which give to the mass a large cohesion, which allow the soils to remain relative stables, even in vertical cuts of up to 150 meters (F.Kooose, 1978). In general, soils at the surface have certain amount of clay or silt with some plasticity. This explains the large cohesion of this soils have and then their capacity to stand in high cuts without lateral confinement.

- **Landslide at km. 11.5 road to El Salvador (Panamerican Highway)**

From a preliminary study (progress report) of INSIVUMEH (1994), it is reported that this landslide appeared on October/1993. However, according to photo interpretation by aerial photos of 1990, instability evidences were obtained from that time. It is known the rainy season of 1993 up to October gave about 1,150 mm of rain and 676 mm accumulated in the previous three months.

According to a well of 80m drilled at that time (July 1994) at the slope on the upper side of the road has a layer of about 20m of clay, and water table was about 10m below it. This fact indicates that water inflow from the subsurface of the slope was producing the instability and that subsurface drainage along the foot of the slope at the road upper side for a length of some 200m and channeled downstream could have been enough for stabilizing the landslide.

Although until now it was not possible to know final report (if exists) or details about further study or countermeasures, in a visit to the field (June 14, 2001) it could be observed that stabilizing structures such as a bridge platform, piles driven and some erosion control mortar carpet were already installed. In the case the abutments of the bridge are fixed to bedrock and that enough number of piles were driven well beyond the sliding surface, this method would work effectively even when expensive. Carelessness of this matter may induce new troubles in the future, thus actions for slope protection at the base are highly recommended.

- **Area of Santa Cruz Chinautla (Old City)**

General

Chinautla is located just half Km downstream of the junction of the Chinautla and Aguacate rivers. Consequently at both riverbanks there are alluvial deposits along the city up to the northeastern area. At the southwestern area there are well welded basal pumiceous deposits. All of this is surrounded by thick air fall and water lain deposits of rhyolitic and rhyodacitic pumice, extensively reworked.

At some section before the entrance to the city the Chinautla River runs along a tectonic depression, one of many faults that are oriented in a northeast direction. Thus, it is supposed that large part of the alluvial deposits may be originated from old big landslides which were produced by the tectonic activity along these faults. The material was fragmented during the previous movements, producing its characteristic instability and then the mass wasting processes. Apparently all this sector located at north of the Guatemala City has these structural characteristics and this may be the concentration of landslides during 1976 earthquake (L.Fauq`ue, 1995).

Most of the tributaries of Chinautla River are used for discharge of waste waters from some large sector (about 50%) of the Capital city, as well as some other neighboring towns like Mixco, increasing its discharge when it runs along Chinautla town. This produce floods in the houses at the riverbanks.

This area is also prone to earthquake. The chain of earthquakes of 1917-12-26 that destroyed the Capital City also inclined the tower of the church and finally it collapsed with the earthquake of 1976.

Landslide at Cantón Amatitlancito (Area of Santa Cruz Chinautla)

As in a report of 1997(M.A.Mota, 1997), it was estimated maximum height of 2 meters, it may be considered that the sliding is occurring at an average rate of 25 cm per year, some years more (as in 1998 during hurricane Mitch) and others less. Besides this, the Chinautla river has an erosive contribution to the base of the landslide, especially during large discharges in rainy season.

According to neighbors the chain of earthquakes of November-December of 1917 (maximum magnitudes Ritcher between 5.7 and 5.8) which affected Guatemala valley, also produced inclination of the tower of the church of this town. This fact may indicate that the intensity in MM could be at least VI in this area and then the landslide could have started from that time too, judging by the large scarp already produced, which in change would be roughly in agreement with preliminary estimated rate of sliding. More investigation is necessary about this point in order to fully understand the sliding process.

Although technically there are many solutions to these type of landslides, from the economic ones of improving the surface and subsurface drainage, as well as the sealing of all the cracks and scarps in order to recover shear strength and avoid infiltration of water, to the expensive ones of piling deep into the bedrock to retain the sliding (retaining wall at the foot would be ineffective), considering the few families affected (about 10-12) and the value of property, it is more economical the withdrawal and resettlement of this people in other safe place, and use this area for forest protection purposes. However, it seems people inside is not well aware of the danger, because one family has recently constructed very nice house with concrete blocks and steeled roof frame, to substitute the older cracked one of adobe. This matter has to be undertaken by responsible institutions like CONRED in order to get the necessary awareness and avoid useless expectations of the people.

- **Settlement of road (Area of Santa Cruz Chinautla)**

At the entrance of the town there is an accumulated settlement of about 3m along some 300m of the road. This is due to a layer of clay that is located under the thin layer of pyroclastic materials. Neighbors say this settlement started about 1976 soon after the earthquake of that year. It seems the movement has continued as a seasonal effect of expansion and contraction of a layer of clay that underlies the road in that section, besides the probable contribution of underground water that flows into the river.

Preliminary it can be stated that solution to this movement may be with the construction of sub drainage at the foot of the slope where the road was constructed at middle cutting. Moreover, any surface water upstream of the road should be diverted or channeled in order to avoid as much as possible the inflow into this section of the road.

b) Quetzaltenango and surrounding area (Totonicapán: Ravine between Cocshaok and Chotakaq Districts (Cantones))

According to the neighbors this ravine may have started to erode some 80 years before. However, in the last 20 years they have noticed it has become bigger. It already has a depth of about 15 meters. At present several houses are discharging their waste waters as well as solid waste to the ravine, producing further erosion. This seems to be a custom in Guatemala, because in some others areas signboards are placed inviting to the neighbors to deposit garbage into the ravine with the purpose of filling it up.

During rainy season the waters flow into the ravine, becoming the stream recipient of the waters.

c) Antigua Guatemala region

In this area no evidence of large landslides were found. One of the reasons may be that considering the area is covered by air fall pumice from Fuego, Acatenango and Agua volcano with which the large infiltration capacity of the materials do not allows retaining water during heavy rains, and there is no susceptibility to earthquakes because of the light weight. However, in the road from Antigua to Guatemala City rock falls are found in several points where slopes are very steep.

d) Central region (Landslide at Patzún Village, Chimaltenango)

According to the residents of this area a retaining wall was constructed between the road and the slip-off slope some years ago, however, during the rainfall last year it was broken and all the debris along the wall flowed down by rainfalls. This was because any structure to retain it should not be based on the same altered material, and then effectiveness can be obtained.

To stabilize this section the weight of the sliding mass should be taken into account. A simple stability analysis considering the real topographic profile in several sections (3 to 5) along the road and considering the saturated condition should give the amount of mass to be removed from the top of the sliding mass in order to avoid sliding even in worse conditions. This is judged to be the most economical method for this case. Simultaneously, surface water should be channeled in order to avoid infiltration of water to the sliding surface.

e) North-West region

♦ **Debris flow at the village of El Paraíso, Huehuetenango (30 Sept/1987)**

According to a preliminary study elaborated by staff of INSIVUMEH[2] at that time, rainfall started at 17:30 (30/Sept, 1987), and lasted about two hours thirty minutes until about 20:00, when the flood started. However, considering the estimated concentration time of the basin was one hour seven minutes (1:07) it is considered that some landslide may have dammed the river and the retained flow until the dam collapsed. After the wave of flow transported large rocks, debris and sediments, which deposited in the low stream of the river where valley is widened, specially in the areas of Finca El Injerto where most of the houses were damaged, and the area around the bridge of the Panamerican road CA-1 connecting the town of La Democracia with the border of Mexico.

During field reconnaissance it was observed the large rocks and material deposited from that event and also the remains of previous ancient deeper deposits, which indicates that this area is prone to this type of phenomenon due to its narrow canyons and steeps hills. According to one resident, about 50 years ago there were some similar events. Also it is known that the basins of this river head are the contacts between Chochal limestone (Permian) and undivided Cretaceous Carbonates at the Injerto River, with large concentration of faulting. At Peña Roja river the contact is between the Chochal limestone and the Todos Santos Formation (Jurassic) with large faulting.

Thus, human and economic damages could be reduced by avoiding construction of houses and farms at the area of deposition of this debris, promoting soil conservating practices at the hillsides, and forest conservation at the margin of the rivers.

♦ **Cantzelá landslide**

This landslide is located at the village of Cantzelá, belonging to the Aguacatán Municipio of the Department of Huehetenango. The landslide has an approximate extension of 300x300m. According to accounts of some older person it had large movements from around 1920, and then on 1998 during Hurricane Mitch. The site is

[2] S.I. Hernández, F. y F. Alvarez, E., 1987. Río Selegua y Cuilco; Situación de la Areas Afectadas por Inundaciones en las Subcuencas de los Ríos El Injerto, Hoja Blanca y Agua Dulce. Informe Preliminar,

located in a contact of Formation Todos Santos (Jurassic-Cretacic), consisting of shales, siltstones, sandstones and conglomerates, with Formation Santa Rosa (Pensilvanian-Permian?), consisting of slates and slaty shales. This area also is surrounded of many local faults produced by the activity of the Chixoy-Polochic. The sliding surface seems to be the shales of Todos Santos.

Within the area of the landslide, a primary school and about 5 houses are settled, with severe damages on the school especially, at the point that they are moving it from the present place. Although it is more advisable for the people to move from this place and locate the school in a safe are out of here, the countermeasures to reduce or stop movement should be associated with the improvement of surface drainage in order to avoid infiltration of water to the sliding surface. Channeling of surface waters to divert surface runoff from hill should be implemented as one of the main activities. After more detailed study and considering the cost/benefit factor, sub drainage also could be implemented.

(7) Flood study background

The Emergency Program for Natural Disasters (*Programa de Emergencia por Desastres Naturales*) compiled by MAGA contains a section, Flood in Guatemala (*Inundaciones en Guatemala*), which analyzes the relationship between the frequencies of floods by basins, basin areas, and water discharge in all the floods that struck in 1931 through 1989.

Generally, a flood is influenced by the geomorphologic and hydrological characteristics. Thus, this section summarized the relationship between the flood risks and the characteristics of the four rivers and surrounding landforms recognized through aerial photo interpretation and field study.

1) Samalá River

a) Basin landforms and flood hazard

The Samalá River originates near Quetzaltenango and flows into the Pacific. Concerning the form, the basin has a large catchment area in the upper reaches and a narrow shape less than 10 km wide in the middle and lower reaches. The river runs in a mountainous area from Quetzaltenango to San Felipe, an alluvial fan area from San Felipe, and a lowland area for a few kilometers up to the coast.

A flood on the Samalá River occurs because lots of volcanic ejecta flow into the Samalá River due to the eruption of Santiaguito Volcano. Since the volcanic ejecta has been accumulated on the bottom of the river to raise the riverbed, a flood easily occurs during heavy rainfalls. Thus, a high flood hazard area exists downstream from the junction of the Samalá River and the Nima I River and Nima II River that flow out from the Santiaguito Volcano.

The Nima I River joins the Samlá River near El Palmar. The Nima I River runs along a deep bottom valley from the junction to San Felipe. Currently, there is no flood problem because little sediment is supplied from the Nima I River.

Photo 2.3.4-2 Samalá River near San Felipe. The front is a terrace surface.

The Samalá River joins the Nima II River near San Felipe. From there downstream, the river runs an alluvial fan area. An alluvial fan is a piedmont alluvial fan formed in ancient times. The surface of an alluvial fan is a terrace because most of the rivers eroded the fan to form a valley.

Photo 2.3.4-3 Lagoon formed on the Mesa River

Downstream from the junction of the Nima II River, the Samalá River becomes wider and has on its riverbed lots of gravel supplied from the Nima II. Since both banks form a terrace 3 to 5 m higher than the riverbed, there is no risk of flooding. This terrace continues up to Santa Cruz Muluá, 7 to 8 km downstream.

Photo 2.3.4-4 Undercut slope of the Samalá River

Near San Sebastián, the river is narrower than the upper reaches and the supplied sediments are accumulated to significantly raise the riverbed. From near the CA2 bridge, in particular, there is no difference in height between the riverbed and the terrace on both banks. Thus, an area prone to floods continues downstream from this point.

Ixpatx River starts around Retalhuleu and it meets Samalá River at the lower San Sebastián. The area along these two rivers, a lowland area without any significant difference in height from the riverbed, is prone to inundation. Retalhuleu, located on an old alluvial fan area (terrace), has no risk of flooding from Samalá River.

Between Retalhuleu and the coast, the Samalá River joins many tributaries that flow down an alluvial fan. At the junction, the riverbed of the Samalá River is significantly raised and sediments accumulate like in a dam to form a lagoon.

The riverbed has been raised until there is little difference in height between the surrounding terrace surface and the riverbed. Thus, sediments flowing into the tributary from the junction and the upstream terrace surface every time a flood occurs are beginning to bury the ravine and expand the floodplain. Downstream from the junction with the Ixpatx River, a floodplain 6 km wide is formed. A floodplain is highly prone to flooding because the river path changes every time a flood occurs.

In a floodplain, a river significantly meanders but, during a flood, tends to overflow on an undercut slope. A flood current overflowing from there is likely to flow into a valley or depression with a shallow terrace and expand the flood.

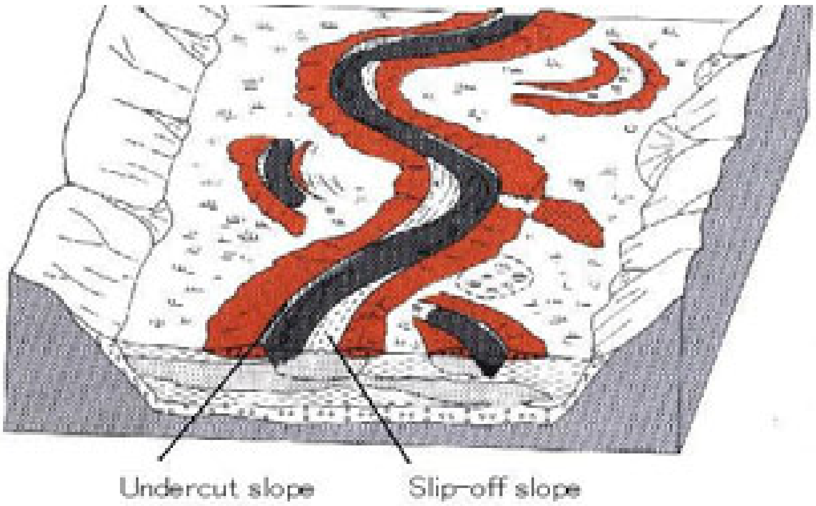


Figure 2.3.4-17 Undercut and slip-off slopes of a river

There is a floodplain 4 km wide in the lowland area in the lowermost reaches. The surrounding terrace is 2 to 3 m higher than the riverbed and resistant to inundation.

Undercut slope: Refers to the outer rim (section) of a winding river path. On an undercut slope, the running water is faster and tends to cause lateral erosion.

b) Hydrological characteristics

On the Samalá River, the water level is observed in Cantel downstream from Quetzaltenango and in Candelaria near El Palmar.

