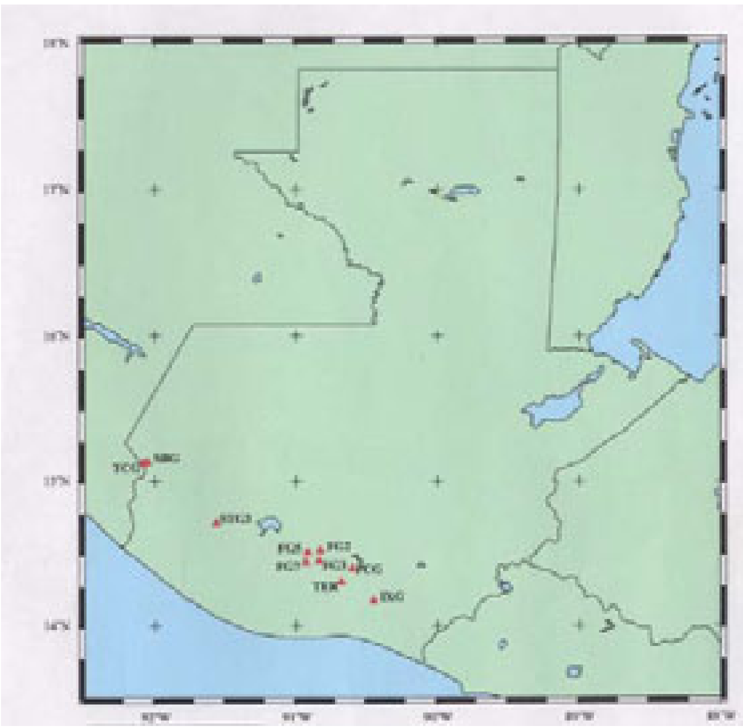

Figure 2.3.2-7 Volcanic observation stations of INSIVUMEH

In addition, the following 4 types of observations of volcanic activity are being carried out.

- Observations by manual observation
- Seismograph

  Those are carried out 24 hrs per day.
- Geochemical Observations〔COSPEC〕

  This is only implemented for Pacaya, Fuego, and Santiaguito Volcano on a temporary basis (about once or twice per month).
- Production of the Isopach map for ash fall

  This map is produced when ash is deposited by a new eruption. To date, only two isopach maps have been made: for the eruptions of Pacaya Volcano on 19 May 1998, and one of Fuego Volcano on 21 May 1999.

The warning system for volcanic activity is carried out in 4 stages as shown below.（Table 2.3.2-4）。

Table 2.3.2-4 Warning system for volcanic activity

Level	Volcanic activity
Green	Low or no activity
Yellow	Low fumarole activity and low seismic activity
Orange	Intensified activity, weak or moderate strombolian eruption
Red	Strong strombolian eruption

The orange level warning would mobilize and assemble the staff of the volcanology section of INSIVUMEH to conduct investigations. If the results indicate a possible eruption in a matter of hours or days, the red level warning will be activated.

The volcanic activity of Pacaya Volcano is outlined in Table 2.3.2-5. From the latter half of February 2001, the volcano has become very active, and the activity from the 12th to the 18th is classified as high level activity (based on a conversation with Mr. Matías).

Table 2.3.2-5 Character of Pacaya Volcano activity and current condition

Level of activity	Amount of volcanic gas (SO_2) 〔ton/day〕	Number of micro earthquake 〔number/day〕
Normal	90～260	100～200
Medium	800～900	300～700
High	1,350～2,450	800～2,000

2) Volcanological data

The following volcanic data are necessary for the production of a volcanic hazard map.

- Eruption history（magnitude, eruption types, hazard factors, affected areas etc.）

- Landforms and Geology
- Physical characteristics (eruption rate, mean grain size, viscosity of flows etc.)

For records on the volcano's past eruption activity, some data can be derived from the home page of the Michigan Technological University. However, even though Pacaya Volcano has been erupting frequently in recent years, including frequent lava flows, a map that shows the areas affected by the lava has never been made.

It is also extremely important to understand the landform and geology of the volcano to determine the kind of damage that may result from an eruption. There are few volcanoes that have a volcanic landform map or geological map. And yet, a detailed map has not been made for either volcano. The maps produced by the Government of Guatemala are the volcanic landform map (1:50,000) of the Tacaná Volcano, and a geological map (1:50,000; Amatitlán) of the area surrounding Pacaya Volcano. However, the scientific studies of a foreign university have produced a Pacaya Volcano landform classification map and conducts geological surveys at Santiaguito.

Several papers on geological characteristics with a mineralogical approach are being collected for probable use as references for the simulation of lava flows. However, all volcanoes do not have the same characteristics, hence, for simulation the cooperation of researchers of the volcanoes of Guatemala is indispensable.

(7) Disaster records

1) Collection of disaster records

INSIVUMEH and CONRED compile records of natural disasters in Guatemala. Records of earthquake disasters in Central America are compiled by Giovanni H. Perald and Walter P. Montero (1999); valuable records of earthquakes that date back to the Mayan Civilization, for the period 1500-1900 corresponding to pre-instrumental times in whole Central America.

There are papers by various researchers of the earthquake that hit Guatemala in 1976.These papers can be used as references to understand the nature of disasters in Guatemala. However, these are not comprehensive as they are strongly characterized by the personal focus and methods.

No other comprehensive records of large catastrophes in Guatemala were collected.

2) Preparations for the production of a disaster map

A disaster map refers to a map that shows the conditions resulting from a catastrophic event and is made based on aerial photos taken after the disaster and field survey results. Several disaster maps of main disasters were collected: the 1969 Hurricane Francelia, 1976 Guatemala

Earthquake, the 1998 Hurricane Mitch, etc.

Although detailed data that could point out exactly where Hurricane Francelia originated from was not collected, the enormous damage at the Rio Achiguate basin was confirmed.

The production of a disaster map for the Guatemala Earthquake is considered possible in some documents show many records of the Guatemala Earthquake, e.g. damage rate distribution map, outline map, documents and photos of damaged areas, etc. Also, there are aerial photos showing conditions after the earthquake.

For Hurricane Mitch, disaster maps such as the damage distribution map, were digitized using GIS and divided into the levels of damages based on a topographic map at a scale of about 1:2,000,000. Although some of the topographic maps show impassable points, flooded areas, and areas where the bridges are destroyed, the fact that they are at a scale of 1:2, 000,000 makes it difficult to determine damaged areas or the extent of the damage. Based on the data prepared by SEGEPLAN, the Reconstruction Program contains the volume of damage and the damage distribution map. Although SEGEPLAN must have compiled a number of data, this was not confirmed during this phase.

There is no agency in Guatemala that actively pursues the production of disaster maps. Therefore, disaster maps are not produced even when severe disasters occur.

(8) Existing hazard maps

1) Hazard map made by the Government of Guatemala

The hazard map made by the Government of Guatemala is one of the GIS thematic maps that cover the entire nation at a scale of 1:2,000,000. There are also several large-scale volcanic hazard maps of various types produced with the assistance of establishments such as Michigan Technological University. Table 2.3.2-6 shows the hazard maps confirmed in this study.

Table 2.3.2-6 Hazard maps published by the Government of 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 futures 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	

Hazard	Object	Year	Scale	Title	Disaster factor	Creator
	Santiaguito	1988	1:50,000	Mapa preliminar de riesgos volcanicos del domo de Santiaguito, Guatemala	Pyroclastic flows, Lahars, Floods, Surge, Crater collapse, Lateral blast, Inundations	INSIVUMEH
			1:500,000	Mapa preliminar de zpnas 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 explociones 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 prelininar 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
	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
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

2) Hazard mapping by donors

Several donor agencies have been active in Guatemala and Central America. Most of these projects are being implemented as part of the Hurricane Mitch response and others as part of ongoing general assistance in the area. Although several countries are providing some form of assistance, the United States has been the most active in the area recently.

USAID has been the most active with emergency response and reconstruction efforts in response to Hurricane Mitch. In 1998 Hurricane Mitch hit Central America and caused widespread destruction of infrastructure resulting in a historical major disaster. USAID is working with and through several other US government agencies to coordinate and distribute assistance to several government agencies in Guatemala. Activities regarding hazard mapping under the Hurricane Mitch Program are being implemented by USGS. Another USAID sponsored project concerns defining zones of threat from earthquakes in selected urban areas based on geologic conditions. The areas covered under this project are Guatemala City, Coban, Escuintla, Antigua, Quetzaltenango, and Zacapa.

USGS has been active in Guatemala for several years and recently under USAID Hurricane Mitch Reconstruction Program. Under that program the USGS has been developing risk maps for volcanoes and landslides. More specifically, the USGS has obtained and is using data from topographic maps, aerial photography, and satellite imagery for risk mapping of floods, landslides, and volcanic debris flows. The USGS is working with INSIVUMEH to install gaging stations to provide near realtime data for flood warning and meteorological information. Gages have been installed in the following basins: Rio Lempa, Rio Motagua, Rio Coyolate, and Villalobos. USGS is working with INSIVUMEH to also map landslides produced by Hurricane Mitch in the mountains around the Motagua and Polochic Rivers. There will be 23 maps of 1:50,000 scale produced. The USGS and INSIVUMEH worked together to prepare pyroclastic flow, debris flow and lahar risk maps for Pacaya, Fuego, and Santiaguito volcanoes. The USGS is using GIS modeling to define zones of risk for these volcanoes.

