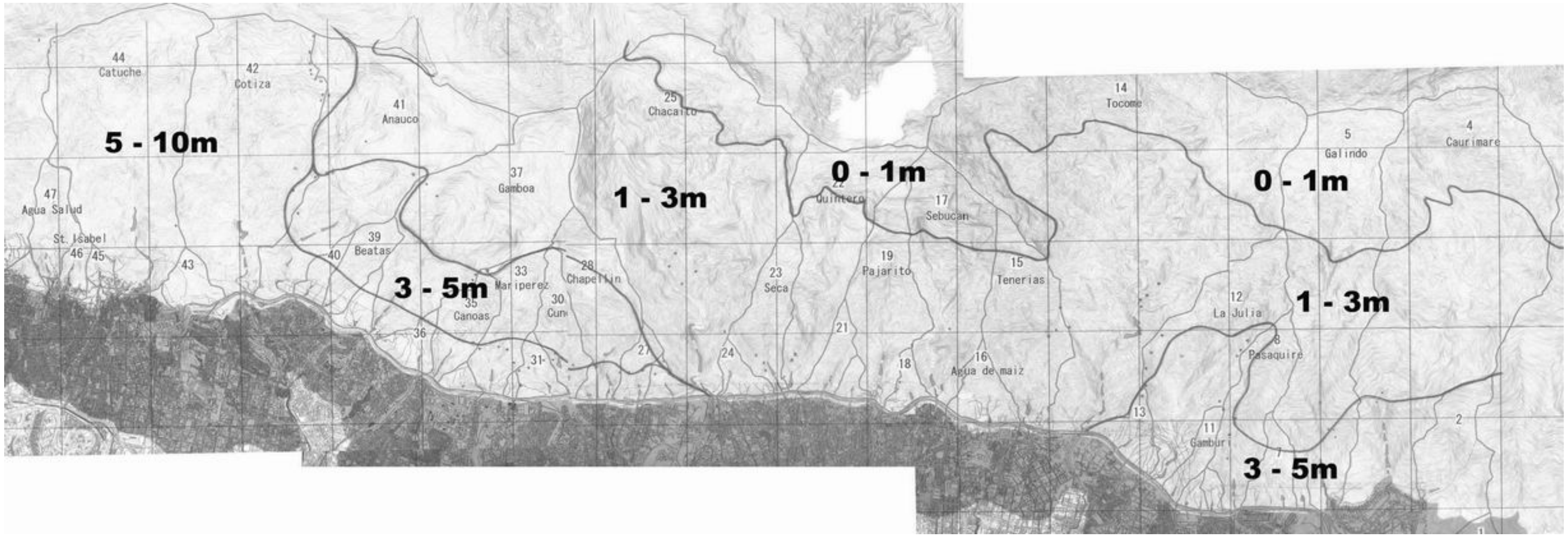


Figure S10-2.2.15 Thickness of Weathered Zone (Grade VI – IV) in Avila Mountains

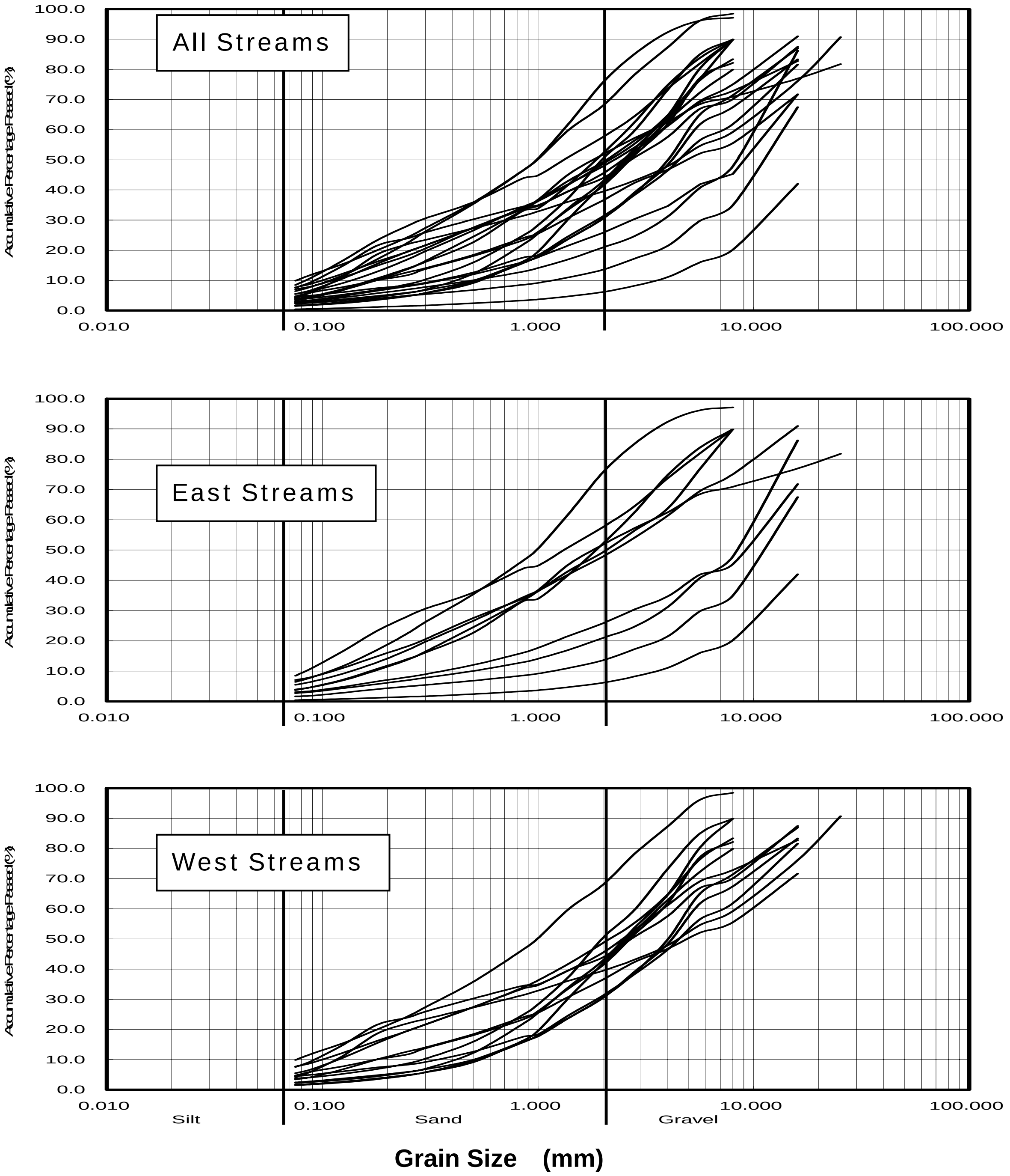


Figure S10-2.2.16 Grain Size Analysis

East Streams : Caurimare - Chacaito

West Streams : Chapellin - Catuche

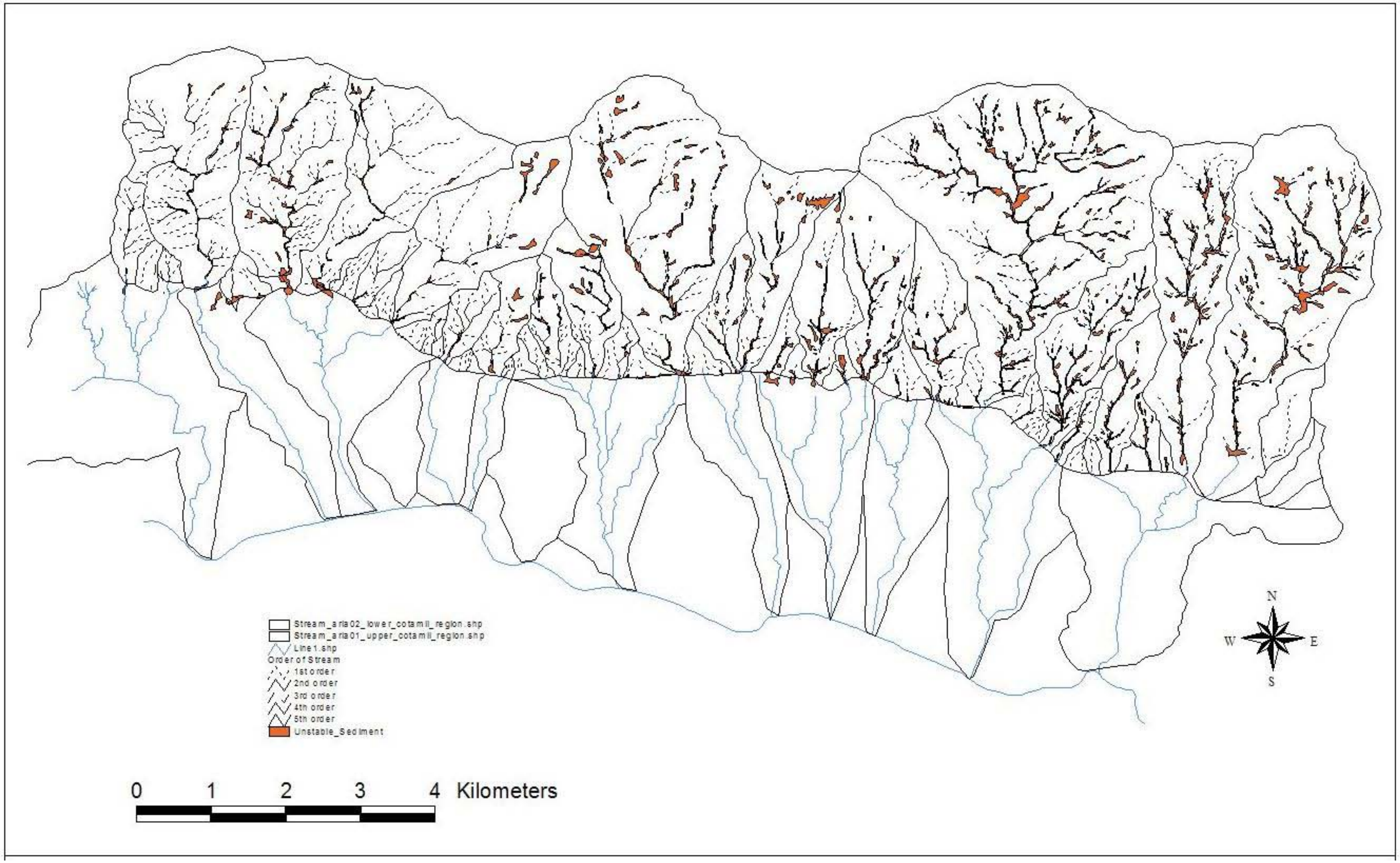
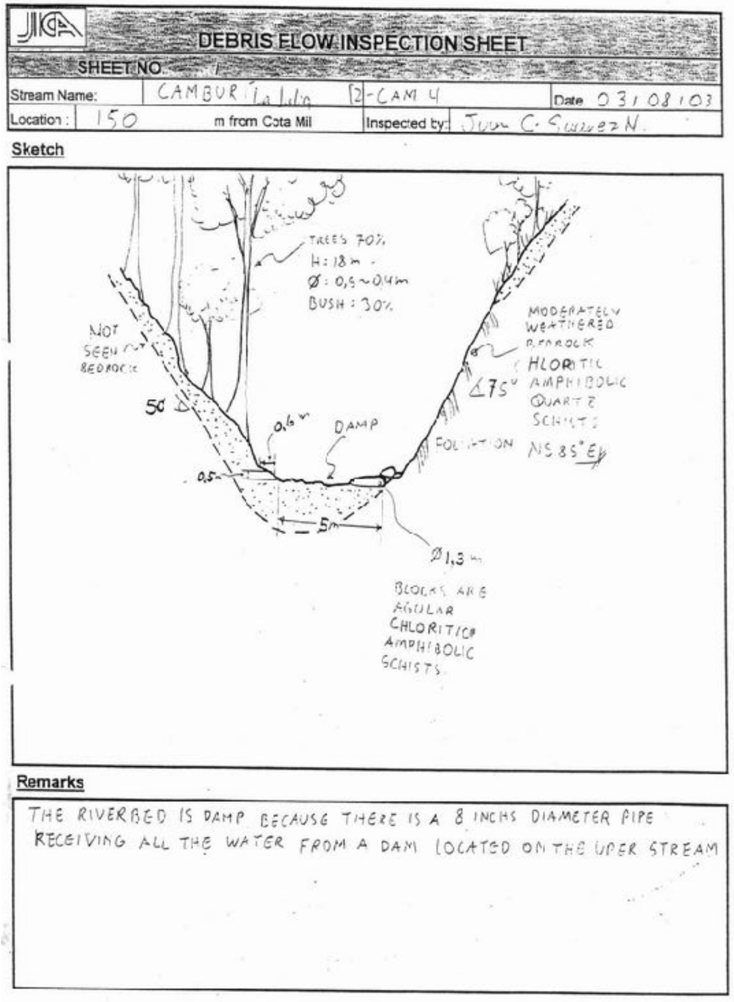


Figure S10-2.2.17   Unstable Sediment on Streambed



DEBRIS FLOW INSPECTION SHEET

SHEET NO.

