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"Risk analysis in Cerro El Volcan in the context of design of a landslide monitoring system"

Dipilto Municipality, Nueva Segovia, Nicaragua

by

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In association with:

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RISK ANALYSIS IN CERRO EL VOLCAN IN THE CONTEXT OF DESIGN OF A LANDSLIDE MONITORING SYSTEM

DIPILTO MUNICIPALITY, NUEVA SEGOVIA, NICARAGUA

By Anne-Sophie GREGOIRE

Final report for **Centre des Etudes Géologiques (CERG 2003) – UNIGE**

AGENCIA SUIZA PARA EL DESARROLLO Y LA COOPERACION COSUDE

INTRODUCTION

This report, thesis of the 'Certificat d'Etude des Risques Géologiques (CERG)' from the University of Geneva, Switzerland, is the result of a work carried out for the Swiss Agency for Development and Cooperation (COSUDE) in Nicaragua, between the 17th of august to the 12th of September 2003. The main objective of my work was the design and installation of a landslide monitoring system in Cerro El Volcan, Dipilto municipality.

Why Nicaragua?

The passage of Hurricane Mitch in October 1998 over Central America showed the extreme vulnerability of Nicaragua not only to volcanic and seismic hazards but also to landslides and hydrological hazards, such as flooding and debris flows. Since then, many institutions, agencies and NGO have produced hazard maps, each using their own symbols and criteria. Although the results of such studies were globally positive, some raised confusion due to the differing symbols and criteria used. In many cases duplication of projects occurred between these agencies.

Context of the project

The METALARN (Methodology for Local Analysis of Natural Hazards and Risks in Nicaragua) project is the third phase of the ALARN project (Local Analysis of Natural Hazards and Risks in Nicaragua) initiated in 1999 by COSUDE. Its aims are:

- Contribute to the unification and standardisation of criteria, symbols, concepts and methodologies for the creation of hazard maps; 1/50,000 scale for the municipalities and 1/10,000 or 1/5,000 scales for urban design are planned. A national forum about this problem was successfully held at the Hotel Camino Real on the 20th and 21st of august 2003 with about 50 professional, from Nicaragua and abroad attending.
- Coordinate all the technical capabilities and specialists of the country for creation of these maps and the realization of some pilot-projects such as the monitoring of landslides.

The collaboration between INETER (Instituto Nicaragüense de Estudios Territoriales) and COSUDE starts with a pilot project of design and installation of a landslide monitoring system in specific areas of the country in order to bring early warning to the population. This method has to be robust, economic and simple enough to be repeated on many other sites of Nicaragua.

Dipilto municipality, located in Nueva Segovia department, was severely damaged by Hurricane Mitch and is one of the most vulnerable to mass movements in Nicaragua. During Hurricane Mitch, hundreds of landslides, rock falls and debris flows occurred. Following this event, the 'Landslides' section of the department of geophysics at INETER studied, for the first time, the triangular area formed between El Volcán, Cerros, Volcán Viejo and El Mojón de Matasanito (Devoli et al., 2000). Subsequently in 2001-2002, COSUDE-ALARN project enabled the creation of a risk analysis report for Dipilto and the production of a hazard map, at a municipal scale, in order to aid urban planning.

For this pilot project, we decided to study the same area as the previous INETER study. COSUDE is project coordinator and provides the finances. Three departments of INETER (geophysics, meteorology and geodesy) were mandated for installation phase, providing both material and human resources.

Objectives of my field work

The design and installation of a landslide monitoring system consisted of the following steps:

- Provide recommendations for the location of the most adequate sites for meteorological devices (pluviometer and pluviograph);
- Design the geodesic network which will help in measuring the movements of the sliding masses (horizontally and vertically). This included the choice of the optimum locations for the construction of the survey monuments and the supervision of their installation.
- Provide advice for the setup of scarps monitoring devices in particular areas, with consideration to their cost and technical feasibility.

In this CERG thesis, I will try to integrate the results of the field work within a **risk evaluation** framework. The first part of the report describes the target area (geographical, socio-economical, climatological, geological, geomorphological and hydrological characteristics). The second part deals with risk assessment in Cerro El Volcan, i.e. hazards and vulnerability assessment. Risk mitigation measures, in particular elaboration of Early Warning scenarios, will be presented in the third part of this report.

1 DESCRIPTION OF THE AREA

1.1 Geographical situation

The municipality of Dipilto is located 240km North of Managua, in the central-north part of Nicaragua and in the north-western part of Nueva Segovia department. It is bordered by: to the north, the Republic of Honduras; to the south, the municipality of Ocotal; to the west, the municipality of Macuelizo and to the east, the municipality of Mozonte (*see figures 1 and 2*).

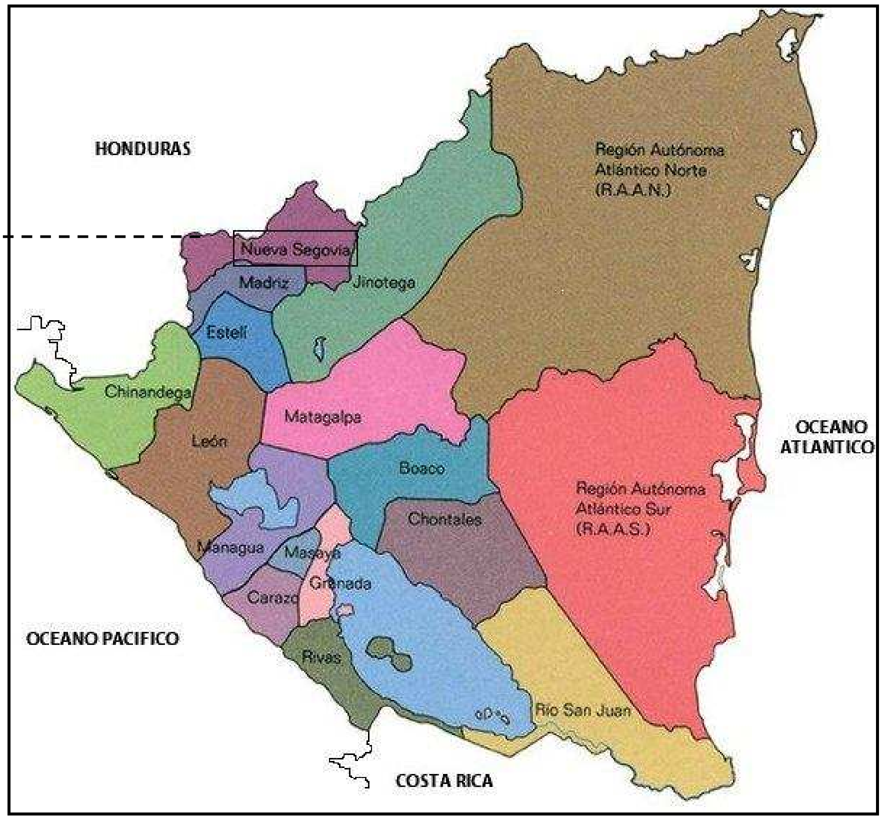


Figure 1: Political map of Nicaragua

Figure 2: Map of Nueva Segovia Department and localisation of Dipilto.

For the pilot project, we chose to study the south-west sides of Cerros Volcan Viejo, the flank of Cerro El Mojon de Matasanito and the flanks of Cerro Las Nubes (*see figure 3*). This covers an area of about 4km^2. The region is the highest of the country with a steep mountainous relief (being part of the Cordillera Dipilto and Jalapa). The altitude varies between 1200 and 1800m. Two tributaries, El Volcan in the south and Las Nubes in the north, join La Tablazon quebrada and form steep narrow valleys, typical for this mountainous area.

Figure 3: Localisation of the area selected for the realization of the pilot project METALARN (inside the red polygon).

1.2 Demographic and socioeconomic aspects

1.2.1 Demography

Dipilto municipality made a census of its population in ‘Plan estratégico 2001-2004’. Total population is 4,457 inhabitants of which 675 inhabitants (14.70%) live in urban areas and 3930 (85.30%) in rural areas. It’s estimated that population increased by 3.5% between 1971 and 1995. Population density is about 42 inhabitants / km². The areas studied (Dipilto Viejo, El Volcán, Las Nubes, and La Tablazón) consisted of the following populations:

Settlements	Population	Number of houses	% Population of Dipilto municipality
Las Nubes	40	24	0.87
El Volcán	389	19	8
Dipilto Viejo	660	111	14
La Tablazón	281	18	6
Total	*1,370*	*172*	***28.87***

(Source: Dipilto municipality 2001-2004)

1.2.2 Housing

There are approximately 828 houses of all construction types within Dipilto municipality (with an average of 6 people in each). Most are of adobe construction consisting of straw ceilings and clay tiles. More than 60% of the houses have been strongly affected by Hurricane Mitch.

Number of houses	Brick without iron	Mixed	Adobe	Woods	% affected by Mitch
828	3%	20%	**64%**	13%	61.7

(Source: Dipilto municipality, 02/2001)

1.2.3 Economy

Agriculture is the most important sector: 56% of the families depend on self-production, 10% are dedicated to cattle for self-consumption and the rest are working where help is needed (non-salaried activities). The main crops are coffee, bananas (no less than 8 types were counted in a field next to the Cooperative), beans and corn. Coffee plants are the most numerous and constitute an important source for exports. There are over 4470 plantations, composed of the following:

Cultures	Bananas	Coffee	Beans	Corn
Number of plantation	300	4000	140	30
Percentage	7%	**89%**	3%	1%

(Source: Caracterización Cuenca del Río Dipilto – POSAF, 2001)

1.2.4 Health

There are three small medical centres in the municipality located in Las Manos, Dipilto Nuevo and Dipilto Viejo. Medical staff consists of two doctors who visit each centre weekly, 4 auxiliaries and 24 health brigades.

1.2.5 Education

There are about 1300 pupils, 40 teachers and 13 schools (mainly pre-schools and primary schools). Most children go to school either in the morning, afternoon or evening and spend the rest of the day working in the fields. In the most remote parts of our area, children have difficulties to join school because of difficult access (especially during rainy periods) and the amount of work required for subsistence.

1.2.6 Water and sanitary aspects

Drinking water is only accessible in the urban areas of Dipilto Nuevo and Dipilto Viejo. Where we were working, water is directly taken from the El Volcan and Las Nubes rivers and quebrada La Tablazon (see §1-6 Hydrology). People use traditional latrines.

1.2.7 Telecommunication

Only two telephone lines, one at the municipality office in Dipilto Nuevo and one at the migration post in Las Manos. Access to these lines is limited. Radios are sometimes available however, as we experienced during the field work, communication is mainly by direct contacts or by shouting over the valleys! These systems proved to be effective, however time consuming…

1.2.8 Energy

Energy services are, once again, limited to urban areas. Outside urban areas, people burn wood for cooking, and arrange their daily lives according to natural light (daylight from 6am to 6pm, almost all year-round).

1.2.9 Access roads

The main access road is the Pan-American Highway which links Dipilto and Las Manos at the Honduran border. Access to our studied area was possible through a network of unpaved roads and access can be difficult during the rainy season. A 4-wheel drive vehicle is essential. Public transportation is available on the main highway. Otherwise, transportation is mainly by bicycle or on foot and if lucky, people can get a ride from the few vehicles passing.

1.3 Climate and precipitation

The area is characterized by a Mountainous Subtropical climate. Average annual precipitation runs between 1000 and 1200 mm and temperatures around 24°C. Rain is well distributed throughout the year. Three meteorological stations are already setup in the area: Las Planos (Las Manos), La Laguna (Dipilto Nuevo) and Ocotal. Since 1958, records show a strong variation of total precipitation with the years. During some dry years (1972, 1992, 1994), the area received only 400 to 600 mm of rain, while in 1958, 1970, 1989 and 1998 it received 1400 mm (in 1998 on the 30th of october 800 mm of rain were recorded, due to Hurrican Mitch). There is some local variation as well: it globally rains more in Las Manos, (1400mm per year) than Dipilto (1160mm) as Las Manos is higher in altitude (1200 m above sea level) than Dipilto (800m). The wettest months are from May to October generally with a peak in September. The chance of hurricanes forming is high in September-October.

1.4 Geology

According to Garayar (1971) and Fenzl (1989), the area studied is part of Palaeozoic and Mesozoic Platforms (North Geological Province) which comprise a large part of northern Nicaragua. The basement of the province is Palaeozoic metamorphic with intrusive cretaceous rocks, covered by sedimentary rocks from Cenozoic/Mesozoic age. It includes the older rocks found in Nicaragua (250 million years old) with the presence of quartzite, schist, micas and other meta-sedimentary and meta-volcanic products from regional metamorphism. According to Zoppis Bracci (1961), the cretaceous intrusion is estimated as being 83 (+/- 3) million years old. It mainly consists of granite, biotite, granodiorite, quartzo-monzonite and quartzo-diorite (Garayar, 1971). In the Rio Dipilto valley, the Cenozoic/Mesozoic rocks are mainly composed of permeable deep sand and conglomerate deposits, .The main tectonic structures are from the metamorphic basement: with schistosity planes and lineation. The area of Dipilto is considered to be seismically active due to the presence of local geological faults. The majority of the seismicity has its origin in a fault passing below the Rio Dipilto valley and oriented NW-SE. Normally the events are relatively small and are only felt in the vicinity of the hypocentre.

During the first two days of the field camp, Miriam Downs and I were accompanied by Gerardo Silva, geologist at the department of geophysics at INETER who is mandated to produce a geological map of the area. By walking up El

Volcan quebrada up to Cerro El Volcan, it was observed that erosion is very important and numerous other quebradas, up to 20m high were also present (*see photo 1*).

Photo 1: Quebrada El Volcan showing the high degree of erosion.

On the south side of the quebrada, schists are predominant. They present a fluid texture. Foliation corresponds to a parallel orientation of planar and lenticular components, giving a laminar structure. Schist suffers from the intrusion of plutonic rocks. On the north side, rocks are mainly of hard granite with numerous fractures. In general, granite is of grey colour and has biotite (fresh condition). When they are near to plans of diaclases, their colour is clearer (silification and hydrothermalism). The material is continuously eroded and is constituted by recrystallized granite (sandy soils) (*see photos 2 and 3*).

Photo 2: Deposits coming from anterior movement in El Volcán quebrada.

Photo 3: Fractured granite on the side of El Volcan quebrada.

However, geological structures are not well understood and one will need more field work to determine in detail the main characteristics.

1.5 Lithology

About 70% of the soils have a clear sandy and /or clay texture. These soils are very acidic (pH <4.8), with less than 1% of organic material and low water retention capacity (<5%). Biomass is low as well as regeneration capability. Evolution of these soils is incipient and genetic horizons can't develop. Two groups of soils are observed, one with fresh material and one as a product of soils strongly eroded.
- The first group has a medium texture and obscure colour. Depth is very superficial; soils are strongly eroded due to bad use. Topography is steep (gradients > 30%).
- The second group has a sandy texture, 20-40 cm deep. Material of origin (granitic rocks) has been meteorized and is covered by a layer of sand. Associated topography is steep, with numerous quebradas. Main vegetations are pines and natural fields. This type of soil has been encountered in the north part of quebrada El Volcan (see §1-4 Geology).