Some of the other countries that are providing various levels of assistance in Guatemala are Portugal, Spain, Canada, Britain, Germany, and Sweden. Portugal is providing limited funding at the local municipal level to improve CONRED’s operations at that level. Spain has been working with INSIVUMEH to provide additional seismic stations and improve the seismic monitoring network. In addition to these assistance programs, many study teams of universities of other countries investigate theme related to natural hazard of Guatemala. Examples are given as follows. Researchers from Switzerland made a hazard map of Fuego Volcano using numerical simulation method. The study team of Geneva University investigated the deformation of Pacaya Volcano with GPS. Michigan Technological University of USA has investigated and mapped Volcanoes of Guatemala for more than thirty years. Additionally, hazard map has been produced for Tacana by Dr. Jose Luis Macias, Dept. of Geophysics of the UNAM from 1998. He also produced hazard maps for Acatenango Volcano.

2.3.3 Disaster history investigation

(1) Overview of disaster history in Guatemala

The history of Guatemala accounts with records of many disasters. Mayan writing includes such images and the book of Quiches "Popol Vuh" mentions the God of Earthquakes among other gods.

According to the registers of disasters in Guatemala, we have obtained an account of 383 events in the period 1469 through May 2003 as shown in Table 2.3.3-1. Among them 60% correspond to earthquakes, 27% to volcanic eruptions and 13% Hurricanes or heavy rainfalls. This register does not classify the severity of these events, it is a compilation of the historical account found in several sources. However, it gives to a certain degree, a trend of the more catastrophic disasters in this period especially for those that are recorded in several sources, and they are well referenced.

Table 2.3.3-1 Disasters in the period 1469—2003(as of May 2003)

Year	Earthquake	Volcanic Eruption	Hurricane
1469—1499	1	2	----
1500—1599	21	14	----
1600—1699	30	22	----
1700—1799	37	22	----
1800—1899	78	22	1
1900—1999	79	21	27
2000—	2	2	2
TOTAL (383):	248	105	30
Percentage	65%	27%	8%

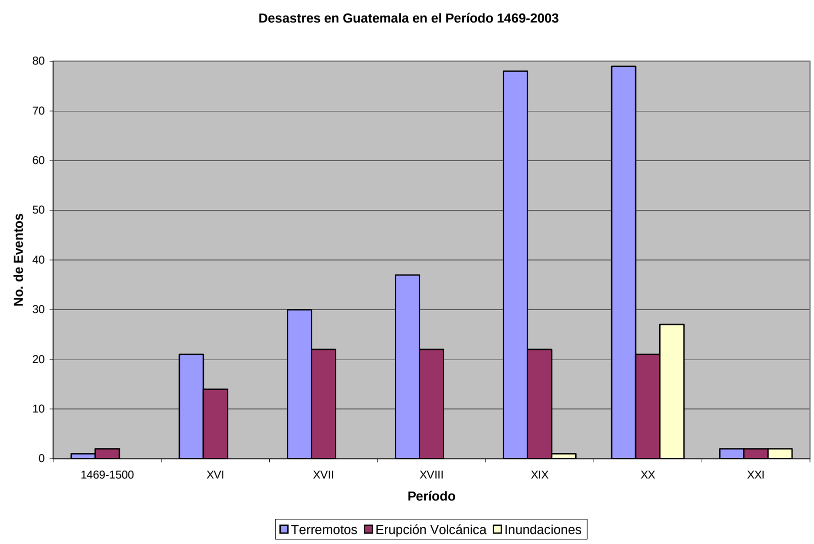

Figure 2.3.3-1 Number of historical disaster in Guatemala (as of May 2003)

Table 2.3.3-2 Large natural disasters in Guatemala, 1469 –2003 (as of May 2003)

Date	Disaster Type	Place and damages
1541	L	Ciudad Vieja (1527-1541), the old Capital City of Guatemala was destroyed by mudflow and debris flow of the Agua Volcano.
1717-9-29	E, V, L	Total destruction in Alotenango and partial in Antigua. About 3,000 houses were damaged as well as all the churches. Max IM=III-IV, Ms<5, D=0 to 5km
1773-7-29	E , L	City of Antigua Guatemala was destroyed by the earthquakes of *Santa Marta* . Max IM=IX, Ms=6.5
1773-12-13	E, L	Partial damages at Antigua. Max IM=VII+, Ms=5.7
1816-7-22	E, V, L	Soloma, Santa Eulalia, San Juan Ixcoy, San Miguel Acatán, San Sebastián Coatán, San Mateo Ixacatán, Todos Santos Cuchumatanes, Santa Catalina Ixtahuacán. Damages associated to the intensity VII or more covered about 13,000 km2. Max IM=VIII, Mag~7.5, D=10 km
1862-12-19	E	Santa Catarina Ixtahuacán, Tecpán. The area of intensity of VIII and VII was 29,444 km2, and that of VI was about 54,000 km2. Max IM=VIII, Ms=7.24, D=30 km
1885-12-18	E, L	Amatitlán, San Vicente, Antigua, Petapa, Villa Nueva, Ciudad Guatemala, Patzicia. Max IM=VIII, Ms=6.0, D=10 km
1902-04-19	E	Sever damages at south-west region, especially Quetzaltenango. Mag=7.5
1902-10-24/25	V	Eruption of Santa María Volcano. About 6,000 deaths.
1917-12-26	E	Chain of earthquakes that destroyed the Capital City and neighborhood. Results: 250 deaths. MR=5.8
1929-9-15	H	Hurricane. 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	V	Eruption of Santiaguito volcano. Killed about 2,500 persons.
1933-9-11	H	Tropical storm. 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	E	The biggest earthquake 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	H	Tropical storm. Total duration: Sept. 27-Oct.6th. Economic losses: US$ 13.6 million.
1969-9-3	H	Hurricane Francelia. About 500 deaths. Economic losses: US$ 6.5 million
1974-9/14-19	H	Hurricane Fifí. About 8,000-10,000 deaths. Economic losses: US$ 30 million.
1976-2-4	E	Most deadlist earthquake. 22,778 deaths and 76,465 injured. Economic losses: US$1,250 million. Max IM=IX, MR= 7.5, D=5 km.
1991-9-18	E	Earthquake. 23 deaths, 185 injured and 2,300 houses destroyed. Max IM=VIII, MR=5.3, D=32 km.
1998-10-27/30	H	Hurricane Mitch. 202 deaths. Economic losses: US$748 million.

Sources:

1) G. Peraldo H, Walter Montero P. , Universidad de Costa Rica, 1999. Sismología Histórica de América Central, Pub. No. 513, Instituto Panamericano de Geografía e Historia.México.

2) Molina, E., Mayol, P., Bungum, H. 1999. Reducción de Desastres Naturales en Centro América, Mitigación de la Amenaza Sísmica, Fase II: 1996-2000, Parte 2, Reporte Técnico (Preliminar) Amenaza Sísmica en el Valle de la Ciudad de Guatemala, INSIVUMEH/NORSAR, Norway.

3) ISIVUMEH, Unidad de Investigación y Servicios Geofísicos,

4) CONRED, Unidad Ejecutora de Proyectos con Cooperación Internacional.

5) NCEP, 1997. The Deadliest Atlantic Tropical Cyclones

6) IGN/Univ. de San Carlos Guatemala, 1972, Evaluación de Crecidas en la República de Guatemala. 7) Several

Local Newspapers

Nomenclature:

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

In Table 2.3.3-2, the main events are classified based on the origin of the damages, death toll or magnitude. Thus, we can summarize from 1541 the most powerful events as follows: 11 earthquakes, 6 hurricanes, and 4 volcanic eruptions. However, it may not be accurate because of lack of data, especially regarding hurricanes and volcanic eruptions. For this reason, it must be regarded as a trial classification.

Lack of some data is explained due to the fact that shortage and delay of installation of the observation instruments as follows.

1856: rainfall registers by raingauge started on a monthly basis for Guatemala City,

1919: Seismometers for measuring earthquake magnitudes installed in Guatemala City started operating.

1928: digitized rainfall available, most of the other stations were installed

After 1969 Hurricane Francelia: most of the other stations were installed

After 1974: five (5) seismograph stations were installed for volcanic observation in a cooperative project with USGS/IGN.

1977: the National Seismological Network was installed parallel with the creation of INSIVUMEH.

Although the records of these kind of disasters are being currently improved, it is necessary to create a data base for each of them in order to know in the future their probable periodicity, and intensity.

The data collected until now regarding the disasters in Guatemala are shown in Appendix (Chronology of Natural Disasters in Guatemala).

(2) Earthquake Disaster(1976 Guatemala Earthquake)

The earthquake occurred in February 4, 1976. The epicenter was located at Los Amates, Department of Izabal. The intensity in the Modified Mercalli scale was distributed as follows: IX at Gualán, Zacapa and some points at the Capital Valley; VIII at Chimaltenango and El Progreso; VII at El Quiché (Figure 2.3.3-2). It is classified as the most destructive earthquake this century in Guatemala. It was produced by the activation of the Motagua fault which represents the boundary between the Caribean and North America plates.