Stream Name: CAMBUR La Julia 2-CAM 4

Date 03 / 08 / 03

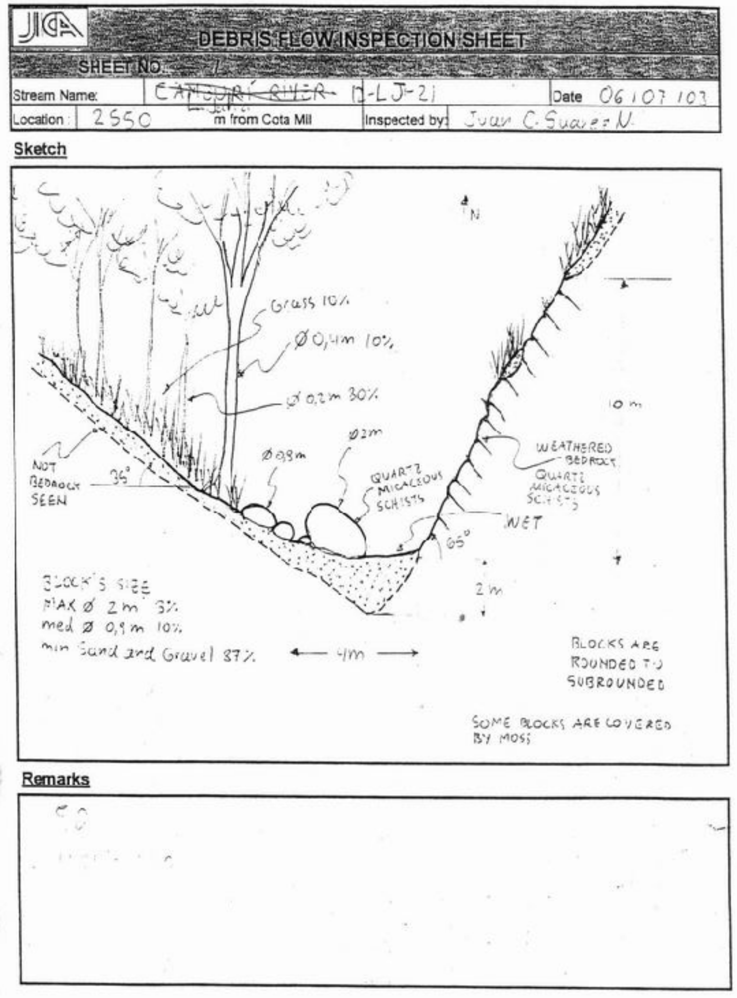
Location: 150 m from Cota Mil

Inspected by: Juan C. Suarez N.

Sketch

Remarks

THE RIVERBED IS DAMP BECAUSE THERE IS A 8 INCHS DIAMETER PIPE RECEIVING ALL THE WATER FROM A DAM LOCATED ON THE UPER STREAM



DEBRIS FLOW INSPECTION SHEET

SHEET NO.

Stream Name: ~~CAMBURÍ RIVER~~ 1-LJ-21

Date 06 / 07 / 03

Location: 2550 m from Cota Mil

Inspected by: Juan C. Suarez N.

Sketch

Remarks

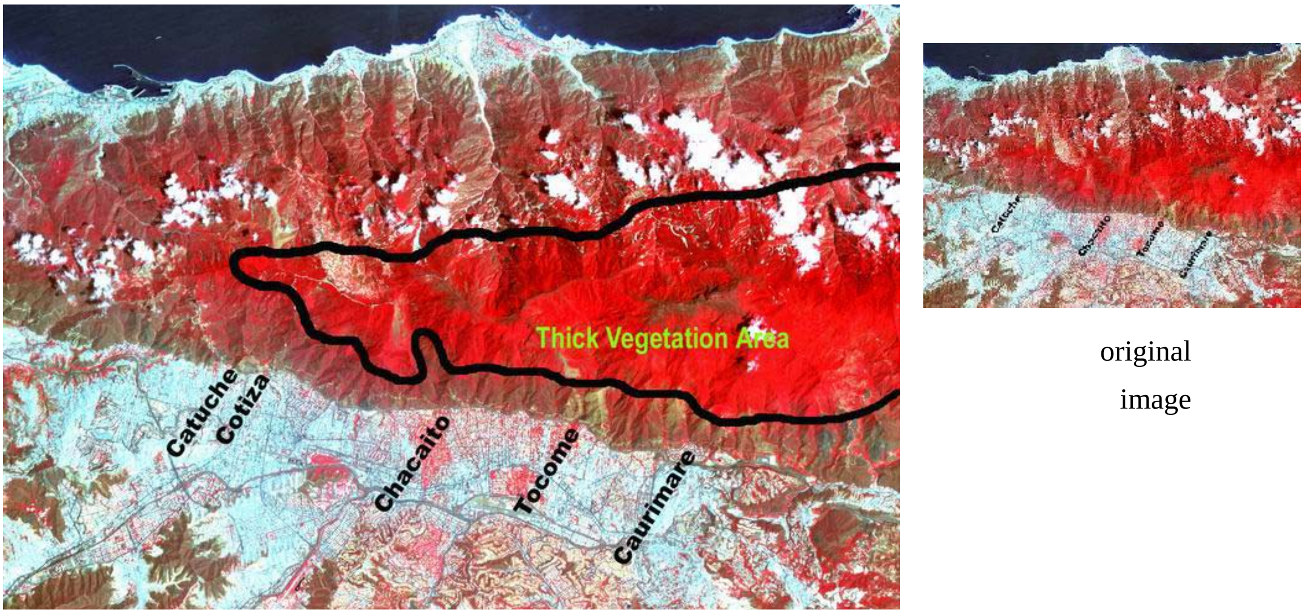
Figure S10-2.2.18 Cross Sections of Streams Drawn in Field Study

Relatively sand rich debris in Chacaito

Big Boulders seem to have fallen from slope beside of stream of Tocome

Round boulders and angular boulders can be seen, in Tocome

Figure S10-2.2.19 Photos of Stream Bed.

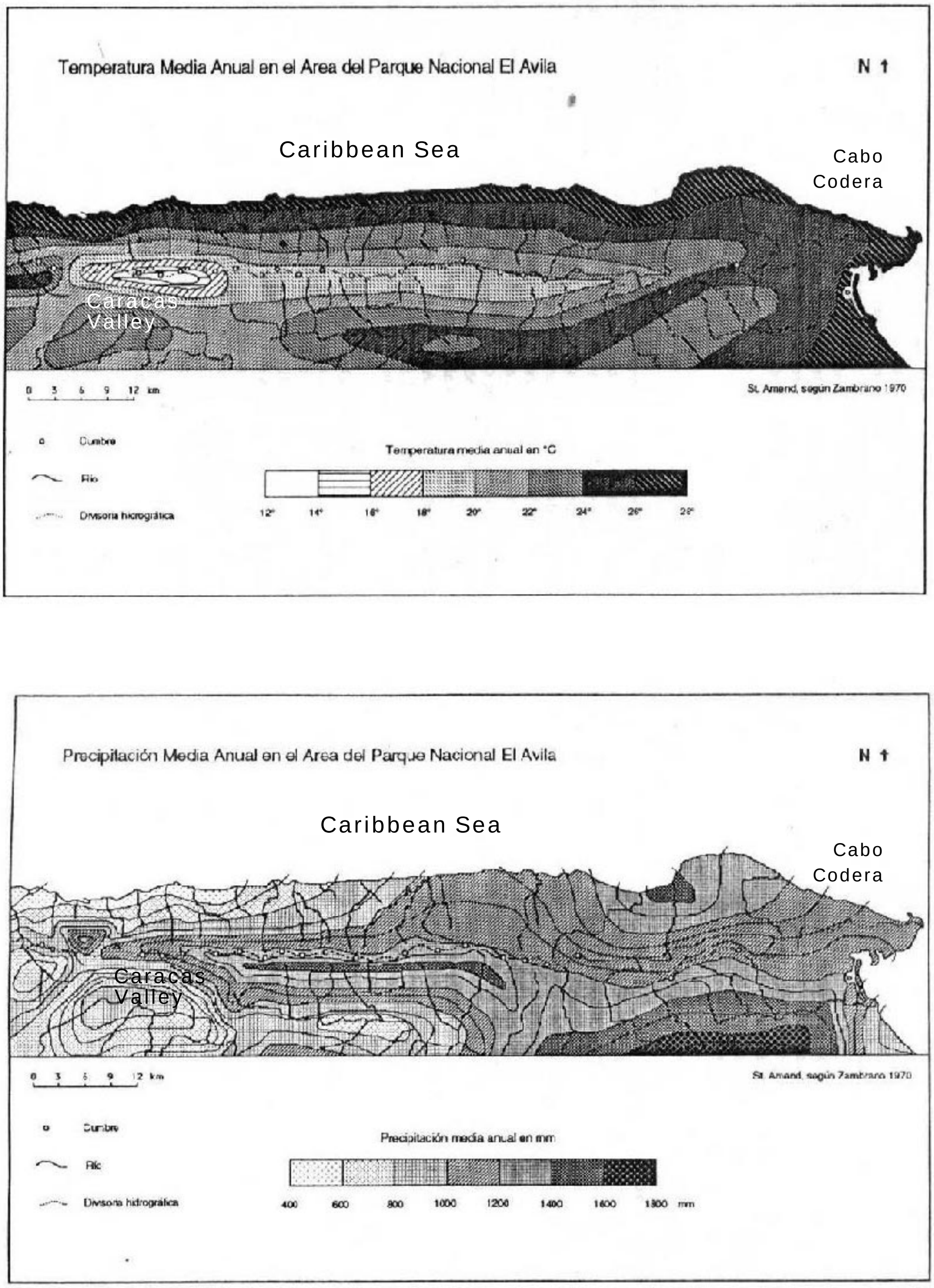


original image

Figure S10-2.2.20　Satellite Image with Infrared Band

Thick Vegetation (middle altitude)　　Weak Vegetation (lower altitude)

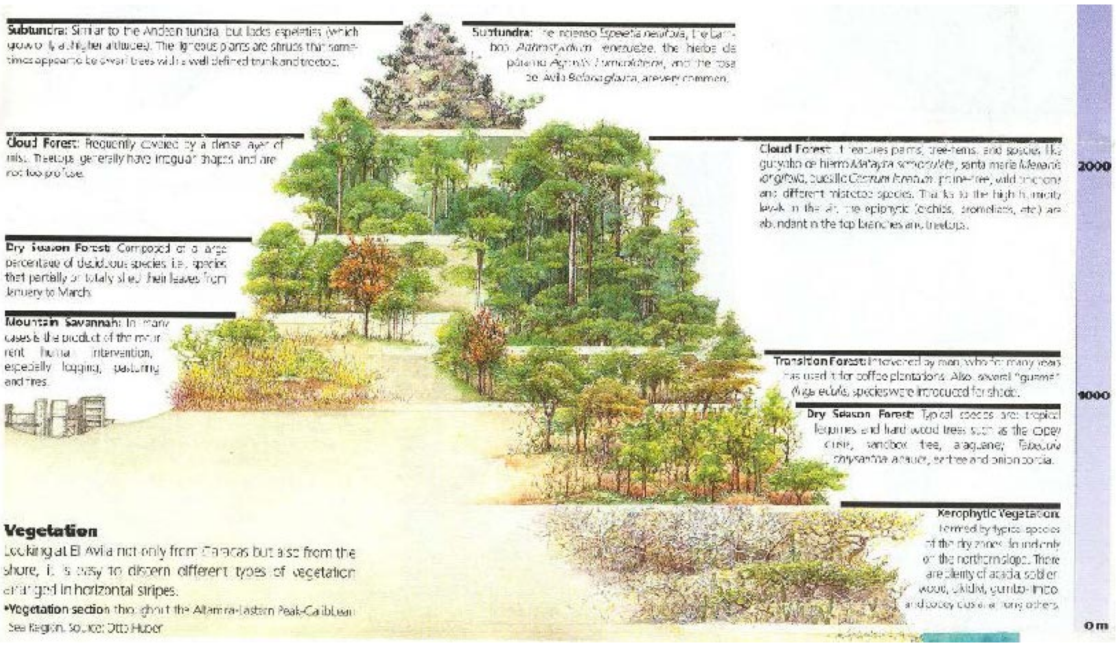
Figure S10-2.2.21　Image of Vegetation



St. Amand, según Zambrano 1970

St. Amand, según Zambrano 1970

Figure S10-2.2.22 Annual Average Temperature and Annual Precipitation Around Avila Mountains$^{S10-6)}$



Subtundra: Similar to the Andean tundra, but lacks espeletias (which grow only at higher altitudes). The ligneous plants are shrubs that sometimes appear to be dwarf trees with a well defined trunk and treetop.

Subtundra: The romero *Espeletia neriifolia*, the bamboo *[illegible]* venezuelae, the hierba de páramo *Agrostis [illegible]*, and the rosa de Avila *Befaria glauca*, are very common.

Cloud Forest: Frequently covered by a dense layer of mist. Treetops generally have irregular shapes and are not too profuse.

Cloud Forest: It features palms, tree-ferns, and species like guayabito de hierro *[illegible]*, santa maría *[illegible] longifolia*, bucaillo *Cestrum [illegible]*, pine-tree, wild [illegible] and different mistletoe species. Thanks to the high humidity levels in the air, the epiphytic (orchids, bromeliads, etc.) are abundant in the top branches and treetops.

Dry Season Forest: Composed of a large percentage of deciduous species, i.e., species that partially or totally shed their leaves from January to March.

Mountain Savannah: In many cases is the product of the recurrent human intervention, especially logging, pasturing and fires.

Transition Forest: Intervened by man, who for many years has used it for coffee plantations. Also, several "guamo" (*Inga edulis*) species were introduced for shade.

Dry Season Forest: Typical species are: tropical legumes and hard wood trees such as the copey clusia, sandbox tree, araguaney *Tabebuia chrysantha*, [illegible], [illegible] and onion cordia.

Xerophytic Vegetation: Formed by typical species of the dry zones, found only on the northern slope. There are plenty of acacia, soldier wood, [illegible], gumbo-limbo and cocoy [illegible] among others.

Vegetation

Looking at El Avila not only from Caracas but also from the shore, it is easy to discern different types of vegetation arranged in horizontal stripes.

***Vegetation section** throughout the Altamira-Eastern Peak-Caribbean Sea Region. Source: Otto Huber

Figure S10-2.2.23 Vegetation Transition in North and South Slopes of Avila Mountains (Ecograph, Caracas, Imparques, Provita)

CHAPTER 3. STUDY ON VARGAS DISASTER IN 1999 AND MARACAY DISASTER IN 1987

In last 20 years, two major debris disasters occurred in the north Venezuela. One is debris flow disasters in Vargas Area in December 1999. The other is debris flow disasters in Maracay Area in September 1987. They are both in mountainous area in La Costa Range. We studied these disasters to find the disasters characteristic in north Venezuela. Their locations are shown in Figure S10-3.1.1.

3. 1 Vargas Disaster

Collapses which occurred in San Julian basin in 1999 Disaster are shown in Figure S10-3.1.2. This collapse distribution map was drawn using aerophotos which were taken on January 14, 2000 after the disaster.