1.6 Hydrology

Dipilto municipality is located in the Rio Dipilto watershed. In general, the relief is very rugged and about 70% of the watershed consists of quebradas and steep slopes. The hydrological system is formed by a main river (Rio Dipilto), secondary rivers and quebradas. These quebradas are mountainous rivers characterized by high slope angle (around 13%) and only 3-5 km long. The hydrological network contains the following:

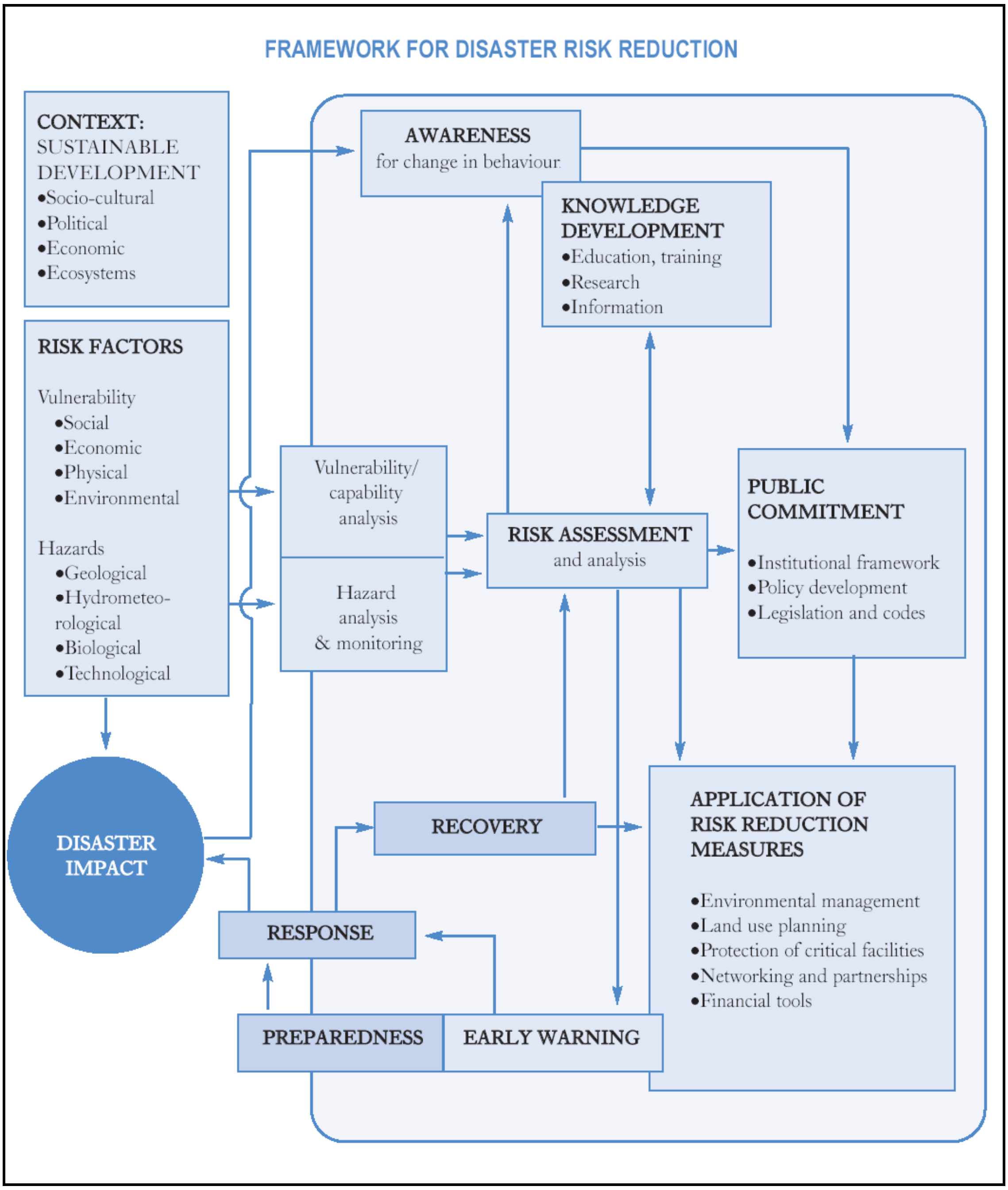
Rivers	Maximum altitude (m)	Minimum altitude (m)	Slope angle (%)	Length (km)	Order
Río Las Manos	1200	900	3.75	8.0	1·
Quebrada La Tablazón	1300	840	**11.5**	4.0	1·
Caño Las Lagunas.	1400	860	10.8	5.0	1·
Río Dipilto.	1500	760	9.8	7.5	2

Quebrada La Tablazón originates from La Tablazón settlement and is formed by the confluence of several short tributaries, such as Las Nubes, El Volcán, El Trigal and Orocuina. This small network is very important, as it can transport large quantities of sediment from the moving masses of Cerro El Volcán. As the slope angle of the river is high, during high intensity short duration hydrological events, energy of transport is high and can cause serious damage to people, infrastructure and natural resources. Therefore, creation of a monitoring system and Early Warning system in the area is of high priority (this will be discussed fully in the next chapter). These bodies of water are also used for human consumption. However, their quality is bad as they are often filled with organic wastes and with sediments from Cerro El Volcan.

2 RISK ASSESSMENT IN CERRO EL VOLCAN

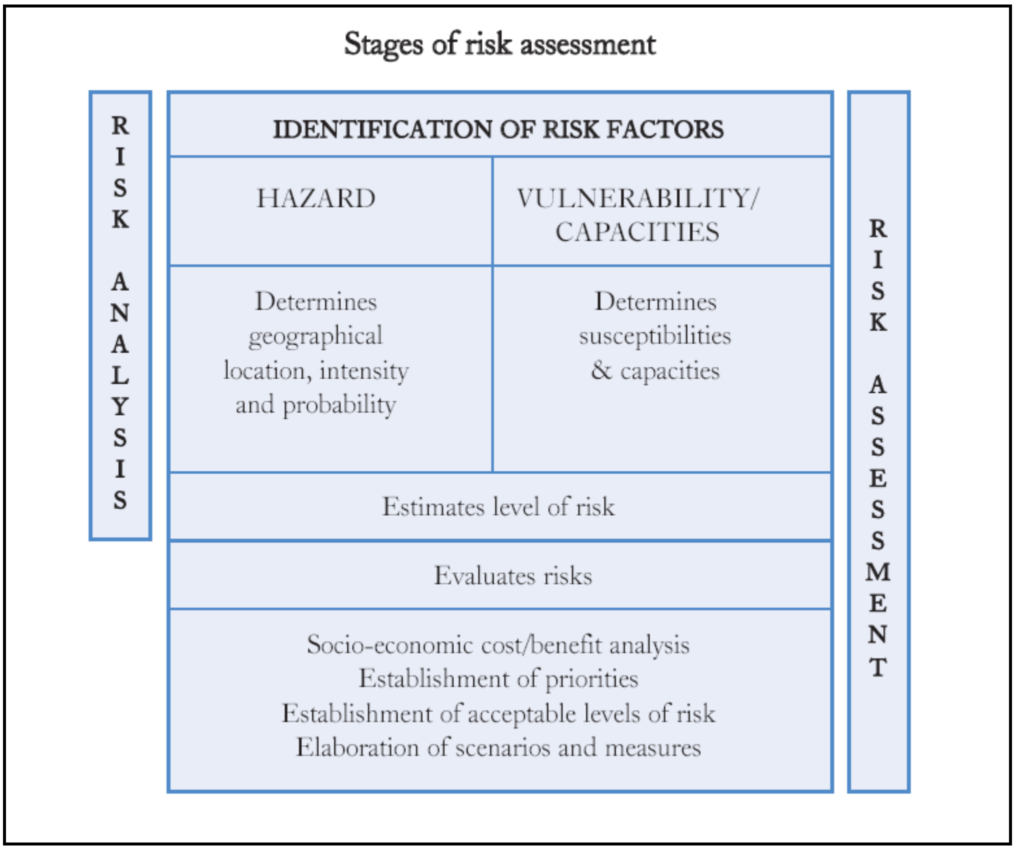
2.1 General definitions

First of all, it's necessary to provide definitions of the terms used in this study. The project belongs to a long term project which aims at reducing the risk of disasters. **Disaster risk reduction** is "the systematic development and application of policies, strategies and practices to minimise vulnerabilities and disaster risks throughout a society, to avoid (**prevention**) or to limit (**mitigation** and **preparedness**) adverse impact of hazards, within the broad context of sustainable development" (United Nations, 2002). To give a general view of the framework, I have included the following schema (United Nations, 2002).



My contribution in Dipilto was, of course, too limited to cover the entire subject. In the next chapters, I will try to assess the risk in Cerro El Volcan area and bring elements for risk reduction measures.

Risk assessment is "a process to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability/capacity that could pose a potential threat or harm to people, property, livelihoods and the environment on which they depend (elements at risk)" (United Nations, 2002).



By going deeper, we can provide the following definitions (United Nations, 2002):

- **Hazard** is "a potentially damaging physical event, phenomenon or human activity, which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation". Hazards can be single, sequential or combined in their origin and effects. Each hazard is characterised by its location, intensity and probability.

- **Elements at risk** means the population, buildings and civil engineering works, economic activities, public services, utilities and infrastructure, etc., at risk in a given area.

- **Vulnerability** is a "set of conditions and processes resulting from physical, social, economical and environmental factors, which increase the susceptibility of a community to the impact of hazards".

Finally, the **risk** is defined by "the probability of harmful consequences, or expected loss (of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human induced hazards and vulnerable conditions". We can express the total risk by the following equation:

Risk = Hazards * Elements at risk * Vulnerability

Therefore, assessing the risk in Cerro El Volcan area means first assess the hazards (description of the phenomena and the monitoring systems), identify the elements at risk and assess the vulnerability.

2.2 Description of the hazards

Even before the heavy rains of October 1998, the slopes of Cerro El Volcan were highly susceptible to major landslides and debris flows due to their steep topography, fragile soil, presence of underlying faults and unstable rock material. Two weeks before, two small landslides were initiated by heavy rains and degenerated into major landslides with the hurricane. Although relatively unpopulated, the impact of the instability was great, especially on the local agriculture. The destruction of coffee, bananas and corn fields was a disaster for the local population. In addition many houses were damaged. Landslides and debris flows are mainly rainfall-induced but can be earthquake-induced due to the seismicity of the region. An earthquake, even of medium magnitude, could trigger important mass movements if it occurs after or during periods of heavy rains. The hazards will be more described in the first part of this chapter.

To better assess these phenomena, forecast their occurrences and be able to take preventive and mitigation measures, we have to determine a) how the mass is constituted and evolves, b) give an estimation of the velocities, depths and directions of the movements and c) determine the critical rain intensity as rainfall is the main triggering factor. This is to be achieved by creating a complete but simple monitoring system. The second part of the chapter will describe the methodology used to setup the meteorological and geodesic monitoring systems. In the third part, I will bring suggestions for improvement and development of the methodology.

2.2.1 Landslides

Before Mitch, the landslide was only rotational. The heavy rains of 1998 subsequently weakened the area and the landslide evolved into complex, mixed and permanent phenomena. Several compartments are now isolated and evolve differently. The total unstable mass occupies the entire west flanks of Cerro El Volcan and Cerro Mojon Del Matasanito. Its extension is great, about 3 km length and over 500m in elevation. During the field work, the most active areas of the landslide were identified: Five areas on the west flank of Cerro El Volcan Viejo (henceforth called compartment 1 to compartment 5 respectively) and one compartment on Cerro Mojón Del Matasanito (henceforth called Arado). See *figure 4* for compartments locations and *photo 4* for a general view of the area.

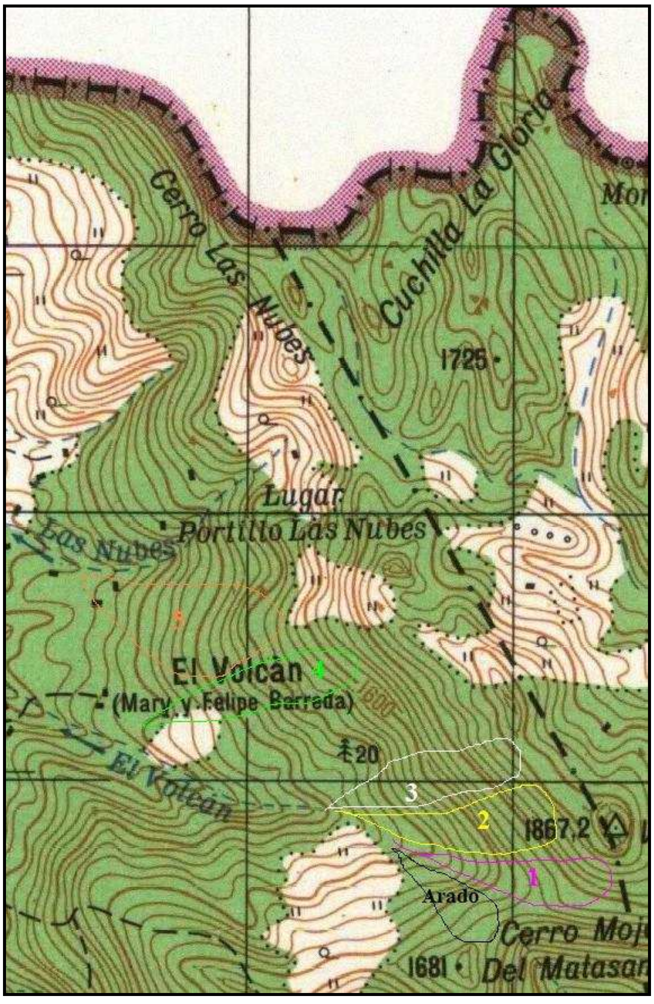


Figure 4: Localisation of the compartments (Arado in black, C1 in purple, C2 in yellow, C3 in white, C4 in green and C5 in orange).

Photo 4: General view from La Tablazon with the compartments and localisation of the Cerros.

From the south to the north:

Arado is a rotational landslide located on the western slope of Cerro Mojón del Matasanito (see photo 5). It shows a high degree of activity indicated by numerous scarps, superficial movements, debris flows and coladas. This movement could affect the numerous cultures of El Volcan. It was initiated by Hurricane Mitch and the process is in acceleration. There are associated debris flows in the frontal and lateral parts moving the direction of El Volcan quebrada. There are tall plants (up to two meters high) and trees growing on the landslide.

Photo 5: View of Arado. The main scarp is 6-8m high, about 30m wide. The black line indicates the limit of instable zone.

Compartment 1 is an active rotational landslide with scarps 3-8m high and 50m wide .It has associated debris flows from its lower part. It is separated from Arado and compartment 2 by stable areas (*see photo 6*).

Photo 6: View of the top of compartment1 located below Cerro El Volcan Viejo (from casita).

Compartments 2 and 3 are superficial movements with scarps 3-5 m high. There is no evidence of rotational movement. We observe numerous quebradas and old debris flows in contact with grey, fractured and altered metamorphic rocks. The soil is meteorized, of pink colour and has high clay content. There are no trees, only tall plants. See *photo 7* for a general view of the two compartments, then *photos 8 and 9* for more detailed view.

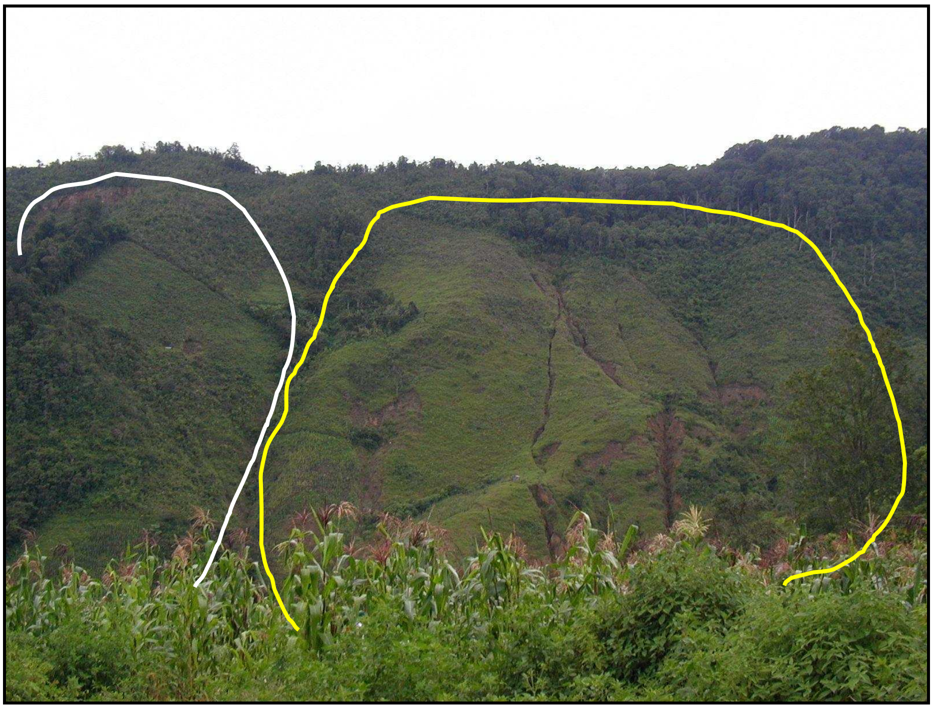


Photo 7: Global view of compartments 2 (right) and 3 (left) from Cerro El Torre.