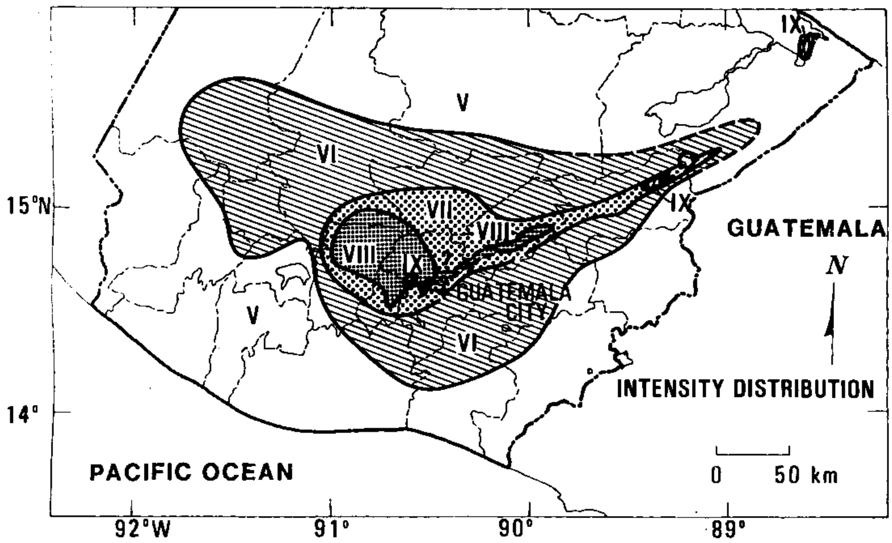

Figure 2.3.3-2 Distribution of the intensity in the Modified Mercalli scale the Earthquake in February, 1976.

A.F.Esipionasa and J. Asturias et. al (1978)

It caused 22,957 deaths and 76,925 injured, 254,751 houses destroyed (1,066,063 people left without house). The economic losses were estimated at 1,250 million Quetzales (1,250 million dollars). Duration of movement was about 25 to 30 seconds. The average displacement along the fault was one meter from Los Amates (Izabal) up to Chimaltenango area (in some places up to 3m of horizontal displacement). Length of the rapture was more than 200 Km. The earthquake affected 60,000 km^2 of the 108,000 km^2 of the country (i.e. 55%), corresponding to 20 of the 22 departments.

The distribution of the number of victims by this earthquake is shown in Table 2.3.3-3.

Table 2.3.3-3 Victims during the Earthquake of February, 1976

No.	Department	Total Population	Deaths	Death ratio % In the nation	Injured	Injured ratio % In the nation	Material Damage (%)
1	Chimaltenango	194,735	13,792	60	32,377	42	88
2	Guatemala	1,108,186	3,350	15	16,264	21	69
3	El Progreso	73,122	2,001	9	7,662	10	90
4	Sacatepéquez	99,988	1,692	7	9,045	12	71
5	El Quiché	298,686	831	4	5,672	7	73
6	Zacapa	105,739	693	3	1,998	3	73
7	Baja Verapaz	106,957	152	1	718	1	83
8	Sololá	127,268	110	0	300	0	10
9	Jalapa	118,074	91	0	473	1	32
10	Izabal	169,818	73	0	379	0	40
11	Chiquimula	158,177	50	0	378	0	50
12	Totonicapán	166,809	27	0	89	0	34
13	Alta Verapaz	59,664	18	0	953	1	68
14	Jutiapa	233,232	13	0	48	0	10
15	Others	1,079,373	64	0	569	1	
	TOTAL:		22,957	100	76,925	100	

Source: Espinosa, et al., 1978. Applying the Lessons Learned in the 1976 Guatemalan Earthquake to Earthquake-Hazard-Zoning Problems in Guatemala Memorias del Simposio Internacional Sobre el Terremoto de Guatemala del 4 de Febrero de 1976 y el Proceso de Reconstrucción.

The data regarding damages by this earthquake were plotted in Figure 2.3.3-3 to show the distribution. Areas that were identified for specific damages were assumed to have similar damage in the area surrounding the identified locations. In other cases, whole districts ("colonias") were identified as "destroyed". Most of the heaviest damages reported and identified occurred in the central mountain areas, especially in the Zones 1,3,5 and 6 of the north of Guatemala City (Figure 2.3.3-4). Information about areas where the ground ruptured or offset was also used to identify heavy damages (Figure 2.3.3-5).

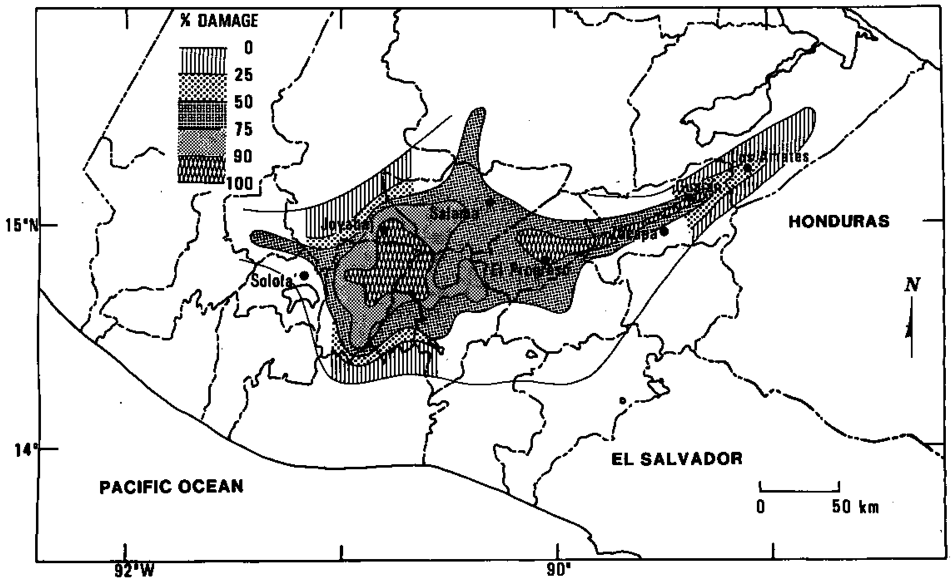

Figure 2.3.3-3 Damage ratio of adobe type houses by the Earthquake of February 1976

A.F.Esipionasa and J. Asturias et . al (1978)

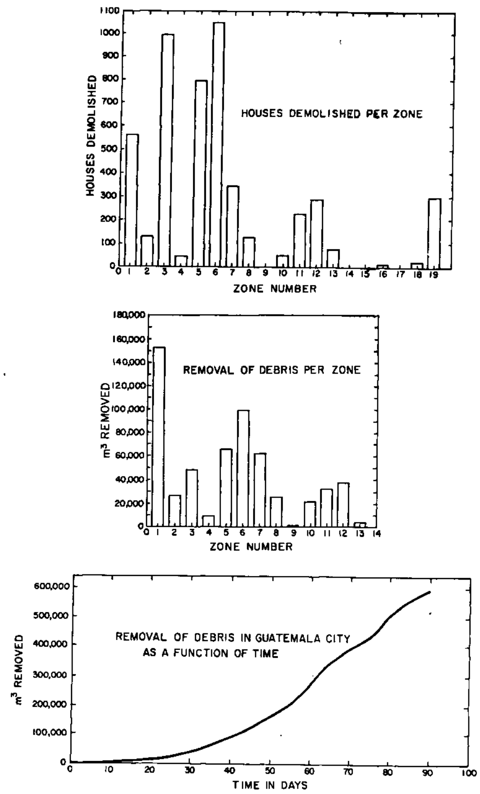

Figure 2.3.3-4 Houses demolished and removal of debris in Guatemala City until May 4 1976

R.Husid and J Ariasi (1978)

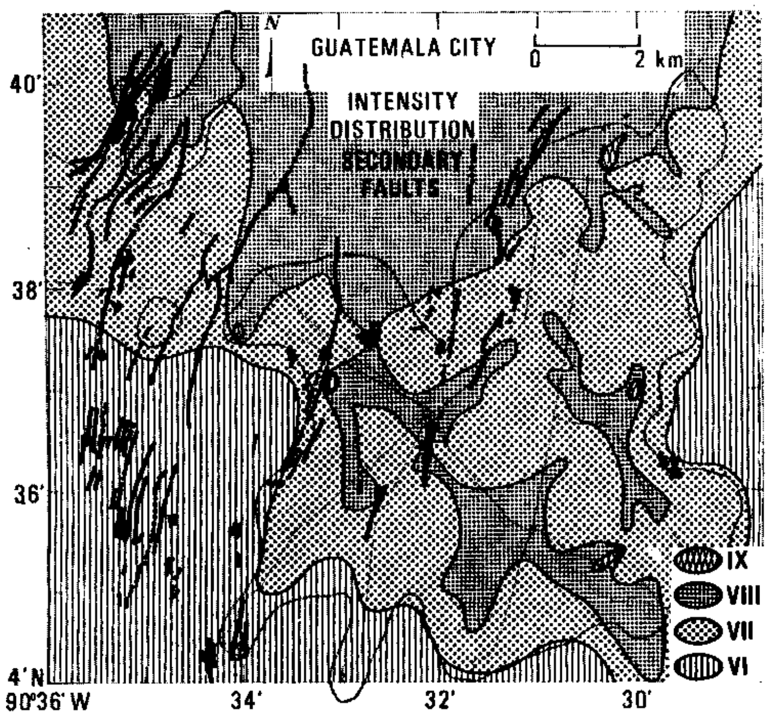

Figure 2.3.3-5 Distribution of secondary fault and the intensity in the Modified Mercalli scale in Guatemala City, 1976

A.F.Esipionasa and J. Asturias et . al (1978)

According to the our investigation of the damage from various documents, the statistics (45% totally destroyed) of the damages were also used to consider the extent of damage. The areas identified and plotted on the disaster maps that we created were colored to show the damage areas. Red was used to show the areas of total or near total destruction, and orange was used to show areas where more than 40 % damage was estimated. Other areas without color were estimated to have less than 40 % damages.