Collapses crowd in the basin except one third top of the basin. Configurations of collapse patterns are different from lower basin to upper basin. It can be classified into four zones from lowest basin to highest basin; lowest zone, lower middle zone, higher middle zone and highest zone as shown in Figure S10-3.1.3. Configuration of collapses in lowest zone is characterized by flat collapses which are shallow and wide. In lower middle zone, it is characterized by deep and crowded collapses. In higher middle zone, it is characterized by big and deep collapses, and in highest zone, there is no collapses. The zoning may reflect altitude difference. The boundaries of the zones are about 400 m, 800 m, 1,500 m in altitude. Lithology in Sun Julian basin, which consist schists and gneisses mostly, is not much different from the engineering point of view. However, in lower part of the basin, two major faults are reported; San Sebastian Fault which is along shoreline, and Macuto Fault which cross the basin at about 1km upper from San Sebastian Fault (Figure S10-1.2.1). These are possibility that two major faults affected on the collapses in only lower potion of the basin.

Figure S10-2.2.22 shows vegetation transition in north and south slopes of the Avila Mountains. It is easy discern different types of vegetation arranged in horizontal stripes in the Avila Mountains. It is possible that the difference of configuration of collapses reflects the vegetation transition, since no much difference of lithology and no much rain fall difference in 1999 Disaster.

3. 2 Maracay Disaster

Collapses which occurred in 1987 Disaster in Limon river basin are shown in Figure S10-3.2.1. This collapse distribution map was drawn using aerophotos which were taken on September 9, 1987, just 3 days after the disaster.

The debris flow was occurred on Guacamaya, Guamira, Corrol de Pladra and El Codra which are tributaries of Limon River. The collapses occurred in upper area of these streams. The collapses are characterized by following;

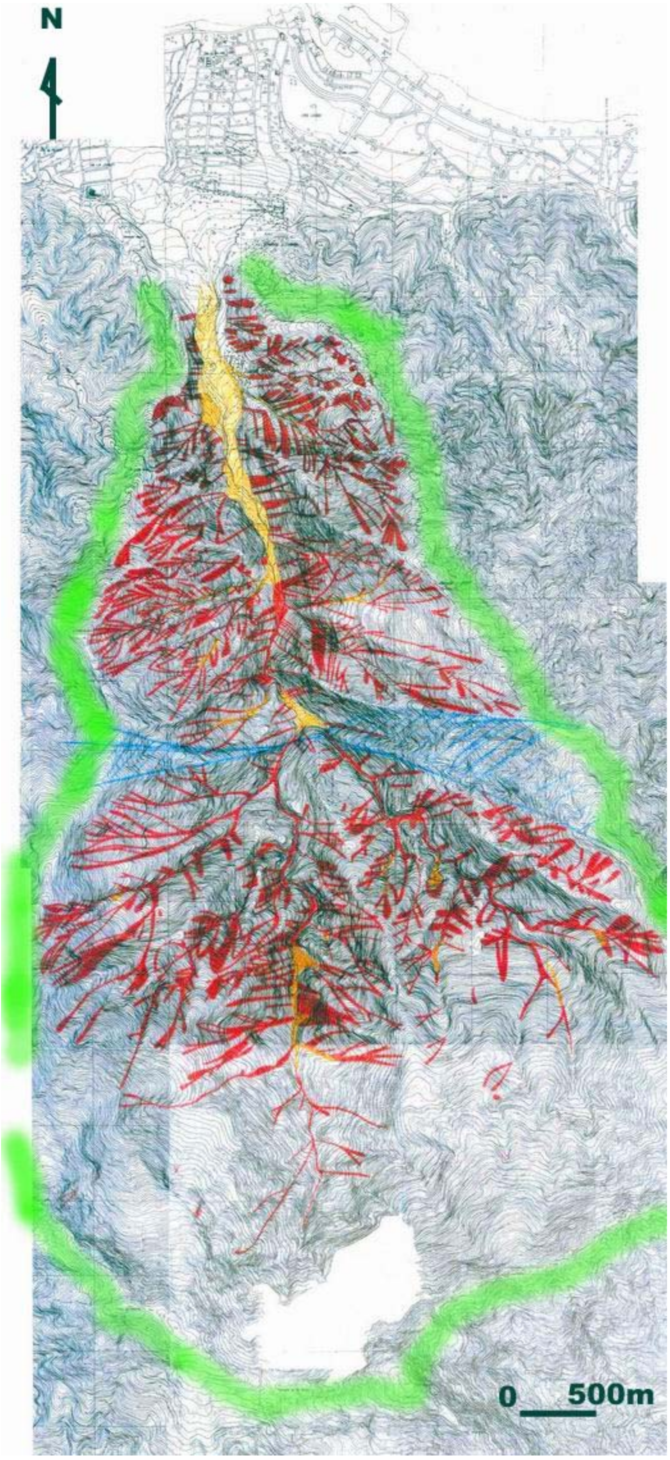
a. Collapses were above 800m

b. Collapses were in limited area (Guacamaya, Guamita, Corrol de Pladra, El Codra)

c. Collapses were on the slopes which face south or east.

d. Locations of collapses were not harmonize with geology and vegetation as shown in Figure S10-3.2.2 and S10-3.2.3.

Figure S10-3.1.1 Location Map of Vargas and Maracay Disasters



red : collapses and erosions
orange : debris deposit

Figure S10-3.1.2 Collapses in San Julian Basin Using Aerophoto Taken on 14 December, 2000

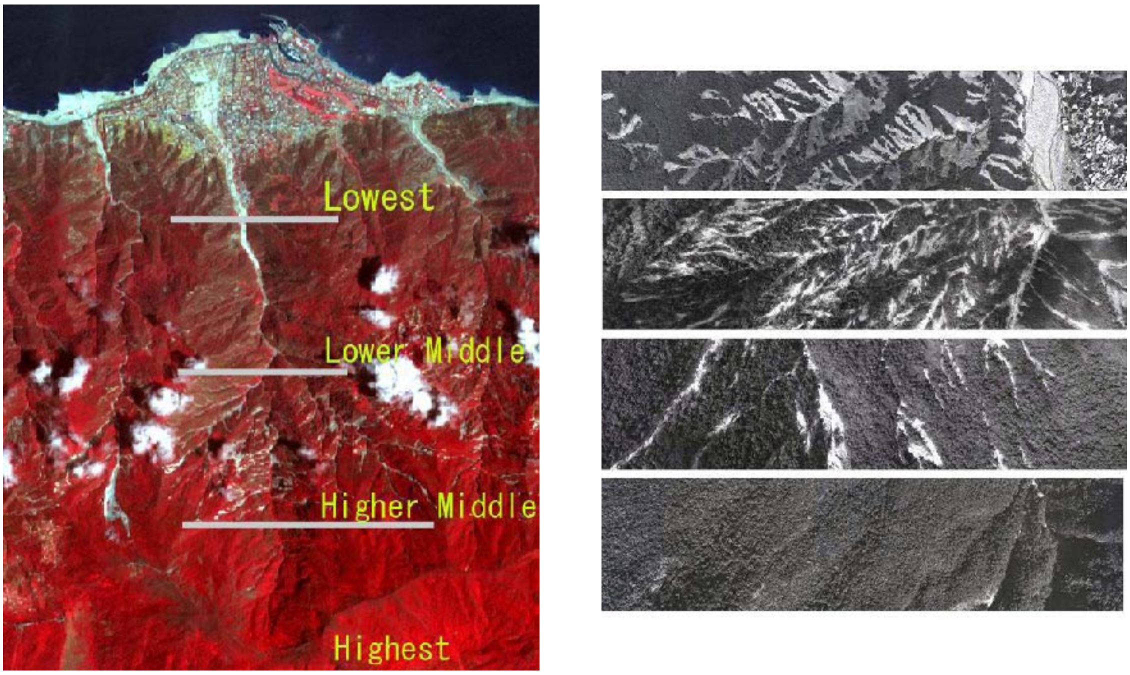
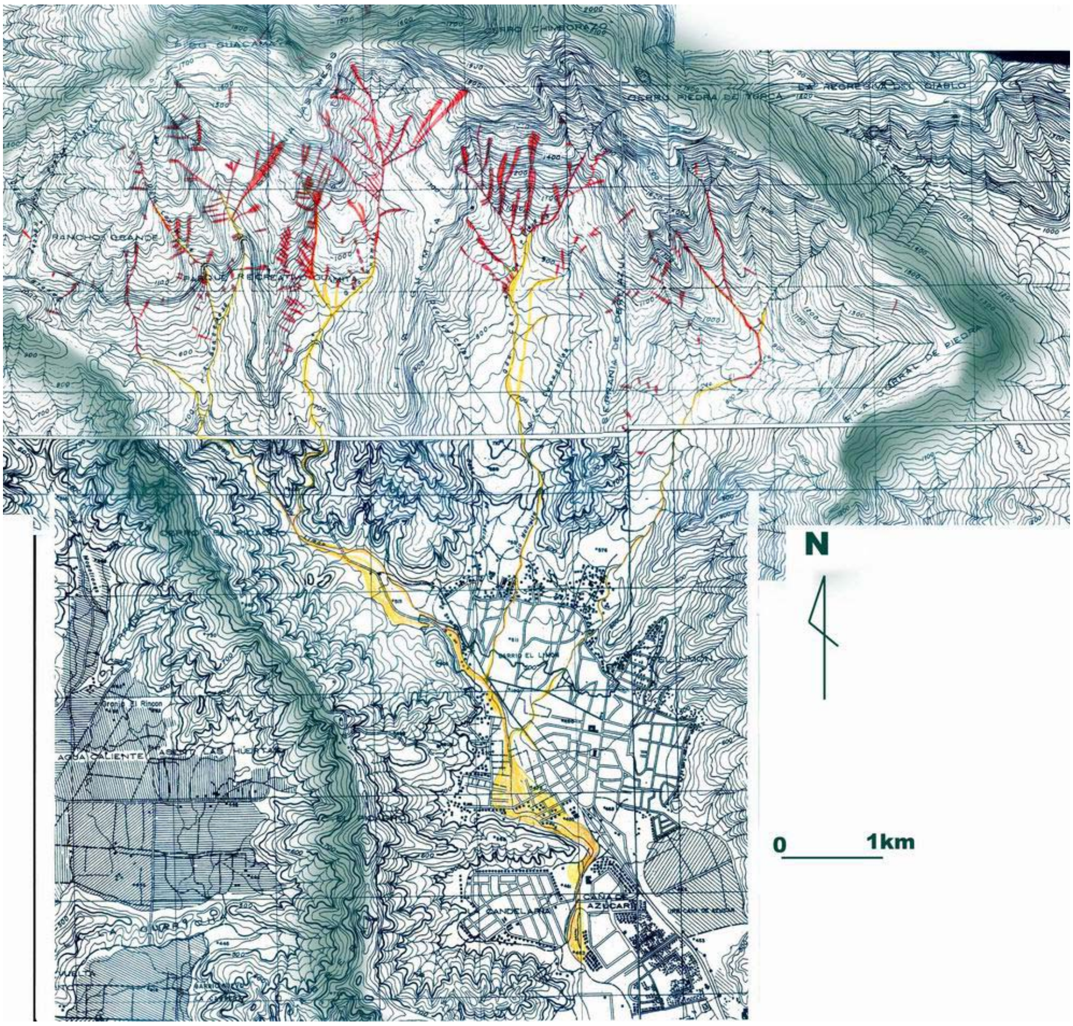
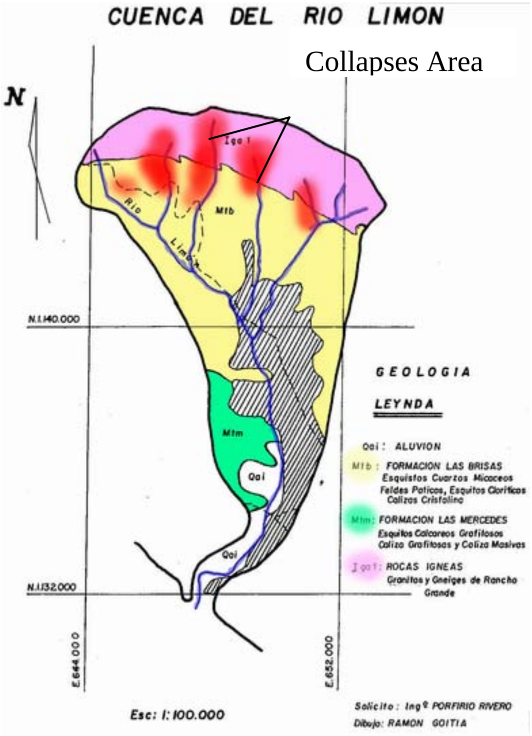


Figure S10-3.1.3 Satellite Image and Aerophoto of San Julian Basin Type of Collapses in San Julian Basin are Classified into Four



red : collapses and erosions
orange : debris deposit

Figure S10-3.2.1 Collapses in Limon River Basin Using Aerophoto Taken on September 9, 1987



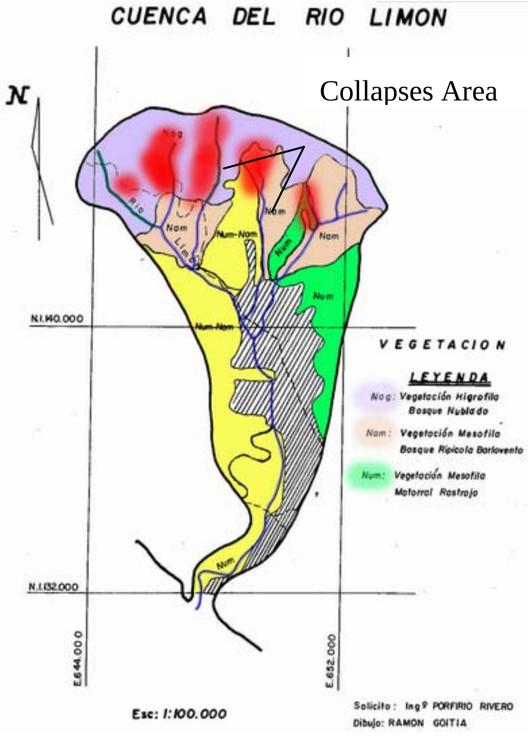


Figure S10-3.2.2 Geological Map

Figure S10-3.2.3 Vegetation Distribution Map

(source; Provided by MARN-Aragua Office)

CHAPTER 4. PRIMARY FACTOR OF DEBRIS FLOW IN THE AVILA MOUNTAINS

The followings are summary of the study in the Avila Mountains;

1. Although relatively soft rocks such as marble or serpentinite are reported in the eastern side, there is no major difference of geology / lithology between the east side and the west side. The density of faults and lineaments is not different between the east and the west.
2. New collapses are more in the west because there were a lot of collapses in December 1999, and old collapses are scattered in the whole area. Although there were quite a few collapses in February 1951, their vegetations have already been recovered and at present they are regarded as old collapses.
3. Weathered zone is thicker in the west than in the east. This may be caused by the terrain. The material of weathered zone is rich in gravel and poor in silt/clay.
4. Debris on streams seems more in the east. This may be caused by that the streams in the east have steps in its profile and have trellis / angular pattern of its drainage pattern.
5. Vegetation is classified from lower altitude to upper altitude of the Avila Mountains. Vegetation above 1,700m altitude is thicker than in below. Therefore, Catuche, Cotiza basins which are mostly below 1,700m have weaker vegetation.