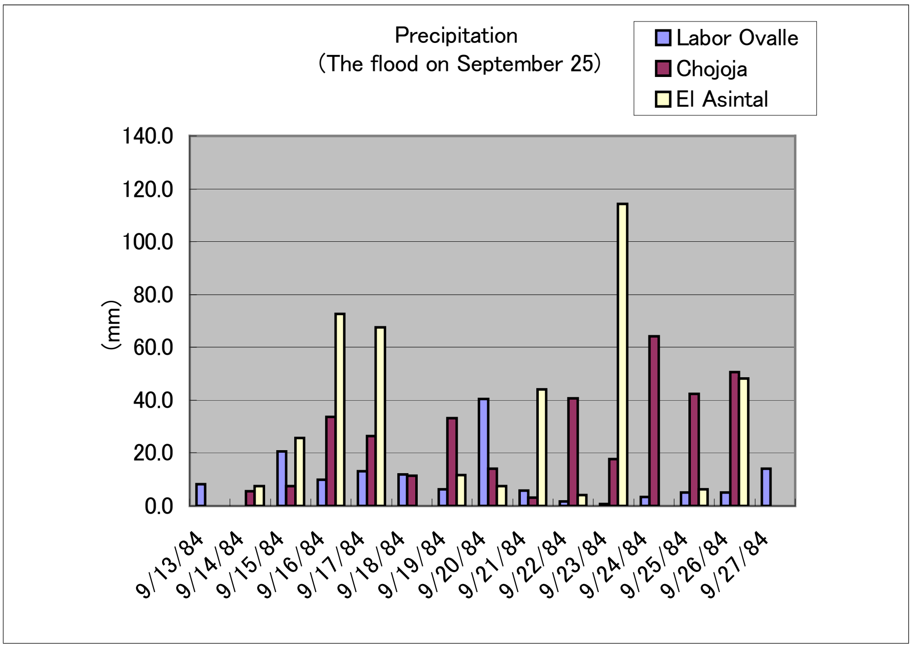
On September 25, 1984, the Samalá River overflowed to cause damage in San Sebastián in the lower reaches of the Samalá River. On September 22, 1988, the Samalá River overflowed to cause troubles on the highways. At this time, 2,000 households were isolated in Champerico in the neighboring basin.

The following figures show the records of water levels and precipitation in these two cases. Candelaria, where the water level observatory exists, is located in a mountainous area upstream from San Felipe. The Labor Ovalle's precipitation observatory is located in Quezaltenango and others are located around Retalhuleu.

For the flood on September 25, 1984, the water level rose from the 18th to 20th and from the 24th to 27th. In Labor Ovalle in the upper reaches, the rainfall was not so great as to contribute to a flood. In El Asintal and Chojoja, however, there was heavy rains from the 17th to 18th and from the 23rd to 27th, which correspond to the period when the water level rose.

For the flood on September 22, 1988, there was little rain in Labar Ovalle in the upper reaches and little change in the water level in Candelaria, either. In Retalhuleu and Las Brillantes, however, intermittent heavy rain was recorded from September 16 to 22.

From the above facts, it is concluded that the flood in the lower reaches of the Samalá River was not caused by the rain in the upper reaches near Quezaltenango but by the rain on the southern slope in the mountainous area.



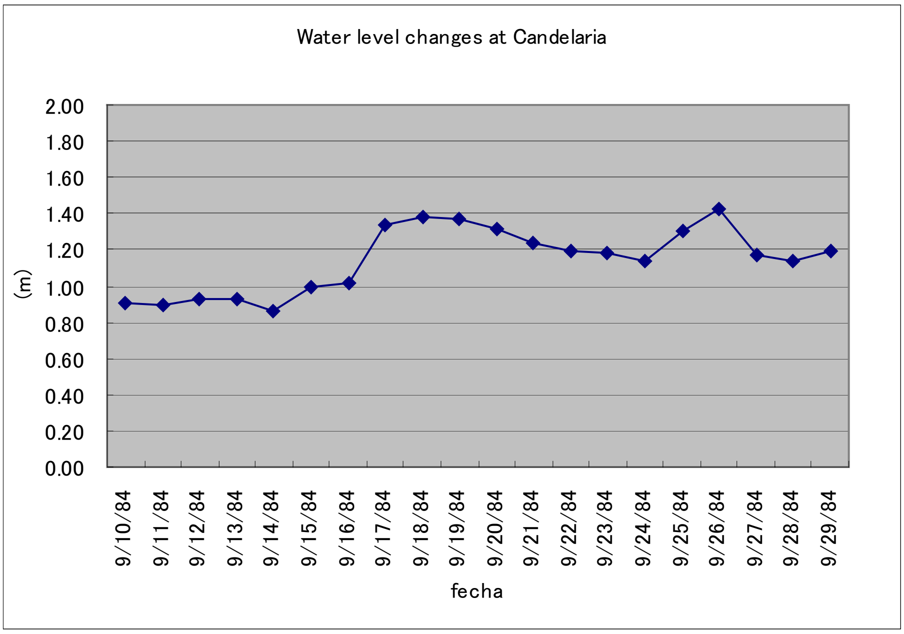
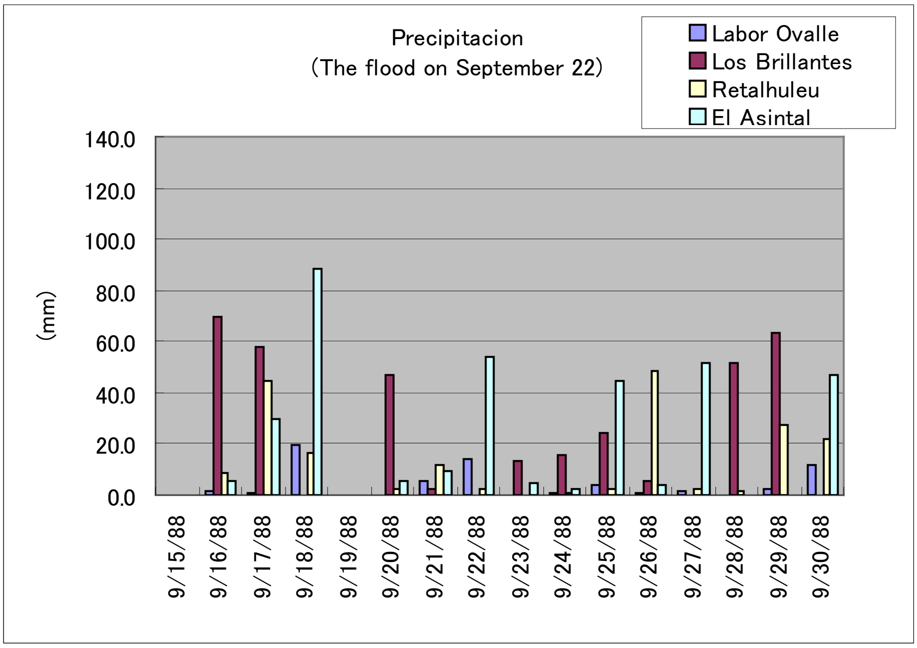


Figure 2.3.4-18 Precipitation and water level changes during the flood on September 25, 1984



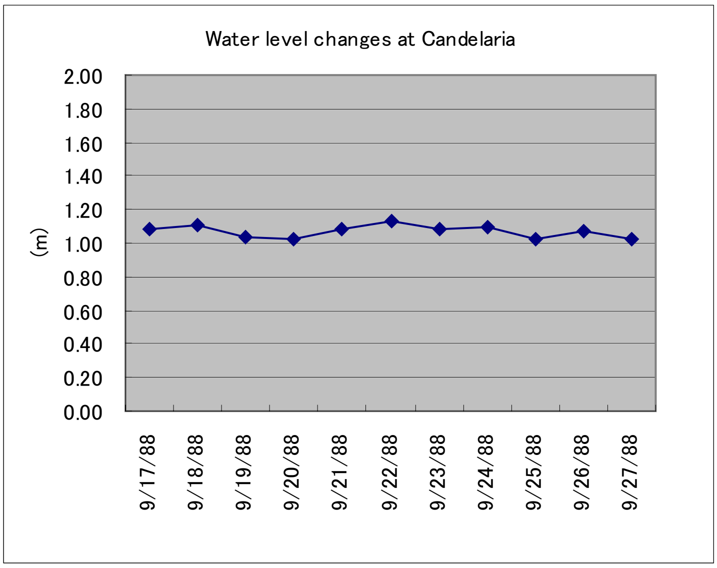


Figure 2.3.4-19 Precipitation and water level changes during the flood on September 22, 1988

2) Acomé River

a) Basin landforms and flood hazard

The basin of the Acomé River is very small. In particular, it is narrow in the upper reaches and there is not a catchment area large enough to cause a flood. The Acomé River flows through an alluvial fan from the upper reaches to La Gomera and a lowland area from La Gomera to the estuary. In the upper reaches, an old alluvial fan surface is eroded to become a shallow valley. The river is only a stream a few meters wide.

On the other hand, the Acomé River flow in a lowland area in the middle and lower reaches. In the lowland area, rivers and channels that diverge from the Seco River, Coyolate River, and Achiguate River run in a network and there is no distinction between any two neighboring basins. There is about 2 m difference in height from the riverbed to the ground surface and a terrace is formed near La Gomera. In such a landform, inundation may not occur every year but, once it occurs, water overflows in a wide range because there is little difference in height in the lowland area. Additionally, a flood tends to be expanded if another river also overflows and a flood stream comes in from there.

In the lower reaches, dunes exist along the coast for about 30 km. Sandhills are 300 to 500 m wide and some of them stand in two rows. Sandhills are 3 to 5 m higher than the lowland area and not prone to inundation. In the rows of dunes 30 km long, only the Acomé River has an estuary. Thus, the dunes prevent the flow of many rivers to form wetlands behind the dunes. If heavy rain comes, flooded streams are concentrated on the Acomé River, the only drain. In such a lowland area behind the dunes, therefore, a flood is expected to occur extensively and stay there for several days.

In short, a flood on the Acomé River is caused by the landforms and hydrologic system. The Acomé River itself does not have a catchment basin large enough to cause a flood. A flood occurs in the Acomé River basin because overflow streams are supplied by many rivers and concentrated on the estuary of the Acomé River.

Photo 2.3.4-5 Lowermost reaches of the Acomé River

b) Hydrological characteristics

There is no water level observatory on the Acomé River and the hydrological characteristics cannot be analyzed. In consideration of the basin form and landforms, it is assumed that the relationship between the rainfall in the basin and the water level of the rivers is not clear but that the water level slowly rises due to the influences of other rivers, remains the same for some days, and then slowly drops.

3) Achiguate River

a) Basin landforms and flood hazard

The basin of the Achiguate River is large. The headwaters of the tributary Guacalate River reach Chimaltenango. The river flows through mountainous and volcanic areas from Chimaltenango in the upper reaches to Escuintla, an alluvial fan from Escuintla to near Masagua, and a lowland area from Masagua to the coast. In particular, a mountainous area that is the catchment area occupy two-thirds of the enter river path and many tributaries join the river where it comes out of the mountainous area into the lowland area. In a basin with such a form, the peaks of rainfall and flooding are one or two days apart. Since flood streams are concentrated on the Achiguate River from the tributaries, a flood tends to occur in the lowland area and the water level does not drop for a few days. Even if the precipitation is not so much in the lowland area, a flood may occur in this area due to rainfall in the mountainous area.

In the upper reaches, the Guacalate River, a tributary of the Achiguate River, flows through a bottom of narrow valley plain from Chimaltenango to Antigua. The river is about 3 m wide and has little water discharge but easily overflows in a curve of the river because there is only a one to two meter difference between the riverbed and the surrounding ground surface. However, a flood does not last for a long time because of the inclination of the riverbed.

Photo 2.3.4-6 Guacalate River near Antigua

In the La Antigua basin, the Pensativo River is problematic. The river course used to flow through the La Aatigua basin. After the river path was artificially changed where it comes out from the mountainous area into the basin, flooding frequently occurs at this location. The river with a narrow width compared with the basin area easily overflows. On the other hand, there is a lowland area about 2 m lower along the Guacalate River in the La Antigua basin, where a flood occurs.

The Guacalate River runs, from Ciudad Vieja to Escuintla, through a valley sandwiched between the Acatenango Volcano, Fuego Volcano, and Agua Volcano. The landform along the valley is a terrace, where there is no risk of flooding. Since sediments that are collapsed lava are flowing in from the Fuego Volcano, the gravel deposits are increasing on the riverbed.

On the east of Escuintla, there is a hilly terrain consisting of ancient debris avalanche deposits (depósito de avalancha de escombros), where there is no risk of flooding. Escuintla is also on the surface of these deposits. The lowland area along the Guacalate River is a terrace, 2 m higher than the riverbed.

The Achiguate River joins the Guacalate River downstream from Masagua and flows through a lowland area until it arrives at the sea. This lowland area is a flat flood plain, where the river water easily covers the ground if the Achiguate River overflows. Furthermore, since many rivers diverge from the Achiguate River, flood streams flow into these rivers, consequently further expanding a flood.

Photo 2.3.4-7 Rivers that diverge from the Achiguate River

Additionally, the Achiguate River has a different river path every time a flood occurs, and the inundation range varies depending on its direction.

In the lower reaches, there are dunes along the coast. The dunes are two to three meters higher than the lowland area and generally not flooded, except when Hurricane Mitch caused a flood. The lowland area inland from the dunes is covered with water for as long as several days after a flood occurs because many rivers are blocked by the dunes. There are dry rivers near Puerto San José, where a flood stream from the Achiguate River flows in to cause a flood. In Puerto San José, a flood frequently occurred due to heavy rainfalls.

Photo 2.3.4-8 The lowermost reaches of the Achiguate River

The Achiguate River is about 50 m wide near the estuary. A flood easily expands in this landform every time the river rises because there is no riverbed inclination or difference in height with the surrounding lowland area.

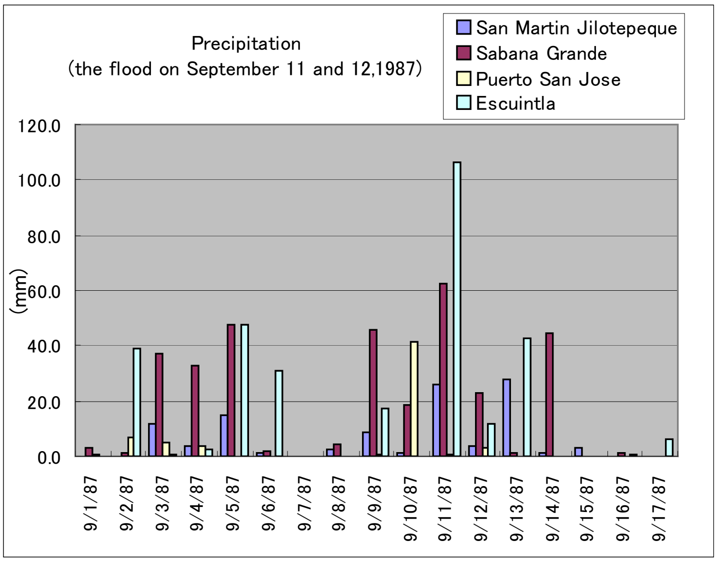
b) Hydrological characteristics (especially based on the downpour in 1987)

There is a record that, for the Achiguate River, heavy rain on September 11 and 12, 1987 caused the Achiguate River and Canal de Chiquimulilla to overflow and flooded 500 houses. The following figure shows the water level record of the Alotenango (Guacalate River) and the precipitation record of the four observatories in the basin at this time. Santa Cruz Jilotepeque is located near Chimaltenango at the uppermost reaches. Sabana

Gurande is located between Alotenango and Escuintla.