According to some studies related to the 1976 earthquake, liquefaction was most observed in pumiceous recent deltaic and fluvial deposits (Figure 2.3.3-6). Over 90 percent of all liquefaction-caused damage occurred on deltas and in stream deposits. The minimum shaking intensity required to induce liquefaction in susceptible deposits was V to VI in the scale of Modified Mercalli. Liquefaction-caused ground failures were landslides of the type of lateral spreads, occurring in slopes with gradients less than 3^o. It damaged many buildings including several well constructed masonry buildings with perimeter foundations. Effects of liquefaction were very widespread covering areas from Polochic valley, Lake Izabal, Amatitlán Lake, Atitlán Lake （Panajachel） in Guatemala to Puerto Cortés and Omoa, in Honduras and Ilopango Lake in El Salvador.

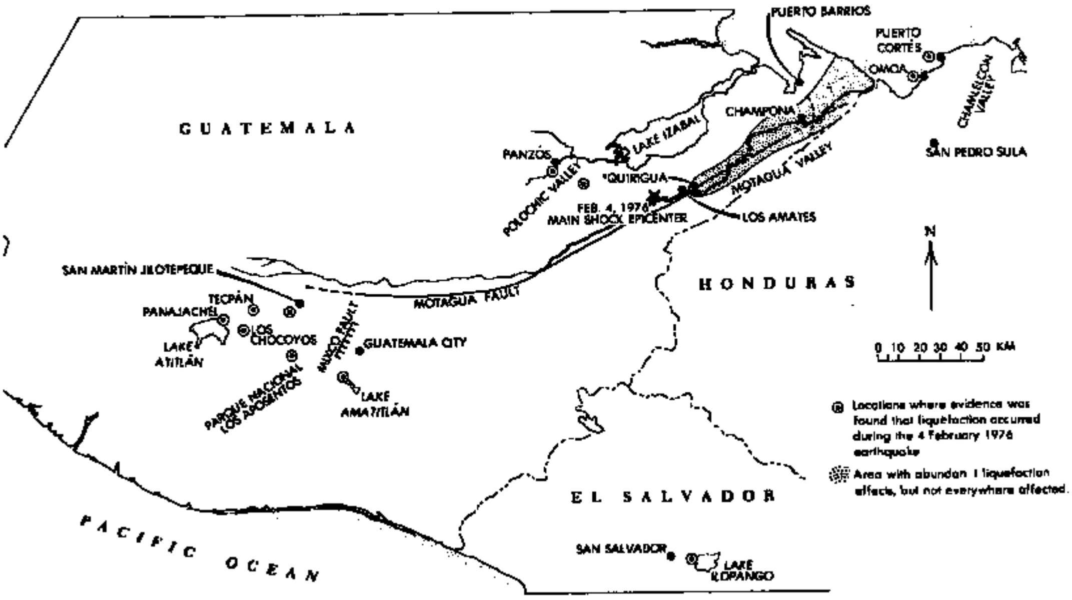

Figure 2.3.3-6 Liquefaction of 1976 Guatemala earthquake (S.N.Hoose,et. al.,1978)

(3) Volcanic Disasters

The detailed eruption history for the volcanoes under investigation is listed in Chronology table in Appendix .

This section describes, among them, the eruptions with significant personal damage as well as disasters due to eruptions that cause serious problems in the recent years.

1) 1902 Santa María volcano eruption

The Santa María Volcano was dormant for at least five hundred to several thousand years but burst into great eruption on October 25, 1902. Prior to this eruption, a series of earthquakes struck Central America to the Carribean region from January to October of that year. Nobody paid attention to these important precursors because no eruption in the past was known. This Plinian eruption killed more than 5,000 people. Major causes of death were diseases. As Blong (1984) summarized, the breakout of malaria after the eruption killed about 3,000 people in total. This is assumingly because mosquito-eating wild birds were killed in many places due to the influence from the eruption. Additionally, the damage due to thickly deposited volcanic ashes was also serious. Blong (1984) summarized the status as “Probably about 40% of the more than 5,000 deaths resulted from collapsing house roofs under the weight of tephra.”

During this eruption, dacitic magma of 10 km^3 was erupted for 36 hours. Figure 2.3.3-7 shows the isopach of pumice. Figure 2.3.3-8 shows the isopach of tephra including pumice in wide area.

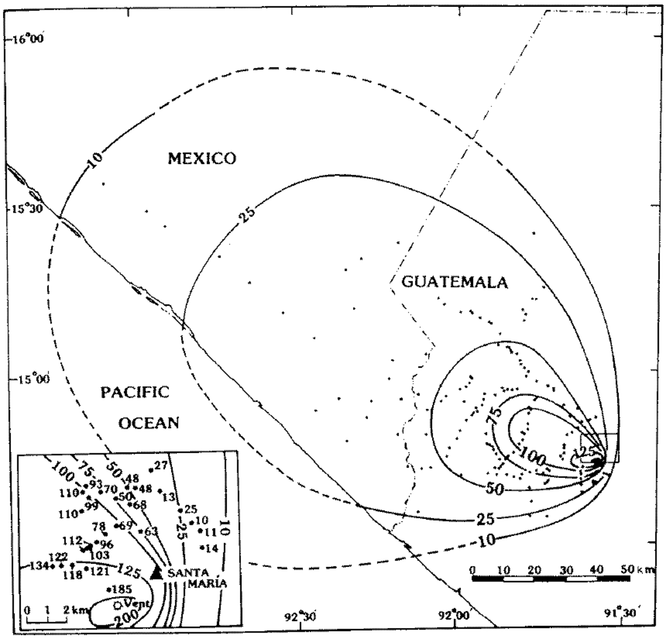

Figure 2.3.3-7 Isopach map of the 1902 pumice deposit of Santa María Volcano as measured by Sapper (1904) (unit: cm).

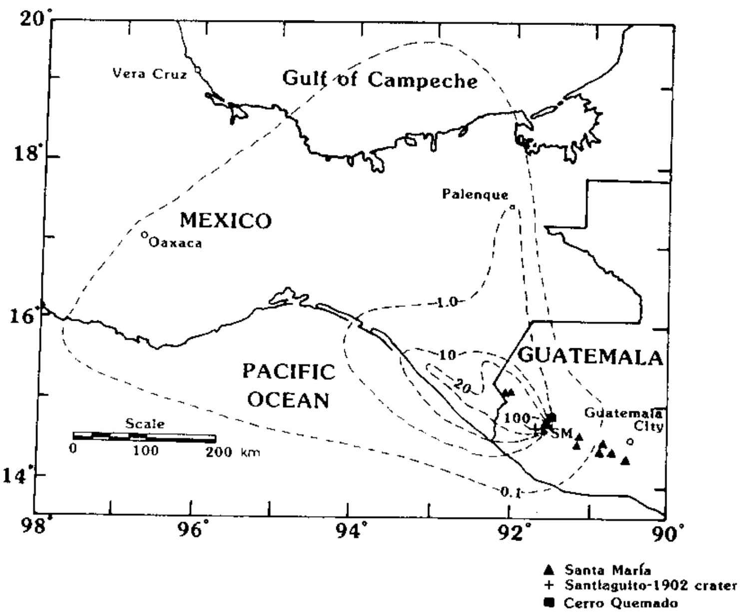

Figure 2.3.3-8 Isopach map of the 1902 plinian eruption deposit of Santa María Volcano (unit: cm).

(Source: Data from CONRED, Michigan Technological University homepage, Williams and Self (1983))

2) Pyroclastic flow of Santiaguito

In 1929, the largest pyroclastic flow since the creation of Santiaguito in 1922 occurred. The pyroclastic flow was generated due to collapse of part of the lava dome that grew to a height of 350 m from 1922 to 1929.

This pyroclastic flow occurred at 9:30 a.m., November 2, 1929. In Figure 2.3.3-9, the area with horizontal wavy lines is where the pyroclastic flow came down in 1929. The pyroclastic flow came down along the Nimá I and Tambor rivers reaching near El Palmar.

No local resident noticed any abnormal phenomenon prior to this pyroclastic flow. This pyroclastic flow is considered to have killed at least a few hundreds of people (also estimated about 5,000) (Reference: Michigan Technological University homepage).