In 1999 Disaster, the occurrence of debris flow did not depend on strength of rain fall but strength of the ground. The ground in the west side should be weaker, since the debris flow occurred in the west side and new collapses can be seen in only the west side. The deference of strength of the ground owes the protection by vegetation.

In the east side, the facts that vegetation is thicker, weathered zone is thinner, stream profiles have steps and steam pattern shows trellis / angular pattern indicate stronger against debris flow.

However, the distribution of old collapses are scattered even in the east side uniformly shows possibility of debris flow in the east side. If strong rain fall was only in the east side, debris flow would occur only in the east.

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S11

LAND SLIDE AND STEEP SLOPE FAILURE

"Be part of the plan, help us to prevent natural disasters!"

Reinaldo Ollarves

STUDY ON
DISASTER PREVENTION BASIC PLAN
IN THE METROPOLITAN DISTRICT OF CARACAS

FINAL REPORT

SUPPORTING REPORT

S11

LAND SLIDE AND STEEP SLOPE FAILURE

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S-11 LAND SLIDE AND STEEP SLOPE FAILURE

CHAPTER 1. GENERAL

The purpose of this study is to identify the slopes that have possibility to collapse and to develop to disaster, and then to make the slope classification map. The slope classification map made by the Study Team in this study shows unstable slopes which would affect inhabitants.

Generally, investigation of slope disaster in Japan is conducted in accordance with the work flow diagram that is shown in Figure S11-1.1.1. The investigation of slope disaster consists of 2 phases, namely “Wide Area Study” and “Individual Slope Study (Minute Investigation)”. JICA study team conducted until “Aero photograph and Topographical map Analysis” and “Identify Potential Collapse Slope (Screening)” in this study. The Study team proposed the criteria for “slope hazard Inspection” which that is next step in Figure S11-1.1.1.

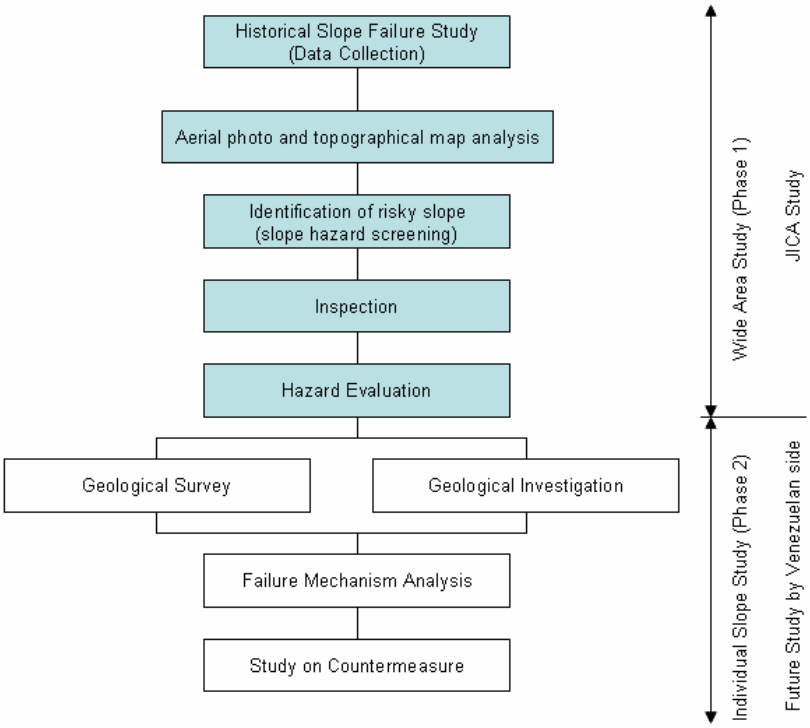


Figure S11-1.1.1 Flow Chart of Slope Study

CHAPTER 2. CHARACTERISTICS OF LANDSLIDE AND STEEP SLOPE FAILURE

Slope failures are divided into two types, namely “Landslide” and “Steep Slope Failure” in this study. This is a common practice in Japan. The characteristics of each type of slope failures are described as follows. Differences between landslide and steep slope failure are shown in Table S11-2.1.1

2. 1 Landslide

Landslide is a kind of slope mass movement. Generally, it occurs in a gentle slope as 5 to30 degrees, and on a slip plane such as thin clay layer or in a zone of weak materials. Movement is continuous, and it tends to recur. Velocity of movement is slow as 0.01 to 10 millimeters per a day. We can see some indications such as clacks, subsidence and bulge etc. on ground surface before landslide happen.

A primary cause of landslide is mainly concerned with geological condition such as type of rock and geological structure, and there are many cases that a zone of fault gouge makes slip plane. The fault gouge is a kind of clay layer on the fault which was generated due to the fault movement. Landslide is reactivated by storm, and artificial modifications to the land such as excavation of the foot of slope or construction of buildings on the slope (Weight of buildings makes increase of the driving force). A new landslide occurs as the result of heavy rain, earthquake and human activities.

2. 2 Steep Slope Failure

Scale of steep slope failure is smaller than that of landside. Generally, a steep slope failure occurs on steep slope as more than 30 degrees. Gradients of the slip plane is 35 to 60 degrees. The velocity of collapse is very fast as more than 10 millimeters per a day. There are not so many symptoms before occurrence of slope failure, and then slope failure occurs suddenly. The steep slope failure often occur on the plane which is corresponding to the boundary between the surface soil layer and the base rock, or the boundary between the severe weathered soil layer and the light weathered soil layer.

A primary cause of steep slope failure is concerned with geological condition such as thickness of overburden or weathered soil layer and geological structure. Steep slope failure is activated by mainly heavy rain and earthquake.

Table S11-2.1.1 Differences of Landslide and Steep Slope Failure

	Landslide	Steep Slope Failure
Geological Condition	Type of rock and geological structure. Thin clay layer can be slip plane.	Thickness of overburden and weathered layer.
Gradient of surface slope	Gentle slope as 5 to 30 degree.	Steep slope as more than 30 degrees.
movement	Continuous, recur.	Sudden
Velocity of Movement	Slow 0.01 to 10mm/day	Fast More than 10mm/day
Structure of Landslide Mass	not disturbed so much	disturbed.
Cause of Occurrence	Rising of groundwater level, earthquake and artificial modification to the land	Rainfall and earthquake.
Scale	Big (1 to 100ha)	Small
Symptom	Clacks, subsidence and bulge. Change of groundwater level.	scarce
Gradient of Slip Plane	10 to 25 degrees	35 to 60 degrees

CHAPTER 3. METHODOLOGY OF LANDSLIDE AND SLOPE FAILURE STUDY

“Historical Slope Failure Study” and “Aero Photo and Topographical Map Analysis” that are shown in Figure S11-1.1.1 were conducted to identify the possibility of disaster of landslide and steep slope failure. Methodology of these studies is described on following sections.

3. 1 Historical Slope Failure Study

Historical slope failures occurred in the study area were analyzed. There data were collected by Civil Protection and Fire Fighters departments of Metropolitan Caracas. Ands also, FUNVISIS has the historical slope failure study report that was compiled from a point of view of seismology, topography and geology.

Especially, the disaster which occurred since 1984 up to 2002 has been compiled by Civil Protection. These data are including other types of disasters such as flood. For this study, the data of slope failures which affected preservation target are picked up from the historical disaster database of Civil Protection and input to the slope classification map.

3. 2 Screening

In this study, the identified target of disasters are “landslide” and “steep slope failure”, and then the identified target of preservation are houses, important facilities and roads that have more than four lanes. Screening was conducted by using aero photographs taken in February 2002 (scale: 1/25,000), Topographical Maps published in 1984 (scale: 1/5,000) and satellite images “Advanced Spaceborne Thermal Emission and Reflection radiometer (ASTER)” taken in April 2003. The slopes that were identified by the screening are considered to be possible landslide or steep slope failure which may cause disasters.

The distinctive point of the study is to identify slope as a unit. Each unit of slope that has possibility to collapse was identified. Slope unit defined by slope pattern (refer to Figure S11-3.2.1). Thus, slope unit is classified as convex slope, concave slope or flat slope. If flat slope is continuous, it is divided into each 200m to 250m width. This criterion is based on the slope investigation standard by the unit of Ministry of Land, Transportation and Infrastructures in Japan.

However in “barrio” on steep slope, most of the houses are distributed on the convex and concave slopes continually without a clear boundary. It is difficult to identify each unit of slope either as concave slope or convex slope clearly. Therefore in case of convex or concave slope on which has "barrio", the slope was divided into two (2) separate unit slope by the slope change line along the slope direction as shown in the most left side figure in Figure S11-3.2.1.

(1) Landslide

It is very important that the reading of trace of landslide by aero photograph and topographical map since landslides have a property of relapse at the slide slope in the past (refer to Photo S11-3.2.1). The slope that is estimated as landslide is identified. Concerning a target of protection of landslide, it is same as the case of steep slope failure; more than 5 houses or important facilities. The notable identification point (refer to Figure S11-3.2.2) of steep slope failure is as follows,

- Landslide scarp :It can be read from landform and transition of slope gradient.
- Landslide mass :Area of landslide mass can be estimated from deference of slope gradient and change of vegetation. And also, vacant land in densely build-up area may be the place where landslide occurred in the past.

(2) Steep Slope Failure

Methodology of identification of steep slope in this study is based on the Law of Sediment Disaster Prevention in Japan. The risky slopes were identified by condition as the height of slope is more than 5m, and gradient of slope is more than 30 degrees (refer to Figure S11-3.2.4 and Photo S11-3.2.1). Having a target of protection such as 5 or more houses or some important facilities (i.e. hospital, school, factory). Additionally, roads having more than 2 lane can be a target of protection in the study (refer to Photo S11-3.2.1).

Geomorphological and geological condition, vegetation and land use condition, obtained from topographical map, aerial photograph and satellite image, were considered for the identification of steep slope failure. Satellite image was used to study the condition of vegetation. The notable identification point (refer to Figure S11-3.2.5) of steep slope failure is as follows,

- slope collapse: The distributed area and type of collapse can be estimated from contrast of shade on aerial photograph, shape of slope and transition of slope gradient. Some slope can be estimated whether the slope failure occurred recently or not by condition of vegetation of aero photograph.
- Singular landform: The knick line on slope, cliff and steep slope can be recognized by the form of ground surface and transition of slope gradient. It can be

estimated whether the ground surface is covered by weathered soil layer or not from degree of slope, change of vegetation and slope form.

3. 3 Classification of Steep Slope Stability

Based on the results of screening and the historical failure records, the selected steep slopes were categorized into three (3) ranks as shown in Table S11-3.3.1.

The site inspection was conducted regarding the slope which was identified by the screening using the topographic map and the aerial photograph. As the result of the site inspection, the slopes judged to be stable obviously from viewpoint of geology were excluded from a category of dangerous slopes.

The locations of slopes which were identified by screening and site inspection were input on the slope Hazard Map of the sediment study area. Each slope has layer number on GIS as follows,

- Layer No. 40: Steep Slope above house
- Layer No.43: Landslide
- Layer No.44: Steep Slope above road

Table S11-3.3.1 Classification of Slope Instability Potential

Grade		Description
1	High Potential	Picked up slopes by the screening, and having past records of failure.
2	Moderate Potential	Picked up slopes by the screening, but having no past records of failure.
3	Low Potential	The slopes except picked up slopes by the screening.