It started to rain on September 9 but there was rain a few days before that. In the basin, it rained heaviest in the mountainous area near Alotenango and Escuintla. In Alotenango, the water level response is quick because the rain area and the observatory are close to each other. The water level started to rise on September 9 and peaked on September 11, when it rained heaviest. The water level dropped afterwards. In Escuintla, the precipitation of 106mm/d at the maximum was recorded on September 11. Since a flood occurred in the Achiguate River and the Canal de Chiquimulilla at the lower reaches on the 11th and 12th, we can see that the rainfall in the mountainous area and the flood are one or two days apart.

Although precipitation of 40mm/d was recorded in Puerto San José on September 10, it was only one day and the major cause of the flood is assumed to be the rainfall in the mountainous area.



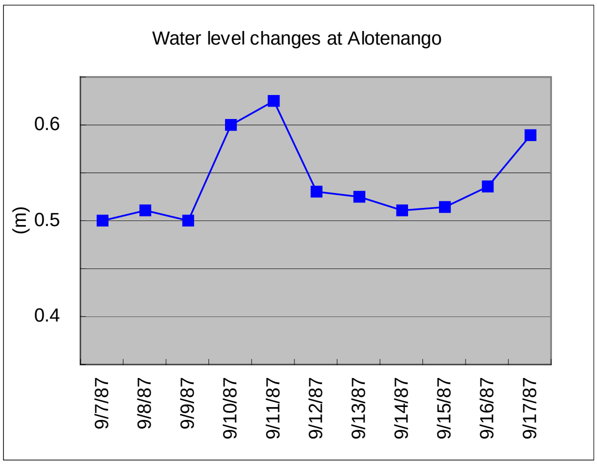


Figure 2.3.4-20 Precipitation and water level changes during the flood from September 11 and 12, 1987

4) María Linda River

a) Basin landforms and flood hazard

The María Linda River has a large basin if the tributary Michatoya River is included. The upper reaches of the María Linda River are a mountainous area. The river flows through a lowland area from near Brito to the coast. The tributary Michatoya River includes the southern half of the Ciudad de Guatemala, from where the rivers flow out to join the Amatitlán Lake, then becomes the Michatoya River from there, and flows through a ravine between the Pacaya Volcano and the Agua Volcano. The river joins the María Linda River near Brito.

Like the Achiguate River, the basin with a large catchment area such as mountains in the upper reaches makes the peaks of rainfall and flooding one or two days apart. Additionally, flood currents from the tributaries join to cause a flood in a lowland area. Even if there is little precipitation in a lowland area, the rainfall in a mountainous area may cause a flood. However, since the Amatitlán Lake has a dam function that temporarily reserves and regulates a flood, heavy rainfall near the Ciudad de Guatemala does not easily cause a flood of the Michatoya River.

In the Ciudad de Guatemala, many rivers join with each other to form the Villalobos River that flows through a valley plain. There is little risk of flooding because the riverbed of this river is two to three meters lower than the ground surface. However, lateral erosion easily occurs at a curve, etc. In the town of Amatitlán, the Seco River that flows from the western mountainous area frequently overflows. This is because an alluvial fan is formed at the exit of the mountainous area and the river path is bent.

The Michatoya River that flows out from the Amatitlán Lake flows through a deep valley between the Pacaya Volcano and the Agua Volcano. There is no risk of flooding here.

Where the Michatoya River and the María Linda River come out from the mountainous area to the lowland area, the landform is a lowland area (floodplain) but the riverbed is a few meters high and forms a terrace. There is little risk of flooding except for a heavy rainfall such as Hurricane Mitch. Additionally, on the west of the Michatoya River lies a hilly terrain (depósito de avalancha de escombros), where there is little hazard of flooding.

There is no more terrace downstream from Burito and the river flows through a very flat floodplain. Unlike the Achiguate River or the Samalá River, the river has no gravel but mostly silt as the riverbed deposits. In the flood plain, many streams and canals that diverge from the María Linda River run. Once a flood occurs, the water is likely to spread endlessly because there is no geomorphological boundary.

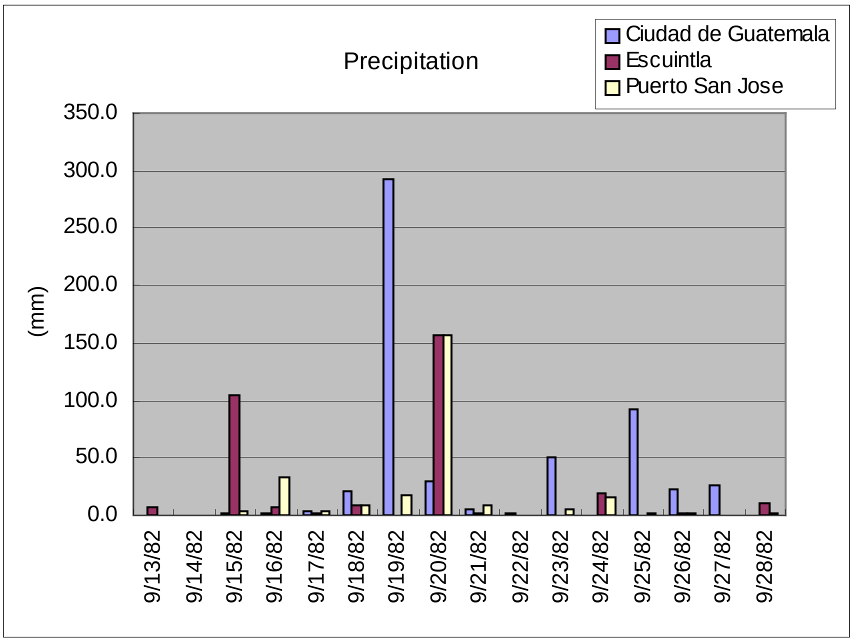
In the lower reaches, there are dunes along the coast. The river runs through these dunes into the Pacific Ocean. Behind the dunes lie a lowland area, a wetland scattered with canals and lagoons. Water is not drained easily on such land. If the María Linda River rises to expand the inundation, the flood is expected to continue for several days.

b) Hydrological characteristics (especially based on the downpour in September 1982)

The María Linda River frequently flooded Puerto San José de Iztapa in the lower reaches. There is a record that, during a flood on September 20, 1982, the river overflowed to flood Puerto San José, forcing people to evacuate. The following figure shows the water level at Palín and the rainfall data three observatories in the basin. Palín is located on the Michatoya River in the south of Amatitlán. The water discharge started to increase on the 19th and peaked on the 20th.

In the city of Guatemala in the upper reaches of the María Linda River at this time, as much daily precipitation as 300mm was recorded on the 19th. Generally, rain that falls on the city of Guatemala flows into the Amatitlán Lake and then temporarily reserved, making a mild correspondence between rainfall and water discharge. Since the correspondence was quick in this case, a downpour must have occurred in a broad range. On the 20th, there were downpours of 150 mm/d also in Escuintla and Puerto San José. These rainfalls merged with each other to cause a flood.

In sum, the inundation of the river seems to be influenced one day later by rain that falls on the mountainous area in the upper reaches or within the same day by rain that falls on the lowland area in the lower reaches.



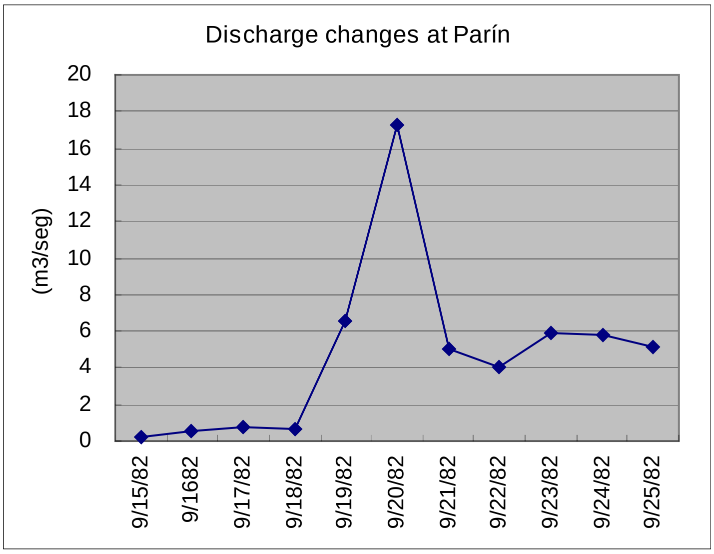


Figure 2.3.4-21 Precipitation and discharge changes during flood on September 20, 1982

2.3.5 Social environment study

Disasters occur not only due to destructive natural phenomena that are assailing elements but also due to fragility of buildings, infrastructures, and land uses as well as disaster resistance of people and the society. Disasters cannot be alleviated through an approach only on natural conditions. Although evaluation of natural conditions is emphasized in this project, it is extremely important to recognize the social conditions in order to create and utilize hazard maps. This section describes the characteristics of social environments based on field study and census.

(1) Recovery and rehabilitation from 1976 Guatemala Earthquake and 1998 Hurricane Mitch disaster

The 1976 Guatemala Earthquake is remembered by many of the then adults who lived in and near the city of Guatemala. In particular, the northern part of the Guatemala city and the Chimaltenango city suffered great damage and the people remember, even in fragments, that catastrophic damage were inflicted on buildings and that they had to endure difficult living conditions. At present, the damage of the Guatemala Earthquake can be identified only in landslides. Most of the houses are rebuilt and no damage done at the time is left anywhere. In January 2001, the mass media took up earthquake damage as the 25th anniversary of the Guatemala Earthquake, offering people a good chance to renew almost forgotten memories.

Hurricane Mitch gave Guatemala such damage as landslides, floods, lateral erosions of rivers, and washout of roads and bridges. Since the marks still remain, residents remember about them well. As far as we saw on the field, roads, bridges, and river structures were repaired only on a first-aid basis, leaving some to be prone to further damage. In particular, river structures have some sections left as they are after severe lateral erosions and remain highly prone to new damage on houses, roads, and farmlands due to lateral erosions. In the farming region on the Pacific cost, the flooded areas are restored as villages in the same form as before, and people live as if nothing had happened. However, the fragility remains almost the same as before Hurricane Mitch.

(2) Population

Data of population are available from the X National Census of Population elaborated on 1994, and published by the National Institute of Statistics (INE) on March 1996.

Accordingly the data of population per Department (Province) are shown in Table 2.3.5-1

The Departments which are included at all or in part in the present Study Area are marked with an asterisk (*).

Table 2.3.5-1 Population of Guatemala per department (1994)

DEPARTMENT	TOTAL			URBAN			RURAL		
	Total	Men	Women	Total	Men	Women	Total	Men	Women
GUATEMALA *	1,813,825	865,663	948,162	1,285,828	606,230	679,598	527,997	259,433	268,564
EL PROGRESO	108,400	53,381	55,019	28,788	13,601	15,187	79,612	39,780	39,832
SACATEPEQUEZ*	180,647	89,379	91,268	127,409	62,767	64,642	53,238	26,612	26,626
CHIMALTENANGO*	314,813	155,357	159,456	130,855	63,761	67,094	183,958	91,596	92,362
ESCUINTLA*	386,534	194,882	191,652	143,414	70,309	73,105	243,120	124,573	118,547
SANTA ROSA	246,698	124,298	122,400	59,377	28,934	30,443	187,321	95,364	91,957
SOLOLA*	222,094	110,618	111,476	73,856	36,418	37,438	148,238	74,200	74,038
TOTONICAPÁN*	272,094	132,670	139,424	29,188	13,920	15,268	242,906	118,750	124,156
QUETZALTENANGO*	503,857	248,162	255,695	200,727	97,294	103,433	303,130	150,868	152,262
SUCHITEPEQUEZ*	307,187	152,876	154,311	92,784	44,571	48,213	214,403	108,305	106,098
RETALHULEU*	188,764	94,487	94,277	52,316	25,223	27,093	136,448	69,264	67,184
SAN MARCOS	645,418	323,323	322,095	83,890	40,304	43,586	561,528	283,019	278,509
HUEHUETENANGO*	634,374	313,259	321,115	92,409	44,127	48,282	541,965	269,132	272,833
QUICHE*	437,669	214,258	223,411	66,459	31,335	35,124	371,210	182,923	188,287
BAJA VERAPAZ	155,480	76,372	79,108	31,807	15,233	16,574	123,673	61,139	62,534
ALTA VERAPAZ	543,777	270,578	273,199	85,875	40,992	44,883	457,902	229,586	228,316
PETEN	224,884	116,464	108,420	60,115	30,085	30,030	164,769	86,379	78,390
IZABAL	253,153	128,182	124,971	50,192	24,153	26,039	202,961	104,029	98,932
ZACAPA	157,008	77,534	79,474	44,892	21,380	23,512	112,116	56,154	55,962
CHIQUIMULA	230,767	113,260	117,507	58,305	27,161	31,144	172,462	86,099	86,363
JALAPA	196,940	96,566	100,374	53,702	25,134	28,568	143,238	71,432	71,806
JUTIAPA	307,491	152,000	155,491	62,499	29,733	32,766	244,992	122,267	122,725
TOTAL:	8,331,874	4,103,569	4,228,305	2,914,687	1,392,665	1,522,022	5,417,187	2,710,904	2,706,283

The population per age group is shown in Table 2.3.5-2

Table 2.3.5-2 Population per age group

	TOTAL			URBAN			RURAL		
Age Group (Years)	**Total**	**Men**	**Women**	**Total**	**Men**	**Women**	**Total**	**Men**	**Women**
Less than 1	258,845	130,867	127,978	73,169	37,063	36,106	185,676	93,804	91,872
1—4	1,053,217	535,722	517,495	306,407	155,605	150,802	746,810	380,117	366,693
5—9	1,229,428	624,183	605,245	363,971	184,845	179,126	865,457	439,338	426,119
10---14	1,124,702	573,143	551,559	359,787	179,775	180,012	764,915	393,368	371,547
15---19	909,903	442,844	467,059	330,301	156,313	173,988	579,602	286,531	293,071
20---24	708,181	331,911	376,270	269,446	124,053	145,393	438,735	207,858	230,877
25---29	552,600	259,481	293,119	217,062	99,300	117,762	335,538	160,181	175,357
30---34	511,315	244,727	266,588	203,105	93,936	109,169	308,210	150,791	157,419
35---39	439,550	207,715	231,835	173,212	78,904	94,308	266,338	128,811	137,527
40---44	369,107	178,540	190,567	146,537	68,217	78,320	222,570	110,323	112,247
45---49	284,007	137,409	146,598	110,272	50,891	59,381	173,735	86,518	87,217
50---54	231,090	112,564	118,526	90,608	41,563	49,045	140,482	71,001	69,481
55---59	175,684	86,280	89,404	68,806	31,644	37,162	106,878	54,636	52,242
60---64	166,735	82,869	83,866	64,934	29,425	35,509	101,801	53,444	48,357
65 and more	317,510	155,314	162,196	137,070	61,131	75,939	180,440	94,183	86,257
TOTAL:	8,331,874	4,103,569	4,228,305	2,914,687	1,392,665	1,522,022	5,417,187	2,710,904	2,706,283

Data of literacy in Guatemala distributed by sex and area are Table 2.3.5-3.