Also in recent years, there were deaths due to pyroclastic flows. The lateral blast accompanying a pyroclastic flow that occurred in July 19, 1990 killed four mountaineers who were climbing al cause ong the eastern edge of the crater of Santa María in 1902. Figure 2.3.3-9 shows the range of influence from 1989 to 1990. The area with vertical lines is the range of influence from lateral blasts and the area with a check pattern is the range of influence from pyroclastic flows and hot blasts.

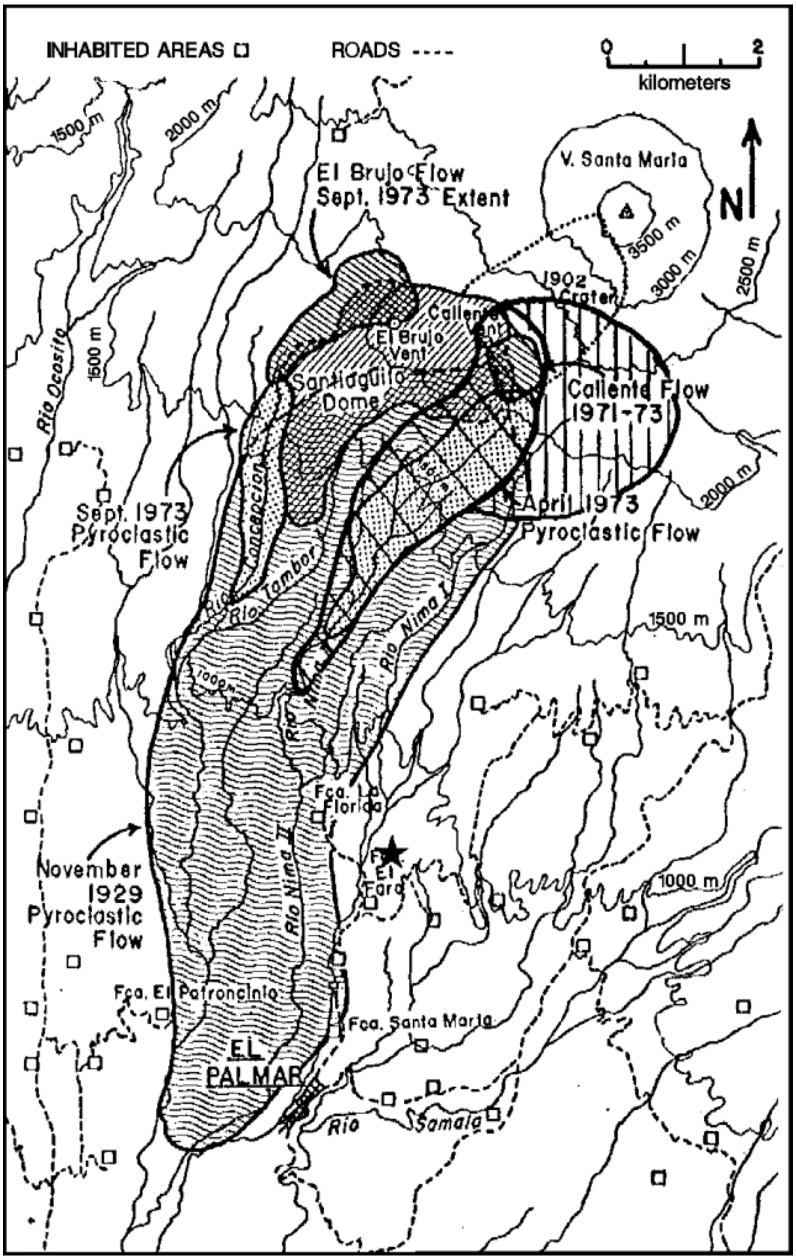

Figure 2.3.3-9 Range of pyroclastic flow in 1929 and range of influence from eruptions in 1989 and 1990 of Santiaguito volcano

(Smithsonian national museum of natural history homepage)

3) Lahars of Santiaguito volcano

Lahar is the largest cause of disaster at Santiaguito in recent years. According to the collected data, the first death by lahar in Santiaguito occurred in September 1978. Even later, lahar frequently occurred on the Tambor, Nimá I, and Nimá II rivers, causing personal and property damage. Table 2.3.3-4 shows the past cases of personal and property damage by lahar.

Although initial damage occurred on the Tambor River and Nimá II River, recent damage occurred on the Nimá I River. El Palmar had to be relocated due to lahar. Even now, sediments are actively supplied from Santiaguito and damage due to lahar continues. On June 1, 2001, a large-scale lahar occurred on the Nimá I River, causing sediments to flow into houses in the Finca El Faro area and damaging furniture in them.

Table 2.3.3-4 Recent mud flow and lahar damage in Santiaguito volcano

Date	Place of occurrence	Personal damage	Property damage
1978. 7.23	Tambor River, Nimá I River, Nimá II River	None	Destruction of bridges Damage on farmland
1978. 9. 2		One dead	
1982. 8	Nimá River	A few hundred evacuated	
1983 rainy season	Nimá I River, Nimá II River, El Palmar	A few hundred evacuated	Complete destruction of dozens of houses
1986.12	Nimá I River, Nimá II River, multiple villages	Evacuation of many families	
1987. 5.31	Nimá II River, Tambor River, El Palmar	None	Damage in El Palmar
1988 rainy season	Samalá River	None	Damage on bridge piers Closure of CA2 Inundation damage on the Ixpatz River
1990. 9.16	El Palmar	None	Destruction of pedestrian bridges
1991. 7	Samalá River	None	Destruction of bridge piers of a bridge near San Felipe
1991. 7	Nimá II River	None	The bank of the Nimá II River was destroyed. The river overflewed into the Nimá I River near Finca Santa Marta.
1995. 5.17	Nimá I River Finca El Faro	None	Destruction of bridges
1998. 5.28	Nimá I River El Palmar	60 families evacuated. Later, the government decided to relocate the village.	
1998. 8	Nimá I River El Palmar	None	Destruction of a cathedral
1998.11	Nimá I River Finca La Mosqueta	None	Damage on a coffee plantation
2001.6.1	Nimá I River Finca El Faro	None	Damage on houses

(source: Smithsonian national museum of natural history homepage, etc.)

4) Disaster of Pacaya volcano

The eruption history of the Pacaya volcano is summarized in chronology table in Appendix.

Table 2.3.3-5 lists personal damages and evacuation carried out for recent eruptions. Since people died from lahars, the villages along valleys need to continue to be careful of lahars in the future. On the other hand, damage frequently occurs due to falling pyroclastic materials. In particular, residents of El Caracol, El Rodeo, El Patrocinio on the leeward side of the prevailing wind frequently suffered from injuries and damage to their houses due to fall of pyroclastic materials. Ash may fall on the northeastern side of the volcano depending on the wind direction, which was observed for example in the eruption of May 20, 1998.

One of the characteristics of this volcano is the outflow of lava, which did not result in any personal damage or damage on houses.

Table 2.3.3-5 Personal damage by the Pacaya volcano

Date	Disaster area	Disaster cause	Personal damage	Other damage
1987. 1.12	Calderas	lapilli, blocks	12 injured	25 house roofs damaged, livestock dead
1987.1.25	El Caracol, El Patrocinio, Los Pocitos	blocks, ash fall	More than 15 injured, 3000 evacuated	63 houses damaged livestock dead
1987. 6.14	El Caracol	Ash fall	600 evacuated	2 house roofs damaged
1989. 3. 7	El Caracol	Ash fall	120 evacuated	Road blocked by lava flow in Patricinio, coffee plantation burned down
1991. 7.21	El Caracol, El Rodeo, El Patricinio	Ash fall, lapilli	3 injured, 1500 evacuated	Crops damaged
1993.1.10	El Caracol, El Patrocinio	Ash fall	Some evacuated	Roads damaged by pyroclastic flows
1994.10.12	Patrocinio, Caracol, Other near village	Ash fall	142 evacuated	
1995.4. 7	Los Rios	Lahar	One dead, some evacuated	Houses buried
1995.6. 7	El Patrocinio, Los Rios	Lahar	Many evacuated	Roads and bridges damaged
1996.10.10	Neighboring village	Ash fall	38 evacuated	
1996.11.11	El Caracol, El Rodeo, El Patrocinio	Ash fall	Some evacuated	
1998.5.20	San Francisco de Sales	Falling scoriaceous bombs	2 injured	La Aurora airport closed for three days due to ash fall
	San Francisco de Sales, El Cedro, and El Pepinal	Ash fall, Bombs	254 evacuated	
2000.1.16	Nearby villages	Ash fall	1500 evacuated	La Aurora Airport was closed.

(Source: Smithsonian homepage)

A disaster not included in the above table but left in the record is a series of earthquakes struck near the volcano on September 18, 1991 (of which the largest is M6.1 at about 39 km north-northeast of the volcano and the depth of 5 km) , killing more than 25 people.

(4) Floods

1) Overview of historical floods

According to a report by MAGA, floods occurred 587 times on the Pacific coast from 1931 to 1989. Floods occurred very frequently on the María Linda River, Achiguate River, and Samalá River on the Pacific coast. In comparison, floods occurred less frequently on the Acomé River. However, floods on the river may not have been easily distinguished as independent ones because the basin area was smaller and the basin zone was less definite than other basins.