Photo 8: Compartment 2 with superficial movements and quebradas. Signs of debris flows. View from Arado.

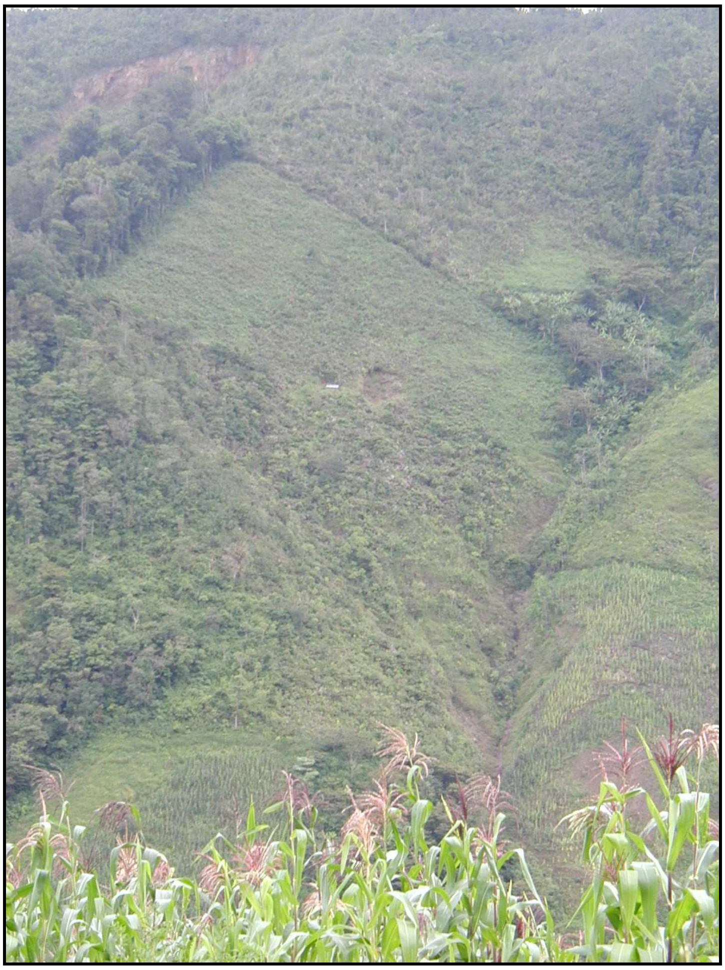


Photo 9: Compartment 3 with superficial movements, old scarps and quebradas. View from El Torre.

Between compartments 3 and 4 we observe three large scarps with associated debris flows. It was not possible to examine these areas as they were too high and there were no access routes.

Compartment 4 is located just above the Cooperative El Volcan (*see photo 10*). This is a rotational landslide: it is deeper than compartments 2 and 3 and is surrounded by two small quebradas which, during Mitch, brought debris down to the Cooperative damaging the house (fortunately people were evacuated beforehand).The scarp closest to the Cooperative is 5-10m high and 100m long. We observe many inclined trees and the slopes are steep.

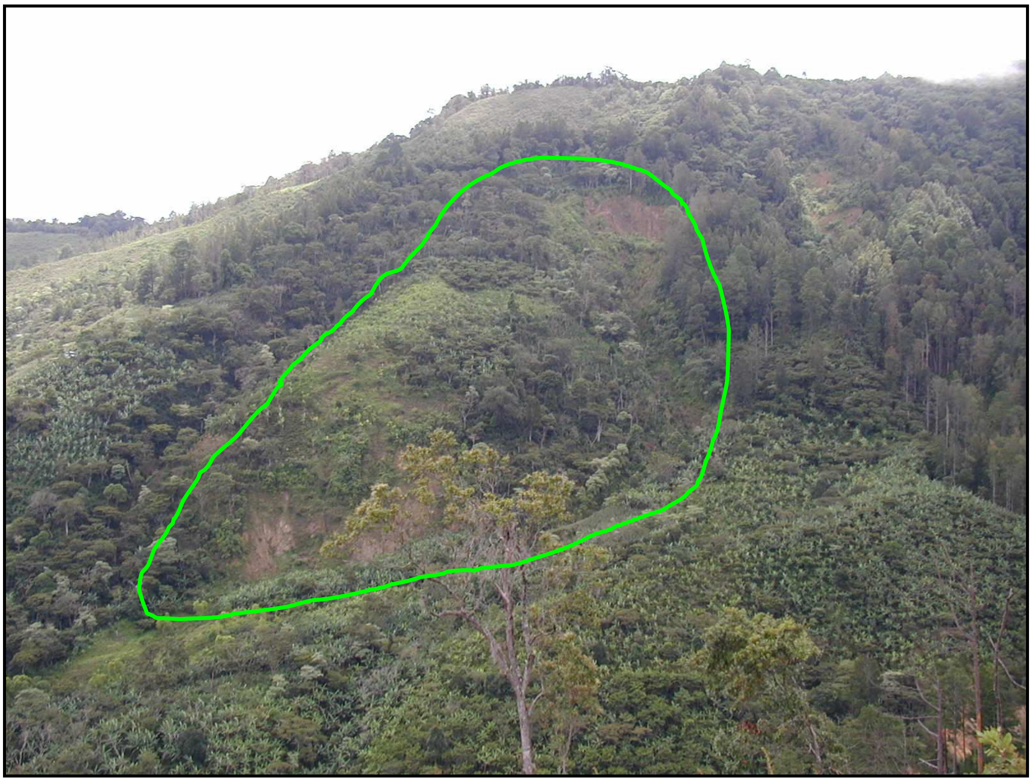


Photo 10: View over compartment 4 from the hill above the cooperative (located on the left bottom).

Compartment 5 is a superficial rotational landslide which has different directions of movement in its upper and lower parts (*see photo 11*). There are intrusive rocks with a high degree of degradation. Here also, trees are inclined and slopes steep. Scarps are 5-20m high. The water content is higher than in the other compartments and some areas were very wet.

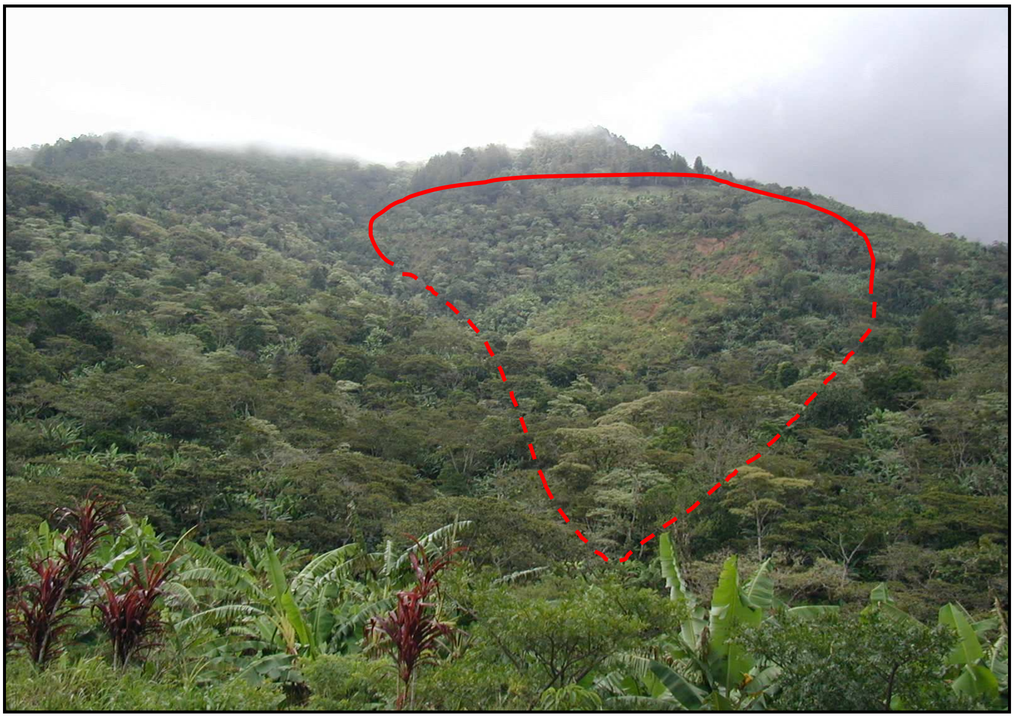


Photo 11: View over compartment 5 from the little church (capilla) in Las Nubes.

2.2.2 Debris flows

They occur frequently and their effects on the plantations and settlements were disastrous with Mitch. In general, generation of debris flows is associated with numerous and simultaneous landslides that bring material to the riverbed, which can be dammed. When this temporary dam is overtopped or fails, the retaining mass of water is suddenly released, carrying the solid materials accumulated and removed from the riverbed. The transported mass travels with high velocity (1-10 m/s) and further away than landslides. In order to forecast the occurrence of an event, an additional objective of the pilot project is to understand better and recognize the conditions that trigger debris flows (Kanji et al., 2003). In our studied area, the main conditions for frequent occurrences of debris flows are present: numerous paths of old debris flows are observed, in particular on the west, steep and eroded flanks of Cerro El Volcan. When walking up quebrada El Volcan, we noticed that the riverbed is filled with sand, gravels and small rocks on its lower and flatter part and with bigger blocks (pebbles and boulders) on its higher and steeper part. Locally, the stream is very narrow and almost blocked by loose material (rocks and trees). These debris flows would be channelled through El Volcan and El Nubes quebradas, into the Rio La Tablazon and finally to the low part of watershed of Rio Dipilto.

2.2.3 Seismicity

Dipilto municipality has been strongly deformed during the different phases of its geological evolution. Due to the presence of the system of faults, oriented NW-SE, the zone is classified as having medium seismicity (*see figures 5 and 6*). Several seismic stations setup by INETER continually record the seismicity of the area. Historical data show that recorded earthquakes are superficial (epicenter located 4-5 km deep) and with a moderate magnitude (3-4 on the Richter scale). During one of the strongest earthquakes (magnitude 3.9, recorded on the 21st of may 1997), several buildings were damaged. According to Keefer (1984), the smallest earthquakes likely to cause landslides are about magnitude 4, which is close to what has been recorded in Dipilto area. Most of these landslides are rock falls, rock slides and disrupted soil slides (soil which comes from steep slopes, travels at high speed and forms deposits at or near the bases of slopes) and are initiated with particular meteorological conditions. We can therefore think that a moderate earthquake happening after and/or during important rainfall could initiate superficial movements and/or flows therefore this hazard has to be considered.

Figure 5: Zone of seismic hazard in Nicaragua (INETER, 2001).

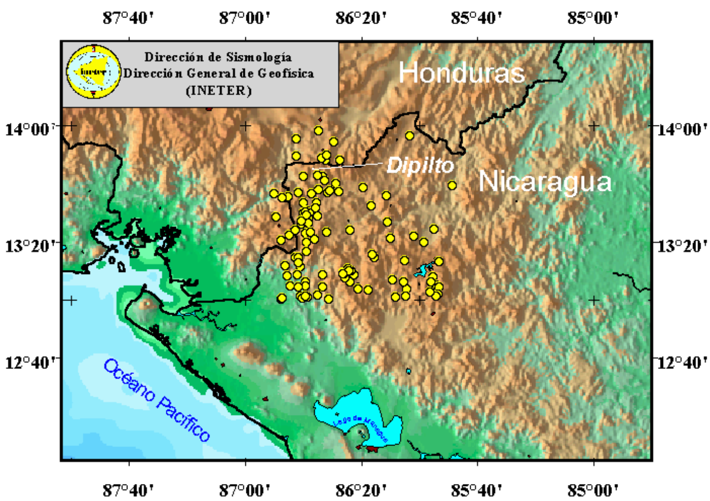


Figure 6: Seismicity of Nueva Segovia department (INETER, 2001)

2.3 Hazard monitoring

In the present section, I will describe the methodology used to design and install the monitoring system of the different compartments composing the unstable mass of Cerro El Volcan Viejo. On a first place, we will concentrate only in meteorological and geodesic monitoring (see details of organisation of the work in *Annexe 1*). Eventual utilisation of other methods will be discussed at the end. The preparation of the field work consisted of the preliminary visit on site, the inventory of the working material and the organisation of the field work.

2.3.1 Preparation of the field work

2.3.1.1 Preliminary visit

On the 23rd of August, Miriam Downs (COSUDE), Olivier Lateltin (Head of the section 'Geologic Risks' of the Swiss Federal Office for Water and Geology) and I drove to the municipalities of Dipilto (Nueva Segovia department) and La Trinidad (Esteli department) to determine which area should be studied. In Dipilto, two sites subject to large mass movements were visited. Firstly the complex landslide at Cerro El Volcan Viejo, and secondly asentamiento San Agustin which is subject to rock falls and landslides and where the municipality plans the construction of 200 houses. In La Trinidad a hospital and school are highly exposed to rock falls and debris flows.

After this visit, we considered that the unstable mass of El Volcan in Dipilto was more appropriate for the pilot project because of its complexity, the variety of monitoring systems required and the fact that Dipilto is one of the poorest municipalities in Nicaragua and is, therefore, a priority zone.

2.3.1.2 Inventory of working material

Back at the office, we tried to collect all information we could find about the area and previous studies.

- **Maps**

The most accessible map is the topographic map produced by INETER at a 1:50,000 scale. The studied area is covered by two maps; in the west by "Dipilto 2857-II" and in the east by "San Fernando 2957-III" These maps are from the Region I, Departamento de Nueva Segovia series. These were compiled in 1963 and updated in 1989 to include the levees of 1960, 1978, 1981 and 1988. Both were produced BEFORE the occurrence of Hurricane Mitch in 1998 and are therefore NOT up to date. We observed that several roads and trails no longer exist and that several new ones have been created. Furthermore, according to the local population, some locations are not correct, which initially caused some confusion.

The maps use the UTM projection and the Nor-American Central datum from 1927, **NAD27-Central**.

Important Remarks In our future descriptions, we will use the real locations (*see figure 7*):
* La Tablazon on the map is, in reality, Las Bromas,
* El Naranjo on the map is, in reality, La Tablazon.

Figure 7: Correction of names for two locations in our studied area.

Spatial maps (number 2857 and 2957) at 1:100,000 scale exist. These are produced by the 'Servicio Cartografia' of INETER department of Geodesy (contact Mr. Noel Ramirez). These are available on CD's but are expensive (about 50$US each) and were produced in 1997, BEFORE Mitch. After inspecting these we decided not to use them as they do not present any more information than the paper topographic maps.

- **Aerial photos**

Very few aerial photos are available. The only ones found at INETER's 'Archivo Tecnico' are from 1981, at a 1:40,000 scale. Furthermore, they cover an area too far south of our studied area to be used efficiently (our zone is very close to the border with Honduras and it was not possible to survey it in 1981). However, here is an example of one aerial photo (*see photo 12*).