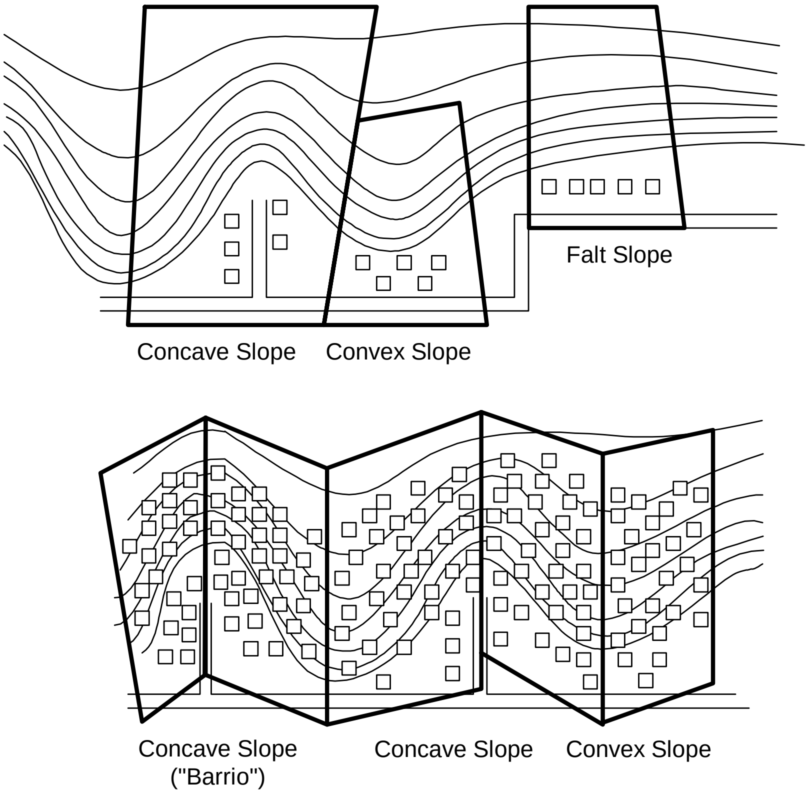


Figure S11-3.2.1 Criteria for Identification of Unit Slope

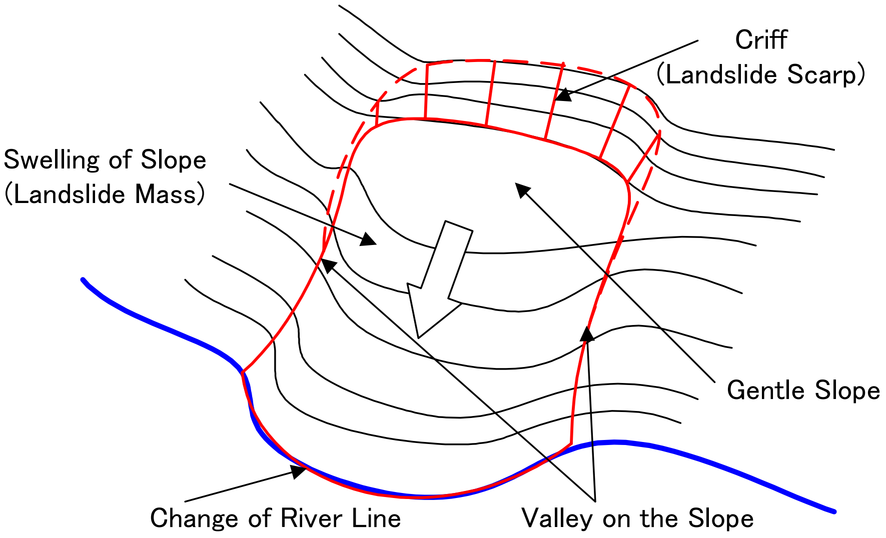


Figure S11-3.2.2 Notable Identification Point of Landslide

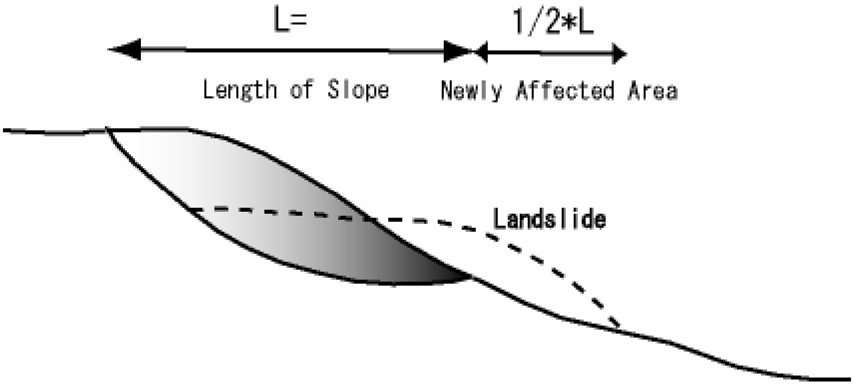


Figure S11-3.2.3 Criteria for Identification of Landslide

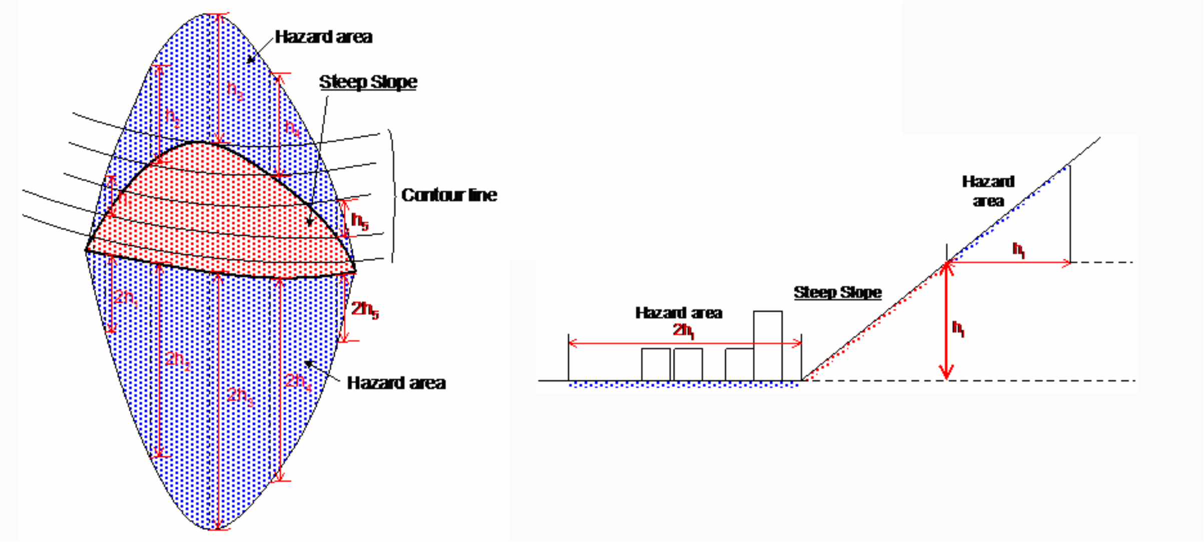


Figure S11-3.2.4 Criteria for Identification of Steep Slope

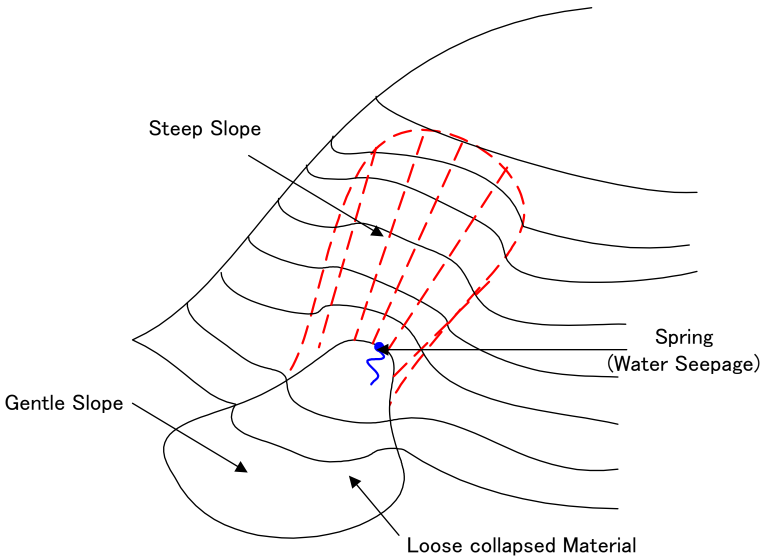
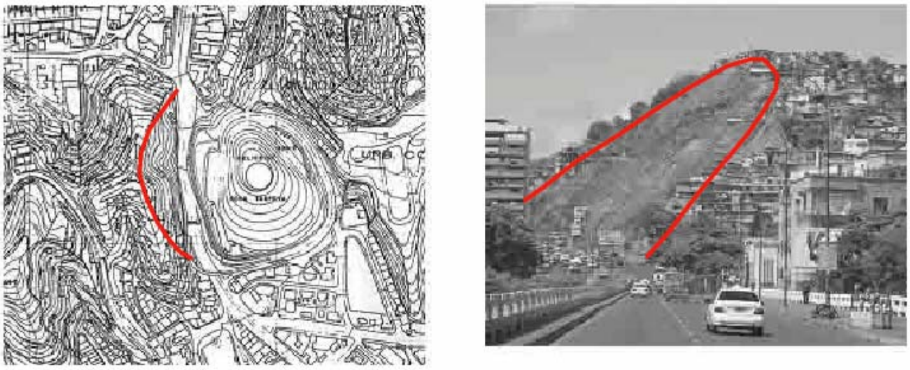


Figure S11-3.2.5 Notable Identification Point of Steep Slope Failure

Steep Slope Failure



Steep Slope Failure above Road

Landslide

Landslide in Tacagua Area

Photo S11-3.2.1 Steep Slope and Landslide in Caracas

CHAPTER 4. RESULT OF LANDSLIDE AND SLOPE FAILURE STUDY

4. 1 Historical Slope Failure Study

(1) Programa Preventivo y de Actuacion en Caso de Lluvias（Civil Protection）

The annual report of disasters in Municipality of Libertador is prepared by Civil Protection. Metropolitan Civil Protection has historical disaster data that is collected since 1984 up to 2002. From 1984 to 2000, disaster data is recorded by the Municipality of Libertador. After 2001, disaster data is covering a whole Metropolitan Caracas by Metropolitan Civil Protection. Municipality of Chacao also prepared annual report of disaster in 2001 and 2002. Compiled these data are shown on Table S11-4.1.1. According to the data, the number of slope failures is very small. It is supposed that almost all slope failures are identified as landslide.

It was difficult to identify the exact locations of slope disaster from the historical disaster data that was prepared by Metropolitan Civil Protection. Therefore, the exact locations of the historical disaster have been put on the topographical map (scale 1/5,000) according to the result of interview with Metropolitan Civil Protection.

(2) The Slope Hazard Map (INGEOMIN)

A slope hazard map was prepared by National Institute of Geology and Mining (INGEOMIN) as a part of “Avila Project”. The slopes were evaluated from the viewpoint of slope stability based on topographical and geological conditions. This slope hazard map shows the unstable slope areas. The slope hazard map was digitized on GIS map. The parameters of classification for slope stability are as follows,

1. Rock classification: Weathering grade and interval of joint development
2. Geological Structure: Relation between direction of major joints and orientation of slope.
3. Topography: gradients of slope
4. Condition of slope: Slope form, transition of slope gradient, erosion and water condition etc.

The slope stability is evaluated based on the result of consideration for each of the parameters. In the Avila project, the slope stability evaluation is applied for Avila mountain area. However, the slopes in the urban area were not studied applying the methodology.

(3) Inventario Nacional de Riesgos Geologicos (FUNVISIS)

This report was prepared in 1983. FUNVISIS conducted identification of slope failures based on the past slope failure data in Venezuela. Most data were obtained from newspaper, documents and photographs that were prepared by the government and historical documents in 17th and 18th century. The point to which the report directing attention are the relation with earthquake, the relation with geological condition and the cause of occasion. The data up to 1981 used in the report. FUNVISIS is preparing the updated report by using the data since 1982 up to the latest.

(4) Historical disaster Database (Fire Fighter Department)

Historical disasters are registered by fire fighter department in metropolitan and each Municipalities. Fire fighter department of metropolitan government collects the disaster data of whole Metropolitan Caracas to make historical disaster database and historical disaster map. The exact disaster locations were put on the topographical map, with the scale of 1/5,000 according as the interview with the Civil Protection.

4. 2 Identification of Risky Slope

In the identification of risky slopes, the slopes that have possibility to collapse and to develop into disaster are identified by using topographical maps, aerial photograph and satellite image.

The number of identified landslide slopes and steep slopes in sediment study area at the moment are shown in Table S11-4.2.1.

According to the result, no landslide nor steep slope except for road were picked up in Municipality of Chacao, in which there is not so many steep slopes steeper than 30 degrees. On the other hand, there are many landslide slopes and steep slopes which were picked up in Municipality of Libertador and Sucre. Especially many traces of landslide and steep slopes were picked up in Carapita area and Tacagua area in Municipality of Libertador and Petare area in Municipality of Sucre.

There are some slope failures in the study area occurred in the 1st study period in Venezuela between May and July in 2003. Loose weathered schist is distributed in these areas. One of these slope failures that occurred in Tacagua area has slip plane that is located on the boundary of bedrock and embankment (refer to Photo S11-3.2.1).

The slope hazard map that shows the picked up landslides and steep slopes was prepared as one of the GIS map in the project.

4. 3 Site Inspection

The Study Team conducted up to the identification of risky landslides and steep slopes in the study. Additionally, we proposed methodology of “Slope Inspection” for each picked up landslides and slopes. It is the next step in the work flow diagram Figure S11-1.1.1.

In the case of Japan, the methodology of the slope inspection is presented by Ministry of Land, Transportation and Infrastructure. The slope inspection has been conducted in all over Japan. Each prefecture government in Japan has constructed the database of slope stability.

The proposed slope inspection sheets are shown in Figure S11-4.3.1. These inspection sheets are prepared based on Japanese methodology. The inspection sheets are composed of sections of General Slope Data, Location Map, Site Sketch, Photograph, Condition of Slope and Existing Countermeasure. In the section of Condition of Slope, the score is marked based on the topography, geometry, material, geological structure, deformation and surface condition. The full score is 100, which means the most dangerous. The score of geological condition is very significant in the total score.

Table S11-4.3.1 is the list of site for which the Study Team made the inspection sheets in the 1st study in Venezuela. Totally 27 sites were inspected in Sucre and Libertador in and around the sediment disaster study area.

Table S11-4.2.1 also shows the number of unstable slopes after the inspection within the sediment study area. However, the above inspection was conducted preliminary in the 1st study in Venezuela. Due to security problems in some areas, all potential areas were not inspected in the sediment disaster study area.

The chart of hazard evaluation of slope inspection is shown on Table S11-4.3.2. The full score is one hundred (100). The higher score means the higher potential on the failure. According to the chart, the four (4) slopes among the inspected twenty seven (27) slopes correspond to High Potential slope. These slopes are supposed to have high potential for collapse, and the more detailed investigation should be carried out.

4. 4 Affected Area and Property (Risk Map) or Hazard Evaluation

In this study, the number of house (building) which is supposed to be affected by slope failure or landslide in the sediment study area has been calculated. The calculation of the risk is used the following standard of supposing affected area.

Landslide: The affected area of landslide is difficult to estimate, since affected distance by landslide mass differs according to the condition of geology, geomorphology and type of landslide. In this study, the affected area by landslide was estimated as a half of landslide slope length from toe of the landslide to the top of it (Hiroyuki Nakamura, “Estimation of Landslide Behavior, diffusion and sediment area”, Fukada-ken Library No. 47, refer to Fig.S11-3.2.3).

Steep Slope failure: Supposing affected area by slope failure shall be provided extent area which is twice as length as the slope height from the toe of the slope (maximum 50m) and extent area which is as length as the slope height from the top of the slope (maximum 50m) (refer to Figure S11-3.2.2).

The number of houses is shown on Table S11-4.4.1. According to the table, the number of affected informal house by slope failure or landslide is as about 20 times as the number of the affected formal house. The cause of the result is considered that most formal houses in sediment study area are on flat area as Chacao municipality, while the most informal houses concentrate on slope area.