Up to the present, major floods frequently occurred in the basins of the four rivers. According to the above report, major historical flood damages were a storm (*temporal*) in 1929, storm in 1933, storm in 1949, Hurricane Francelia in 1969, and Hurricane Fifí in 1974. Except for Hurricane Fifí, all flood damages occurred on the Pacific coast (*Costa sur*). In particular, floods often occur in September and October.

According to the interview survey of the residents, most of the lowland areas in the lower reaches were flooded by Hurricane Mitch in 1998 but greater flood damage was caused by Hurricane Francelia in September 1969.

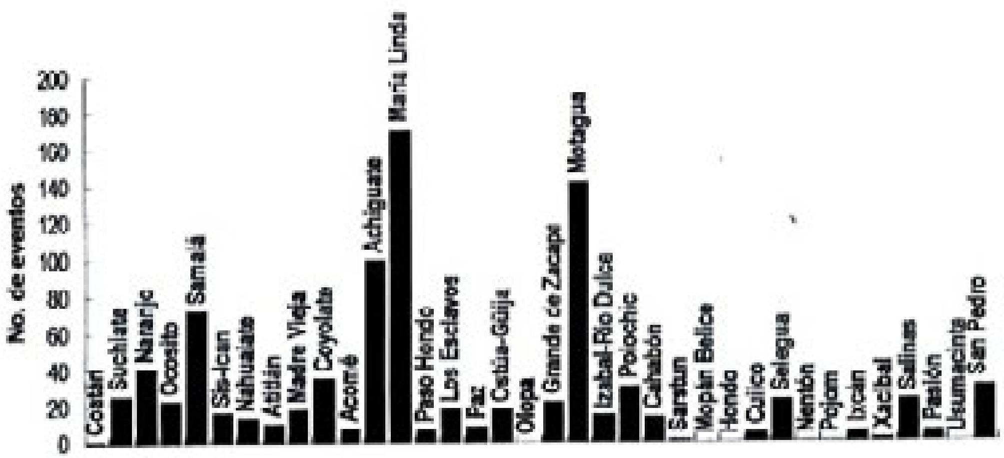

Figure 2.3.3-10 Occurrence of events in the Guatemala river basins from 1931 to 1998

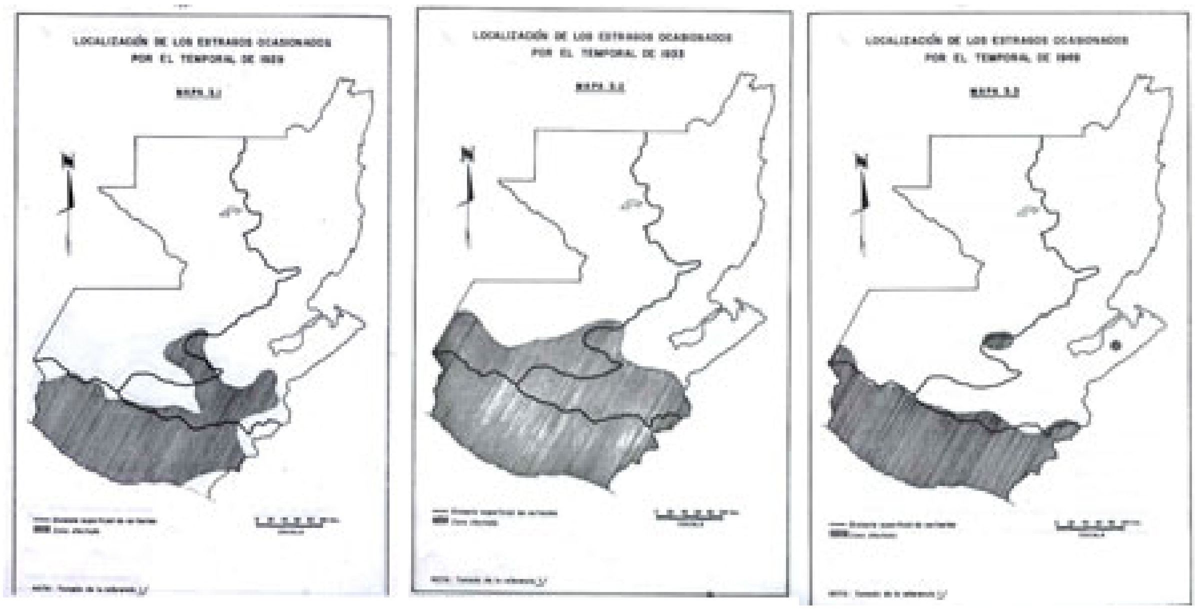

Figure 2.3.3-11 Regions damaged by floods in 1929, 1933, and 1949

2) Flood history of the 4 study rivers

Floods often occurred in the basins of the four rivers in the Study Area. The details of these floods are unknown because no “disaster report” was left to cover such records as the range of flooding, damage, and hydrologic data. Therefore, flood history was summarized using the reports covering historical floods by INSIVUMEH and MAGA, hydrologic and meteorological data stored by INSIVUMEH, and results of interviews with the residents.

The “Mapa de Amenaza de Inundacion (registro histórico de inundaciones en el país)” by INSIVUMEH summarizes such records as dates, river names, and damage of historical floods classified by departments based on newspaper articles.

a) Samalá River

Floods occurring on the Samalá River can be classified into three. The first are the floods occurring in Quetzaltenango. The second are the floods occuring in Retalhuleu to the lowland area in the lower reaches, which greatly influence the agriculture and stock in the area of the lowland up to the coast. The third are the floods occurring in the Nima I River and Nima II River, tributaries of the Samalá River, accompanied by lahar from the Santiaguito Volcano.

Looking at historical floods of the Samalá River, floods occurred in Quetzaltenango in the upper reaches up to the 1970’s. Since the 1980’s, eruptions of Santiaguito Volcano frequently caused floods accompanied by lahars on the Nima I River and Nima II River, greatly influencing El Palmar and surrounding villages. Thus, El Palmar was relocated in

1998.

In the lower reaches of the Samalá River, floods frequently occurred downstream of the bridge at CA2 near San Sebastián. Although no large towns exist in the lower reaches, the area along the Samalá River and Izpatz River that diverge from near Retalhuleu accumulated sediments supplied from the upper reaches every time a flood occurs until extensive floods began to occur. Through interviews with the residents in the lower reaches, it was learned that flood damage often occurred due to Hurricane Mitch and other downpours.

b) Acomé River

Few records remain for floods that occurred on the Acomé River. This is probably because floods occurring on the river cannot be distinguished from those occurring on the Achiguate River, etc.

Hurricane Francelia in September 1969 caused major floods on the Pacific coast, submerged La Gomera, and killed 71 people.

The heavy downpour in September 1979 had a daily rainfall amount of 210.0 mm in Puerto San José and caused floods on the Pantaleón River west to the Acomé River, evacuating 480 people.

c) Achiguate River

Floods frequently occurred on the Achiguate River and Guacalate River. For the Guacalate River, floods frequently occurred on the Pensativo River that joins it at Antigua Guatemala. In the lower reaches, floods caused damage many times in the coastal lowland area extending from near Masagua to the coast, particularly in Puerto San José.

Prior to Hurricane Mitch, floods in 1933 and 1969 caused great damage. The storms in September 1933 and October 1949 caused the Guacalate River, Pensativo River, and Achiguate River to overflow their banks and flood Antigua Guatemala, Masagua, and Puerto San José. Hurricane Francelia in September 1969 caused the Achiguate River and Guacalate River to overflow their banks and flood the lower reaches of Escuintla and more than 500 people in Puerto San José had to be evacuated. According to the residents near Escuintla, greater damage was caused by Hurricane Francelia than by Hurricane Mitch.

Even in recent years, floods occurred almost every year on the Pacific coast and floods occurred in Puerto San José and the areas along the Achiguate River.

d) María Linda River

The María Linda River frequently flooded in the lowland area of the lower reaches. In particular, inundation often occurred in Canal Chiquimulilla and Puerto San José near the estuary. Very few floods occurred on the Michatoya River, a tributiary, but the Seco River, its tributiary, overflowed its bank in the town of Amatitlán.

The area near Brito in the middle reaches was flooded by Hurricane Mitch in 1998 and Hurricane Francelia in 1969 but no flood occurred in the period inbetween. Hurricane Francelia in September 1969 caused the María Linda River and Achiguate River to overflow their banks to flood the entire area of the Pacific coast. According to records, this flood killed 50 people, injured 100 people, and isolated many residents and livestock. In Iztapa, the María Linda River flooded to isolate many residents and livestock.

(5) 1998 Hurricane Mitch disaster in Guatemala

1) Meteorological characteristics

Hurricane Mitch started as a tropical depression on Oct. 22, 1998 at the latitude 12.80 degrees and the longitude -77.90 degrees, in the Caribbean Sea. The track of Hurricane Mitch is shown in Figure 2.3.3-12 (from Unisys Weather Homepage). It was most powerful around Oct.26-27 offshore of Honduras. This period is shown as a white line in the figure. Maximum wind speed was 155 knots, and minimum air pressure was 906hPa. From that time, Guatemala had been affected by heavy rain caused by the hurricane. The hurricane went across Guatemala from Oct. 30 to Nov. 1.