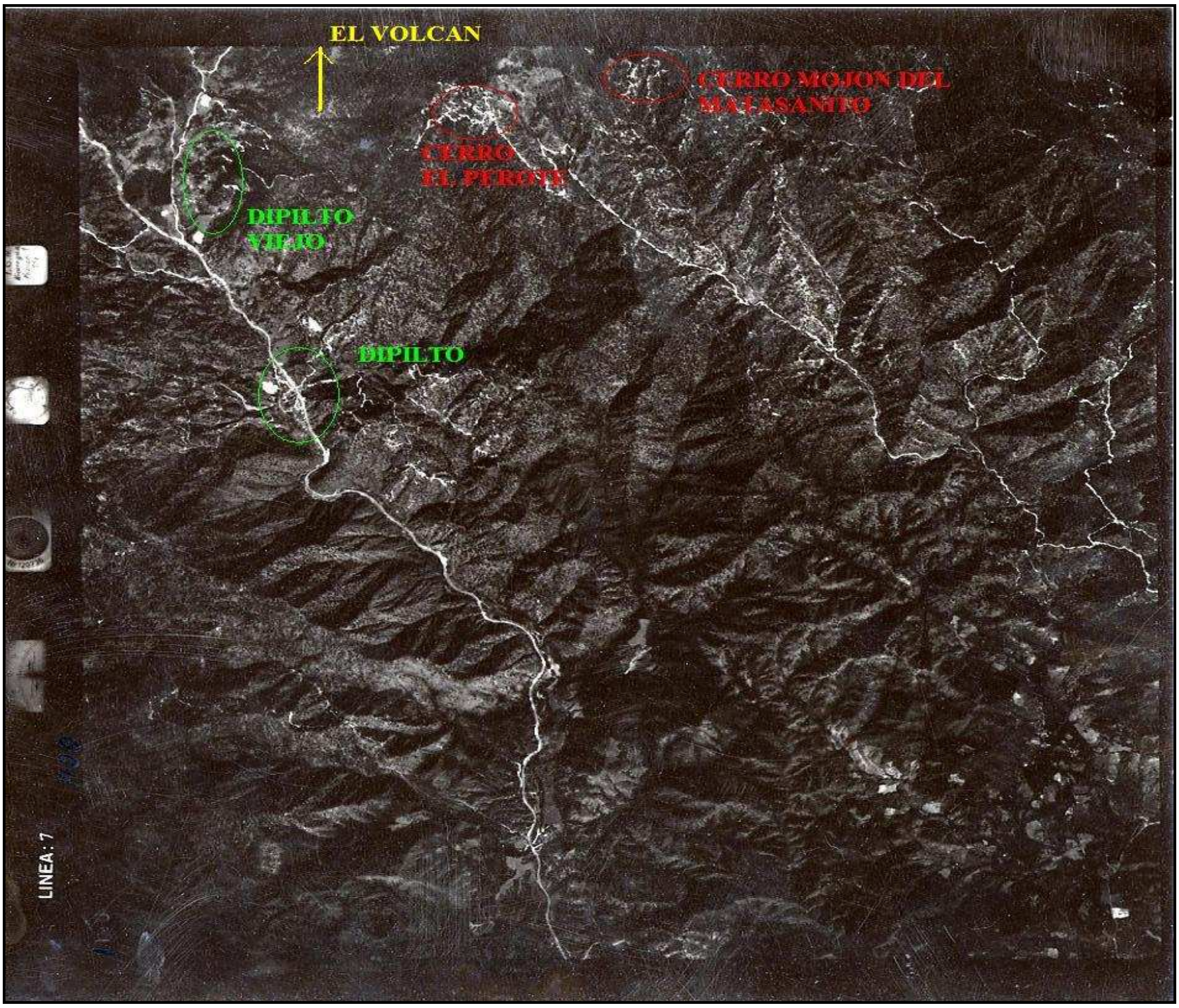


Photo 12: Aerial photo of Dipilto area (scale 1:40,000; 1981).

The USGS (United States Geological Survey) produced many aerial photos after the Hurricane. However these are all too far to the south or west of Dipilto to be of use.

- **Previous studies**

As stated earlier, two main studies exist: the first one was produced by the 'Landslides' section of the department of geophysics at INETER (Devoli et al., 2000); the second in 2002 by COSUDE, SNPMAD/PNUDD, under the ALARN project. This analysed all natural risks in the municipality and made proposals for disaster reductions (COSUDE, 2002).

2.3.2 Installation of meteorological instrumentations

2.3.2.1 Goals

It's essential to get long-term reliable data from the two meteorological stations in the Cooperative and La Tablazon. By correlating daily, weekly and monthly data with mass movements, it will be possible to assess what are the conditions which trigger landslides and debris flows and what are the threshold values. Return periods of the rains should be integrated.

2.3.2.2 Instrumentation

Meteorologists from INETER present for the setup (Mr. Saul Flores, Luis Oliva and Mauricio Rosales Rosales) recommended the installation of two pluviometers and one pluviograph for this project.

2.3.2.3 Type of information

- **Monthly total precipitation**

The pluviometer (*see photo 13*) collects the rain in a graded tube. Every day the total precipitation (in mm) is recorded manually. At the end each month, we calculate the total rain precipitation (in mm) and determine the number of days with and without rain: This will help to detect the 'at risk' months (in particular the wettest ones).

Photo 13: Pluviometer in El Volcan cooperative and myself.

- **Rain intensity**

A pluviograph will give a more complete and precise set of information (*see photo 14*). This is recorded automatically (on paper) and indicates the intensity of the precipitation (measured in mm/unit of time) by showing when the rain started and stopped and how much rain fell during this period

Photo 14: Detail of the pluviograph setup in El Volcan cooperative.
Below the paper, is the needle which records the amount of rainfall collected in the tube as a function of the time.

2.3.2.4 Selection of the sites

The first site selected was the Cooperative in El Volcan where we installed a pluviograph (*see photo 15*) and pluviometer. Here, there is a permanent settlement of about 20 people and it is directly affected by any landslides and/or debris flow. The hacienda was partially destroyed during Hurricane Mitch in 1998. The people feel very concerned and are keen on helping us. According to the locals (and verified by us during the field work), this site receives more rain than Dipilto and areas located further down. This is due to its location surrounded by high summits. Clouds get stopped by these high summits and discharge the rain.

There are already three meteorological stations in the area, in Las Planos (next to Las Manos), La Laguna (Dipilto Nuevo) and Ocotal. The other pluviometer was setup, away from the unstable zone, in La Tablazon approximately 3km west from the Cooperative (*see photo 16*). Added to the existing stations, data interpolation will be more accurate and information about the behaviour of the studied zone more precise. Below are the coordinates of the stations in Latitude/Longitude and UTM (datum NAD27-Central).

Position	Code	Coordinates in degrees		UTM Coordinates		Altitude in m
		North	*West*	*Northing*	*Easting*	
Cooperative	METEO1	N 13.7505246	W 086.4951784	1520.193	554.575	930
La Tablazon	METEO2	N 13.7599975	W 086.5163192	1521.236	552.287	1240

Photo 15: *Pluviograph in El Volcan Cooperative (surrounded by Saul Flores and Miriam Down).*

Photo 16: *Pluviometer in La Tablazon.*

2.3.2.5 Construction

The instruments were simply cemented into the ground to insure their stability. A protective barrier was erected around the instruments at the cooperative to prevent interference from children and animals. These barriers were installed by the owner of the cooperative and consisted of a wire mesh fence supported by wooden posts (*see photo 18*). It was not necessary to install a barrier in La Tablazon (*see photo 16*).

Photo 17: *Construction and setup of the meteorological station at the Cooperative.*

2.3.2.6 Tasks

Information for both instruments is retrieved at 7am each morning. In the case of the pluviometer somebody records on paper the height of water collected in the instrument (in mm) over the previous 24 hours (*see photo 18*). The pluviograph creates of a graph on paper indicating the intensity of precipitation for 24h, from 7am one day to 7am the next. This graph has to be changed daily at 7am. Every Monday the instrument is reinitialised for the week by turning a key 8 times in clockwise direction.

Photo 18: *Every-Morning task for Don Guillermo Montenegro and his children (at 7am).*

2.3.2.7 Training

The owners of the land in La Tablazon and El Volcan Cooperative will be in charge of the daily maintenance and to transmit the information to INETER. They have been trained to use each instrument by someone from INETER. In addition at the cooperative, two other people have also been trained: José Ramon Marchena from the civil defence and Don Antonio Montenegro. This will insure the continuity of the observations if the owner is unable to (*see photos 19 and 20*).

Photo 19: The way to fill up the observations sheets (with Don Antonio Montenegro, José Ramon Marchena and I).

Photo 20: Demonstration of the functioning of the pluviograph. All the team is present!

When I left, no radio was installed in the stations. Their setup is important in order to insure Real time transmission, regular quality control of the data and as warning instrument.

2.3.2.8 Interpretation of the data

Rainfall-induced landslides and debris flows are triggered under different conditions of precipitation: shallow slides and debris flows mainly occur under intense and short rains (minutes or few hours) after a preceding period of rains of smaller intensity while deep-seated landslides correspond generally to less intense but longer precipitation (in days or weeks). In general, it's considered that rainfall of about 1mm/min during several minutes following a period of rains of larger duration and lower intensity is enough to trigger debris flows. More than 125mm of accumulated rain in a month can be considered as a potential threat, while more than 250mm of rain is very dangerous (Mora and Vahrson, 1994).

When data will be available, they could be analysed as described by Kanji et al. (2003) who plotted accumulated rain against respective time causing debris flows and landslides. He determined a) a **triggering line** which defines the limit between rainfalls capable of inducing landslides and those that are not; b) a **generalized landslide line** showing great probability of landslides with possible occurrence of debris flows and c) a **catastrophic line** describing the highly catastrophic occurrences always developing debris flows. Determination of these lines could help to setup Early Warning systems for the population, in particular for people living in the Cooperative, located on the path of the debris flows and at the foot of a deep-seated landslide.

2.3.3 Installation of the geodesic network

The installation of meteorological stations was done by INETER department of meteorology and we just gave advices about the most adequate locations. Most of our work before and during the field work was about the design and the installation of the actual geodesic network. This is the first time that a geodesic network has been setup in Nicaragua to survey and monitor a large unstable mass.

2.3.3.1 Goals

Monitoring of a landslide with geodesic measurements is essential. The goal is to detect any displacement (vertical and horizontal) of points located on an unstable mass in relation to fixed points located in stable zones. This will give us information about the directions and velocities of the mass movements. Relating this data with meteorological data will improve our understanding of how the compartments move and the mass behaves. Ideally, the measurements should be taken automatically and in real-time, however this would be very expensive too. As this type of work is new in Nicaragua and the cost of the installation must be low, a more practical approach is to setup the network and perform survey measurements at regular intervals. Frequency of the surveys will be then discussed.

2.3.3.2 Design of the network

- **Principles**

The design of the geodesic network is based on a project done in Ecuador by PRECUPA-CSS (Cooperation Switzerland - Ecuador). It consists of three parts:

- *Primary order* network, with 3 points of reference, located in stable areas and linked to the national network.
- *Secondary order* network, with 3 points, in stable areas, from which the geodesic network of the unstable zones will be linked (basis for the monitoring). These points are visible to each monument on the unstable compartments
- The *network of the observed points*, which consists of several survey monuments in each unstable area. A total of 11 points were erected on the landslides.

Measurements will be done using a Leica SR399 differential GPS and the expected precision is 1mm. Modern differential GPS is a highly developed and accurate system and we chose to use this method rather than traditional triangulation methods. Satellite visibility was excellent with generally 8 satellites in view.

- **Code used for the designation of the points**

Survey monuments were named using the following codes:

PD- = Primary Dipilto;

SD- = Secondary Dipilto;

VD-x-y = Volcan Dipilto = for the five compartments located on the south-west flanks of Cerro El Volcan:
* x denotes the number of the compartment, from 1 to 5, from the South to the North;
* y denotes the number of the point inside each compartment, incrementing from higher to lower altitude (for parts 1, 4 and 5) or from south to the north (for part 2).

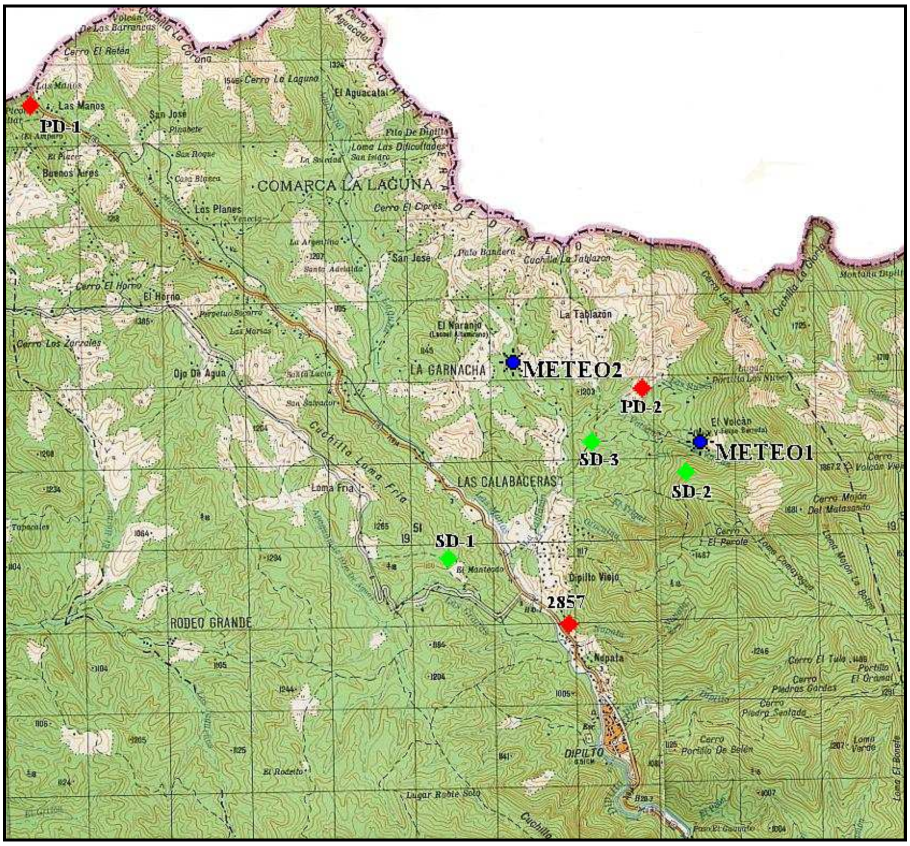
AD = Arado Dipilto = for the monument located on the south flank of Cerro Mojon de Matasanito.

METEO1 = meteorological station in The Cooperative.
METEO2 = meteorological station in La Tablazon.

- **Location of the monuments**

Primary and Secondary order

The first step was to setup the primary and secondary order networks to which further observations can be linked. To reduce uncertainties in further measurements, 3 points are used for each network. At the time of writing the coordinates obtained by the department of Geodesy of INETER were unavailable. Preliminary coordinates obtained using my own handheld GPS are given in *Annexe 2*. These networks are only necessary if measurements are done using traditional triangulations methods. There were three stations of primary order (from the national network) already installed in the area. One in Dipilto next to the main road to Las Manos, one on the top of Cerro El Volcan and one on the top of Cerro La Picona, next to Las Manos, on the Honduran border. The monument on El Volcan is inaccessible due to the presence of mines on the upper slopes and could not be used. La Picona is at the border and would cause border crossing difficulties. It is also covered by trees and therefore could not be used. Only the one in Dipilto (2857-II), next to the main road, was easily accessible. For the other two points, one was chosen next to Las Manos, on the slopes of La Picona (PD-1) and one at the small chapel (PD-2). The points of secondary order are closer to the target zone, on stable areas. The furthest is on a hill in El Manteado (SD-1) and the other two closer to the landslide, on the crest above the Cooperative and next to the school (SD-2 and SD-3 respectively). See *figure 8* below.