Table 2.3.5-3 Population of 15 years and over, per literacy, sex and area(1994)

AREA	TOTAL			LITERATE			ILLITERATE		
	Total	Men	Women	Total	Men	Women	Total	Men	Women
URBAN	1,811,353	835,377	975,976	1,506,973	741,880	765,093	304,380	93,497	210,883
RURAL	2,854,329	1,404,277	1,450,052	1,488,938	864,095	624,843	1,365,391	540,182	825,209
TOTAL	4,665,682	2,239,654	2,426,028	2,995,911	1,605,975	1,389,936	1,669,771	633,679	1,036,092

(3) Buildings

1) Present condition of buildings

This section sums up the statistical survey results concerning the number of buildings by areas and the building structures. The next section describes such items as the construction codes, regulations, and earthquake resistance diagnosis.

Data used as reference are the results of survey on population and houses in March 1996 conducted by INE (Instituto Nacional de Estadística).

Table 2.3.5-4 shows the number of buildings. The number of buildings by village is shown in data at the end of this report.

Table 2.3.5-4 Number of buildings by departments (source: INE1996)

Departamento	urbana (propoción)		rural (propoción)		total
Guatemala	281,612	72%	111,644	28%	393,256
El Progreso	7,405	28%	19,277	72%	26,682
Sacatepéquez	24,778	70%	10,652	30%	35,430
Chimaltenango	27,750	42%	37,711	58%	65,461
Escuintla	32,168	37%	55,415	63%	87,583
Santa Rosa	14,087	25%	43,188	75%	57,275
Sololá	15,885	35%	29,880	65%	45,765
Totonicapán	7,091	12%	50,358	88%	57,449
Quetzaltenango	41,719	39%	64,200	61%	105,919
Suchitepéquez	20,726	31%	45,904	69%	66,630
Retalhuleu	11,641	28%	29,540	72%	41,181
San Marcos	18,038	13%	116,147	87%	134,185
Huehuetenango	21,288	15%	118,283	85%	139,571
Quiché	16,490	17%	79,203	83%	95,693
Baja Verapaz	8,248	23%	28,102	77%	36,350
Alta Verapaz	17,787	17%	89,243	83%	107,030
Petén	13,644	27%	36,384	73%	50,028
Izabal	12,267	21%	46,418	79%	58,685
Zacapa	10,912	29%	26,220	71%	37,132
Chiquimula	13,840	27%	37,723	73%	51,563
Jalapa	12,179	29%	29,318	71%	41,497
Jutiapa	15,498	22%	55,869	78%	71,367
Total	645,053	36%	1,160,679	64%	1,805,732

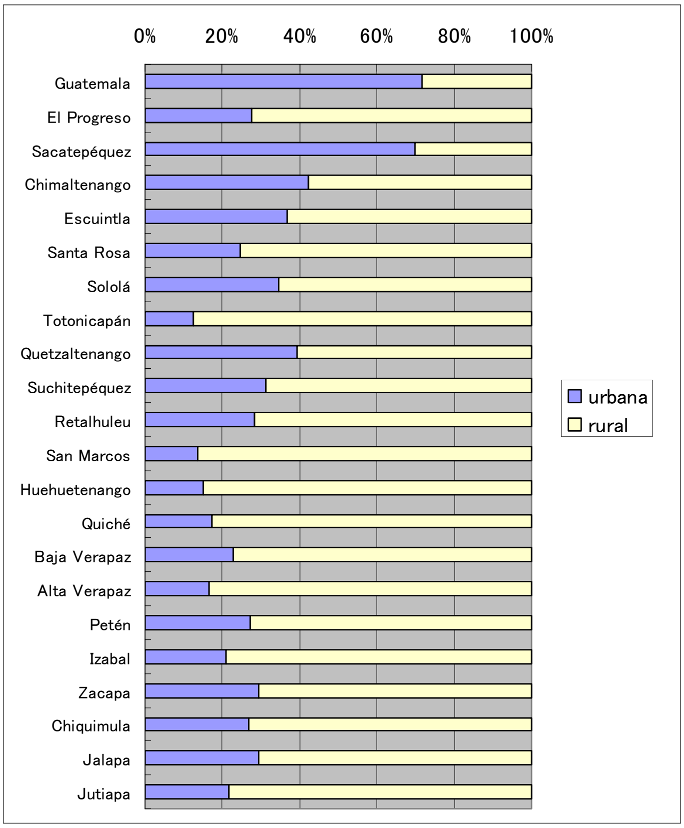


Figure 2.3.5-1 Ratio of buildings in urban and rural areas (source: INE1996)

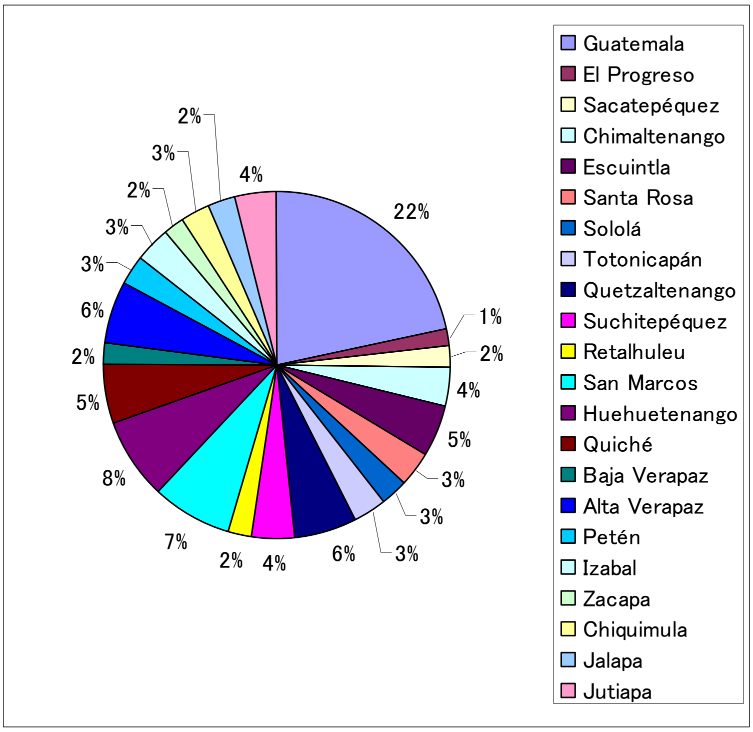


Figure 2.3.5-2 Ratio of buildings by departments (source: INE1996)

Figure 2.3.5-1 shows the ratio of buildings in the urban and rural areas by Departments. In Guatemala and Sacatepequez, buildings are concentrated in the urban area. In other Departments, there are more buildings in the rural area. Figure 2.3.5-2 shows the ratio of buildings by Departments. All through the country, there are about 1.8 million buildings, 20% of which are concentrated in Guatemala.

In this study, the number of buildings by wall and roof materials (Meterial Predominante en Paredes y Techo) is surveyed but the number of buildings by Departments is not shown. The data is shown in this section, because a nation-wide tendency is indicated.

In the entire country, exceedingly many of the buildings are made of blocks and adobe. As for buildings made of adobe, the wall material itself has a low earthquake resistance. In addition, about half the buildings have tile roofs, making them top-heavy and still less earthquake-resistant. In comparison, many of the buildings in the urban area are made of blocks and many of the buildings in the rural area are made of adobe or wood. Note that more than half the buildings have roofs made of Lamina Metalica, presumably making them prone to damages by strong winds of hurricanes, etc.

Table 2.3.5-5 Number of buildings by wall and roof materials (nationwide)

Techo / Paredes	Concreto	Lamina Metalica	Asbesto Cemento	Teja	Paja, Palma o Similar	Otro	Total
Ladrillo	44,126	22,249	5,887	6,247	479	795	79,783
Block	93,034	371,874	22,394	12,250	6,950	3,950	510,452
Concreto	16,749	19,021	1,951	1,742	435	276	40,174
Adobe	0	245,087	3,199	259,133	27,930	3,467	538,816
Madera	0	233,878	1,992	17,035	36,705	5,146	294,756
Lamina Metalica	0	27,399	0	0	0	262	27,661
Bajareque	0	38,394	0	16,393	30,604	1,345	86,736
Lepa, Palo o Caña	0	71,114	0	5,820	113,913	3,718	194,565
Otro	0	23,790	326	1,108	4,678	2,887	32,789
Total	153,909	1,052,806	35,749	319,728	221,694	21,846	1,805,732

(source:INE1996)

Table 2.3.5-6 Number of buildings by wall and roof materials (urban area)

Techo / Paredes	Concreto	Lamina Metalica	Asbesto Cemento	Teja	Paja, Palma o Similar	Otro	Total
Ladrillo	38,881	14,322	4,655	2,964	17	603	61,442
Block	77,550	202,976	14,332	5,748	401	2,109	303,116
Concreto	15,609	8,301	1,213	815	16	129	26,083
Adobe	0	77,126	1,062	47,354	654	1,187	127,383
Madera	0	65,387	781	2,239	1,476	942	70,825
Lamina Metalica	0	12,654	0	0	0	133	12,787
Bajareque	0	6,811	0	1,698	943	610	10,062
Lepa, Palo o Caña	0	15,049	0	327	4,011	1,016	20,403
Otro	0	11,414	173	204	310	851	12,952
Total	132,040	414,040	22,216	61,349	7,828	7,580	645,053

(source:INE1996)

Table 2.3.5-7 Number of buildings by wall and roof materials (rural area)

Techo / Paredes	Concreto	Lamina Metalica	Asbesto Cemento	Teja	Paja, Palma o Similar	Otro	Total
Ladrillo	5,245	7,927	1,232	3,283	462	192	18,341
Block	15,484	168,898	8,062	6,502	6,549	1,841	207,336
Concreto	1,140	10,720	738	927	419	147	14,091
Adobe	0	167,961	2,137	211,779	27,276	2,280	411,433
Madera	0	168,491	1,211	14,796	35,229	4,204	223,931
Lamina Metalica	0	14,745	0	0	0	129	14,874
Bajareque	0	31,583	0	14,695	29,661	735	76,674
Lepa, Palo o Caña	0	56,065	0	5,493	109,902	2,702	174,162
Otro	0	12,376	153	904	4,368	2,036	19,837
Total	21,869	638,766	13,533	258,379	213,866	14,266	1,160,679

(source:INE1996)

2) Legal framework for buildings

Guatemala has a wide variety of buildings and structures. Adobe is still commonly used for residential construction, especially in the smaller towns, villages, and some areas of the cities. Additionally, construction in the settlements (shanty towns) is primarily scrap materials. Newer residential construction uses cement or cinder blocks, usually with steel rods for reinforcement. Most commercial and public buildings and structures are constructed with blocks or steel frames.

Construction codes, regulations, recommendations, inspections, and procedures exist in local government agencies in each of the earthquake hazard areas. Evidence of building permit procedure was found in all areas but implementation or enforcement was somewhat arbitrary and applied primarily to commercial and public buildings and structures. In Guatemala City, there is a building code but it is old and does not strictly include seismic factors for construction considerations. Another document, a construction recommendation created in 1996, has seismic factors integrated into the codes but it is only a recommendation and has not been adopted officially. A second edition of this recommendation is being prepared and is expected in 2001. Other communities have some form of building regulations but they are not comprehensive and enforcement is either arbitrary or not strict.

Related with the hazard countermeasures in Guatemala there are several regulations which dealt with matters related to building standards, prohibitions of construction in certain areas, and some other regulations. The main regulations are dealt with in the following sections.

a) Building By-Laws (Reglamento de Construcción)

These By-Laws were established on 1970 by the Municipality of Guatemala City and still are effective. It regulates the construction activities within the Guatemala City for private and public buildings, which is stated as follows:

"Article 25. It is exclusive responsibility of the Municipality the issuing of permits to construct, amplify, modify, repair or demolish a building."

However, these by-laws were elaborated before the 1976 earthquake, and do not consider the risk areas, and consequently do not restrain constructions in there. Nevertheless a new by-law issued by the Municipality of Guatemala City in 1999 already considers it.

b) By-Laws of Urban Control for the Zones Under Special Management of Risk Protection (Reglamento de Control Urbano para las Zonas Bajo Regimen Especial de Protección por Riesgos)

These By-Laws are effective from 28-6-1999. Main features of these regulations are as follows:

"Article 2. Definitions:

- Area of Protection for Risks: Limited for housing, due to probability of occurrence of potentially destructive natural phenomenons.
- Area of Ecological Conservation: Necessary for the sustainability of the urban development due to their forest cover, the species and other natural resource".

"Article 3. Though all the risk areas is not defined, this by-law regulates the ravines and basins of the following rivers:

Ravines and basins of the rivers within the Municipio de Guatemala:

Zapote River and all its tributaries.

El Naranjo River, which is the limit between Zona 7 and Municipio de Mixco.

La Barranca River, which is the limit between Zona 7 and Zona 2 and 3.

El Bosque River, which is the limit between Zona 2 and 3.

El Marrullero River, in Zona 2 and El Aguacate River which is the limit between Zona 2 and 6.

Las Vacas River, which is the limit between Zona 6 and 18, and all its tributaries.

Negro River and El Sauce River, which are the limits between Zona 10 and 15.

Contreras River, which is the limit between Zona 15 and 16.

Riachuelo de Santa Rosita and Quebrada Agua Bonita in Zona 16.

Canalitos River and all its tributaries within Guatemala City.

Méndez River, Monjitas River, Acatán River, Aceituno River, and Agua River Tibia, all of them in Zona 17.

Quebrada El Toro, in Zona 18

Pinula River, which is the limit between Zona 14 and Municipio de Santa Catarina Pinula.

Guadrón River and Guadroncito River, which are limits between Zona 12 and 13.

Quebrada El Frutal, which is the limit between Zona 12 and Municipio de Villanueva.

Molino River and Quebrada El Arenal, which is the limit between Zona 11 and Municipio de Villa Nueva."

"Article 4. All persons, owners of these zones (areas of protection for risk) should establish a maximum index of occupation of 20%, for any use; and the remaining area should be used as *ecological conservation area*."

"Article 6. The owners of these *areas of protection for risk*, besides the compliance of the Building By-Laws should fulfill the following requirements:

- ♦ Based on the standards recommended by the Guatemalan Association of Structural and Seismic Engineering, should submit the following:
  - Geotechnical Judgment Type IV, of the whole land
  - Technical Notes of calculations of the anti-seismic structures, for the area to be used for the construction
- ♦ For the area to be used as ecological conservation (80% of the land) it should submit a

management plan of the area and its natural resources, based on the afforestation, conservation and protection of the animal and vegetal species, and the cooperation for the recovering of polluted basins.

- ♦ Feasibility study of the areas of ecological conservation (80% of the land), including costs of management and maintenance of the area as well as obligations of the owner.
- ♦ For the case of ecological parks it should include the urban and architectural designs."

c) Structural Standards of Design and Construction Recommended for the Republic of Guatemala (Normas Estructurales de Diseño y Construcción Recomendadas para la República de Guatemala)

These standards have been elaborated by the Guatemalan Association of Structural and Seismic Engineering in 1996. Although there are several features, which still have not been covered within the standards, it is worthy to mention those related with our study as summarized in the following.

- ♦ Level of Seismic Protection

The seismic index (Io) is defined as a relative measure of the expected severity of seismicity in a locality. It has effect on the seismic protection necessary to design a building or structure.

- ♦ Map of Seismic Macro zoning

For the use of these standards, the Guatemalan territory is divided in four macro-zones characterized by their seismic index as Io=2 to Io=4. Due to its high seismicity there are no 0 and 1 values. The distribution is shown in Figure 2-2/1 of the Standards, Chapter 2-2.1

- ♦ Seismic elements for Structural Design

For the design of structures, three kinds of design spectrums are used:

① Basic

"Basic seismicity" is based on the following function:

Sa (T)=Ao*D (T)

Where:

Sa(T): is the maximum seismic response of a simple elastic oscillator

Ao: is a measure of the maximum effective acceleration of the land, corresponding to the basic design seism.

