Strategy for Flood Mitigation in Mocoties Basin, Merida, Venezuela, after the Torrential Event on February 11th, 2005

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Abstract

The Mocoties basin is located in the Venezuelan Andes, southwest of Merida State. It has an area of 524.4 Km², in a high mountain region with 70 % of its area having a slope of more than 60%. On February 11th, 2005, it had one the most catastrophic floods in Venezuelan history. There was an estimated discharge of 900 m³/s after a rainfall of 110 mm fell upon saturated soils. This happened between 4 pm and 1 am. 99 people were killed and 5,000 were disenfranchised. In addition 622 houses were totally destroyed, 588 were partially destroyed and 30 Km of road was severely damaged. Bridges, rural schools, crops and cars were also damaged. The public services, water supply, electricity, sewers, and telephone lines were affected. The storm increased its destructive power by moving downstream through the main river channel. This river channel is 53 Km long and descends from 3,600 meters to 320 meters above sea level. The storm took place almost simultaneously over the small lateral watersheds, which generated a lot of debris flows. The annual rainfall varies between 1,200 mm per year in the lower regions and 685 in the upper regions. The most frequent rocks are gneisses, schist, and granites in a region with a system of geologic faults and seismic activity. The Mocoties basin belongs to three municipalities. The actual population is 87,554 people, distributed mostly in three main towns and in small rural villages located in the alluvial fan and terraces. The people located in the upper regions cultivate potatoes, carrots and flowers. In the middle regions people cultivate coffee without tree shade. The forest covers 30 % of the basin. The main road which connects the towns with the rest of the country is located closely parallel to the river making it highly vulnerable. In this paper we present a summary of the damages of this event and also identify areas that are still at risk. We will propose a set of indicators that may be used to monitor the risk evolution. Also, we will propose programs as an integrated approach to a) mitigate the hydro-geomorphogic hazards by means of the reduction, retention, delay and/or diversion of the liquid and solid discharge and b) control the development of the socioeconomic activities in high risk areas.

Keywords: Flood mitigation, tropics, Mocoties, Venezuela.

Introduction

The Mocoties River basin is located in the tropical Andes, in the southwestern part of Venezuela. The coordinates are 916,000 and 940,000 N and 180,000 and 216,000 East (Fig. 1). The Mocoties is a torrential river of high mountain located in the state of Merida, specifically in the northern section of the Andes. Mocoties is the indigenous name of the settlers of this valley before the arrival of the Spanish. In this basin, on February 11th, 2005, one of the worst natural disasters in Venezuelan history happened.

The aims of our work are characterize the basin, identify the most vulnerable alluvial fans, and document the damages and sites affected by this extraordinary flood. We also propose a set of indicators to measure the effects of the recovery and prevention measures.

Methodology

We have identified the most hazardous areas by means of overlapping relevant maps of geology, slope, climate, vegetation and land use. We have used several sources to characterize the damages and access the area’s vulnerability. These include technical reports, field studies, aerial photos and newspapers. By quantifying the problems related to the flood event, we have identified the indicators that we propose to measure the evolution of the hydrology risk.
Results

**Main basin characteristic**

The Mocoties is a tropical basin of high mountain with an area of 524.4 Km². The River is called Zarzales and begins at 3,510 m in the Portachuelo’s high plateau. After seven kilometers downstream it changes its name to the Mocoties river (Fig. 2). It continues in a marked straight line, direction SW-NE, due to the control of the traces north and south of the Bocono’s faults. At 320 meters above sea level it joins with the Chama River (Hernandez and Valbuena, 2001). Its main channel is 53 Km long, getting five big torrents from the right hills slope and more than 20 small ones from the left slope, most of them with permanent discharge. The upper section has a rectangular shape and is 10 Km wide. In the lower part, the basin is wider, reaching 18 Km, and then in a narrow strip drains to the Chama river. It is an asymmetric basin. The main channel flows through the weak area produced by the Boconó fault. Seismic activity happens frequently.

The left hillslope receives more sunlight than the right, making it dryer and less vegetated. It has 170.86 Km² making it only 32.6 % of the whole basin area. The torrents are short, less than three Km, with a steep gradient, and has a high velocity and strong erosion power. The drainage pattern is rectangular. On the other hand, the right hillslope is longer, wider and higher. It has 353.54 Km² and represents 67.4 % of the total basin. The torrents of this slope are bigger with higher peak discharge. The valley formed by the alluvial fans and terraces of the Mocoties River represents 37.3 % of the total area, and it has slopes of less than 15 %.