<u>Figure 8</u>: Localisation of the points of primary (in red lozenges) and secondary order (in green lozenges). The meteorological stations are in blue.

Tertiary order

During the campaign, we walked through each compartment in order to determine the most adequate position for the geodesic monuments. Where possible, we positioned them in the most active parts, above and below the main scarps and where the movements are the most evident. If several scarps were present, we installed several monuments in order to detect the respective movements in this compartment. The coordinates are in *Annexe 2* and the locations shown in *figure 9*. From all tertiary monuments, we can see two points of secondary networks. It's not important if we only use differential GPS for the measures but would be necessary if using traditional triangulation methods.

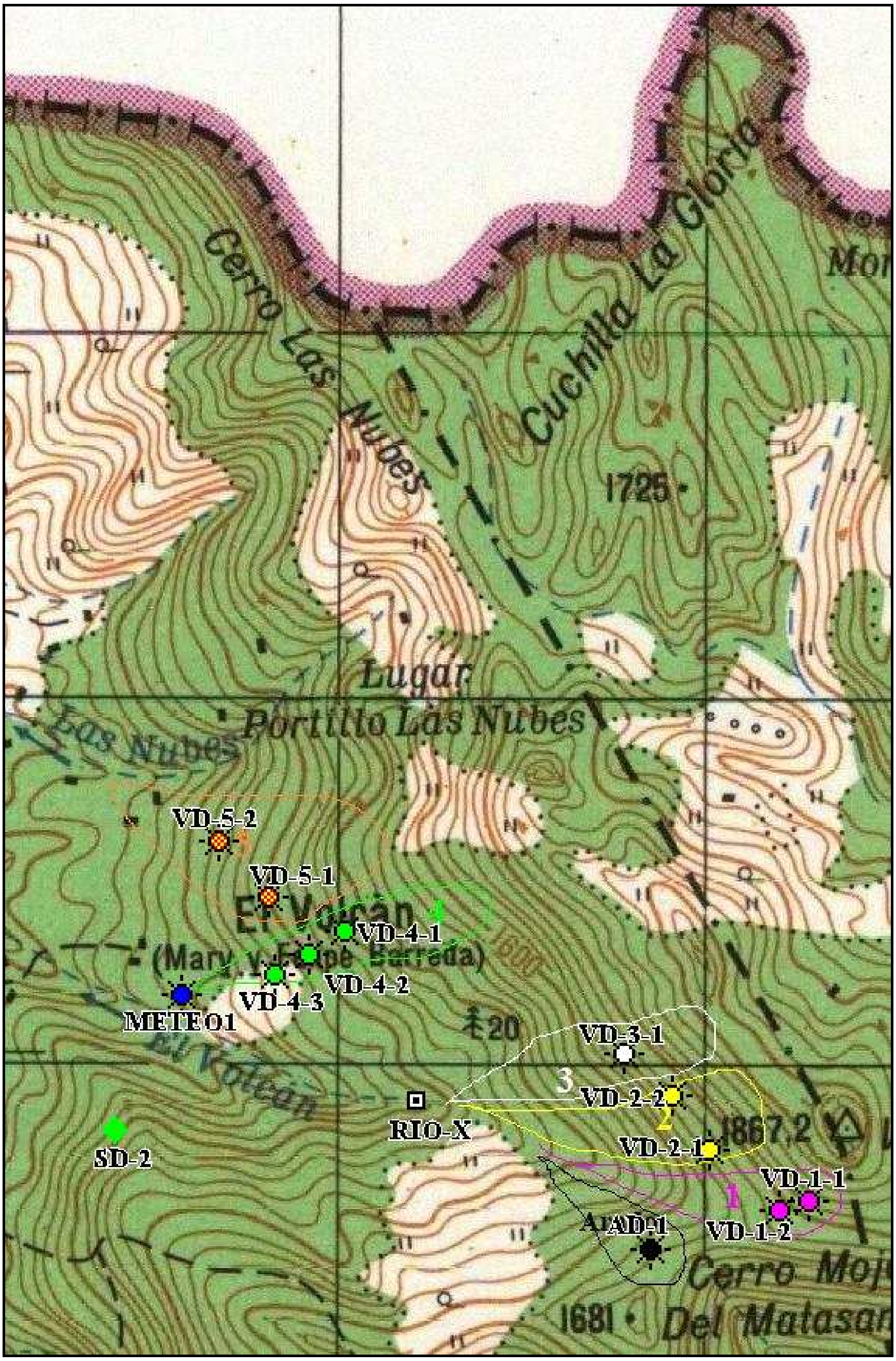


Figure 9: Location of monuments within the compartments. We used the same colours as for figure 4 to draw the compartments: Arado in black, C1in purple, C2 in yellow, C3 in white, C4 in green and C5 in orange.

Arado

There is just one monument in this compartment called AD-1 (*see photo 21*). There are two routes of accesses; one from la quebrada El Volcan along the crest to the south and one along El Torre crest, south of the cooperative.

Photo** 21: Localisation of the monument in Arado compartment above the most important scarp**. The black arrows indicate the direction of the mass movements.

Compartment 1

Two monuments (VD-1-1 and VD-1-2) have been setup, above and below the main scarp located at the pass between Cerro El Volcan Viejo and Mojon Del Matasanito (*see photo 22*). There are also movements higher up but access is prevented by the presence of land mines Many have been removed since the end of the war in 1990 but plenty were not mapped and, in addition, were remobilized because of heavy rains and landslides (especially with Mitch). Therefore, the upper zone is still not clean and it's not safe to explore.

Photo 22: Localisation of the monuments in compartment 1. ***These are called VD-1-1 (high) and VD-1-2 (lower part).*** *The black arrows indicate the direction of the mass movements.*

Compartments 2 and 3

There are three monuments, two in the second compartment and one in the third, respectively called VD-2-1, VD-2-2 and VD-3-1 (*see photo 23*). We were unable to setup more points because access is very difficult. There is no path; we have to go first from El Volcan quebrada through the corn field then up a steep path created with machetes during the field work.

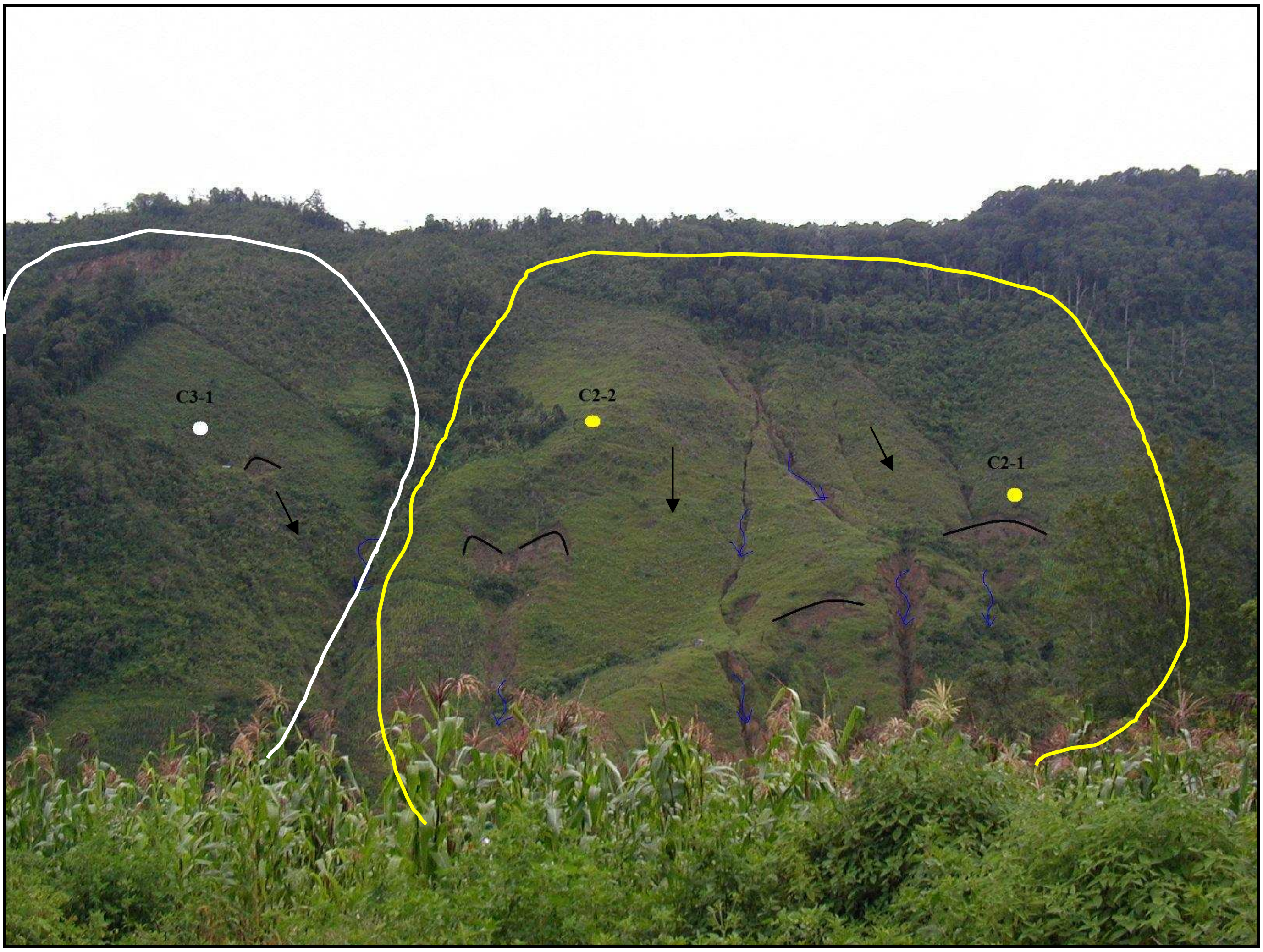


Photo 23: Localisation of the monuments in compartments 2 and 3. From right to left (south to north), we have VD-2-1, VD-2-2 and VD-3-1. The black arrows indicate the direction of the mass movements, the blue lines the direction of the debris flows.

Compartment 4

This is the most hazardous for people and plantations zone as it is located just above the cooperative. We chose to setup three monuments, ranging from 1350 to 1500m altitude, above and below the main scarps, called from top to bottom VD-4-1, VD-4-2 and VD-4-3 (*see photo 24*). There is another scarp higher up but it is inaccessible due to the presence of mines.

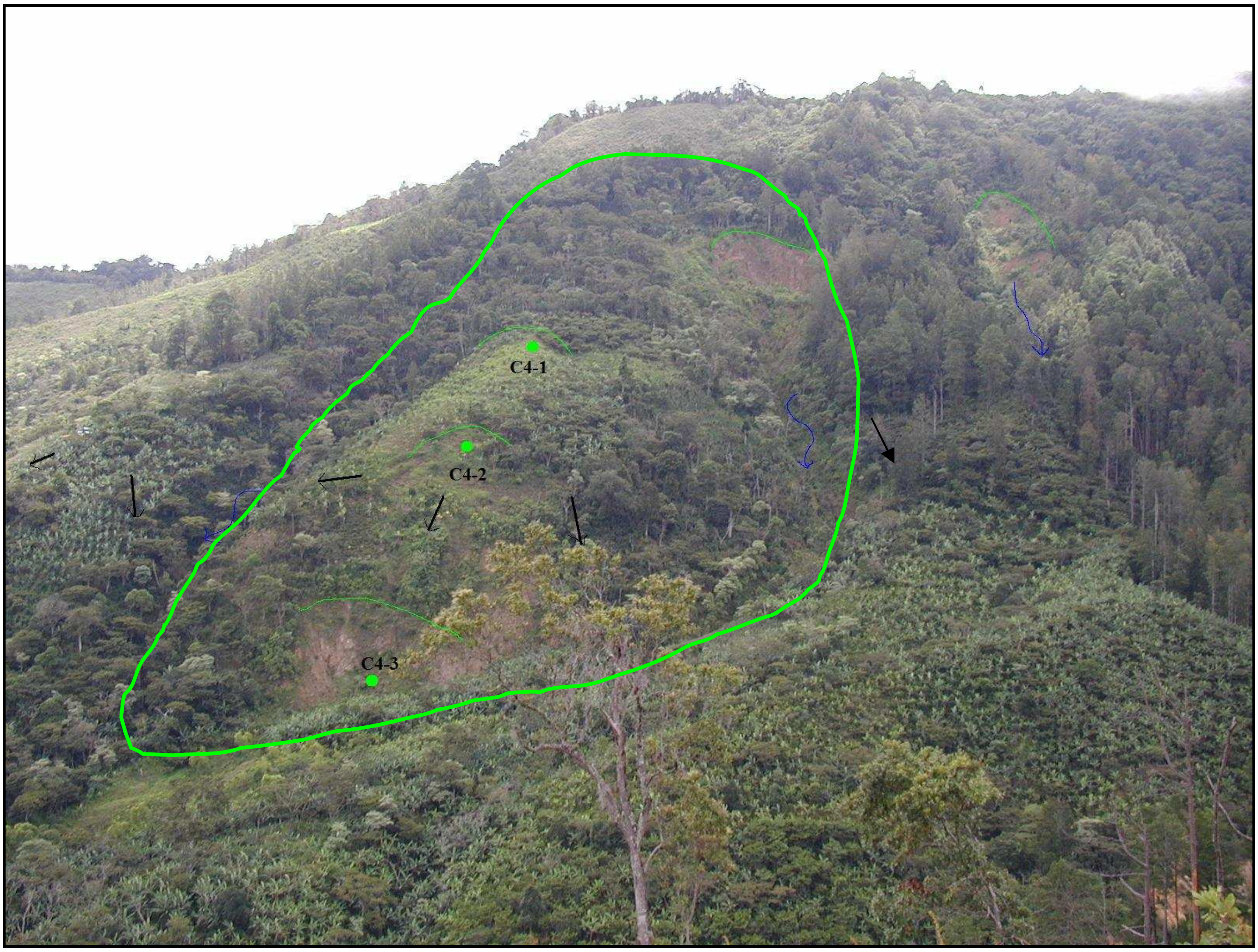


Photo 24: Location of the monuments in compartment 4. From top to bottom; VD-4-1, VD-4-2 and VD-4-3.The black arrows indicate the direction of the mass movements, the blue lines the direction of the debris flows. On the left, we have compartment 5.

Compartment 5

Two points are setup. The highest is close to a small cooperative. There are many coffee and corn plantations. It is impossible to walk further up and to the north (where there is the left scarp). Below the lower point VD-5-2, there is a succession of minor scarps which would be good to monitor. However, there is a high water content in these zones (even in dry weather) and it would be difficult to erect monuments.