T: is the vibration period of the oscillator and represents the fundamental period of vibration of the structure.

D(T): Is the maximum amplification of the maximum response of the simple elastic oscillator. It is a function of T, and depends of the type of soil profile in the site of construction.

Soil Profiles: as shown in Table 2.3.5-8.

Table 2.3.5-8 Classification of Soil Profiles

Soil Type	Shear Wave Velocity (m/sec)	Soil Depth (m) SD	Characteristics
S1	>800	<50	Rock of any type or stiff soil of which basement is less than SD of depth and constituted of volcanic ash, sands, dense gravel and stiff clays.
S2	>800	>50	Stiff soil of which rock basement is more than SD of depth and deposits are of volcanic ash, dense granular soils, dense silts and stiff clays. In general stiff and stable soils that profiles do not classify as S1 or S3.
S3	<200	>10	For ash, sands, silts, from loose to medium dense. Soft or semi-soft clays with or without sandy layers interbedded. In case of doubt the critical condition of S2 and S3 with the taken.

② Frequent

"Frequent seismicity" is that with high probability to occur once or more during the lifespan of a structure. It is based on the following function:

Sf(T)=Af*D(T)

Where:

Sa(T): idem

Af: is a measure of the maximum acceleration of the soil, corresponding to the "frequent seismicity".

③ Extreme

"Extreme seismicity" is that with maximum intensity (probability) to occur in the site. It is based on the following function:

Su(T)=1.3*Ao*D(T)*ku(T)

Where:

Ao and D(T) as previous.

Ku(T): Modifying factor to re-calibrate the function D(T).

④ Classification of Geotechnical Judgments

Table 2.3.5-9 Summary of the classification of geotechnical judgments

Type	Characteristics
I (easy)	Written report by the engineer, geotechnical civil engineer if necessary, based on the judgment of the first
II	General geological reconnaissance of the area, and study of subsoil by the geotechnical civil engineer.
III	Study of subsoil by the geotechnical civil engineer for the design of special structures requiring evaluation of soil-structure interaction or for special foundations.
IV	Study of subsoil by the geotechnical civil engineer, with the temporary support of the geological engineer or geophysics. These study will emphasize in the dynamic characteristics of the foundation soil.
V (detail)	Study of subsoil by the geotechnical civil engineer, requiring the active participation of the geologic engineer and/or geophysics, as in the case IV but for works or more complexity and dimensions.

(4) Poverty problem

There is a poverty issue at the root of fragility against disasters. In particular, indigents mostly living in the mountainous area (rural community) suffer the most from poverty. They continue to have a very low level of living because they do not have means for steady agricultural production or field of production. Poverty is depriving them of chances of education, resulting in a low literacy rate.

The poverty issue is important also in prevention of disasters and protection of environment. In the urban area, the poor live in bad living environments. Many of the poor people live on slopes and lowland areas along rivers, i.e., areas with high disaster risks. In the city of Guatemala, a shantytown is often formed near a ravine on a pyroclastic flow plateau. A shantytown on such a slope is prone to a slope collapse. Additionally, houses are highly likely to be lost due to the lateral erosions of rivers. The government's efforts on disaster prevention through transfer from hazardous locations seem not to be effectively working in the vast stream of urbanization in the middle of poverty.

The low environmental consciousness of the poor is another serious problem. Many of the urban rivers including those in the city of Guatemala are seriously contaminated because all the sewage and garbage in shantytowns are discharged into rivers. Rivers and slopes are used as sewers and garbage dumps. The Authority for the sustainable management of the Amatitlan Lake Basin (AMSA) is creating various pamphlets and guiding the residents. However, there is no prospect of attaining the goal for purifying rivers because the awareness required for environmental protection of rivers has not been developed.

The Amatitlan Lake into which half the sewage of the city of Guatemala is flowing is still seriously contaminated. The lake is expected to be developed as a sightseeing spot with a beautiful caldera lake on the mountain foot of the Pacaya volcano. However, there is only a small sightseeing facility at one end of the lake because the water quality is low.

Big cities like Guatemala are seeing two vicious circles at the same time: (1) “Population growth and immigration --- Poverty --- Deterioration of environment --- Increase of hazardous areas” and (2) “Rapid urbanization --- Deterioration of urban environment --- Fragile urban infrastructures --- Increase of hazardous areas and number of inhabitants in the areas”.

(5) Land use and hazard

Land uses and hazards have a close relationship in terms of volcanic disasters, floods, and landslides.

In a region around a volcano, a location closer to the volcano is more easily influenced by ejecta while an area along a valley is prone to damage from pyroclastic flows and lahars. Villages, often formed along a valley around an active volcano, are prone to flowage hazards. Here and there, land uses with a blade thin margin from volcanic disasters are seen such as part of the Quetzaltenango city on the northern foot of Cerro Quemado, sitting on the past debris avalanche deposit or the expansion of villages and farmlands on an alluvial fan of the Samalá river downstream from Santiaguito, where production of sediments are rapidly increasing.

When a flood occurs, the lowland area along a river or the undercut slope of a river is prone to inundation or lateral erosion. Additionally, the lower reaches of a river that flows into the Pacific, having no embankment, has an exceedingly large range of inundation and tends to flood many farms and villages.

As to landslides, a location more distant from a slope is, of course, less prone to disasters. However, many people have no choice but to live near a steep slope or on a slope due to restriction of land and economic reasons. The habitation limit on a slope is about 35degrees and no colony of squatters is formed on any steeper slope. In the city of Guatemala, many colonies of squatters are formed on slopes with inclination of about 25 degrees. In the northeastern region (Quiche and Huehuetenango Departments), population is not so concentrated as to cause people to live on slopes. However, houses are scattered and villages are formed in an alluvial fan or cone at a mountain foot, just under a slope, or on a landslide pediment.

As to earthquake disasters, no one can avoid influences to a certain degree, because vibration damage can basically occur anywhere. Although there are some differences depending on the distance from the seismic center fault and the location in relation to an active fault. For land use, care must be taken about phenomena strongly influenced by the ground and geomorphological conditions such as slope collapse and liquefaction.

(6) "Determinación de Vulnerabilidades en Nueva Asentamientos Humanos del Área Metropolitana de Guatemala" by CONRED

This report was made for the BID Project "Reducción del Riesgo Asociado a Desastres Naturales en Asentomientos Humanos del Área Metropolitana de Guatemala" and was disclosed in February 2002.

This research was undertaken on vulnerability in cooperation with residents at a settlement with bad conditions from the aspect of disasters in Guatemala City. This research followed on the technical guidance by Dr. Juan Carlos Villagrán De León. Looking at a local community from the aspect of disasters, its vulnerability came into the limelight. Due to political and economic reasons, many people migrated from rural areas into Guatemala City and, as the city grew, they started to live in areas with high hazard such as slopes and valley planes without sufficient preparation, to form a shanty town. These people from rural areas often do not have any skill to get a decent job in the city. Having fled from poverty in the rural areas, they still suffer and have no choice but to live in more dangerous locations than they used to. This research did not result in finding any effective means for removing the vulnerability of the shanty town but led to the recognition of the necessity that people should know the presence of CONRED and that CONRED would provide them with information. The agencies related to disasters are required to supply disaster prevention training to the most vulnerable and children, using words easy to understand instead of difficult terms.

(7) Analysis of Status Quo of Society by JICA Study Team

1) Vulnerability of the Society

In view of social conditions, the vulnerability in social aspects such as poverty, lack of disaster cultures, and absence of visions for land policies is closely related to the occurrence of disasters. Poverty deprives people of choices of land, forcing them to live on a land that is not appropriate for living such as steep slopes and lowland area along rivers. Furthermore, people and communities living in such land do not have sufficient disaster prevention facilities such as communication devices and evacuation routes. They often get disaster information through television or radio and would escape on their own decision. There are not yet sufficient evacuation centers or escape routes that allow people to go up slopes to safe plateaus. Slope collapses occur immediately when an earthquake strikes, leaving them no time for evacuation.

Furthermore, the experiences of disasters are not communicated in a proper way because the migration of people is intense and there are many new residents. The inheritance of disasters, i.e., communication of the past disasters to the next generation or newcomers, is effective in alleviating the vulnerability.

Furthermore, the Government has not yet put restrictions on residence or land use in dangerous areas in order to develop a community immune or resistant to disasters. Though, the governmental agencies were actively working on disaster prevention, after Hurricane Mitch, the biggest problem in disaster prevention for many people live in hazardous areas has not been solved yet.

As far as we know from the field survey, roads and river structures are repaired only on a first-aid basis or they apparently were left mostly unattended. As for the mountain roads, even major roads have untreated faces of slopes after being cut, on which rock falls and minor slope collapses frequently occur. Some of the bridges are prone to dangers of scouring.

In view of flood control and water quality management, watershed management is important. Guatemala is a superior agricultural country that uses a large part of slopes as farmland. A slope with an inclination of 15 degrees or more tends to have a significant washout of soil, causing debris flows and floods. The development on the mountainside of Agua Volcano constitutes one of the causes for the debris flow disaster that occurred in Ciudad Vieja in June 2002. There remain some major tasks to be completed such as assistance for tree planting in the upper reaches, restrictions on land use based on land use evaluation along rivers, setup of planned flood discharges, and planning for constructing revetments and embankments.

2) Tasks in Various Organization Levels

a) Country Level

A country represents the most basic unit for disaster prevention activities. The national agencies should make serious efforts for the national disaster prevention plans of various developing countries. Currently, the concerned agencies are successfully cooperating and sharing tasks with CONRED operating as the central figure. However, each of the agencies does not have sufficient human and physical resources. The ability for disaster prevention must be improved through efforts of the Guatemalan Government and the effective assistance from the donor countries and agencies.

INSIVUMEH, organized to supply prompt and accurate information and estimation of natural phenomena to agencies related to disaster prevention, should actively improve the observation devices, analysis devices and software, and increase the staff of observation and analysis engineers. For appropriate disaster estimation, the observation networks must be improved in order to acquire data such as air pressure, wind velocity, precipitation, earthquake data, and volcano observation data at appropriate intervals.

b) Department Level

In the department level, a catchment area or basin should constitute a unit of disaster prevention activities. The department-level hazard map to be created in the Project should be used to develop a safe and attractive region by making a wide-area land use plan in view of disaster prevention, for example, restriction on tree planting and logging, and establishing a production system as a region and thus decrease the number of people who have no choice but to leave their villages.

c) Municipality Level

Municipalities must increase the disaster resistance of communities by giving them guidance. Using hazards map to be created in the Project, a municipality will be able to provide the residents with education and guidance on disaster prevention. Furthermore, a municipality is required to make efforts in eliminating vulnerability by restricting the land use in hazard areas, for example.

d) Community Level

The community must have such awareness that both sustainment and safety of life are compatible with each other, while residents must have high awareness for disaster prevention so that not only people in this generation but also their children and grandchildren can live in a safe environment. They must also recognize that, spatially, cities and rural villages, upper and lower reaches, and areas up and down cliffs are linked with each other in terms of disaster prevention. The upper level organizations must provide information in easy-to-understand vocabulary because it will be difficult for residents to have such understanding on their own

(8) Countermeasure for flood

As to hardware countermeasures for flooding, a survey was conducted on four rivers in the study area.

For the Samalá River, gravel on the riverbed near San Sebastián is dug using heavy equipment in order to prevent the riverbed from rising and maintain the river course. However, an overwhelming volume of sediments is coming down from the upper reaches, making the riverbed

Photo 2.3.5-1 Status of exavation on the riverbed

continue to rise. In San Sebastián where damage often occur due to floodings, an embankment made of gabions has been built on the left bank. After this embankment had been built, no flood damage occurred in San Sebastián, according to the inhabitants. Downstream from the diversion point with the Ixpatx River, another embankment was built on the curve of the river.

Photo 2.3.5-2 Gabions for prevention of erosion

No significant flood-preventing facility was found on the Acomé River during the field study. On the Achiguate River, gabions have been built at a curve in Pastres in the uppermost reaches. No other significant flood-preventing facility was found. Along the María Linda River, an embankment of two to three meters high which are made of mounds are built in each of the Haciendas or Fincas. No other significant flood-preventing facility was found.

2.3.6 Geomorphogical study

(1) Purpose of the study

The intension of landform classification through preliminary interpretation is: (1) to smoothly perform survey of disaster history accompanied by maps of landform changes such as recent landslides and volcanic disasters as well as scouring of rivers by Hurricane Mitch and (2) to extract landforms strongly related to occurrence of disasters that are required to create a hazard map and understand the relationships between landforms and disaster history and between landforms and future disaster risks. Especially in preliminary photo interpretation, priority was placed on general landform classification, extraction of disaster causes in the study areas, and confirmation of disaster hazard locations and checkpoints for efficient implementation of the field study.

Landforms are created as substances move near the earth's surface. Movements of substances indicate movement of sediments and rocks, which is one of the direct causes of disasters. Also even disasters not accompanied by movement of substances are greatly influenced by landforms because river water runs along landforms. A landform can be represented by the following equation:

Landforms＝Function（agents・materials・time）

Agents here refer to violent phenomena such as downpours, earthquakes, and volcanic eruptions. On the other hand, there are agents that work slowly or in a long term, such as temperature changes, sunshine, chemical action, and gravity permanently working.

Materials refer to substances that make up slopes and level surfaces and determine how easily a slope can be eroded (i.e., how easily a landslide can occur). Since, as for an earthquake disaster, seismic vibrations are propagated through a material (i.e., ground), the characteristics of vibrations vary depending on the material (ground).

Time refers to the progress of geomorphic processes. Bedrock that makes up a slope weathers more and more as time elapses. An alluvial fan becomes larger and has a higher sedimentary surface because more deposits are supplied from the upper stream as time elapses.

However, landscape changes are by no means constant. A river with an erosion tendency may suddenly come to have a sedimentation tendency because of a slope collapsing or a landslide in the upper reaches. In Guatemala, a country with earthquakes and volcanoes, constant landform changes do not always occur but abrupt landform changes sometimes occur due to diastrophism or a volcanic eruption.

The landform classification is an effective method of estimating various landform changes and geological conditions strongly related to occurrence of disasters. When compared with the medical science, geomorphology is the internal medicine. As a physician carries out diagnosis through interview and exploration, a geomorphologist studies in detail the appearance or bird's-eye view of a landform to estimate its creation process or future landform changes.

A geomorphological map can be created more easily than a topographical map, because they are created only by interpreting aerial photographs and performing supplementary field study. Additionally, a geomorphological map shows the relationship with a disaster more clearly than a topographical map, so is effective for disaster risk evaluation. In the Republic of Guatemala, with little information on geological features, landform classification is extremely effective in creating a hazard map.

In Guatemala, however, landform classification is not widely known and no geomorphological map has been published yet, except 1:250,000 scale maps produced by MAGA. There are several possible reasons for this situation. There are only a few geomorphology classes at universities and a few researchers. Geography or geomorphology courses are available only at Universidad de San Carlos and Universidad del Valle de Guatemala and there are very few geomorphologists. Additional reasons for not performing detailed landform classification are that topographical maps are being created behind schedule and with insufficient accuracy and that new aerial photographs are not available.