4. 5 Slope Classification Map for the three (3) Municipalities

In this study, the identification of risky slopes was done for the entire 3 municipalities. Those selected areas were mapped on the slope classification map as shown in Figure S11-4.5.1.

Table S11-4.5.1 shows the number of slope instability for the entire 3 municipalities.

Table S11-4.1.1 Summary of Historical Disaster data by Protection Civil

Year	Total	Landslide	Slope Failure	Others	Target
1996	279	215	0	64	Libertador
1997	255	92	3	160	
1998	181	59	1	121	
1999	199	197	2	0	
2000	357	128	1	228	
2001	387	70	3	314	Caracas
2002	220	19	6	185	

Table S11-4.2.1 Number of Slope Instability Potential (Sediment Study Area)

Municipality	Steep Slope		Steep Slope above Road		Landslide	
	Before Inspection	After Inspection	Before Inspection	After Inspection	Before Inspection	After Inspection
Libertador	136	89	25	25	5	7
Chacao	0	0	12	12	0	0
Sucre	110	89	17	15	1	1

Table S11-4.3.1 List of Preliminary Inspection Site

Slope ID	Type of Disaster	Municipality	Target for Preservation	Score
1	Slope Failure	Sucre	Residencial, Factory	54
2	Slope Failure	Sucre	Residencial, Factory	63
3	Slope Failure	Sucre	Residencial	58
4	Slope Failure	Sucre	Commercial	39
5	Slope Failure	Sucre	Commercial	15
6	Slope Failure	Sucre	Residencial	57
7	Slope Failure	Sucre	Residencial	46
8	Slope Failure	Sucre	Residencial	23
9	Slope Failure	Sucre	Residencial	62
10	Landslide	Sucre	Residencial	41
11	Landslide	Libertador	Residencial	63
12	Slope Failure	Libertador	Residencial	41
13	Slope Failure	Libertador	Residencial	51
14	Slope Failure	Libertador	Residencial	48
15	Slope Failure	Libertador	Residencial	59
16	Slope Failure	Libertador	Residencial	59
17	Slope Failure	Libertador	Residencial	67
18	Slope Failure	Libertador	Residencial	69
19	Slope Failure	Libertador	Residencial	68
20	Landslide	Libertador	Residencial	40
21	Slope Failure	Libertador	Residencial	47
22	Slope Failure	Libertador	Residencial	39
23	Slope Failure	Libertador	Residencial	66
24	Slope Failure	Libertador	Residencial	53
25	Slope Failure	Libertador	Residencial	48
26	Slope Failure	Libertador	Residencial	51
27	Slope Failure	Libertador	Residencial	45

Table S11-4.3.2 Number of Slope Instability Potential

Risk Potential	Score	Steep slope	Landslide
Very High	R>=75	0	0
High	65<=R<75	4	0
Moderate	50<=R<65	10	1
Low	R<50	10	2

Table S11-4.4.1 Number of Houses affected by Steep Slope Failure and Landslide

	Interpreted House		Affected House		Total	
	Formal	Informal	Formal	Informal	Formal	Informal
Slope Failure	49	6797	304	5197	353	11994
Landslide	2	383	16	139	18	522

Table S11-4.5.1 Number of Slope Instability Potential (3 Municipalities)

Municipality	Landslide	Steep Slope (Road)
Libertador	**45**	**1,427 (57)**
Chacao	**0**	**0 (12)**
Sucre	**6**	**659 (33)**
Total	**51**	**2,086 (102)**

SLOPE INSPECTION SHEET

SHEET 1 / 4

General Slope Data

Type of Disaster	[✓ *Slope Failure*] / *Landslide*	Municipality	*SUCRE (Lebrun)*
Slope ID	*1*		
Date Checked	*28/7/2003*	Data Inspected	*9/7/2003*
Checked by	*Fumihiko Yokoo*	Inspected by	*Takashi Hara*
Vegetation /Cultivation	*Primary Forest / Trees / Grass* [✓ */ Others*]		*Barrio*
Target of Preservation	[✓ *Residencial*] */ Hotel / Commercial /Hospital /* [✓ *Factory*] */School / Others* *Ranchos, Factory*		
Disaster Record	*No Records*		
Existing Countermeasure	*Nothing*		
Hazard Score	**54**	Comment: *The almost all surface of the slope is covered with Ranchos.* *Toe of the slope is put some countermeasure partially.*	
Proposed Countermeasure			
Cost Estimation	Quantity	Unit Rate	Amount

Location Map (1:5,000)

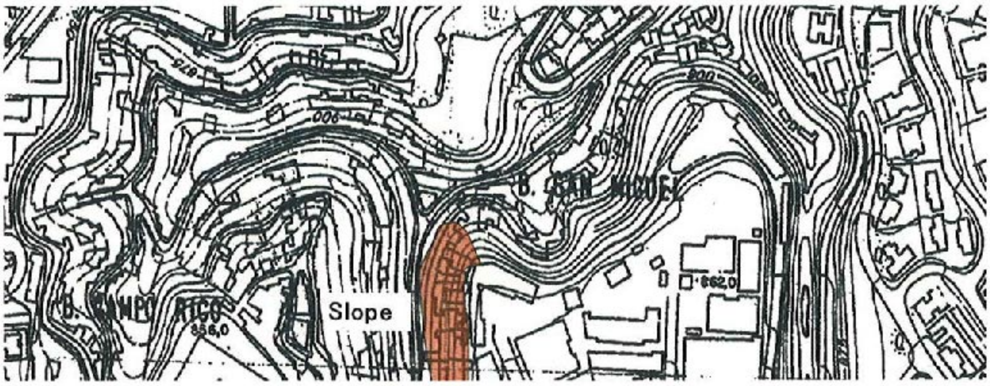


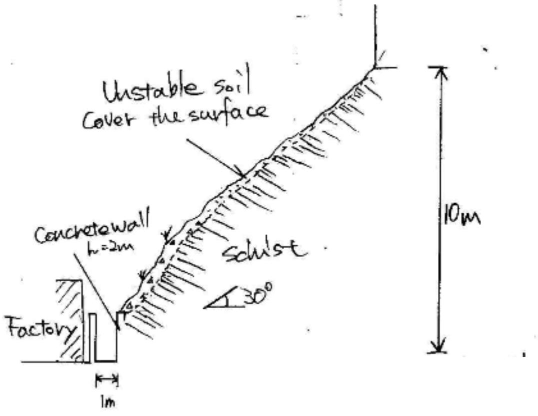
Figure S11-4.3.1 Slope Inspection Sheet (1/4)

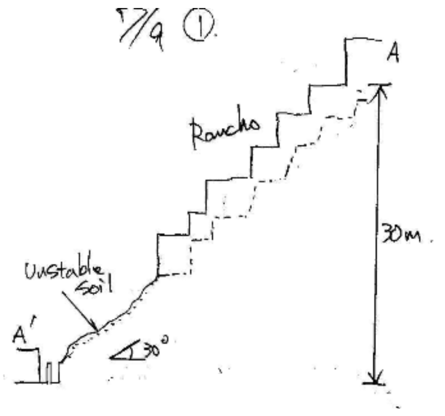
SLOPE INSPECTION SHEET

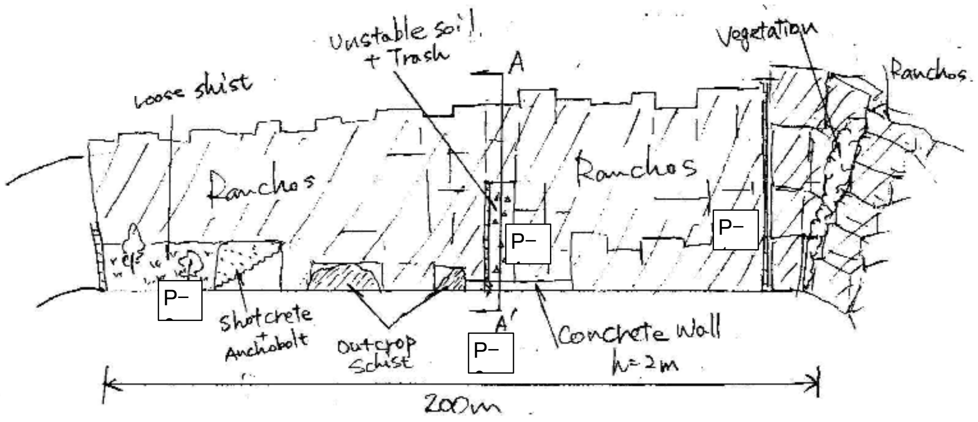
SHEET 2/4

Slope ID	*1*	Type of Disaster	*[✓ Slope Failure] / Landslide*	Date *9/7/2003*

Sketch







Remarks

-Weathered Schist distributes in this area.
-The almost all surface of the slope is covered with Rnachos.
-Some parts of the slope on which Rancho have not been constructed is covered with unstable soil.
-Some parts of toe of the slope are put countermeasure, but the other parts of toe of the slope still

Figure S11-4.3.1 Slope Inspection Sheet (2/4)

SLOPE INSPECTION SHEET

SHEET 3/4

Slope ID	*1*	Type of Disaster	*[✓ Slope Failure] / Landslide*	Date *9/7/2003*

Photograph

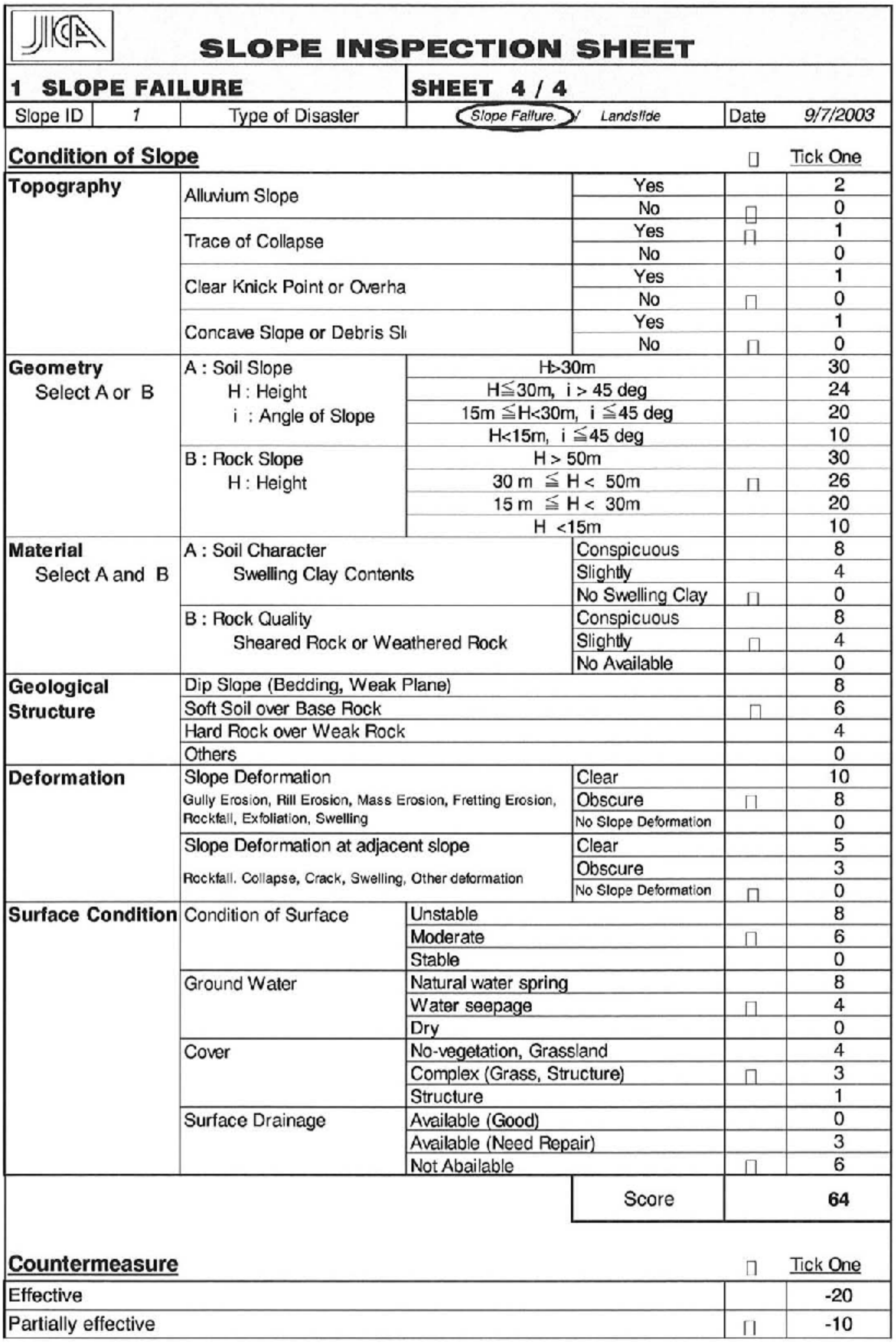
P-1 General View

P-2 The bare slope situation

P-3 Existing Countermeasure

P-4 Closs view fo the bare slope

Figure S11-4.3.1 Slope Inspection Sheet (3/4)