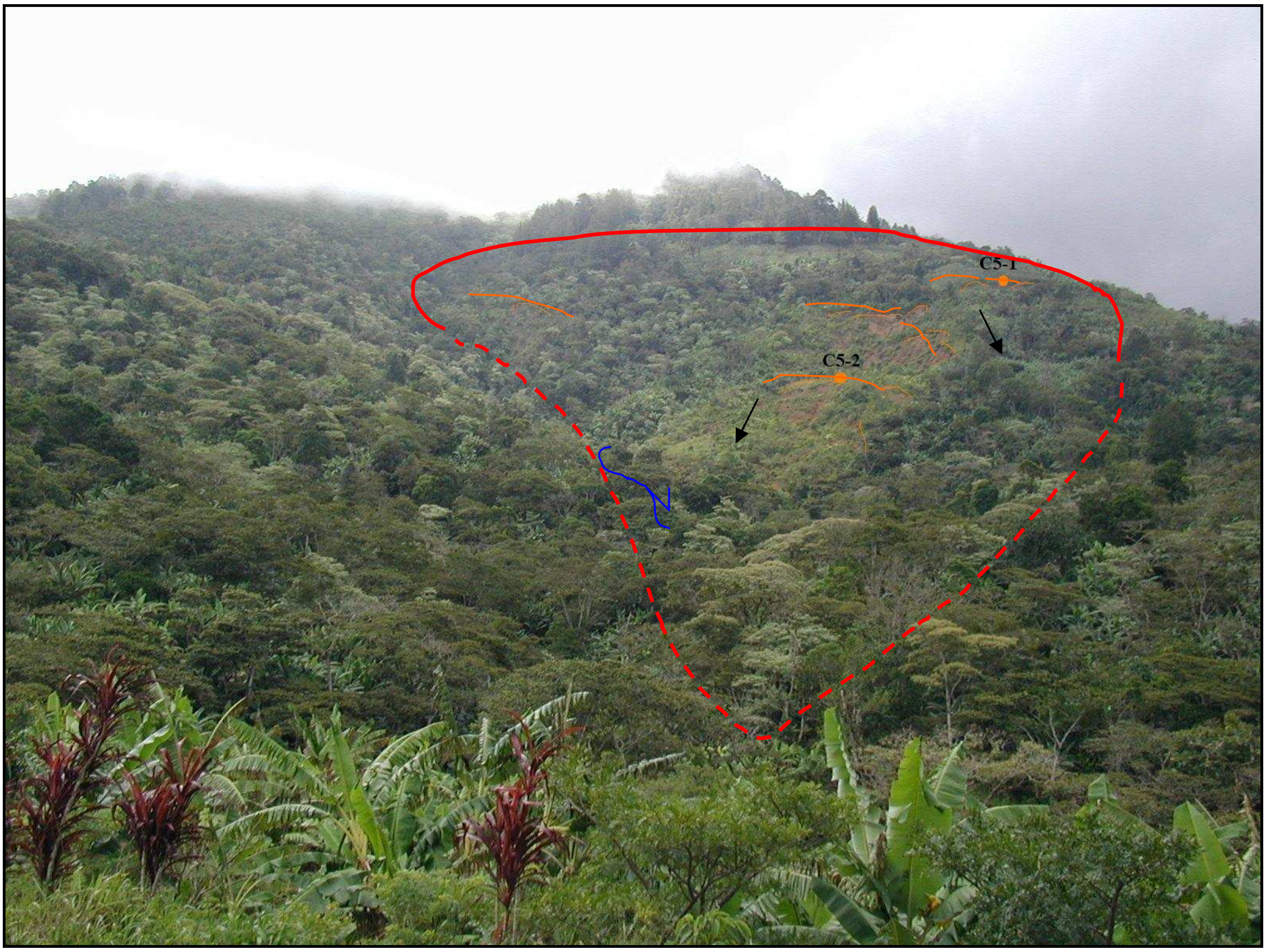


Photo 25: Location of the monuments in compartment 5. From top to bottom (south to north; VD-5-1 and VD-5-2. The black arrows indicate the direction of the mass movements, the blue line the direction of eventual debris flows.

2.3.3.3 Construction of the monuments

- **Primary and Secondary networks**

The monuments are cement blocks (surrounded by pine wood, *see photo 26*) with a 40cm by 40 cm cross section. They are painted in white and are 1m high above ground, 1m deep. In the centre of the top flat part, we added a nail to focus the instrument and, above some of them, a 15 by 15cm zinc plate to help stabilizing during the measurement (*see photo 27*). We achieved the construction of 3 monuments when the geodesic team arrived. Then, we were told that they were too big for the utilization of the tripod and it would be enough with a 30cm high monument. Therefore the secondary order point at the school is only 30cm high with 50cm cementation. The geodesic team then gave advice for the construction of the ideal monument; please refer to 'Suggestions for improvement' part further down.

Photo 26: Preparation of the construction of primary and secondary monuments.

Photo 27: Primary order monument PD-2 in the chapel (Las Bromas).
With Jose Ramon Marchena, chauffeur Don Marcial and three village children.

- **Tertiary network**

The monuments are PVC tubes (10 cm diameter), painted in white and filled with cement. These are 40cm high, with a 50cm diameter cement base. They are up to 1m deep to avoid the movement of the monument with superficial slides. A nail in the centre of the monument represents the geodesic point. For one monument, we used 1 bag of cement (about 40kg), 6 bags of sand and 40 litres of water. The biggest problem was to carry all the material up to the locations, which in general were difficult to access. In some cases, we had to use animals to carry it (*see photo 28*) but, most of the time, it was done by the men! The following pictures (*see photos 28 to 33*) show the sequence in which the monuments were built during the field work.

Photo 28: Loading of the animal at the Cooperative.

Photo 29: Digging of the hole at position VD-3 (in front geologist Gerardo Silva).

Photo 30: Little rest before cementation. From left to right, Eddis Dias, Marvin Ayestas, Rafaël Dias and Gerardo Silva.

Photo 31: End of the construction; it will dry for the night under banana leaves.

Photo 32: Monchito painting the ‘volcancito’ at thebase of the monument.

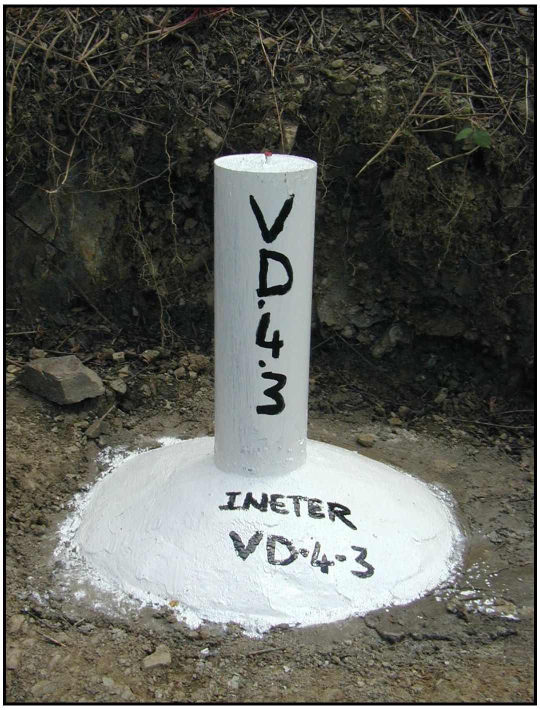


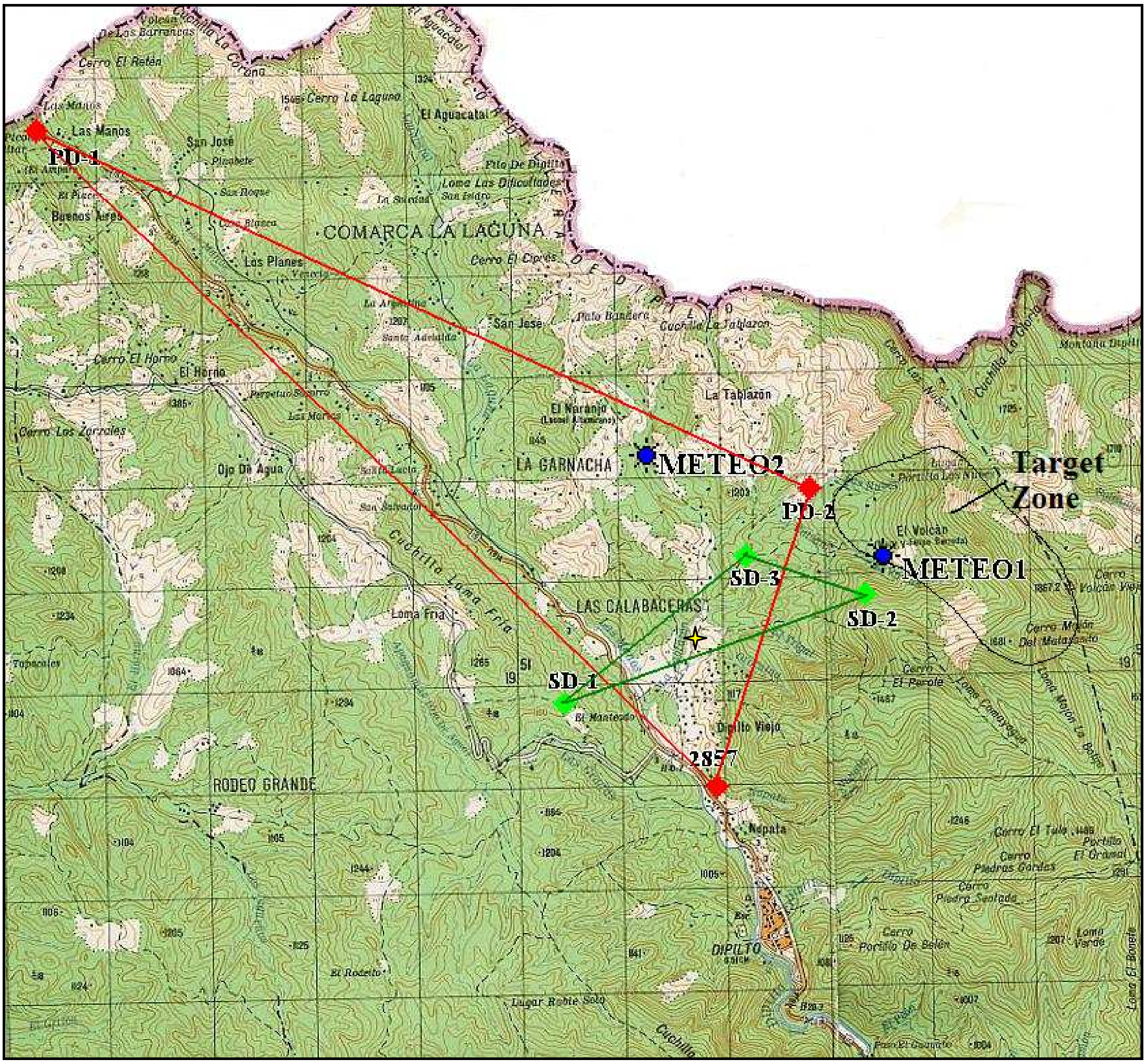
Photo 33: Final painted monument with its name and INETER mark.

2.3.3.4 Geodesic measurements

During my stay, nine triangulations were done to position accurately primary and secondary stations (*see figure 10*):

PD-1 / 2857 / SD-1	PD-1 / PD-2 / SD-1	2857 / PD-2 / SD-1
PD-1 / 2857 / SD-2	PD-1 / PD-2 / SD-2	2857 / PD-2 / SD-2
PD-1 / 2857 / SD-3	PD-1 / PD-2 / SD-3	2857 / PD-2 / SD-3

Although they spent 5 days in the field, the team didn't have time to visit the points on the landslide. The next part of the survey was planned ten days later, from the 17th to the 23rd of September 2003.



<u>Figure 10</u>: Triangulations between the stations. I have just noted for clarity the primary (in red) and secondary (in green) networks. The actual measures are always done between 2 primary stations and 1 secondary station.

Some triangulations have long and flat shapes, like PD-1/2857/SD-1. I am aware that SD-1 would have been in a better location in Las Bromas (see the yellow star on the previous map) because less far to the studied area, enabling a better triangulation and visible from all tertiary points. It could be worth trying again to put a monument after some negotiations with the owner of the land…

Below are pictures (*photos 34, 35 and 36*) of the installation and geodesic measurements at the school (SD-3) with GPS Leica SR399.

<u>Photo 34</u>: Installation of the tripod and the base of Leica instrument.

<u>Photo 35</u>: Focus over the nail located in the centre.

<u>Photo 36</u>: Start of the measurements with the GPS.

2.3.3.5 Interpretation of the data

- **Type of data collected**

The goal of geodesic measurements is to determine *vectors of displacement* in each point of the unstable masses. After two surveys, at each point, we can determine:

- Horizontal and vertical displacements (in mm or cm);
- Azimuth (in °), i.e. the direction of the movement;
- Horizontal and vertical velocities (in mm/unit of time or cm/unit of time).

After several surveys are done, we can determine the motion characteristics of each point and better understand the behaviour of the unstable masses and establish danger maps. Two parameters are used to determine the degree of dangers in an unstable zone: intensity and probability (Lateltin, 1997)

Intensity describes the level of danger for people inside or outside their houses and damages to infrastructures. There are three level of intensity: ***high*** (immediate danger inside a house and destruction of buildings), ***medium*** (danger mainly outside, important damages to infrastructure) and ***low*** (slight danger for people and partial damage to infrastructure). For landslide, intensity can be considered as low when average annual movements are inferior to 2cm, medium from 1 to a few dm a year. High intensity is often linked to strong reactivation. Values of intensities can directly be translated into danger classes. For areas where debris flows can occur, intensity depends on the width of the layer of material which can be removed. A low intensity is proposed if the layer is less than 0,5m wide, medium between 0,5 and 2m wide and high if more than 2m.

Phenomena	Low intensity	Medium intensity	High intensity
Landslide	$v < 2cm/an$	v: dm/an ($v > 2cm/an$)	$v > 0.1m/day$ for superficial landslides and displacement > 1m by event
Debris flows Potential Real	 $w < 0.5m$	 $0.5 < w < 2m$ $h < 1m$	 $w > 2m$ $h > 1m$

With v: average sliding velocity (on a long term).
w: width of the layer of material which can be removed.
h: width of debris flow deposits.

Evaluation of the **probability** of occurrence (frequency) for landslides is difficult because these are not repetitive phenomena like floods. However, active sliding phases are linked to weather conditions and probability of occurrences of special meteorological conditions. Combination of meteorological and geodetic data will enable a better estimation of these factors.

- **Frequency of the measurements**

Ideally, geodesic measurements should be done *every month* and after special events, like *heavy rainfalls*, the *rainy season*, after unusual ground noise comes from the area, appearance of new scarps, rock falls, presence of red material in the rivers…If time is missing, we could concentrate measuring points which are suspected to move quicker every months and the other ones only 2 or 3 times a year. Better estimation will be possible at the end of the first campaign.

- **Estimated time for the measures**

Differential GPS instrument have to be done for a period of 2.5 hours on the monuments of primary order, 2h on the ones of secondary order and 1h for the monuments on the unstable zones. We don't need to locate positions of primary and secondary monuments each time as these are presumed to be stable. However, they should be monitored from time to time or if movement is suspected. If we have more instruments, time will be naturally reduced. I would have thought that measurements of the position of tertiary monuments can be done in **maximum 5 days**. With three GPS, INETER staff spent 5 days locating points from the primary and secondary order. They estimate they will need another 10 days to finish the measurements. This part is then still on the go.

I haven't seen how the positioning of the unstable points was made in the field so it's difficult for me to give more precise estimation. The time spent is well over our first estimations. It would be good to review the method used with the geodetic team to make sure there is no confusion (why have systematic triangulations of primary and secondary networks been done if using differential GPS?) or duplication of measures.

2.3.4 Suggestions for improvement of hazard assessment

The previous parts describe the preparation and organisation of the field work as well as the actual installation of the monitoring system during the field work. The third part consists of providing advice and suggestions for further monitoring, improvement and replication of the experience.

2.3.4.1 Advice for further monitoring in the zone

- **Other methods**

Other type of devices exists to monitor landslides; piezometers, extensometers, inclinometers and geophysical methods. The choice of the methods depends on:

- type of movements present (creep, sliding, falls);
- size of the sliding mass;
- accessibility (steep, flat, wooded, free) and location of measurement points (subsurface or surface);
- magnitude of expected movement and degree of endangerment;
- difficulty and cost of installation.