(2) Preliminary photo interpretation

Landform interpretation through preliminary interpretation using aerial photographs was performed to grasp general characteristics of landforms. Prior to field study, the Team cooperated with counterpart engineers to interpret aerial photographs for disaster locations, natural conditions (landforms and geological and hydrological features), and social conditions (land uses and anti-disaster facilities) in aerial photographs (Table 2.3.6-1). Among the elements shown in Table 2.3.6-1, those concerning the social conditions have only been checked for existence.

Table 2.3.6-1 Overview of preliminary photo interpretation for hazard maping

Purpose	Classification	Significance of interpretation
Disaster history	Disaster locations of Hurricane Mitch	Recognizing flood and landslide hazard areas
	Landslide locations of Guatemala earthquake	Recognizing landslide hazard locations during earthquakes
Natural conditions	Distribution of landslide areas	Recognizing existing landslide areas and landslide hazard locations along major roads
	Distribution of active faults and fault landforms	Estimating where earthquakes occur
	Distribution of soft ground	Estimating the liquefaction and ground disaster hazard locations
	Distribution of volcanic landforms and ejecta	Estimating the range in which volcanic ejecta can reach
	Marks of old floods	Estimating the flood path
Social conditions	Distribution of houses and buildings	Estimating the distribution and fragility of possible disaster victims
	Distribution of anti-disaster facilities	Evaluating the general disaster resistance
	Major infrastructures	Estimating the distribution and fragility of possible disaster victims

1) Interpreting disaster history

The disaster situation of Hurricane Mitch could not be very clearly recognized during interpretation of aerial photographs.

In the city of Guatemala, many collapses occurred in ravines. However, collapses due to Hurricane Mitch could not be easily identified because they did occur in various places before and after Hurricane Mitch. Only a few collapses were confirmed to have resulted from the hurricane based on the field photographs provided by the related organizations or through interviews of the persons in charge.

Bridges, having been restored promptly after the disasters, could not be identified from aerial photographs. Additionally, faces of slopes on roads were left bare after construction and thus minor collapse locations could not be found from aerial photographs.

Aerial photographs taken about three years after the disaster were not sufficient to identify flooded areas in detail but were useful in estimating the range of flooding. On the other hand, the lateral erosion locations of rivers could be sufficiently identified through interviews in the field and from the washout of residential and agricultural land and the progress of bank protection work.

2) Interpretation of natural conditions

Aerial photographs are exceedingly effective in distinguishing landforms and surface geology among the natural conditions related to disasters. In particular, a disaster accompanied by movement of substances near the earth's surface cannot be investigated without the use of aerial photographs. The study team extracted specific landforms strongly related to occurrence of disasters in all the study areas.

a) Distribution of steep slopes (in the landslide study area)

In the city of Guatemala, steep slopes are found in many places. Most of them are valleys, dissected plateaus of sediments from large-scale pyroclastic flows, most of which consist of pumice stones. Such a valley and a slope are collectively called a barranco (ravine). The flat plane of a plateau and the ravine diverge at a clear knick point. The area near a knick point tends to become the head of a landslide and may be called an erosion front.

A 1:50,000-slope classification map has been created for the central region (Department of Sacatepeques, Department of Chimaltenango, and Department of Solola) and northwest region (Department of El Quiche, Department of Huehuetenango, and Department of San Marcos). These regions have a high landslide potential due to fragile geology represented by large-scale pyroclastic flow deposits, crush zones due to dislocation movements, and steep slopes. In these regions, existing landslide areas and hazardous locations along major roads were extracted.

b) Distribution of active faults and fault landforms (in the earthquake study area)

Active faults that are the causes of earthquakes and fault landforms that may be active faults are often found. While the Motagua fault and the Chixoy-Polochic fault cross the country east and west, there are many other faults that run parallel to or intersect these faults. While these major faults do not exist in the earthquake study area, some active faults, fault landforms, and cracks generated during the 1976 Guatemala earthquake were extracted through interpretation of photographs.

c) Distribution of soft grounds (in the earthquake study area)

Soft ground that amplifies seismic vibrations can be identified from aerial photographs. In the earthquake study area, soft ground is distributed only in the Puerto Barrios region. Through photo interpretation, a distribution of soft ground, although scarce, was discovered near the estuaries of rivers and along the coast.

d) Distribution of volcanic landforms and volcanic products (in the volcano study area)

Each of the four volcanoes to be studied has a characteristic volcanic landform.

The Tacana volcano is characterized by lava domes near the peak and lava flow landforms often found on the northern slope. For the Santiaguito volcano, a new volcano emerging after the collapse of the southern slope of the Santa Maria volcano, lava domes, lava flows on the southern slope, and many lahar deposit landforms in the south at the foot of the mountain were mainly identified. For the Cerro Quemado volcano, highly viscous lava flow units, sector collapse marks, and expansion of resultant debris avalanche deposit landforms were identified. The Pacaya volcano consists of several volcanoes, of which the main Pacaya volcano on the southwest is currently active. Volcanic structures and new lava flows extending from the southern to western slope were mainly identified. For the Pacaya volcano, a geomorphological map created by Shigeru Kitamura (2001) was used as reference.

During photo interpretation through preliminary interpretation, attempts were made to identify the characteristics of volcanic landforms and the distribution of volcanic ejecta as described so far.

e) Old flood marks (in the flood study area)

At the four rivers that flow into the Pacific Ocean, floods often occurred in addition to those by Hurricane Mitch. Since the rivers have no embankment, the river paths shifted significantly and the past flood marks are found in the entire lowland area. Since the next flood may not occur in the current river path position, the identification of flood marks in the lowland area will be useful in estimating the flood hazard areas and assuming the flood path. For the Samalá River, at which a great volume of gravel comes down from the upper reaches due to volcanic activities of the Santiaguito volcano to significantly change the landforms, landform classification was performed based on the gravel deposit direction and distribution. For the other three rivers, the river path marks from the middle to lower reaches and the flood-prone depressions and shallow valleys were identified.

3) Interpretation of social conditions

Aerial photographs are effective in recognizing land uses and distribution of various facilities among the social conditions related to disasters. Precious information can be obtained from aerial photographs because the relationship between the disaster hazard areas such as ravines and lowland areas along rivers and the land uses can be seen simultaneously. Although this study mainly concerns geomorphological interpretation, the following work that is strongly related to disasters and for which aerial photo interpretation is effective was generally performed.

a) Distribution of houses and buildings

Through photo interpretation, the distribution of houses and buildings and their scale can be identified.

The central area of the Guatemala City has land conditions with a low flood and landslide disaster risk. On the other hand, the shantytown located on slopes has a high hazard risk, fragile housing structures, and land uses prone to hazards because of lack of sufficient evacuation routes during disasters.

In the lowland area on the Pacific side, houses of workers are scattered across a vast ranch. The houses are cheaply built and prone to floods.

In the area around the volcanoes, no big town exists but houses of workers in the community and coffee plantations are scattered. Most of the residents are not aware that their villages are built on the recent volcanic eruptions. Very few residents seem to know that the zona 1 of the Quetzaltenango city is located on the sector collapse deposit of Cerro Quemado that occurred about 1150 years ago.

In the northeastern region, towns are formed along a valley in a mountainous area. In particular, the towns and the villages along such rivers as the Blanco River and the Cuilco River that flow along the Chixoy-Polochic fault are located on alluvial cones or fans, equipped with no landslide prevention facilities whatsoever, and thus highly prone to debris avalanches. In this region, the land area is small but there are not so many residents, resulting in only a few people in a ravine. Even on slopes on the heights in the Department of Huehuetenango and the Department of El Quiche, houses area are scattered, some of which were destroyed by landslides in the past.

b) Distribution of anti-disaster facilities

Only a limited part of anti-disaster facilities can be identified on aerial photographs. Large-scale concrete retaining walls for landslides, landslide prevention dams, reservoir dams, and buildings of disaster prevention organizations can be identified. However, in the study area there are no such facilities and the rivers and slopes are mostly left in their natural states.

The only embankment for a river in the Study Area is the one in the middle reach of the Samalá River. Here, gabions are piled up to prevent flooding of massive debris supplied from the upper reaches of the Samalá River. However, the effect is by no means permanent because of the quantity of supplied sediments and consequent rise of the riverbed. There are no river embankments in the middle and lower reaches of the Acome River, Achiguate River, and Maria Linda River.

The landslide prevention measures are installed only in a limited area. Most of the slopes and faces of slopes on roads were left bare, exposing weathered rocks and pumice layers. What can be identified as large-scale constructions include shotcrete and retaining walls made after the disaster recovery construction in Residenciales Vista Al Valle on what is commonly called the El Salvador road and in Villa De Mixco, both along CA-1.

Some dams for power generation and drinking water are found here but they are not for flood control purposes.

Despite the limitation on extraction of disaster prevention facilities through photo interpretation, the disaster prevention measures in terms of these facilities are by no means sufficient in the Republic of Guatemala.

c) Infrastructure

Infrastructures such as, traffic, power, and communication facilities can be identified on aerial photographs. Among the traffic facilities, the highways are the most important. Among the roads that run through mountainous areas, disaster-prone sections that run along slopes and across mountain streams were extracted through photo interpretation. Among the power facilities, power stations and transformer substations can be identified. Among the communication facilities, relay towers are barely identifiable.

(3) Production of geomorphological maps

1) Area of geomorphological mapping

The following geomorphological maps were created through photograph interpretation and field study. These results were input to digital maps that are 1:10,000 scale orthophotomaps or 1:50,000 scale topographical map(Tacana volcano). Output scale of geomorphological map are 1:25,000 except Tacana Volcano study area..

Table 2.3.6-2 Scale of geomorphological maps

Cities, Areas and Basins	Earthquake	Volcano	Landslide	Flood
Guatemala city	1:25,000		1:25,000	
Quetzaltenango	1:25,000		1:25,000	
Mazatenango	1:25,000			
Escuintla	1:25,000			
Puerto Barrios	1:25,000			
Tacana		1:50,000		
Santiaguito		1:25,000		
Cerro Quemado		1:25,000		
Pacaya		1:25,000		
Antigua Guatemala			1:25,000	
Northwest Region			--	
Central Region			--	
Samala basin				1:25,000
Acome basin				1:25,000
Achiguate basin				1:25,000
María Linda basin				1:25,000

Note: A landslide distribution map (in GIS data) was created for the Northwest and Central Regions.

2) Legend of Geomorpholgical map

Table 2.3.6-3 shows the legends of geomorphological map.

Table 2.3.6-3 Legend of geomorphological map

English	Español
Slope	Talud
Gentle slope	Talud suave
Valley plain	Planicie de valle
Round shaped valley	Valle de forma redondeado
Slope collapse	Derrunbe
Slope collapse	Derrunbe
Landslaide	Deslizamiento
Cliff	Acantilado
Lava dome	Domo de lava
Lateral volcano - pyroclastic cone	Volcán lateral - cono piroclástico
Lateral volcano - lava dome	Volcán lateral - domo de lava
Crater bottom	Fondo de cráter
Lava flow	Flujo de lava
Volcano slope	Ladera de volcán
Pyroclastic flow plateau	Meseta de flujo piroclástico
Volcano foot alluvial fan	Abanico aluvial al pie de volcán
Caldera bottom	Fondo de caldera
Caldera wall/crater wall	Pared de cardela/pared de cráter

English	Español
Dissected valley	Valle bisectado
Mad flow deposit	Depósito de flujo de lodo
Terrace 1- low	Terraza 1 - baja
Terrace 2 - middle	Terraza 2 - media
Terrace 3 - high	Terraza 3 - alta
Terrace scarp	Escarpe de terraza
Terrace scarp	Escarpe de terraza
Debris avalanche deposit plateau	Meseta de depósito de avalancha de escombros
Shallow vally/depression	Valle poco profundo/ depresión
Talus	Talus
Alluvial cone	Cono aluvial
Alluvial fan	Abanico aluvial
Lowland	Tierra baja
Flood plain	Llanura de inundación
Delta	Delta
River bed 1 - bare ground	Cauce1- terreno raso
River bed 2 - with bush	Cauce2 - con matorral
River bed 3 - high	Cauce3 - alto
Abondoned channel	Cauce antiguo
Raised riverbed	Cauce elevado de río
Wadi	Río seco
Flood trace	Marca de inundación
Swamp	Pantano
Sand bar	Banco de arena
Dune	Duna
Beach ridge	Cresta de playa
Inland water(River/Lake/Lagoon/Reservoir)	Agua interior(Río/Lago/Laguna/Embalse)
Caldera lake	Lago de caldera
Water fall	Cascada
Spring	Manantial
Cut slope	Corte de talud
Landfill	Terraplén
Embankment	Dique
Dam	Presa
Fault scarp	Escarpe de falla
knick line	Línea de cambio de pendiente
Fissure/Step	Grieta/Escalón
Gully	Cárcava
Ravine head	Cabeza de barranco
Principal divide	Parteaguas
Earthquake area	Área de terremoto
Volcano area	Área de volcán
Flood area	Área de inundación
Landslide area	Área de deslizamiento

3) Geomorphological characteristics of each study area

a) Guatemala city

In the city of Guatemala, erosion is generally prevailing. The plateau is significantly dissected by deep valleys and the valley heads are cutting more and more into the plateau. The erosion of valley heads has reached the current urban area and its vicinity. Whenever a downpour occurs, valleys are extended, washing away houses and farmland on the plateau. Although control of surface water is important in preventing erosion at valley heads, surface water runs directly into valleys at many locations. During photo interpretation, knick points and valley heads that are front lines of erosion were carefully extracted.

Among the rivers, the sedimentary trend is found only near Chinautla on the Chinautla River in the north. Many of the rivers cut into plateaus as well as terraces made of alluvial deposits. They meander to cause lateral erosion and excavation near the river path. Even in the delta in the lowermost reaches of the Villalobos River in the south, the river path digs about five meters into the alluvial plain except near the Amatitlán Lake.

Much of the land has been artificially modified because soil can be collected relatively easily. Distributed all over the city are cutaway faces of slopes, from which soil is washed away.

b) Quetzaltenango

Quetzaltenango is characterized by a large pyroclastic flow plateau and a valley plain that dissects it. In the center of the urban area, there is only a low risk of landslides or floods. Near Cerro La Pedrera in the south, however, there is a lava flow front, making the block lava unstable. Also, the alluvial lowland area along the Seco River in the east is easily submerged, causing us to presume that there is an area with rather loose alluvium distributed. During photo interpretation, the lava flow front and the alluvial lowland area were carefully identified.

c) Mazatenango

Mazatenango is located on an ancient volcano foot fan. The alluvial fan on which the urban area is located is dissected by the Sis River that flows in the east. No landform deeply related in particular to disasters is found because the study range is small and the landforms are relatively simple. This area, being an alluvial fan, is presumed to consist of a gravel ground.

d) Escuintla

Escuintla is located on a dissected fan consisting of ancient debris avalanche deposits. The urban area is located on the watershed of the Guacalate River and María Linda River water systems. No landform deeply related in particular to disasters is found because the study range is small and the landforms are relatively simple. The team carefully identified debris avalanche mounds found on a dissected fan and lowland areas along the Guacalate River. The ground is presumed to be a gravel ground.

e) Puerto Barrios

The west side of the urban area of Puerto Barrios is located on a delta. This delta was formed by the Escondido River that flows in the middle of the urban area. The Escondido River that formed this delta has a small catchment area and no mountainous area in the upper reaches, the alluvium is presumed not to be thick. At present, the delta is not growing so much.