SLOPE INSPECTION SHEET

1 SLOPE FAILURE | **SHEET 4 / 4**

Slope ID: 1

Type of Disaster: [✓ Slope Failure] / Landslide

Date: 9/7/2003

Condition of Slope			☐	Tick One
Topography	Alluvium Slope	Yes		2
		No	☐	0
	Trace of Collapse	Yes	☐	1
		No		0
	Clear Knick Point or Overha	Yes		1
		No	☐	0
	Concave Slope or Debris Sl	Yes		1
		No	☐	0
Geometry Select A or B	A : Soil Slope H : Height i : Angle of Slope	H>30m		30
		H≦30m, i > 45 deg		24
		15m ≦H<30m, i ≦45 deg		20
		H<15m, i ≦45 deg		10
	B : Rock Slope H : Height	H > 50m		30
		30 m ≦ H < 50m	☐	26
		15 m ≦ H < 30m		20
		H <15m		10
Material Select A and B	A : Soil Character Swelling Clay Contents	Conspicuous		8
		Slightly		4
		No Swelling Clay	☐	0
	B : Rock Quality Sheared Rock or Weathered Rock	Conspicuous		8
		Slightly	☐	4
		No Available		0
Geological Structure	Dip Slope (Bedding, Weak Plane)			8
	Soft Soil over Base Rock		☐	6
	Hard Rock over Weak Rock			4
	Others			0
Deformation	Slope Deformation Gully Erosion, Rill Erosion, Mass Erosion, Fretting Erosion, Rockfall, Exfoliation, Swelling	Clear		10
		Obscure	☐	8
		No Slope Deformation		0
	Slope Deformation at adjacent slope Rockfall, Collapse, Crack, Swelling, Other deformation	Clear		5
		Obscure		3
		No Slope Deformation	☐	0
Surface Condition	Condition of Surface	Unstable		8
		Moderate	☐	6
		Stable		0
	Ground Water	Natural water spring		8
		Water seepage	☐	4
		Dry		0
	Cover	No-vegetation, Grassland		4
		Complex (Grass, Structure)	☐	3
		Structure		1
	Surface Drainage	Available (Good)		0
		Available (Need Repair)		3
		Not Abailable	☐	6
		Score		**64**
Countermeasure			☐	Tick One
Effective				-20
Partially effective			☐	-10

Figure S11-4.3.1 Slope Inspection Sheet (4/4)

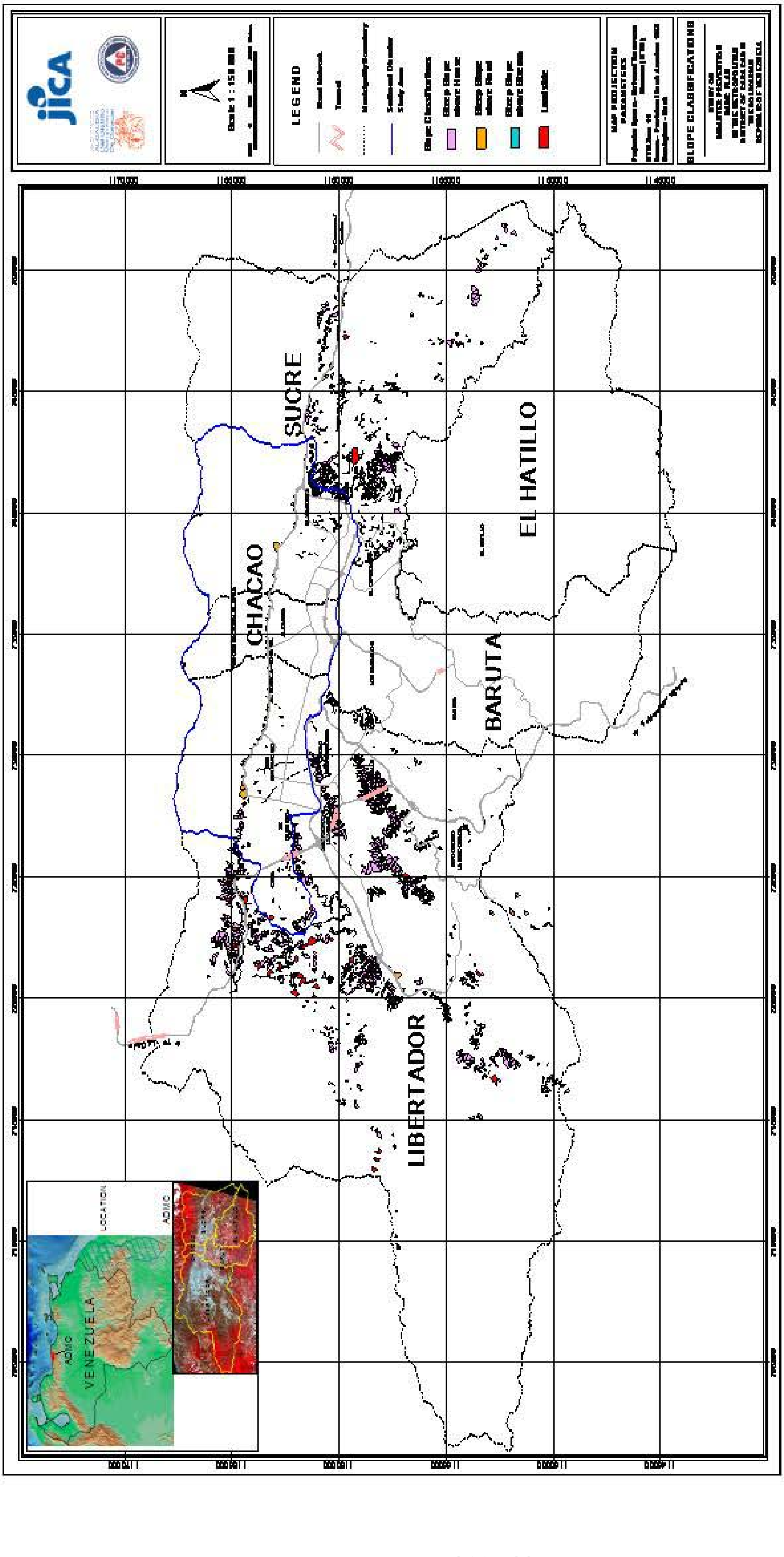


Figure S11-4.5.1 Slope Classification Map

CHAPTER 5. RECOMMENDATION

The Study conducted up to the identification of risky landslides and steep slopes. Additionally, draft methodology of “Slope Inspection” for each picked up landslides and slopes, which is the next step to the slope identification, is suggested. The result of the slope inspection shall be modified to make database. These data could be useful for a future plan of disaster prevention (decision of measuring priority order for the slope disaster) and an urban development plan which is considered implementation of protection measure or relocation of residence, important facilities and infrastructures which located in dangerous area. Almost residence in Barrio area shall be relocated because they are located in estimated affected area by slope disaster. If it is difficult to relocate, some countermeasures for mitigation of slope disaster is necessary. There is a drain problem which is an important factor in the slope collapse occurrence. For example, providing of drain system on the slope surface, which can guide rainwater and domestic wastewater from residence to river or drain under the slope is considered to be reduce potential of slope disaster. The providing of opened and closed drain works could be conducted under moderate cost, and is expected effect on slope disaster mitigation.

It is desirable that integrating the historical slope disaster data managed with INGEOMIN, the fire fighter department, Civil Protection, and FUNVISIS. These data shall be updated on database system, and the construction of the system by which related organs which is necessary to use the data can refer freely to data is preferable.

This study has extracted only the slope where the possibility that a slope collapse happens is high. More detailed investigation (e.g. geological reconnaissance, Dynamic Cone Penetration Test, Drilling survey) for each slope is necessary for consideration of countermeasure. The targets of protection such as houses or facilities, which are located below the slopes identified in this study, shall be watched during abnormal event as earthquake or heavy rain. Additionally, the attention shall be paid especially that the following phenomenon are found on the slope.

=>Crack found on the slope.

=>Water seepage found on the slope ordinarily.

=>Rock fall from the slope found.

When some cracks are found in landslide area, iron or wooden pile shall be placed across the crack. It could be simple monitoring for landslide activity measuring the distance between the piles.

Slope failure (Collapse) would be difficult to predict the occurrence as a collapse occurs unexpectedly. Therefore, it is desirable to construct the system that related organs or district manager patrol in abnormal weather, and that they can correspond to unexpected situation.

S12

DEBRIS FLOW AND SEDIMENT STUDY

"The worst of a tragedy,

is that never you know what to do. Prevent, get the information"

Francisco Layrisse

STUDY ON
DISASTER PREVENTION BASIC PLAN
IN THE METROPOLITAN DISTRICT OF CARACAS

FINAL REPORT

SUPPORTING REPORT

S12

DEBRIS FLOW AND SEDIMENT STUDY

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S-12 DEBRIS FLOW AND SEDIMENT STUDY

CHAPTER 1. POTENTIAL OF DEBRIS FLOW

1. 1 General

1. 1. 1. Study Procedure

The study of debris flow covers from the basic investigation to the estimation of debris flow potential for the usage in the next steps such as hazard mapping, structure and non-structure measures.

The description from section 1.2 to section 1.6 followed the table of contents of a guideline on study for potential debris flow stream in Japan.

1. 1. 2. Definition of Technical Term

This section shows the definition of various technical terms used in the sediment study in general.

Mountain Stream

Mountain stream is defined as principal stream which is originating from the southern slope of the Avila and joining to the Guaire River passing through the Caracas Valley. Mountain stream is called “quebrada” in Spanish language in Caracas.

1st order stream

See section 1.2. This concept is the basis how large the unit catchment is defined for the sediment study.

Unit Catchment

Unit catchment is a basic catchment for the sediment runoff estimation. When the sediment runoff volume is calculated from individual slope collapse and unstable sediment on the stream, one (1) volume is calculated for one (1) unit catchment. In this study the unit catchment was defined as the catchment of 2nd order stream considering the catchment size of principal stream.

Basic Point

Basic point is a section of principal stream course at which the total sediment volume upstream is estimated for the debris flow countermeasures. In other words, all the countermeasures such as sabo dam are proposed the basic point upstream for the estimated sediment volume. In the study the basic points of most of the principal streams are the Cota Mil crossing section, which are corresponding to alluvial fan apex.

Debris Flow

Debris flow is a flood flow containing significant sediment and water which is generated in upper part of mountain stream because of slope collapse and erosion of unstable sediment on stream bed.

1. 2 Identification of Potential Stream for Debris Flow

A stream can be defined as topography with a valley on the topographical map of scale 1:5,000. The stream has several orders such as 1^{st}, 2^{nd}, 3^{rd}, etc.

The 1^{st} order stream can be defined as a stream which has the following conditions.

- the length of “b” is longer than “a”.
- episodes of debris flow and evidences from which debris flow could occur.

Generally, the sediment analysis is conducted based on the unit catchment concept. The Figure S12-1.2.2 shows the stream order concept of Strahler. When this concept is applied, it is convenient to compare a lot of mountain stream catchments on a common condition for sediment transport phenomena. In the case of the study area, the 2^{nd} order stream should be treated as a unit catchment to consider the entire catchment size and the drainage density.

Figure S12-1.2.3 shows the sub-catchment boundary for the 2^{nd} order stream unit catchment in the mountain streams. The delineation was conducted based on the scale 1:5,000 Topographic Map of 1984 and 1954.

The total number of unit catchment is 195. Among the 47 mountain streams, the Tocome stream catchment has 26 catchment units as the maximum.

The maximum stream order is five (5) in the Tocome stream. The catchments having 4^{th} order streams are Catuche, Cotiza, Chapellin, La Julia, Galindo and Caurimare as well as Tocome.

1. 3 Identification of Potentially Affected Area by Debris Flow

The Valley of Caracas was formed by the sediment deposit generated from the Avila. Indeed as Dr. Singer indicated, the alluvial fans were developed downstream from the limit between the mountainous area of the Avila Massif and the Valley of Caracas. The streams, affluents of the Guaire River that have their origin in the mountainous zone, abruptly change of slope, giving rise to the deposition of alluvial fans.

The potentially affected area by debris flow from the Avila is definitely the alluvial fan within the Caracas Valley. From the geomorphologic viewpoint, such alluvial fans can be regarded as the area definitely affected by debris flow.

In addition, the fan apex downstream is highly occupied by valuable property such as barrio houses and formal house / building.

In Japan, a potentially affected area by debris flow is defined by topographical conditions. In principle, the potentially affected area by debris flow is the area from the debris flow generation point in the mountain to the alluvial fan whose slope is about 2 – 3 degree. In this Study, this criterion in Japan can be applied to the sediment study area in Caracas.

1. 4 Categorization of Potential Stream for Debris Flow[1]

In Japan, the potential stream for debris flow is categorized based on the type and the number of target property to be protected. The type is for example residential house and public building, etc. The number of the property is more than five (5) or less. In the sediment study area, the potentially affected area by debris flow is already highly occupied by residential houses and public buildings, etc. The number of the property is far beyond five (5). In this study, the potential stream for debris flow is not categorized in terms of the type and the number of target property to be protected.

1. 5 Factors for Occurring of Debris Flow

1. 5. 1. Streambed Slope

Generally the relation between the debris flow generation and the stream bed slope is as follows,

Slope Category	General Description of Section
$20^{\circ} < \theta$	Generation
$15^{\circ} < \theta <20^{\circ}$	Generation and Transport
$10^{\circ} < \theta <15^{\circ}$	Transport
$3^{\circ} < \theta <10^{\circ}$	Deposition

Figure S12-1.5.1 shows the stream bed slope profile along the trunk stream of major mountain stream in the Avila. In the upper part of the stream there are both reaches of debris floe generation and transport. Below the elevation 1,000 m there are mainly reaches for deposition.

---

[1] “Ministry of Construction, Guideline for the study of debris flow prone torrents and debris flow risky area, 1999”

1. 5. 2. Catchments Area

The catchment area of the basic point upstream is shown in Table S12-1.5.1. The basic point of each principal stream is corresponding to the point at which the debris flow starts to spread (flooding). Actually the basic point of each principal stream is the Cota Mil crossing point.

1. 5. 3. Streambed Condition

Figure S12-1.5.2 shows the distribution of unstable sediment on the streambed based on the field survey in this study. It can be seen that the eastern catchments have more unstable sediment on the streambed. Because in December 1999 among the debris flows which happened in the Avila, only the debris flows in the western catchment arrived at the fan apex downstream. The debris flow in the eastern catchment remained in the Avila.

1. 5. 4. Mountain Slope Condition

Figure S12-1.5.3 shows the distribution of potential slope collapse based on the field survey in this study. The new collapses including the active collapse are assumed to be those which happened in December 1999. The new collapses are mainly recognized in the upper part of the western catchment, while some new collapsed are seen in the middle part of eastern catchment. The old collapses are assumed to be of time scale several hundred and thousands years. The old collapses are mainly distributed in the eastern catchment, especially the lower part of catchment.

1. 5. 5. Condition of Sediment Control Structure

(1) Condition in the nearby Cotamil

Boyaca Avenue so called “Cota Mil” in Spanish is the significant structure for the mountain streams from the Avila. The principal streams for debris flow were categorized depending on the relation with the “Cota Mil” (Table S12-1.5.2).