Extensometers; These would be useful in areas where we have the most active scarps, like in *Arado, compartments 1, 4 and 5*. Most extensometers proposed by geotechnical suppliers (see list in Annexe 6) are too expensive and complicated to be setup in Dipilto. Engineer Christophe Bonnard, from EPFL (Ecole Polytechnique Fédérale de Lausanne) suggested using rudimentary extensometer made from a line and a bicycle wheel. It's better to use a line not sensible to variations of temperature and humidity but one in nylon is sufficient. The principle is to measure the movement of a mobile point located next to a scarp, where the extremity of the line is, in relation to a fixed point. At this last point, a bicycle wheel is fixed in a vertical plan corresponding to the direction to the movement. Axis of rotation has to be perfectly stable! The line is passing through this wheel and is maintained by a 5kg weight to avoid the effects of the wind on the line. When the mobile point moves, it takes the line with it and the wheel turns. Numbers can be written down on the spokes of the wheel so we can see the position of the spoke in comparison with a reference line. The frequency of the measures depends on the speed of the movement and will be more frequent in case of bad weather or unusual behaviour. The precision can be up to 1mm.

Piezometers; in *compartment 5*, the area below monument VD-5-2, is saturated with water. We could therefore think of the setup of piezometers. One could be installed in area relatively unexposed to major flows. According to Mr Bonnard, the risk is to measure water levels lower than the actual pressures in the area of the sliding plane. An important thing is to check frequently, a continuous record being ideal. Prices are variables as well.

Geophysical methods; Once the movements better understood, we should think of using geophysical methods in particular electric and electromagnetic methods to determine depth of the sliding plane of the landslide. We could then have a better estimation of the volume of the masses. Results are normally very good. INETER department of geophysics could be given responsibility and purchase of instruments have to be considered (check on the Internet for principles of the methods and ask geophysicists).

Inclinometers; I don't think that setup of inclinometers has to be considered because their installation is difficult (with drills, in a borehole) and they are very expensive.

A good reference is John Dunnicliff's book from 1988: "Geotechnical instrumentation for monitoring field performance". John Wiley & Sons Inc., New York, 577p.

- **Mapping**

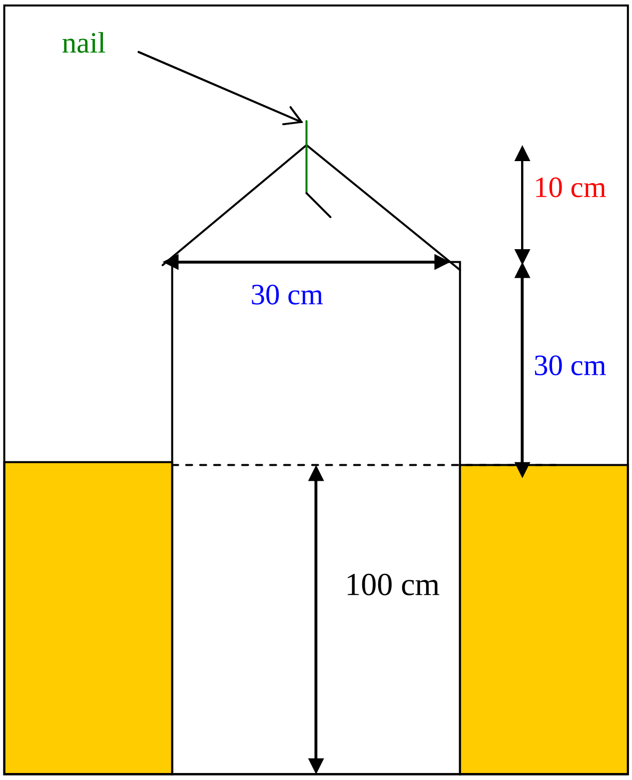
It's not accurate enough to have a **topographic map** at 1/50,000 scale. INETER department of geodesy has should be required to map all the target zones at a 1/10,000 scale. If an aerial survey is planned over the area, one should not forget to ask for **aerial photos**.

2.3.4.2 Replication of the experience

The pilot project in Dipilto has just started so the following suggestions won't be complete. These are the first remarks and critics we have about the first phase of the project and should help for replication of the experience. They mainly concern the construction of the monuments and organisation of the work.

- **Amount of material**

We used more material than we thought, making the organization more difficult and increasing the initial cost (see details of purchases and payments in *Annexe 3*). I don't think we can use less material for the construction of monuments on the *unstable zones*; otherwise we may record movements which are more superficial than deep. It would be a shame as well to build things not able to resist time. However, we can use less material for the *primary and secondary order networks*; by decreasing the height of the monuments this should cut the amount of cement, sand and water required which corresponds to a significant reduction in handling effort. According to people from department of geodesy, the ideal monument is smaller, with a pyramid shape at the top with a nail in its apex as in the diagram below. They suggested that it was enough with only a 50 cm deep monument and that's how the one at the school was built. However, we should maintain 1m deep basis as the monuments could be affected, on a long term, by superficial movements, erosion, or unwanted shocks!



- **Transport of material**

The most difficult and time-consuming activity was not the construction of the monuments but transport of the material to the actual location, in particular for the monuments located on unstable zones. For each of them, we had to use 1 bag of cement (42kg), 6 bags of sand and 40 l of water. As we were working compartment by compartment, we had to carry material for the construction of several monuments through the small, steep and slippery paths. Therefore it's important to work with fit people able to carry large weight and knowing very well the working area. In our case, the work team, composed by four campesinos, has just been amazing and perfect to work with. COSUDE vehicle used during the field work was inappropriate and difficult to drive: it was too low and didn't have tyres adapted to rough muddy roads. The height cannot be changed only the tyres. Once back in Managua, these have been changed and it should be OK from now on.

2.4 Description of the elements at risk

In comparison with some other cases, one could consider there are not many elements at risk as the area is scarcely populated and rural. Directly in Cerro El Volcan area, the main elements at risk are the Cooperative where about 20 people live, a small farm north of the cooperative (compartment 5), coffee plants, fruit and vegetable cultures. Otherwise, nobody lives permanently on the slopes of El Volcan and the houses we can see are only used for seasonal period. There are no important towns, lifelines, industries or other vital infrastructures like in La Trinidad for example where a school and hospital where located on debris flows trajectory.

2.5 Vulnerability assessment

Vulnerability is “a set of conditions and processes resulting from physical, social, economical and environmental factors, which increase the susceptibility of a community to the impact of hazards” (United Nations, 2002). The present analysis is mainly based on the report ‘Análisis de riesgos naturales y Propuesta de Plan Municipal de Reducción de Desastres, República de Nicaragua, Departamento de Nueva Segovia, Municipio de Dipilto’ written by COSUDE (2002) but I will add elements coming from my field experience. Vulnerable conditions identified in Dipilto municipality are physical, structural, environmental, geological, socio-economical and institutional.

2.5.1 Physical vulnerability

Dipilto municipality was one of the areas of Nicaragua more affected by Hurricane Mitch. Its physical vulnerability is **very high** due to steep slopes, sandy soils which are easily eroded and over-used, and non favourable geological and climatic factors (such as geological faulting and high precipitation). According to a national study published in 2001 (*Programa Socioambiental y de Desarrollo Forestal (POSAF)*, Rio Dipilto is the most vulnerable and destabilized watershed in the country. The consequences are that the territory suffers from regular and important landslides and flooding which may affect the population of Dipilto directly but also that of Ocotal located downstream. These have the potential to seriously damage infrastructure (bridges and Pan-American Highway), cultures and buildings.

2.5.2 Structural vulnerability

Structural vulnerability is **high**: most of the houses in the area are made of adobe material or wood without structural reinforcements (such as steel or even layers of clay). These structures are highly vulnerable in periods of intense and prolonged precipitation because the material deteriorates gradually until it collapses. Some roofs are constructed of heavy materials, which increase the load on the structures making them more vulnerable to earthquakes as well. These roofs represent an extremely dangerous hazard if they were to collapse. For buildings made of concrete, the quality is low due to the high cost of the materials: we were informed that, in Dipilto, people use one bag of cement for 6 to 8 bags of sand, to reduce the cost. However one bag of cement for three of sand is the rule in Managua! The national codes for construction are not applied and there is no regulation or quality control for building activities. Eventual measures to reduce this vulnerability have been slowed down since Mitch because priorities have been given to reconstruction of infrastructure (bridges, roads) and shelters. For example, the Pan American highway, now in very good condition, was cut for weeks after the Hurricane. New bridges are numerous along the road. Most of the local people who worked with us for the construction of the survey monuments had their houses destroyed and were relocated.

2.5.3 Environmental vulnerability

The municipality has **high** environmental vulnerability: the slopes are steep and have been mostly deforested which has lead to much erosion. There are no plans for reforestation and more appropriate use of the soils. The north slopes of the Cooperative, located between compartments 4 and 5, are mainly used for coffee and corn plantations. To be able to access and work on them, people had to create many paths but slopes are now cut and we noticed that soil is moving even without precipitation. Other factors which increase the vulnerability are quality of water, anarchic urbanization and lack of maintenance of infrastructures. Water for daily consumption comes from the local streams and rivers. However, they pass through settlements, coffee plantations and small industries and are contaminated by bacteria and chemicals. Water is therefore a limited resource both in quality and quantity.

2.5.4 Geological vulnerability

Geological vulnerability is **high** due to the presence of many fractures and the physical, chemical and mineralogical characteristics of the rocks, which are of three types:

- Metamorphic (Palaeozoic - Mesozoic age), the oldest in Nicaragua. They constitute clayey soils very unstable because of their stratification, fracturation and alteration. They are very susceptible to large amplitude landslides, debris flows and even rock falls. These are more present in the lowest part of our target area.
- Intrusive (Mesozoic – Cenozoic age), mainly granitoide. These are mainly meteorized in zones intensively fractured with a NNE-NE orientation and are very susceptible to erosion and debris flows.
- Alluvial and/or residual deposits (Quaternary age) which combine tectonic and meteorization processes. These soils are generally composed by residual material coming from the granitic rocks and are very susceptible to erosion and debris flows.

These characteristics combined with particular climatic conditions, presence of local faults and deforestation increase the vulnerability of the area to landslides, debris flows and other hazards. Very few areas in our zone can be considered stable and they can easily move or become reactivated during times of heavy rainfall.

2.5.5 Socio-economic vulnerability

Socio-economic vulnerability is **high** due to the high level of poverty and the high dependence on a limited number of crops. It appears that the average daily wage is between US$1 and US$3 a day. Local economy is based on cultivation of coffee and the exploitation of pine trees. People are highly dependant on these activities. Damage to coffee plantations, collapse of the price of coffee, fires or disease within the pine forest, would all mean economic disaster for the community. Exotic fruits and vegetables are abundant but only for local consumption and not for trade: people get only US$1 for about 80 bananas! Each week an American NGO provides foods not cultivated in the municipality such rice, oil and sugar. At the Cooperative, about 20 people of all ages come to live and work, generally for long periods (depending on the work activities available). They are provided with food and shelter but wages are very low, around 2US$ a day, sometimes less.

2.5.6 Institutional vulnerability

COSUDE concluded in its report that the population and authorities had a medium to high level of awareness of natural hazards in the municipality and I completely agree on this remark. However, vulnerability was considered as high because nothing was planned, coordinated and organised to deal with natural hazards; important organisations like Red Cross, Firemen or Civil Defence were absent. Two years later, I would say institutional vulnerability is lower and of **medium** level. Meetings are regularly organised and the municipality allowed one of its employee from the Civil Defence to work with us all the time. People from the brigade were also engaged in our pilot project and authorities were enthusiastic in helping us. On a different problem, we saw Tee shirts aiming at fighting fires wore by a few people.

After assessing different factors of vulnerability, we can therefore conclude that the vulnerability of our studied area is high. In the next part, I will try to assess the risk by combining hazards, elements at risk and vulnerability.

2.6 RISK ASSESSMENT

In the last part of this chapter, I will try to combine hazards and vulnerability assessments to produce a risk map. The map is only a raw, qualitative estimation of the risk level as I don't have any results and figures.

I estimated that deep-seated landslides, located in Arado, compartments 1, 4 and 5, are more dangerous than superficial landslides (compartments 2 and 3). Their velocity is probably comprised between 2 and 10cm/year. These zones will be attributed a medium to high danger level. The element at risk most prone to landslides and debris flows is the Cooperative. By combining preceding information, I chose to give a high risk to the area around compartment 4, medium risk to zones around Arado, compartment 1 and 4 and low risk to zones comprising compartments 2 and 3. Transition zone between compartment 3 and 4 are medium risk because scarps and deeper movements are suspected (we can see numerous scarps but there is no access) and it represents a transition between low and high risk zones. Areas are then extended to the watershed to take into account debris flow hazards.

On the map, three levels of risk are defined: high (in red), medium (in orange) and low (in yellow).

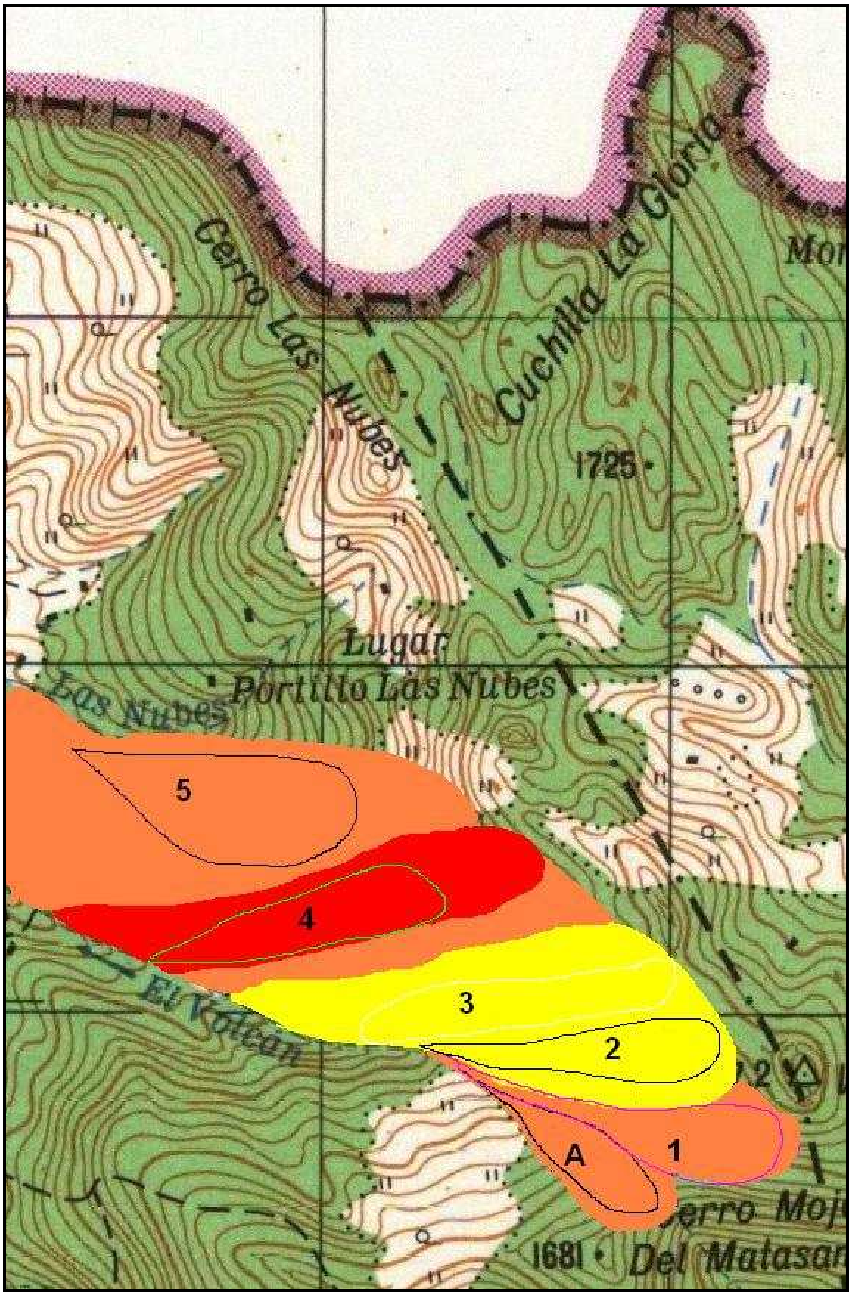


Figure 11: Attempt of risk map in Cerro El Volcan area.