In the right hillslope has fractured phyllite and shale that produce soils of clay textures. “In the left slope (Fig. 3) we found gneiss and granite rocks of the Pre-Cambrian, soils with sandy textures and strong infiltration. Also, schist, phyllite, and quartzite that produce soils with fine textures as loam clays. In the right hillslope, the low sector, near the river mouth is very unstable due to the fact that the sandstones, quartzite, phyllite and lutites are very fractured. There exists a delicate geological balance and high susceptibility affected by seismic activity” (Dugarte, 2002).

The basin has a rainy period from April to November. The dry season is from December to March. Nevertheless, the catastrophe of 2005 took place in February, indicative of the irregularities in the climatic pattern. The annual rainfall ranges from 1,300 mm per year, in the lower areas of the basin to 685 mm in the upper zones. That is to say, the rainfall decreases as one move upward. According to the Mocoties rainfall gradient, the basin can be divided in to 3 zones. (Fig. 4).

“The mean annual temperature in the lower part of the basin is 24.1°C. In the middle sector it is 21.9°C with very little monthly variation. In the upper part it is less than 11°C. The temperature changes greatly with the altitude” (IMPRADEM 2005).

The basin has a long tradition of settlers prior to Christopher Colon’s arrival. Previously Mocoties Indians inhabited the region. Today, three important populations and small communities exist, belonging to three municipalities. The municipality Rivas Davila, whose capital is Bailadores has a population of 18,516 people (Valbuena, 2000). The municipality Tovar, located in the central part of the basin, whose capital is Tovar has a population of 38,219. The third municipality, located in the lower part of the basin is called Pinto Salinas, whose capital is Santa Cruz and has a population of 30,819. The total population of the area is 87,554 with a mean growing
The Mocoties basin rate of 2.2 % per year. The three cities are connected by a road named “Trasandina”. It is relatively narrow, located near the river and at the foothill of the mountain. There are three threats, the flood risk by the river, the crossing of the torrents and the geomorphological risk of landslides.

The land is mainly used for three purposes. In upper zone, above 3,000 m. we find “paramo”. Its soils have very good infiltration properties. The cloud forest in the region is immediately below. Together they represent 30% of the total area of the basin. Below the forest vegetation, where the climate is more comfortable and where the slope is less steep there are potatoes, cabbage, carrot, beet, strawberries and flowers (Fig. 5).

At the basin’s lower section the principal crop is coffee. Before the flood, it was cultivated as an agroforestry system with trees that provided shade for the coffee. In the last few years the coffee has been replaced with genetic varieties of coffee that do not require shade. This is because they have a higher yield and fewer problems with the plagues, although they provide less soil protection. Tourism is an important part of the local economy.

The hazards

There are 49.07 Km$^2$; or 9.4 % of the basin area that is highly unstable with active mass movements. The unstable areas are located in the middle and lower section of the sub watersheds. They are called San Francisco and Mejia, and are in the right hillslopes of Tovar and Santa Cruz. There are a combination of steep slopes, highly fractured rocks, high precipitation, secondary faults and seismic activity.

There are landslides, debris flows and gullies in the left hillslope near the populated center of Santa Cruz. This town is near the rocky outcrops of the Association Tostós, which were created during the cretaceous period. It is important to note that these outcrops are very unstable (Fig. 6). Also, 18.5 % of the area has scour, mainly at the middle and lower part Mocoties River and its torrents (Fig. 7).

“26 % of the area has conditions very favorable to rotational and planar slides, mostly located in the right hillslope. It is a very active basin from a geologic point of view.” (Dugarte, 2002) We have identified the flood risk areas by integrating various sets of data. These include information from geological, geomorphologic, climatic, hydrological sources, and land use data and past flood reports.
The more dangerous area is located near the town of Santa Cruz, where the torrents reach the main river (Fig. 8). There is a moderate hazard level in the middle of the basin. The minor threat zone is in the headwaters of the Mocoties River, including the upper areas of the torrents. This indicates that the municipalities of Santa Cruz and Tovar are potentially the most susceptible for floods, debris and mud flows. It is very possible that the areas of hydrological threat will increase. This is due to higher overland flow, associated with new areas for coffee plantation, and the lack of trees in steep slopes. The risk may also increase due to the possibility of roads constructed without suitable drainage controls mechanisms. Climate change may also affect the rainfall pattern.
Fig. 5. Main land use and cities. Mocoties basin.

Fig. 6. Landslides near Santa Cruz.

Fig. 7. The Mocoties River at the lower reach

The damages of the flood, February 11th, 2005.