The east side of the urban area is a gently undulating hilly terrain already significantly eroded. Here, many small valleys are formed, but from the types of valleys, the alluvium is presumed to be thin. On the west and north sides of the urban area, there is a lowland area around an eroding river that is classified as a valley plain (planicie de valle). On the north of the urban area, there are easy slopes on a severely undulating hilly terrain, eroded in the same way as the urban area. Valley plains are also distributed along the river. The land where the airport is located is artificially modified land, created by leveling off a hilly terrain.

f) Tacana volcano

The Tacana volcano is located on the border of Guatemala and Mexico. Since the volcano slope is steeper on the Mexican side, the flow hazard is greater on the Mexican side. In this study, geomorphological classification was performed on the Guatemalan side. Found on the Tacana volcanos are lava domes that make up the summit and many lava flows. During photo interpretation, mainly lava landforms and valleys deeply related to downflow of pyroclastic flows and mudflows were identified.

g) Santiaguito volcano

Santiaguito erupts even now around the summit and the 1999 lava flow is still moving.

Near El Palmar, downflow and accumulation of lahar or river capture occurred. Thus, we performed geomorphological classification while estimating the transitions of river paths or changes of landforms in the future.

h) Cerro Quemado volcano

Cerro Quemado is characterized by thick lava lobes and collapse landforms. The thick lava lobes are characterized by high viscosity and relatively gentle inclination in the downflow area. The edifice collapse that occurred 1,150 years ago and the debris avalanche that accompanied it are the recent major events. During photo interpretation and geomorphological map creation, we attempted to define the range of debris avalanche deposits assumed to have reached Zona 1 of the city of Quetzaltenango.

i) Pacaya volcano

Since the Pacaya volcano is a complex volcano, major classification was performed on the volcano edifice according to Kitamura, 1995. The recent activities are the Strombolian eruption at the MacKenney crater and outflow of lava. Thus, photo interpretation and geomorphological classification are performed, bearing in mind that we must estimate the downflow direction of lava and the downflow and arrival range of a pyroclastic flow if it occurs.

j) Antigua Guatemala

Although Antigua Guatemala is in the landslide study area, there are a few landslides in the study area. Although it was attempted to extract landslide locations and potentially hazardous locations, only a few were found on the face of slope of National Highway 10. On the other hand, a certain kind of pumic is collected as a material for cinder blocks in some places, where a resultant subsidence or collapse occurs.

k) Northwest Region

Although the slope map creation was limited to the northwest region, landslides were identified in the entire region in order to check the relationship between landslides and slopes. During the process, necessary information was provided from the counterpart engineer and identified as many landslides as possible in 1:40,000 scale aerial photographs. Many landslides occurred in relation to complex geological features along the Chixoy-Polochic fault and the Los Chocoyos ignimbrite distributed along the valley. Additionally, the inhabitants and houses suffered from serious damages. A section of CA-1 runs along a transverse valley (a valley that crosses a mountain range at right angles), and a rear slope becomes steep, long, and massive at some locations. During photo interpretation, these hazardous slopes along roads were also extracted.

l) Central Region

For the central region as well as the northwest region, landslides and hazardous slopes along roads were identified. Along a valley that cuts into a pyroclastic flow plateau, there are many landslides, of which major ones were identified in the field study. Since USGS created a landslide distribution map for the 1976 Guatemala Earthquake, it was attempted to carefully extract those landslide locations indicated in this map. Small-scale surface landslide locations cannot be easily found on photographs because vegetation has regrown on it.

m) Samala river basin

The Samalá River in the study area forms a floodplain as wide as 5 kilometers because it has accumulated sediments supplied from the upper reaches whenever a flood occurs. In the floodplain, the current river path, the previous river path, and a flood mark can be identified. In a tributary, a lagoon is formed. This is because sediments accumulated at the junction of the Samalá River and the tributary dammed up the stream. If sediments continue to flow in, the tributary is going to be filled up in a dozens of years or so.

Around the floodplain, there is an old alluvial fan, which was classified as a terrace during photo interpretation. This terrace is eroded by a river to form a shallow valley (valle poco profundo). Although the terrace is a few meters higher than the riverbed, the intense supply of sediments from the Samalá River filled up the terrace plain from the upper reaches to expand the floodplain.

n) Acome river basin

The Acomé River in the study area flows down flat and lowland area. During photo interpretation, this was classified as a floodplain. La Gomera in the upper reaches is located on land a little higher than the riverbed. Around the Acomé River, a much lower terrace can be identified. In the lower reaches, one or two rows of dunes exist along the coast and towns such as Sipacate are located. Inland from the dunes, there is a marsh.

o) Achiguate river basin

In the upper reaches of the study area, the Guacalate River, a tributary of the Achiguate River flows down a valley in lowland and mountainous areas of the Antigua basin. Downstream from Escuintla extends an area the most important for geomorphological classification concerning a flood. Since Escuintla consists of a dissected fan, a little higher than the riverbed, the area was classified as a terrace. This terrace, downstream from Masagua, has no difference in height from the riverbed and flood marks, dry rivers. Roads washed away by floods were found. Thus, the landform in this region was classified as a floodplain. In the floodplain, we paid attention to how the flood current of the Achiguate River flows and identified flood marks. On the other hand, distributed along the coastline are the rows of dunes, which are important in a flood hazard map. Thus, we identified the distribution of these dunes.

p) María Linda river basin

The María Linda River in the upper reaches flows down valleys in a mountainous area. The middle and lower reaches are the most important range for geomorphological classification for flooding. The land near Brito, a little higher than the riverbed, is classified as a terrace. The land downstream from this location, having no difference in height from the riverbed, is classified as a floodplain. In the floodplain, many water channels and rivers diverge from the river, and there are many marks of floods that flowed down. As with the Achiguate River, there are rows of dunes on the coast. Inland from the dunes, large marshes and lagoons are distributed.

(4) Production of slope angle classification maps

There are two major study regions: Northeastern and central regions. For the northeastern region, a discrepancy was found between the coverage of a 1:50,000 scale topographical map and a slope angle classification map. To resolve the discrepancy, Director of INSIVUMEH, Director of IGN, and Leader of JICA Study Team discussed with each other on August 23, 2001 and agreed that a slope map should be created within the coverage of the 1:50,000 scale topographical map that had been created. Thus, a slope map should be created in the following area:

Northeastern region: The area after the change is:
about 5,000km^2 (6,600km^2 before the change)

Central region: about 1,200km^2 (no change)

It was determined that the entirety of the above two regions should be evaluated for inclination of slopes that concern the most occurrences of landslides.

1) Methods

A slope classification map was created as follows:

We created a program for calculating an inclination based on a digital elevation model and calculated inclinations in the landslide study areas. Then, we drew grids 40 meters apart from each other, obtained the inclination of four triangle planes created around grid intersections, and took the average inclination of t he four planes as the inclination of the intersection. Figure 2.3.6-1 shows how to calculate an angles.

The figures represent the altitudes of grid intersections. The values a1 to a4 represent the inclinations of triangles. In this case, (a1+a2+a3+a4)/4 is taken as the inclination of a point in the center.

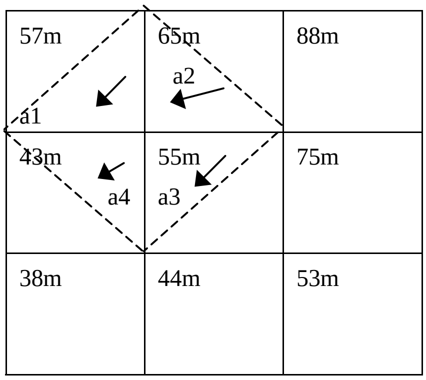


Figure 2.3.6-1 Calculation of angle

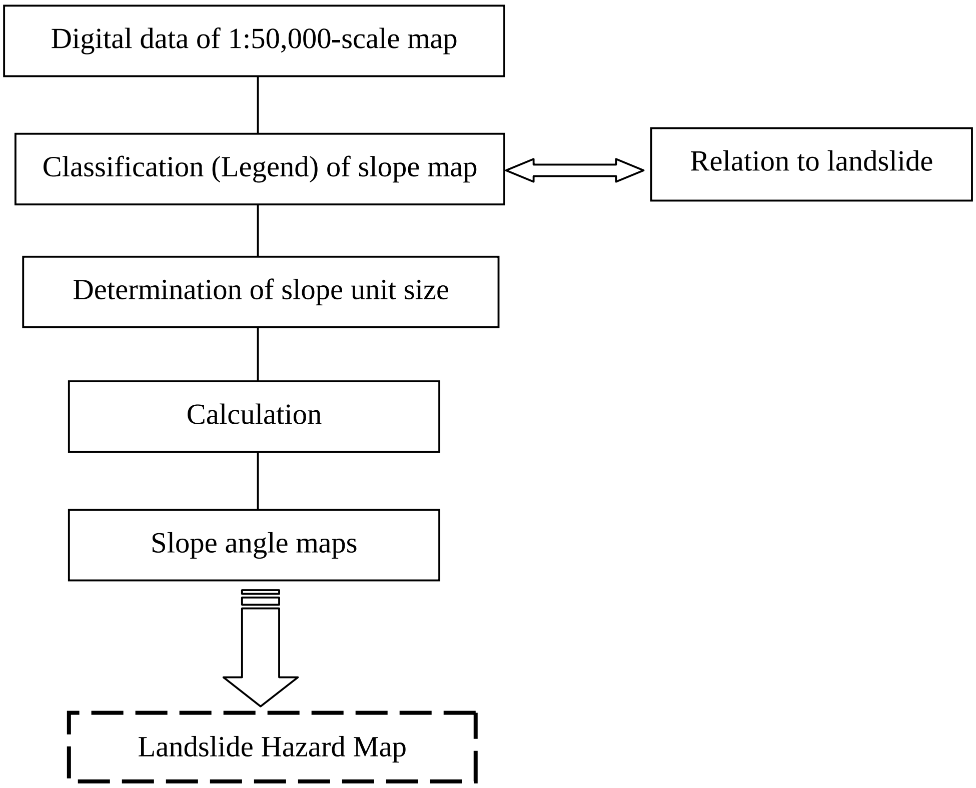


Figure 2.3.6-2 Schematic diagram of slope angle classification maps creation

2) Legend of slope angle classification map

The legends of a slope angle classification map are as follows:

Inclination groups

- Inclination 40° to 90°
- Inclination 30° to less than 40°

- Inclination 20° to less than 30°
- Inclination 10° to less than 20°
- Inclination 5° to less than 10°
- Inclination 0° to less than 5°

2.3.7 Field investigation and soil tests

(1) Outline

Fieldwork was carried out with counterparts to investigate past disasters, confirm features in the aerial photos, investigate natural conditions, and investigate social conditions in 2001 and 2002. The following table sums up the overview of the field investigation. The characteristics of the study areas are described in Section (2). In all the study areas, the disaster history study on the 1998 Hurricane Mitch was carried out.

Table 2.3.7-1 Overview of field investigation in 2001 (Earthquake hazard study)

Date	Study areas	Investigation items	JICA team	Counterpart
June /12-13, 2001	Guatemala City	Investigation of 1976 June earthquake damage, Collapse hazard location due to earthquake (steep slope land), General inspection of building structures	Wilkinson Tsukamoto	Molina
June /21, 2001	Quetzaltenango	Investigation of 1976 earthquake damage, Investigation of 1998 earthquake damage, Collapse hazard location due to earthquake (steep slope land), Collection of well data	Wilkinson Takeuchi Gutierrez	Molina Mota
June /22, 2001	Mazatenango	Investigation of 1976 earthquake damage, Investigation of 1942 earthquake damage, Collection of well data	Wilkinson Takeuchi Gutierrez	Molina Mota
June /14 2001	Escuintla	Investigation of 1976 earthquake damage, Collapse hazard location due to earthquake (steep slope land), Collection of well data	Wilkinson Takeuchi	Molina
July /3-5 2001	Puerto Barrios	Investigation of 1976 earthquake damage, Investigation of 1999 earthquake damage, Collection of well data	Wilkinson	Molina

Table 2.3.7-2 Overview of field investigation in 2001(Volcanic hazard investigation)

Date	Study areas	Investigation items	JICA team	Counterpart
July /26	Tacaná Volcano	Overview of landforms near the volcano * Due to safety reasons, staff did not enter the volcanic area to perform investigation. Such investigation will be performed in the future as required.	Tsukamoto Gutierrez	Mota
July /5 2001	Santiaguito	Ejecta from 1902 Santa Maria Volcano eruption, 1999 lava flow, Lahar damage and deposits, Landforms around the volcano, Relationship of landform changes in Santiaguito and Samalá river	Takeuchi Ishikawa	Chigna Coy Santos
June /21, 2001	Cerro Quemado	Ejecta around the volcano (geology), Distribution of debris avalanche deposits, Landforms around the volcano	Takeuchi	Molina
July /31- Aug ./1 2001	Pacaya Volcano	Ejecta around the volcano (geology), Distribution of debris avalanche deposits, Landforms around the volcano	Takeuchi	Chigna Coy

Table 2.3.7-3 Overview of field investigation in 2001 (Landslide hazard investigation)

Date	Study areas	Investigation items	JICA team	Counterpart
June /12-15 2001	Guatemala City	Investigation of 1976 earthquake damage, Landslides due to rainfall, Landslide hazards (steep slope land), Damage from 1998 Hurricane Mitch along the Villalobos river	Gutierrez Takeuchi Ishikawa	Mota Tax Santos
Aug /6-7 2001	Guatemala City	Soil sampling	Gutierrez Tsukamoto	DGC engineers
June /20-21 2001	Quetzaltenango Totonicapan	Investigation of 1976 earthquake damage, Investigation of 1902 earthquake damage, Landslides due to rainfall, Landslide hazards (steep slope land),	Gutierrez Takeuchi Wilkinson	Mota Molina
July /18 2001	Antigua Guatemala	Landslide hazards (steep slope land) and geological features	Gutierrez Tsukamoto	Mota
July /17-18 2001	Central Region	Investigation of 1976 earthquake damage, Landslides due to rainfall, Landslide hazards (steep slope land)	Gutierrez Tsukamoto	Mota
July /23-27 2001	Northwest Region	Investigation of 1976 earthquake damage, Landslides due to rainfall, Landslide hazards (steep slope land)	Gutierrez Tsukamoto	Mota

Table 2.3.7-4 Overview of field investigation in 2001 (Flood hazard investigation)

Date	Study areas	Investigation items	JICA team	Counterpart
July /4,6 2001	Samalá River	Damage due to 1998 Hurricane Mitch, Investigation of other flood history, Inundation and flood hazard locations, Landforms around the river, Relationship of landform changes in Santiaguito and Samalá river	Ishikawa Takeuchi	Santos Chigna Coy
June /20-22 2001	Acomé River Achiguate River	Damage due to 1998 Hurricane Mitch, Investigation of other flood history, Inundation and flood hazard locations, Landforms around the rivers	Ishikawa Tsukamoto	Perez
June /6-8 2001	María Linda River	Damage due to 1998 Hurricane Mitch, Investigation of other flood history, Inundation and flood hazard locations, Landforms around the river	Ishikawa Tsukamoto	Santos Tax

Table 2.3.7-5 Overview of field investigation in 2002

Date	Study areas	Investigation items	JICA team	Counterpart
June /10 2002	Guatemala City	Geological condition	Tsukamoto Matsumoto Gutierrez	Mota
June /13,21 2002	Pacaya Volcano	GPS observation	Tsukamoto Takeuchi Ishikawa Yoshimura Shukunobe	Mota IGN
June /15,19 2002	Ciudad Vieja	Lahar disaster	Tsukamoto Matsumoto Gutierrez Takeuchi Ishikawa	Santos
June /20,21 2002	Central Region	Landslide	Matsumoto Gutierrez Kiyota	Mota
June /27,28	Escuintla and Santiaguito Volcano	Geological condition and Santiaguito volcanic activity	Tsukamoto	Chigna
July /1	Guatemala City	Soil sampling	Matsumoto Gutierrez	DGC
July /10-12	Tacana Volcano and Cerro Quemado Volcano	Volcanic ejecta around the volcano (geology), Distribution of tephra, landforms around the volcano	Matsumoto Takeuchi	Mota

(2) Characteristics of each study areas

1) Guatemala City

The city of Guatemala, as the capital, has a long history of natural disasters and the current location of the capital is the result of a devastating disaster. The valley is subject to earthquakes, landslide, flood and volcanic eruptions for being near volcanoes, as well as weather related events.