3 RISK REDUCTION MEASURES IN CERRO EL VOLCAN

The previous chapter identified the hazards threatening the area; the methodology used to understand better the behaviour of the moving masses and recognize conditions which trigger mass movements; the different elements at risk and conditions of vulnerability. The present chapter will bring some elements of risk reduction measures.

Key elements of any disaster reduction strategies are (United Nations, 2002):

- **prevention** = "activities to provide outright avoidance of the adverse impact of hazards";
- **mitigation** = set of "structural and non-structural measures undertaken to limit the adverse impact of natural hazards";
- **preparedness** = "activities and measures taken in advance to ensure effective response to the impact of disasters, including the issuance of timely and effective early warnings and the temporary removal of people and property from a threatened location".

Risk can be reduced either by decreasing hazards through prevention or decreasing vulnerability by reinforcing population resilience. In Dipilto, there are no current projects to stabilise the slopes so we can't decrease the hazards. The only way to reduce the risk is to reduce the vulnerability. Setup of landslide monitoring systems is then worth it because it will help bringing **Early Warning** to the population without an enormous cost for the institutions (see Annexe 3). Even if the sums will increase with the successive campaigns of measures, it will still be reasonable and the best investment for risk reduction.

3.1 Early warning system

3.1.1 Definition

The objective of Early Warning is to empower individuals and communities, threatened by natural or similar hazards, to act in sufficient time and in an appropriate manner so as to reduce the possibility of personal injury, loss of life and damage to property, or nearby and fragile environments. Early warning can only be used in areas where the cause of natural hazards is properly understood and the measurements are performed close to the actual location, properly calibrated and validated.

Once meteorological, geodesic and seismological data will be available and combined, it will be possible to

- recognize exceptional behaviour of the moving masses;
- elaborate several scenarios of evolution;
- define different states of alert, with eventual evacuation.

Early warning contains several levels (normal, pre-warning, warning, evacuation and return to normal) which have to be defined precisely. No data are available for the time being but I will try to elaborate a few scenarios.

3.1.2 Scenarios

Danger for people is particularly high when people don't expect it. Time needed to alert people can be a way to evaluate a situation of danger. For landslides, time of alert is relatively long and eventual measures of evacuation can be taken on time. For debris flows, estimating the time is very difficult but they are triggered by particular precipitation conditions. If adequate measures are taken, there shouldn't be any bad surprises.

People living in Cerro El Volcan area are working every day for long hours in the landslide zone. They know it very well and remark straight away any changes and/or unusual events. We can define different states: normal, pre-alert, alert, evacuation and return to normal.

Normal state is when there are none (dry season) or no limited precipitation (< 30mm/month). One should be aware of any changes in the landscape like new cracks, increase of tilted fences or trees, presence of large debris and material into the river (creation of an artificial dam) or unusual noise close to the moving masses.

Pre-warning could correspond to periods of prolonged rains (for days, even weeks) with large accumulation (between 30 and 250 mm/month). People at the Cooperative are the most at risk but also the ones who can be the best informed. They should:

- Listen to radio for warning of intense rainfall and be prepared for evacuation if instructed by the civil defence.
- Be alert when intense, short bursts of rain occur, which increase risks of debris flows.
- Listen for any unusual sounds that might indicate moving debris, such as trees cracking or boulders knocking together. Falling mud or debris may precede larger landslides.
- Be alert for sudden increases or decreases in water flow and for a change from clear to muddy water. Such changes may indicate an increase of landslide activity upstream. Material may dam the river and will be release quickly in case of overtopping or failure
- Be prepared to move quickly.

Warning: occurrence of intense storm (from 1mm/min) after prolonged rains (more than 250 mm/month) and/or observance of the phenomena described in pre-warning stage.
People should evacuate as soon as such event occurs because the Cooperative is located in such a place (at the foot of a deep landslide and between 2 rivers) that it would be difficult to escape or find shelters.

Evacuation

- People should try to stay in areas generally considered safe, like areas that have not moved in the past, relatively flat-lying areas away from drastic changes in slope (school) or areas at the top of or along ridges set back from the tops of slopes (on the crest closest to the Cooperative where SD-2 geodesic monument is setup).
- If escape is too late and not possible, people could curl into a tight ball and protect their head.

Return to normal
Just after occurrence of a landslide and/or debris flows, it would important that people:

- Stay away from the slide area because of the risk of additional slides.
- Check for injured and trapped persons near the slide, without entering the direct slide area.
- Listen to local radio and authorities for the latest status of the situation.
- Watch for flooding, which may occur after a landslide or debris flow. Floods sometimes follow landslides and debris flows because they may both be started by the same event.
- Replant damaged ground as soon as possible to prevent erosion caused by loss of ground cover.

3.2 Awareness and education

Awareness of population and authorities plays an important role in disaster reduction strategy. While in Nicaragua, I had the impression that authorities and population are fully aware of the numerous hazards to which they are exposed and I was impressed by their motivation to reduce the risk. For example,

- **National level**: a national conference was held during my stay to harmonize criteria for elaboration of hazard maps. Collaboration between INETER and COSUDE was at its premise but both managed to organise efficiently the field work for the pilot project in a very short time.
- **Local level**: Dipilto municipality welcomed us very well and brought its support. Great participation of local people who looked very happy that institutions and organisations were present to setup a monitoring system. They gave us precious indications about previous events (in particular during Hurricane Mitch) which helped us to select the most appropriate sites. The sites have then been chosen in agreement with the people from the Civil Defence. They participated as well in the construction of the geodesic monuments.

It's essential that the results from the processing and interpretation of the data collected are explained to the people, in particular the triggering conditions. It's already a good thing that people are aware of the danger. The next step is therefore to let them know what to do according to the different situations explained further up.

CONCLUSION

The main objective of the CERG thesis was to present a risk analysis in an area prone to natural hazards and highly vulnerable. Nicaragua is strongly affected by natural hazards (seismic, volcanic, storms, landslides, floods…) and many zones could be studied. Due to a tight time schedule, selections had to be made. For this reason, I chose to concentrate my work on mass movement hazards in Cerro El Volcan (north of Nicaragua) because this area was severely affected by Hurricane Mitch in 1998 and still has difficulties to recover from the disaster. It's one of the poorest parts of Nicaragua and therefore a priory zone for the government and international institutions like COSUDE.

Slope of Cerro El Volcan are highly susceptible to major landslides and debris flows due to their steep topography, fragile soil, presence of underlying faults and unstable rock material. Landslides and debris flows are mainly rainfall-induced but can be earthquake-induced due to the seismicity of the region. To better assess these phenomena, forecast their occurrences and be able to take preventive and mitigation measures, the first step is to setup simple but robust monitoring systems. My field work consisted in the design and installation of a landslide monitoring system, with both meteorological and geodesic devices and is therefore integrated into a risk reduction framework. As seen earlier, the work can't stop at this stage. Acquisition, processing and interpretation of good quality data are essential, as well as the spread of the information to the population, first concerned by the occurrences of the phenomena.

In the framework of COSUDE pilot project, the next area to study should be in La Trinidad. While Dipilto is rural with low population, La Trinidad is an urban centre whose hospital and school are continuously threatened by rock falls and debris flows, which are fast and damaging phenomena. Setup of simple but efficient Early Warning devices on the top scarps would be easy to do. Field measurements would enable the modelling of trajectories of rock falls and debris flows thanks to available software.

ACKNOWLEDGMENTS

First of all, I’d like to acknowledge people from COSUDE office in Managua, in particular Ali Neumann and Barbara Rothenberger who accepted me in their organisation. Miriam Downs has been excellent to work with and I’ve been very impressed by her efficiency, motivation and enthusiasm in all the activities she’s doing for COSUDE. I’d like to thank Olivier Lateltin from BWG for having proposed this subject, bring his support and advices and trust me for the realization of the project. Christophe Bonnard from EPFL gave us very important explanations, advices and estimations for the setup of the geodesic network and I’d like to thank him particularly. I’d been very happy to work with a few people from INETER; in particular Mr Gerardo Silva whose help was precious at the beginning of the field trip…I will never forget my stay in Dipilto and its extraordinary people. It’s been a unique experience. Ramon Marchiena alias Mochito has been essential and the ‘comandó francés’ thanks him a lot. Special thanks to family Neumann-Basabe who have welcomed me so well and let me feel at home; Andy who had the patience to read the report and correct spelling mistakes. Finally, I’d like to thank all the people who participated. Hopefully, Little Anna and the other living close to Cerro El Volcan will never be scared again or hit by disastrous landslides thank to this project.

ANNEXE 1: Organisation of the work from the 28/08/03 to 10/09/03

The field work started on the 28th of august and ended the 7th of September 2003. This field work has been preceded by a visit on the 23/08/03 with Miriam Downs and Olivier Lateltin from Switzerland in order to identify the main characteristics and define the work to do.

28/08/03 *Contact with the municipality and local people – Installation of meteorological devices – Exploration of the landslide*

6am Departure Managua with Miriam Downs (COSUDE), Geraldo Silva (INETER, department of Geophysics);

10am Arrival Alcadia Dipilto – Meeting with the people responsible of the municipality and from the department of meteorology (INETER);

11am Observation of the site to decide where to install the meteorological instruments;

12am Arrival at the Cooperativa del Volcan;

1pm Start of the installation of the pluviometer and pluviograph; Walk up to El Volcan to identify compartments of the landslide and to start the geological map;

5pm Return from El Volcan; Drive to Ocotal which will be our base camp during all the field work.

29/08/03 *Exploration of the landslide – End of the installation meteorological devices – Bought of the material*

9am-4pm

- Walk to the landslide located just above the Cooperative and further north (Las Nubes); Identification of new compartments and elaboration of the geological map.
- End of the setup of meteorological devices; Training for the local people;

5pm Bought of the material for the construction of the geodesic monuments.

30/08/03 *Meeting with people from civil defence – Evaluation of the material and human resources needed – Construction of the first monument*

7am Meeting with the 4 people who will build the monuments.

8am-5pm Organisation of the future work and construction of the first monument.

31/08 - 06/09/03 *Construction of the geodesic monuments – Start of the geodesic measurements*

7am-6pm

- Bring of the material to the chosen site and construction of the monuments;
- Identification of the points for future implementation (secondary and tertiary order points);
- Verification and finalization of each monument (painting, writing of inscriptions).

02/09/03

10am Arrival of 4 people from the department of geodesy (INETER);

11am-4pm Identification of the primary order sites.

03/09 -> 06/09

7am-4pm Triangulations between primary and secondary order points. One triangulation is missing due to battery and short signal problems. No visit to the points on the unstable zones. Start again on the 10/09/03.

03/09/03

10am-4pm Installation of the second pluviometer at La Tablazon by the department of meteorology.

07/09/03 *End of the first part of the field work.*

09/09/03 *Return Managua.*

10/09 – 12/09/03 *Elaboration of the preliminary report – Financial check.*

ANNEXE 2: Coordinates of the monuments

Primary order

Position	Code	Coordinates in degrees		UTM Coordinates		Height in m
		North	*West*	*Northing*	*Easting*	
Dipilto	PD-2-II-2	N 13.7306091	W 086.5105005	1517.987	552.923	930
Las Manos	PD-1	N 13.7900181	W 086.5706317	1524.545	546.410	1240
Capilla	PD-2	N 13.7566681	W 086.5017014	1520.871	553.868	1185

Secondary order

Position	Code	Coordinates in degrees		UTM Coordinates		Height in m
		North	*West*	*Northing*	*Easting*	
El Manteado	SD-1	N 13.7382127	W 086.5240628	1518.825	551.455	1165
El Torre	SD-2	N 13.7471825	W 086.4968320	1519.823	554.397	1370
Escuela	SD-3	N 13.7508932	W 086.5075170	1520.231	553.241	1135

Tertiary order

Compartment 1

Position	Code	Coordinates in degrees		UTM Coordinates		Height in m
		North	*West*	*Northing*	*Easting*	
High	VD-1-1	N 13.7453378	W 086.4793264	1519.623	556.290	1745
Medium	VD-1-2	N 13.7450771	W 086.4800485	1519.594	556.212	1680

Compartment 2

Position	Code	Coordinates in degrees		UTM Coordinates		Height in m
		North	*West*	*Northing*	*Easting*	
South	VD-2-1	N 13.7479492	W 086.4827893	1519.760	556.018	1680
North	VD-2-2	N 13.7465819	W 086.4818419	1519.911	555.915	1650

Compartment 3

Position	Code	Coordinates in degrees		UTM Coordinates		Height in m
		North	*West*	*Northing*	*Easting*	
High	VD-3-1	N 13.7489915	W 086.4839988	1520.026	555.784	1675

Compartment 4

Position	Code	Coordinates in degrees		UTM Coordinates		Height in m
		North	*West*	*Northing*	*Easting*	
High	VD-4-1	N 13.7520533	W 086.4910590	1520.363	555.020	1500
Medium	VD-4-2	N 13.7514946	W 086.4919667	1520.301	554.922	1455
Low	VD-4-3	N 13.7510081	W 086.4928279	1520.247	554.829	1360

Compartment 5

Position	Code	Coordinates in degrees		UTM Coordinates		Height in m
		North	*West*	*Northing*	*Easting*	
High (Casa)	VD-5-1	N 13.7529163	W 086.4930088	1520.458	554.809	1450
Medium	VD-5-2	N 13.7543294	W 086.4942638	1520.614	554.673	1370

Arado

Position	Code	Coordinates in degrees		UTM Coordinates		Height in m
		North	*West*	*Northing*	*Easting*	
High	AD-1-1	N 13.7441617	W 086.4833249	1519.492	555.858	1640

ANNEXE 3: Cost of the project for the period 28/08 – 10/09/03

Material (All the prices are in $C)

Construction of the monuments

Cement	20 bags	1500.00
	1 cuchara	21.00
Sand	75 bags	1500.00
PVC tubes	6 de 4''	1090.00
Plastic bags	6 yards	90.00
Painting	7 l white,black, red	237.00
	4 pincels	70.00
	4 l gasoline	40.00
Wood	8 pieces	338.00
Small material	2 Meter	32.00
	Clavos	44.00
	Lamina de zinc	46.00
Library		85.00
Divers		124.00

Meteorology

Material		1058.40
Maya	13 m	297.50
Protection pluviometer	Guillermo Montenegro (Coop. El Volcan)	200.00

Car

Petrol	40 gallons	1220.00

TOTAL Material in $C	7992.90

People (All the prices are in $C)

José Ramon Marchena	Alcadia Dipilto / Defensa Civil	11@100 + 5@50	1350.00
Rafaël Dias	Defensa Civil	8	800.00
Eddis José Dias		7	700.00
Marvin Ayestas	Defensa Civil	8	800.00
Ruben Alberto Lopez		8	800.00
Antonio Ayestas		1	100.00
Animals		8	800.00
Antonio Montenegro		3	300.00
TOTAL People in $C			5650.00

TOTAL in $C	13642.90
TOTAL in $US	900

ANNEXE 4: List of the illustrations

ANNEXE 5 Bibliography

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United Nations, 2002 - Living with Risk: A global review of disaster reduction initiatives, Geneva.

ANNEXE 6 List of geotechnical suppliers

Extensometers, Inclinometers and Piezometers

Applied Geomechanics	www.geomechanics.com
Slope Indicator, Inc.	www.slopeindicator.com
Geokon	www.geokon.com
Phoenix Geometrix	www.phoenixgeometrix.com

Laser Ranging Devices

NovaRanger, Inc.	www.novaranger.com
Migatron Corporation	www.migatron.com

Precipitation gages

Met One Instruments	www.metone.com
Rainwise	www.rainwise.com

Data Loggers

Logic Beach	www.logicbeach.com
Data Electronics	www.dataelectronics.com

Information at www.sensorsmag.com.