Between February 7th and 13th the Venezuelan Andes had an extraordinary amount of rain. The most intense rainfall happened on February 11th, between 4:00 pm and 1:00 am (MARNR, 2005). Official numbers do not exist on the quantity of rainfall. By indirect methods it has been estimated that about 110 mm fell in 9 hours with a return period of 50 years (Laffaille et al. 2005). The peak discharge at the mouth of the basin was estimated to be between 900 and 1,100 m$^3$/s. The most intense rainfall took place in Santa Cruz. The impact was increased by the extraordinary amount of debris that came through the Mejías torrent from the right hillslope, and the Cedros torrent (Fig. 9) from the left side of the river (Wikipedia, 2005).

Reports indicate the death of 99 people, a total loss of 500 houses and 1,504 people affected, 496 were from Santa Cruz (Fig. 10), 388 from Tovar, and 169 from Bailadores. Most of the deceased were the passengers of approximately 10 buses, who were at the bus station of Santa Cruz waiting for the end of the storm. This station was constructed on the flood area of the Mocoties River. (IMPRADEM, 2005)

The storm severely damaged the regions infrastructure. These damages included, sedimentation in the principal road, the destruction of bridges and recreation facilities, electrical and water supply damages. The economic and social functions of the area were paralyzed for several months.

The vulnerability.

Every year the magnitude of the damages increases due to the fact that many houses and public infrastructures are located in flooding areas. Many of these constructions are fragile and vulnerable. The bridges do not have the capacity to handle big floods.
The local newspaper reported a big flood on July 23rd, 1910 affecting the population of La Playa, between Tovar and Bailadores. It destroyed 14 houses and many crops. The losses were estimated to be approximately 40,000 dollars. There was no loss of human life because people were not living in flood areas.

On November 11th, 1933 there was a strong flood of the Mocoties River and the Carrizal torrent. This flood destroyed the bridge that connects San Francisco and Tovar. It also destroyed the channel of the electrical plant. It is not by chance that the historically populated central areas are located far from the rivers. The strongest flood damages of the last decades have mainly affected the recent infrastructure because it has been poorly located and the community has not undertaken appropriate prevention measures (Fig. 11) (Universidad de los Andes 2005).

A clear example of this concept is illustrated in Lafalle and Ferrer (2005) using aerial photos of Santa Cruz. In the first one, taken in 1967, it is observed that the river had a large meander. The second photo, taken in 2000, illustrates that part of the road occupies what was once part of the river (Fig. 12).
The proposed programs

The February disaster produced a serious collapse in the economic and social life of the Mocoties population and neighboring areas. Certainly, the national, regional and local government has been acting to solve the most immediate problems (Corporación de Desarrollo de los Andes, 2005). Nevertheless there exists more important problems. In order to solve these problems it is necessary to reduce the vulnerability for future events and the number of victims. It is necessary to solve the lack of safety houses and ensuring acceptable traffic flow (Weinmeister, 2000).

In order to attack these objectives, we propose to applied the following programs:

- To develop formal and informal activities to educate the population on the ways to mitigate the natural hazards.
- To promote social organization for self-protection in case of hydrology and geomorphologic hazards
- Municipal zoning of the alluvial fans and terraces on the basis of their flood risk.
- Apply an aggressive program of housing construction in places without flood risk.
- Establish a massive program for the construction of dams, closed and open dikes, for the purpose of selective retention in the high risk areas.
• Establish in each community an alarm system and contingency plans.
• Protect the headwaters with agroforestry and forestry systems.
• Monitoring and evaluating the hydrologic risk evolution. We propose that the communities of each watershed, with the help of the Municipalities and the Department of Environment initiate a semiannual monitoring using the followings indicators:
  – Number of houses and people living in high risk areas.
  – Death count due to flood events.
  – Number of vulnerable bridges with inadequate section, to high floods.
  – Number of traffic interruptions in the principal routes of the municipality.
  – Amount of monetary losses from floods and rehabilitation costs.
  – Number of hydraulic works constructed.
  – Number of alarm systems properly functioning.
  – Number of community organization with people trained in dealing with flood emergencies.

Conclusions

In the Mocoties basin has had floods since 1910 but the most critical event took place February 21th, 2005. An extraordinary rainfall of more than 100 mm in nine hours moved downstream affecting the whole basin. The growing vulnerability associated with improper localization of houses and public infrastructure at high risk has increased dramatically. Santa Cruz and its surroundings areas is the most vulnerable sector. However, due to the geologic instability, the rainfall and land use patterns, other sectors are very critical also. In order to tackle this complex problem we have proposed eight programs which should be implemented in a systematic manner with a well financed strategy supported by the national government, Department of Environment, regional and local offices and community organizations.

References