The most notable disaster in recent history was the earthquake of 1976. It has been extensively documented and used in textbooks as teaching material for earth science classes. The city continues to suffer from constant seismic activity and will continue to be affected by natural disasters.

a) Landslide at the valley head of Guacamaya River (zone 19)

Several areas of landslides were visited along the Salaya, Tzalja, Sapote, and Guacamaya rivers in zona 19. The largest landslide at the area has a depth of 80 m (from 1500m at the start of Guacamaya river bed to 1580m at the top of plateau). Its geology is tephra interbedded with pumiceous diamictons and fluvio-lacustrine sediments. This is the characteristic of the ravines (*barrancos*) in Guatemala City which stand in depths between 25 and 150 m. In this site during the 1976 earthquake many slope failures (18) were observed. Also before these earthquake many clues of old slope failures are shown. Along 7th Avenue in the Primero de Julio neighborhood, a crack or a fault was observed with obvious cracks in the road and an offset gate. This area would be highly vulnerable to earthquake and landslide damages.

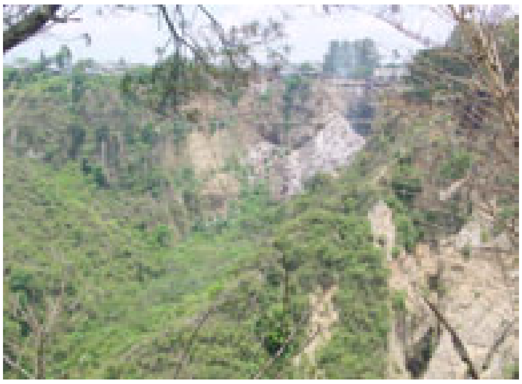


Photo 2.3.7-1 Landslide at the valley head of Guacamava River

b) Colonia Nino Dormido (zone 7)

Housing developments (Colonia Nino Dormido) and settlements (Colonias Buena Vista, Trinidad, and La Ruedita) were observed to investigate the slope and unstable conditions where homes have been built in those neighborhoods.

c) Ciudad Nueva (zone 2)

Ciudad Nueva is a residential area of better economic level but intense land usage near the edge of the ravine was observed. Further investigation showed buildings perched on the edge of nearly vertical slopes of the ravines. Some of them were reinforced to compensate for erosion and gradual slope movement but obviously slope failure will result in total destruction of many of these structures.

Photo 2.3.7-2 Base ground was eroded and subject to failure

d) La Limonada (zone 1 and 5)

The oldest settlement (pre 1976), La Limonada, was visited to observe general construction and social conditions. Most of the homes and structures are built from scrap materials along the slopes of the valley. Narrow networks of footpaths wind through the settlement. Some of the more recently constructed buildings were constructed with cement blocks. The poor construction and extremely limited access within this hillside settlement make it highly vulnerable to natural disasters.

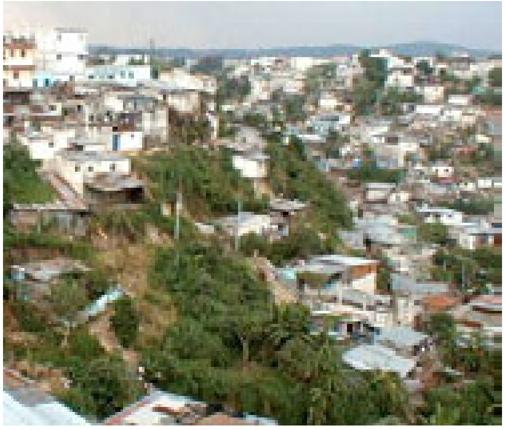


Photo 2.3.7-3 The settlement of La Limonada

e) San Rafael and La Mirada (zone 15)

The area of San Rafael and La Mirada are affluent neighborhoods with many grand houses constructed on the hillside. The streets have cracks and depressions from slumping and movement of the slope. These areas are very unstable and will continue to move, and could result in severe destruction if triggered by heavy rains or an earthquake.

Photo 2.3.7-4 Landslide at San Rafael (the wall is sticking out)

f) Landslide at km. 11.5 Road to El Salvador (Panamerican Highway)

This landslide appeared on October/1993. It is known the rainy season of 1993 up to October gave about 1,150 mm of rain and 676 mm accumulated in the previous three months. Although until now it was not possible to know final report (if exists) or details about further study or countermeasures for stabilizing this landslide, in a visit to the field (14/6/2001) it could be observed stabilizing structures such as a bridge platform, piles driven and some erosion control mortar carpet were already installed. However, the erosion control structure is not protected against gully erosion below it where the lack of vegetation threat to undermine the base of the slope of 62^{o} inclination at the lower side of the road.

Photo 2.3.7-5 Landslide at km. 11.5 Road to El Salvador (erosion control mortar carpet were already installed)

g) Landslide at Tzaljá River side (Chinautla Area).

It is located at the left side of Tzaljá River in a section called La Culebra (*The Snake*). The first landslide which is recalled by the neighbors occurred during 1976 earthquake, and later, was enlarged by heavy rains during Sept/1995, and Hurricane Mitch on 1998. This is a slump type landslide. Geology of the landslide area is typical pumice deposits, distributed around Guatemala City area.

Because there were no houses below this no damage was reported. The end of landslide tongue seems to have reached the river stream, but no report of damming was found. However in future slides it may produce the temporary damming of the river or it may become the source of flow out debris to down stream.

Photo 2.3.7-6 Landslide at Tzaljá River side

h) Cantón Amatitlancito (Santa Cruz Chinautla)

This landslide was activated during the earthquake of 1976. The main scarp has an approximated height of 20 m. From main scarp up to the river side there is horizontal length of about 200 m. At the base of the landslide at the margin of the Chinautla river there is a block of 15x30m which is sliding as a rotational slump, surface has rotated backward facing the slope, however at the upper part the slide is advancing in two steps of about 3 meters each (as of August/2001). Cracking and inclination of walls of houses downwards in this area shows successive settlements due to periods of saturation during rainy season (expansion) and drying during dry season (compaction due to loss of density).

Photo 2.3.7-7 Landslide at Cantón Amatitlancito

Additional investigation in 2002

In the Guatemala City area, we confirmed the geological features for new team members as well as some questions in terms of landform classification. We conformed the distribution and properties of lucustrine sediments located in the upper part of Los Chocoyos pyroclastic flow deposits. The lucustrine sediments were accumulated in a lake formed in a shallow, depressed ground created after the Los Chocoyos pyroclastic flow is accumulated. The very-fine-grain deposits close to diatomaceous earth and the sandy deposits were sandwiched by pumice deposits. The layer reaching a thickness of almost two meters, showed a clear stratification. It is assumed that these lucustrine sediments were accumulated in a lake or then lowland dammed after the Los Chocoyos pyroclastic flow deposits or its secondary deposits were accumulated. Around Guatemala City, there were several zones after a few layers of pumice flow sediments. These layers may easily become impermeable and concern the occurrence of landslides. These layers may also affect slightly the

Photo 2.3.7-8 Lucustrine sediments found in southern part of Guatemala City Area

Photo 2.3.7-9 Monogenetic volcano lava in the western part of San José Pinula

amplification of ground motion.

Since monogenetic volcano landforms were found around San José Pinula, we executed the geological survey in the field in order to confirm the existence of lava in the ancient period. These volcanoes are not likely to reactivate.

2) Quetzaltenango

Quetzaltenango is located in the Quetzaltenango Valley, an intermontaine 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. Nearby volcanoes include Santa Maria, Santiaguito, Cerro Quemado, Siete Orejas and several volcanoes. There are two major faults that bound Quetzaltenango Valley, the Olintepeque fault to the north and the Cajola fault to the northwest. Both have displacements of over 300 meters.

Photo 2.3.7-10 Small canal in La Línea

Photo 2.3.7-11 Dangerous cliff at La Pedrera

a) La Línea

The area of La Línea was visited to check historic and current flooding problems and water levels in the area. A canal overflows regularly because small bridges have been built to access homes on the other side, resulting in lowering of the nal wall in those areas. Armando Velasquez, the assistant mayor, informed us about seasonal flooding in zone 5.

Photo 2.3.7-12 Chuicaracoj road cracking

b) Rock Falls at Cerro La Pedrera

La Pedrera (meaning *quarry* in Spanish) is a hill with an elevation of 2,749 masl. As its name indicates it is the main source of building stone in Quetzaltenango. It is located at the south edge of the city. There are rock falls during earthquakes or rainfalls. The hazard is permanent due to fractured rock at the top of the cliff. There are about 40 houses of the Barrio Santa Ana in danger of damages by rock falls. An earthquake in 1998 caused damage and cracks in several houses.

c) Settlement at Chuicaracoj

This is a section of road of some 100m which presents some cracking at the side of the cliff. Some settlements have appeared in two sections of about 10m each. Protection of the slope with deep rooted shrubs is necessary.

3) Mazatenango

Mazatenango is located along the coastal plain at the foot of the Pacific slope with several prominent volcanoes rising up in the north, behind the town. Laharic and fluvial sediments characterize the geology of the area. These fan deposits are the result of mudflows and fluvial deposits. The fluvial deposits are primarily reworked deposits of volcanic origin.

At the local CONRED office, they informed us that only minor damages have occurred from recent and historic earthquakes, including the 1976 earthquake.

4) Escuintla

a) Field investigation in 2002

Escuintla is located along the coastal plain at the foot of the Pacific slope with a distance from Agua, Fuego, and Pacaya volcanoes. The geology in the Escuintla area is primarily older volcaniclastic rocks and more recent lahar and fluvial deposits primarily from Agua volcano. These deposits are well cemented and resistant to erosion. The regional geological map shows two faults passing just north of the city. However, these are not considered to be active faults and the locations are not known precisely.

Photo 2.3.7-13 The well of Aguas Vivas

Photo 2.3.7-14 Quarry at La Estancia

The municipal offices informed us that the primary concern and problem is local flooding and pointed out areas of flooding problems on a map. Several sites were visited including wells, springs, flood zones, and other areas of geographical interest. Observation of water levels in local springs helped to confirm groundwater levels in the area. The Naranjales settlement was visited to confirm the risk of flooding conditions. Several wells and a quarry at La Estancia were visited to confirm locations with GPS and make observations.

b) Additional investigation in 2003

In Escuintla, we confirmed the geological features and deposits of debris flow from Agua or Fuego Volcano. Debris flow mounds were distributed not only in the urban area of Escuintla but also in its vicinity. Boulders (lava blocks) making up the mounds as well as mega blocks that used to be part of the volcano were confirmed. Furthermore, the western hilly terrain (between a new national road and Rio Guacalate) that was assigned as volcanic rock in the Tertiary period in an old geological map was found with debris flow deposits in the Study. In the eastern part of the Escuintla urban area, there is a thick alluvial-fan-like conglomerate layer (30 meters or more) because debris flow and flood had come in from the direction of the Pacava volcano. In the Escuintla area, there is tight soil mixed with large conglomerates, inside or outside the range of debris flow deposits or alluvial fans.

The soil types in the study area can be roughly classified as follows:

- ♦ Western and eastern mountain range (near the outskirts of the study area)

The rim of the mountain range consisting of the Tertiary volcanic rocks concerns bedrocks. Rock falls and slope collapses may occur in case of earthquake. However, this region is not inhabited.

- ♦ Lowland area along the Guacalate River

The latest lahar deposits from Agua or Fuego Volcano has accumulated. Large conglomerates are lying about.

- ♦ Western and eastern volcanic alluvial fans

In the western part lie volcanic alluvial fans formed as terraces located on the western side of the Limoncillo River, with a gentle slope from the

Photo 2.3.7-15 Debris Flow Deposits in Western Part of Escuintla

north to the south. Graval layers mixed with boulders can be observed in the outcrop along the river. In the eastern part lies a volcanic alluvial fan formed on the eastern side of the Marroquin River. A boulder layer with a thickness of more than 30 meters is found in the outcrop along the Michatoya River on the eastern end.

- ♦ Central part of urban area (debris avalanche deposit area)

An area formed as terraces is located on the eastern side of the Limoncillo River. This area is two or three times higher than the volcanic alluvial fans. The debris avalanche deposits were reported to be at least 20 meters thick or about 30 meters thick on the average (Jim Vallance et al., 1988). On the surface, debris flow mounds are distributed extensively. Tumps often consist of blocks a few tens of centimeters in diameter but sometimes of mega-blocks that have a diameter of nearly ten meters. The entire outcrop is not too hard to cut a road although the contained rocks are hard. The source from which debris collapsed is estimated that the debris collapsed from Agua volcano (Otoniel Matias).

5) Puerto Barrios

Puerto Barrios is located along the Caribbean coast in the Bay of Amatique, at the inlet to the Bay of Santo Tomas. Recent alluvial deposits and some older sedimentary deposits characterize the area. This area is at the margin of two tectonic plates, the North American and Caribbean plates. The Chixoy-Polochic fault zone, a very active area of seismicity, marks this boundary and passes through the Bay of Santo Tomas and just south of Puerto Barrios.

The municipal offices informed us that detailed geology is not available for this area,

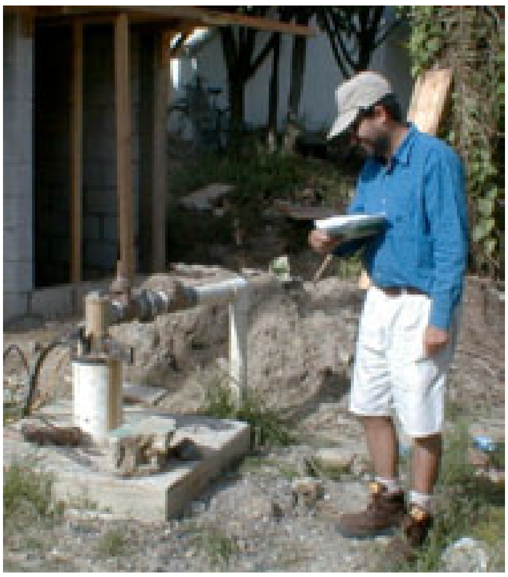


Photo 2.3.7-16 Verifying location of well

Photo 2.3.7-17 The damage of 1999 earthquke at Customs building, Puerto Barrios