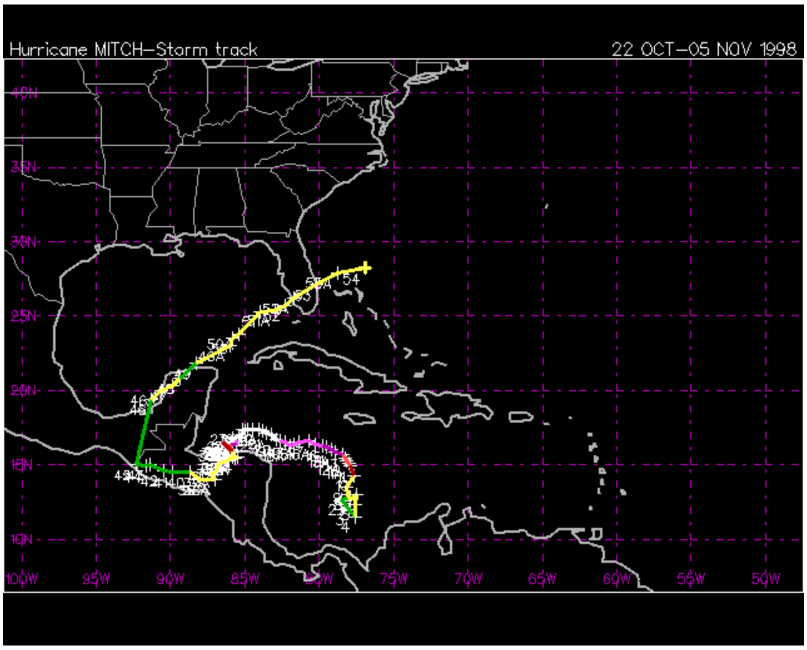

Figure 2.3.3-12 Track of Hurricane Mitch (source: Unisys Weather homepage)

The rainfall amount at INSIVUMEH Station from Oct.23 to Nov.10 is shown in Figure Figure 2.3.3-13 and Table 2.3.3-6. The daily rainfall amount on Nov. 2 was almost 200mm at INSIVUMEH. The hurricane continued to affect Guatemala even after it passed the country.

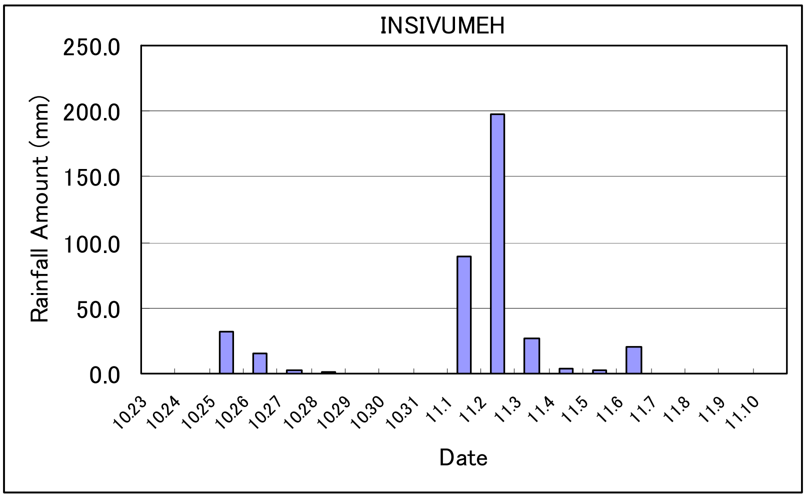

Figure 2.3.3-13 Rainfall amount at INSIVUMEH Station

Table 2.3.3-6 Rainfall during Hurricane Mitch in Guatemala (mm)

Place	Day											TOTAL
	Oct/ 27	28	29	30	31	Nov/ 1	2	3	4	5	6	
Sabana Grande, Escuintla						85.5	219.0	27.0	51.0	7.1	45.4	435.0
Pto. San José					112.0	86.0	467.0	284.0	77.8	3.8	18.8	1049.4
Camantulul, Escuintla						13.0	174.0	43.5	28.8	65.8	11.7	336.8
Labor Ovalle, Quetzaltenango						36.6	59.8	30.9	10.4	1.6	15.9	155.2
Ciudad Guatemala					48.4	89.7	198.3	26.7	4.1	2.4	20.8	390.4
Pto. Barrios, Izabal	35.8	49.8	105.2	164.4	9.2							364.4

Source: 1) INSIVUMEH, 2) CEPAL, 1999. Guatemala: Evaluación de los Daños Ocasionados por el Hurricane Mitch, 1998.

2) Damage

In Guatemala, the number of the victim and infrastructure damages were as follows:

202 deaths,

63 injured,

46 missing persons,

56,125 evacuees,

2087 houses damaged (565 destroyed) and

46 bridges damaged.

396 community water supply systems were severely damaged

According to some sources[1], the agricultural losses were US$ 258 million, and 7% of all farmland was affected. About 10,000 agricultural workers lost their jobs. The summary of damages by Department produced by Hurricane Mitch in Guatemala are shown in Table 2.3.3-7. Additionally the costs of the damages are shown in Table 2.3.3-8.

It can be observed that most of the damages were located in the Departments of Zacapa, Alta Verapaz, Izabal, and Guatemala. In terms of destroyed dwellings, the area of Guatemala City was the most affected. It is because the largest concentration of population is in the capital city, and the tendency of some very poor people to settle their dwellings in areas prone to inundation and landslide at the margin of rivers, where no owners claim property. These become illegal settlements when many people are grouped, which in some cases become very large. The same situations happen in the areas near ravines where people settle and remains at risk of any potential disaster. Flood damage was also severe. Especially, mid stream and downstream along the Motagua River, Maria Linda River and Achiguate River, inundation occurred very widely and a lot of residents were evacuated. The inundation areas were shown in the disaster map (our final products).

[1] World Neighbors, 2000. Lesson from the Field, Reasons for Resiliency: Towards a Sustainable Recovery after Hurricane Mitch, p.7.

Table 2.3.3-7 Damages in Guatemala during Hurricane Mitch

(October and November 1998)

Place	Persons							Dwelling			Bridges
	At Risk	Evacuated	Injured/ Sick	Hurt	Affected	Missing	Died	At Risk	Affected, Moderate	Destroyed, Severe	Damaged
Alta Verapaz	-	12,819	-	6	42	1	45	-	92	1	4
Suchitepequez	-	2,700	-	-	-	-	-	-	419	-	1
Solola	-	145	-	-	-	-	9	-	29	-	-
Santa Rosa	-	924	-	-	-	-	15	-	-	25	5
San Marcos	-	-	-	-	-	-	-	-	-	-	1
Retalhuleu	-	463	-	-	-	-	-	-	35	-	-
El Quiche	-	597	-	-	-	-	3	-	43	4	3
Quetzaltenango	-	-	6	-	-	-	12	-	-	-	-
Jutiapa	-	152	-	-	300	-	2	-	58	14	2
Jalapa	-	-	-	-	-	-	-	-	-	-	1
Izabal	261,772	11,001	1	-	1,500	1	13	-	17	-	-
Huehuetenango	-	207	1	-	-	-	3	44	11	18	-
Escuintla	-	1,800	-	-	-	-	9	-	-	-	1
El Progreso	-	-	-	-	-	-	-	-	-	-	-
Chimaltenango	-	800	-	-	-	-	-	-	-	-	-
Zacapa	84,722	10,397	1	846	-	30	18	-	539	74	23
El Peten	-	1,418	-	-	-	-	-	-	60	-	-
Chiquimula	-	6,520	-	-	-	2	-	-	-	-	-
Guatemala	-	6,182	54	-	6	12	73	-	175	429	5
Total:	346,494	56,125	63	852	1,848	46	202	44	1,478	565	46

Source: SEGEPLAN

Table 2.3.3-8 Economical cost of the damages by Hurricane Mitch (US$ Millions)

SECTOR	Total	Direct	Indirect	Reconstruction Cost	Imported Component
Social Sectors	48.1	33.0	15.1	52.2	
Housing	35.3	24.5	10.8	38.0	3.0
Health	4.9	1.1	3.8	1.9	1.0
Education	7.9	7.4	0.5	12.3	2.9
Infrastructure:	115.8	56.3	59.5	82.2	
Roads, Bridges, Railroads	89.7	40.1	49.6	60.4	15.6
Water and Sewerage	16.1	10.5	5.6	13.8	
Electricity	10.0	5.7	4.3	8.0	
Production	579.0	193.4	385.6	217.2	
Agriculture, Fishing, Forestry	499.4	187.6	311.8	211.3	
Manufacture	61.6	2.8	58.8	3.2	
Commerce, Restaurants, Hotels	18.0	3.0	15.0	3.0	
Environment	5.1	5.1		63.9	
TOTAL:	748.0	287.8	460.2	415.5	

Source: CEPAL, 1999. Guatemala: Evaluación de los Daños Ocasionados por el Hurricane Mitch, 1998.

Also it can be noticed that total costs were US$ 748 million and 40% of them are direct costs. Among them production costs mostly related to losses in agriculture were the most important, followed by infrastructure (mostly bridge and roads collapses) and in the social sector the housing related damages. This means that these kinds of disasters have an overall effect in all the sectors of the economy, and that reducing these effects would be of large help for the development of this country.

According to the field investigation of the past flooding in 2001, not only houses and infrastructures but also farmland and agricultural products were damaged severely. Especially, along mid and down stream of the Motagua river on the Carribean Sea side, the Maria Linda river, the Achiguate river and the Acome river basin on the Pacific coast side, flood damage for farmland was more than 900km2.The disaster map of hurricane Mitch is explained in next section.

3) Disaster mapping

Based on the field survey conducted in 2001, aerial photograph interpretation, and materials of various organizations, disaster maps representing the damages due to Hurricane Mitch were created. Topographical maps with a 1:50,000 scale were used as the backgrounds of these disaster maps. The resulting disaster maps cover the basins of the four rivers and the city of Guatemala, which are the flood study areas in this Project.

On the other hand, a system that displays damages in a map using GIS was created in addition to the map. When seen on-screen, points represent items other than the flooded area, each of which displays a table of damage count when clicked. The target area of this system includes all the areas subject to this Project as well as the flood study area.

Table 2.3.3-9 Items of disaster map

<table>
<tr><th colspan="2">Input item</th><th>Map</th><th>Data</th><th>Source</th></tr>
<tr><td colspan="2">Flooded area</td><td>○</td><td>○</td><td>Inhabitant interviews and photograph interpretation</td></tr>
<tr><td colspan="2">Inundation depth and duration</td><td>○</td><td>○</td><td>Inhabitant interviews</td></tr>
<tr><td colspan="2">Landslides (including house damage points)</td><td></td><td>○</td><td>MAGA materials</td></tr>
<tr><td colspan="2">Lateral erosion points of rivers</td><td>○</td><td>○</td><td>Aerial photograph interpretation</td></tr>
<tr><td rowspan="3">Number of damages</td><td>Number of evacuees</td><td></td><td>○</td><td>CONRED materials</td></tr>
<tr><td>House damages (Numbers of buildings totally and half collapsed)</td><td></td><td>○</td><td></td></tr>
<tr><td>Personal damages (Number of persons missing, dead, and injured)</td><td></td><td>○</td><td></td></tr>
</table>

(6) Recent disaster investigation

1) Mudflow in Ciudad Vieja in 13 June, 2002

A mudflow occurred in Ciudad Vieja in the evening of June 13, 2002, at the foot of Agua Volcano, causing disasters including two missing children, destroyed houses, and flooded farmland.

We cooperated with INSIVUMEH in the field investigation, created a disaster map, and reported a proposal of policies for disaster prevention measures.

a) Description of damages

The mudflow occurred in three places (hereafter called Streams I, II, and II counting from the Antigua Guatemala side). All of these streams are brooks about two meters in diameter flowing from the mountainside of Agua Volcano, dry rivers receiving water only when it rains. The land along the upper reaches of the river is used for farms. The river originally emerged due to concentrated surface runoff water on the mountain pass for farmers. The land along the middle and lower reaches is found in the alluvial fan formed by these brooks and the brooks are raised river bed.

Stream I had no water channel in the lowermost reaches and directly ran into a road. Lots of mud accumulated thus on the road and blocked the traffic for 200 to 300 meters. Furthermore, the stream destroyed fences along the river and caused mud to flow into the neighboring residential areas and farms. In the middle reaches of the river, there were marks of lateral erosion and riverbed erosion.

Stream II caused the accumulation of mud in the residential areas along the river in the lowermost reaches. The mudflow carried away two children who went missing. The sediments that flew into the Guacalate River dammed the river, forming a dammed lake for several days in the coffee plantation downstream of Ciudad Vieja in the upper reaches of Guacalate River.

Stream III caused no damage to houses, etc. because it ran through the coffee

Photo 2.3.3-1 Mouth of stream I

Photo 2.3.3-2 Dammed lake

plantation but caused sediments to accumulate on the road over a distance of 100 meters.

b) Causes of mud flow

The peak observatory of Agua Volcano and a farm in Ciudad Vieja recorded 24-hour precipitations of 71.8 mm and 76.1 mm on June 13, respectively. With the lack of rainfall during the day and based on the interview with the residents, we conclude that the mud flow was caused by a heavy rain shower that lasted two to three hours toward evening.

The mud flow was caused by a rainfall exceeding 70 millimeters that occurred in a short period of time and surface runoff water in the mountainside were concentrated to streams. On the mountainside of Agua Volcano in particular where trees are planted as coffee plantation, a rainfall tends to be concentrated directly into streams. According to an interview with the residents, the rain started at around 4:00 p.m. and the mud flow occurred three times, namely at 5:00 pm, 5:30 pm, and 6:00 pm. Since no collapse occurred on the mountainside, the sediments accumulated in the lower reaches were supplied by lateral and downward erosion caused by flood currents that dashed down the streams.

Since no mudflow occurred on June 3 at the time of a rainfall of 51.8 mm, we may be able to set a standard beyond which an alarm for occurrence of a mud flow would be issued, between 50 and 70 mm.

Table 2.3.3-10 Records of precipitation (June 2002)

Date	Volcán de Agua	Ciudad vieja
3	51.8 mm	
4	23.5 mm	
5	0.0 mm	
6	0.0 mm	
7	10.5 mm	
8	5.9 mm	4.6 mm
9	2.5 mm	0.0 mm
10	8.8 mm	6.4 mm
11	22.5 mm	0.0 mm
12	19.0 mm	4.1 mm
13	71.8 mm	76.1 mm
14	0.0 mm	0.0 mm
15	9.5 mm	0.0 mm

(Source: INSIVUMEH Records)

c) Creation of disaster map

We created a disaster map (Figure 2.3.3-14) using an orthophoto map of 1:10,000 scale based on the result of field investigation. To create the map, we used GIS to mark the location where the mud flow occurred, the range in which mud accumulated, and the range of a dammed lake.

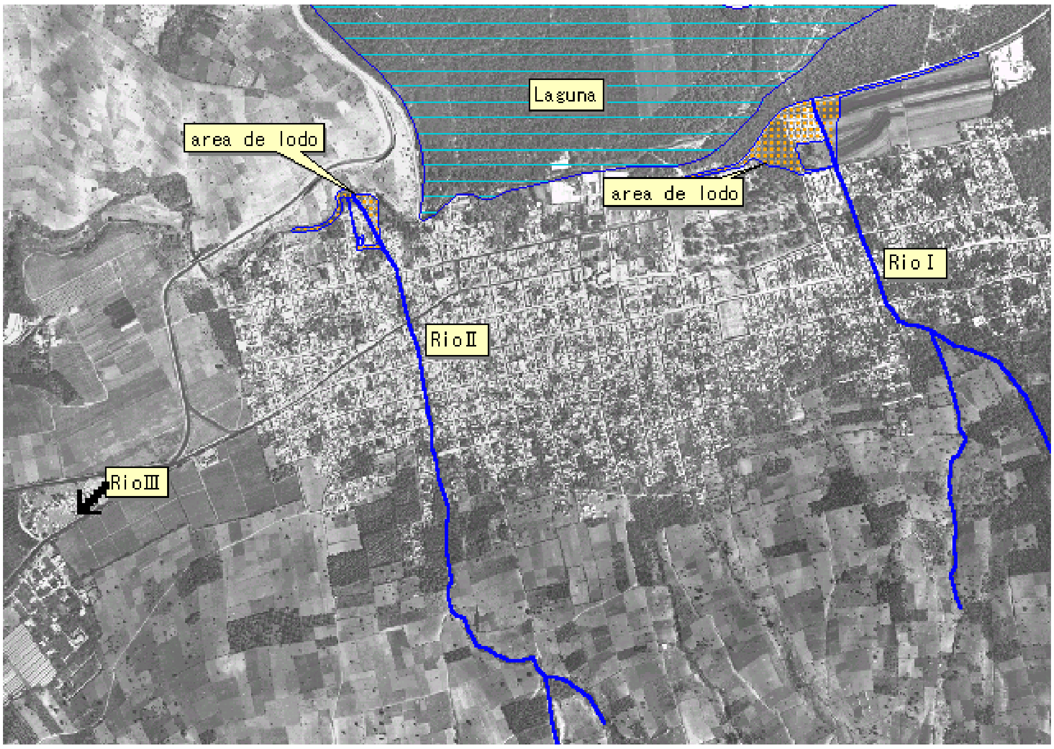

Figure 2.3.3-14 Disaster map in Ciudad Vieja, 13 June 2002

d) Proposals for countermeasures

It would be effective to plant trees in the upper reaches to delay the outflow peak, install structures in the middle reaches to prevent riverbed and lateral erosion and supply of sediments, and lower the riverbed and widen the river path in the lower reaches to let down increasing water flow. However, these countermeasures apply only to sediment outflow due to concentration of surface runoff water. Other countermeasures will be necessary for sediment outflow due to collapses occurring in the upper reaches.

Table 2.3.3-11 Proposals for countermeasures

	Stream I	Stream II	Stream III
Upper reaches	Planting trees	Planting trees	Planting trees
Middle reaches	Installing river path works or gabions	Installing river path works or gabions	Installing river path works or gabions
Lower reaches	Expanding the river path Excavating the river bed Installing culverts Installing river path works	Expanding the river path Excavating the river bed Installing river path works	Expanding the river path Excavating the river bed Installing river path works Expanding the culverts