Among the totally forty seven (47) principal streams, the streams which are not affected by “Cota Mil” at the basic point are five (5) streams west of the Cotiza stream and the three (3) streams east of the Caurimare stream.

The remaining thirty nine (39) principal streams are crossed by “Cota Mil” at their fan apex, that is the basic point in this study. The types of the crossing way are bridge, embankment with large culvert and embankment with small culvert / pipes. The bridge crossing can be seen in the Tocome, Chacaito and Gamboa streams. Comparatively large size culverts can be seen in the Cotiza and Anauco, Caurimare streams. Including these, for other streams, the collected or confirmed information on the site were shown in the Table S12-1.5.2, however, most of the sites are occupied by private and public ownership and also there was a security problem, so that the detailed site confirmation was difficult for the study team.

(2) Others

There are few sediment control structures in the Avila at present. Only an abandoned concrete weir for water supply in the Galindo Stream was recognized during the field visit. Also from the aerial photos, there were quite a few small scale gabions on the stream bed.

1. 6 Sketch of Mountain Stream Condition

In the mountain stream survey, the sketches for typical section, slope and weathering column were made as shown in Table S12-1.6.1. The location of each sketch is shown in Figure S12-1.6.1.

1. 7 Sediment Volume

1. 7. 1. Sediment Balance

For the evaluation of the possibility of debris flow in the mountain streams, it is significant to analyze the mechanism on sediment runoff. For El Avila Mountain, the December 1999 disaster is the only example available for the sufficient analysis.

(1) Sediment Balance in December 1999

During the event of December 1999 flood, the significant sediment runoff to the urban area took place in the Catuche, Cotiza and Anauco streams. In other streams the sediment movement might occur within the catchment, however, the runoff to the urban area was quite few. Here taking the phenomenon in the Catuche, Cotiza and Anauco streams in 1999 as a material, the ratio of the runoff sediment volume to the unstable sediment in the catchment is evaluated.

Figure S12-1.7.1 shows the schematic image of the unstable sediment in a catchment before and after the 1999 event. Before 1999 there was an amount of unstable sediment on the streambed.

For the event of December 1999, it is assumed that the steep slope, so-called the active collapse and new collapse, collapsed and went out to the connecting streams. Some part of the collapsed sediment and the unstable sediment on the streambed went out to the downstream urban area. The runoff sediment volume in 1999 was 50,000 m^3 in the Catuche (after the Study), 39,000 m^3 in the Cotiza after PREVENE and 31,000 m^3 in the Anauco after PREVENE.

After the December 1999 event, there has been no major sediment runoff so far, the remaining sediment deposits on the streambed.

The lower part of Figure S12-1.7.1 explains the sediment budget at the event of 1999 for the 3 streams. The left column of each stream is the summation of the sediment runoff in 1999 (=A) and the present unstable sediment on streambed. The right side column of each stream is the summation (=B) of the collapsed sediment in 1999 and the sediment deposit on streambed before 1999. The only unknown factor is the sediment deposit on streambed before 1999. This can be calculated if the left and right column were equal.

The objective sediment and its assumed thickness and runoff ratio are shown below:

Sediment Type	**Thickness (m)**	**Ratio of sediment runoff to connecting stream**
Unstable sediment on streambed	Varied on order of stream	-
Active Collapse	1.5	1.0
New collapse covered with grass	2.0	0.7

The ratio of the runoff sediment in 1999 to the unstable sediment before 1999 can be calculated as follows,

$$R = \frac{A}{B}$$

A is the runoff sediment volume in 1999. B is the summation of the collapsed sediment in 1999 and the sediment deposit on streambed before 1999. The collapsed sediment in 1999 means here the active collapse and new collapse covered with grass. The volume A of the Cotiza and Anauco streams includes the deposition just upstream of the Cota Mil.

The resultant ratio (=R) is 0.20, 0.25 and 0.27 for the Catuche, Cotiza and Anauco streams, respectively.

Based on this result, taking a safety side, the ratio of 0.30 can be applied for the evaluation of the sediment runoff in the next rainfall event that is corresponding to the December 1999.

(2) Sediment Balance for Future Event

Assuming the rainfall event corresponding to the December 1999 one, for the 47 mountain streams, the runoff sediment volume was estimated as follows (Figure S12-1.7.2), The ratio of the area of active slope collapse to the whole catchment area was calculated as 3.7 % for the western part of the Avila, in which significant slope collapses occurred in 1999 (Figure S12-1.7.3). This calculation was done based on the geomorphologic map made in the Study.

The assumed slope collapse area for the scenario event was calculated as the product of 3.7 % multiplied by each catchment area.

The sediment volume generated from the assumed slope collapse area was calculated as the product of the above collapsed area, thickness and the ratio of remaining sediment volume.

Thickness (m)	Ratio of remaining sediment volume to collapsed slope volume
2.3	0.3

Finally in order to estimate the sediment runoff volume below the control point of each catchment, the ratio of the runoff sediment for the future event to the present unstable sediment is assumed as R = 0.3 for the major catchment whose area is larger than 1.0 km^2, while R=1.0 was applied to the remaining small catchment.

The above sediment runoff volume below the control point is a kind of potential value based on the condition in the upper part of the Avila. The runoff sediment volume below the control point is actually affected by the topographic condition around the control point and the hydrological condition. As it is widely done in Japan, the following sediment volume was calculated as the value possible through the control point.

$$Vec = \frac{10^3 \cdot Rt \cdot A}{1-\lambda}\left(\frac{Cd}{1-Cd}\right)\cdot fr$$

Where A: Catchment area in km^2, Rt: 24 hours rainfall in mm for the selected return period, λ: void ratio(= 0.4), fr: runoff ratio, Cd: sediment concentration as a function of stream bed slope.

Cd is calculated as follows,

$$C_d = \frac{\rho \cdot \tan\theta}{(\sigma - \rho)(\tan\phi - \tan\theta)}$$

$\rho : density \quad of \quad water$

$\sigma : density \quad of \quad se\dim ent$

$\phi : \mathrm{int} ernal \quad friction \quad angle \quad of \quad se\dim ent$

$\theta : average \quad bed \quad slope \quad 200m \quad upstream \quad of \quad basic \quad po\mathrm{int}$

Fr is calculated as follows,

$$fr = 0.05(\log A - 2.0)^2 + 0.05$$
$$A : Catchment \quad area\ (km^2)$$

If the calculated Vec is smaller than the assumed sediment runoff volume, the Vec is selected as the design sediment volume.

Figure S12-1.7.4 shows the estimated runoff sediment for each principal catchment. The catchment No.14 is at the Tocome Stream, which has the largest runoff sediment volume among all. The second largest volume is expected in the Caurimare stream (No. 4). The Catuche (No.44) and Cotiza (No.42) streams have smaller estimated sediment volume compared with the eastern part of El Avila, because the unstable sediment in those two streams already went out of the catchment in 1999.

Figure S12-1.7.5 indicates the comparison of the estimated runoff sediment in Caracas and that in Vargas and Japan. The specific values per km^2 in Caracas are positioned in lower part compared to that in Vargas. This is because the rainfall amount for the data in Vargas is much larger than in Caracas. The two (2) parallel straight lines indicate the range of specific sediment runoff volume in Japan for the similar geological condition to Caracas. The assumed sediment volume in Caracas is basically also positioned in lower part compared to Japan.

1. 7. 2. Debris Flow Potential

In terms of the streambed slope there is no significant difference among the forty seven (47) mountain streams as well as among the unit catchments. So the total amount of unstable sediment volume and new and old collapse area is a major factor to indicate the potential of debris flow.

As the principal catchment-wise, the Tocome, Caurimare, Galindo, Chacaito and Cotiza have much sediment in this order to be generated at the future flood as shown in Figure S12-1.7.4.

Table S12-1.7.1 is the summary of sediment runoff volume for 100 years return period and 25 years return period.

Table S12-1.5.1 Crossing Condition of the Mountain Streams at Cota Mil

No. of Catchment	Catchment name	Catchment Area	Storage Volume at Cota Mil upstream	Crossing Condition at Cota Mil				
		(km2)	(m3)	Bridge	Large Culvert	Small Culvert	No Info.	Remark
–	Agua Salad							
47	Agua Salud	0.48						
46		0.08						
45	St. Isabel	0.09						
44	Catuche	4.50						
43		0.27						
42	Cotiza	3.80	444,852		*			3.5m*2.3m 2 Box
41	Anauco	3.69	116,246		*			5.5m*9m 1 Box
40		0.19	176				*	
39	Beatas	0.43	680				*	
38		0.19	14,941				*	
37	Gamboa	3.07	–	*				Bridge with pier (Open)
36		0.27					*	
35	Canoas(Sarria)	0.57	21,338			*		1300mm 1nos.
34		0.09					*	
33	Mariperez	0.70	72,161				*	
32		0.06					*	
31		0.24	3,270		*			2.0m*2.0m 1 Box
30	Cuno	0.60	9,462		*			2.0m*2.0m 1 Box
29		0.07				*		Dia.1070mm 1 nos.
28	Chapellin	1.19	7,353		*			Dia.2440mm 1 nos.
27		0.25				*		Dia.1520mm 1 nos.
26		0.16				*		Dia.1520mm 1 nos.
25	Chacaito	6.33	–	*				Bridge (Culvert 6m*10m)
24		0.21				*		Dia.1520mm 1 nos.
23	Seca	0.78			*			2.2m*2.2m 1 Box
22	Quintero	1.97			*			
21		0.27			*			2.5m*2.5m*1 Box
20		0.11				*		Dia.1520mm 1 nos.
19	Pajarito	1.37					*	
18		0.17					*	
17	Sebucan	1.57			*			2.0m*2.7m 1 Box
16	Agua de maiz	0.38				*		1500mm 1 nos.
15	Tenerias	1.40	10,835		*			4m*3m 1Box
14	Tocome	9.45	–	*				Bridge with pier (Open)
13		0.33					*	
12	La Julia	2.10				*		1 Box
11	Gamburi	0.25					*	
10		0.06					*	
9		0.12					*	
8	Pasaquire	1.14					*	
7		0.36					*	
6		0.09					*	
5	Galindo	3.85			*			Water Supply Dam H=15m
4	Caurimare	6.35			*			5m*3m 2 Box
3		0.08						
2		0.99						
1		0.16						
TOTAL		60.84		3	12	8	16	

Table S12-1.6.1 List of Sketch for Section, Slope and Column

Steep Slope		
No.	Stream	Serial No.
1	Tocome	T-1
2	Tocome	TO-33
3	Tocome	TO-31
4	Pasaquire	LJ-13
5	Cota Mil	CM-3
6	Pasaquire	PAS-2
7	Galindo	CAU-4
8	Tocome	TO-14
9	Gamboa	GAM-10
10	Gamboa	GAM-03
11	Cotiza	COT-02
12	Cartafuegos	RD-14
13	Road	RD-12

Weathering Column		
No.		
1	Road1	Car-2
2	Road1	Car-8
3	Road1	Car-14
4	Road1	Car-15
5	Road2	Rd-4
6	Road2	Rd-5
7	Road2	Rd-7
8	Road2	Rd-9
9	Road2	Rd-10
10	Road2	Rd-12
11	Road2	Rd-17
12	Tocome	TO-6
13	Tocome	TO-9
14	Caurimare	CAU-12
15	Quintero	Q1
16	Tenerias	TE-1
17	Tenerias	TE-5
18	La Julia	LJ-1
19	La Julia	LJ-3
20	La Julia	LJ-25

Cross Section		
No.	Stream	Serial No.
1	Caurimare	4-CAU-14
2	Caurimare	4-CAU-25
3	Caurimare	4-CAU-26
4	Galindo	5-GAL-1
5	Galindo	5-GAL-2
6	Galindo	5-GAL-4
7	Galindo	5-GAL-8
8	Galindo	5-GAL-9
9	Pasaquire	8-PAS-4
10	Camburi-La Julia	12-CAM-3
11	Camburi-La Julia	12-CAM-4
12	La Julia	12-LJ-20
13	La Julia	12-LJ-21
14	Camburi-La Julia	12-LJ-27
15	Camburi-La Julia	12-LJ-28
16	Camburi-La Julia	12-LJ-36
17	Tocome	14-TO-02
18	Tocome	14-TO-03
19	Tocome	14-TO-21
20	Tocome	14-TO-36
21	Tenerias-Tributary	15-TE-06
22	Tenerias	15-TE-09
23	Tenerias	15-TE-11
24	Sebucan	17-SE-01
25	Sebucan	17-SE-02
26	Sebucan	17-SE-05
27	Pajaritos	19-PAJ-02
28	Pajaritos	19-PAJ-03
29	Pajaritos	19-PAJ-07
30	Quintero	22-Q-4A
31	Quintero	22-Q-4B
32	Quintero	22-Q-5
33	Quintero	22-Q-7
34	Quintero	22-Q-8
35	Quintero	22-Q-17
36	Quintero	22-Q-32
37	Chacaito	25-CH-1
38	Chacaito	25-CH-2
39	Chacaito	25-CH-3
40	Chacaito	25-CH-5
41	Chacaito	25-CH-6
42	Chacaito	25-CH-8
43	Chacaito	25-CH-10
44	Chacaito	25-CH-12
45	Chapellin	28-AV-2
46	Chapellin	28-AV-3
47	Chapellin	28-AV-6
48	Chapellin	28-AV-7
49	Mariperez	33-MARi-1
50	Canoa	35-CAN-1
51	Canoa	33-CAN-2
52	Canoa	35-CAN-3
53	Canoa	35-CAN-4
54	Canoa	35-CAN-5
55	Canoa	35-RD-11
56	Gamboa	37-GAM-2
57	Gamboa	37-GAM-3
58	Gamboa	37-GAM-5
59	Anauco	41-ANA-2
60	Anauco	41-ANA-6
61	Cotiza	42-COT-11
62	Cotiza	42-COT-06
63	Catuche	44-CAT-04
64	Catuche	44-CAT-10
65	Catuche	44-CAT-18

Note: Serial No = Principal Stream No. + Location Number

Table S12-1.7.1 Sediment Runoff Volume

Principal Stream	Catchment Area	Potential				Return Period 100 yr.			Return Period 25 yr.			Cota Mil Pocket Capacity
		Unstable Sediment	Slope Failure Sediment	Runoff Sediment (Ve)	Specific Runoff Sediment	Transportable Sediment(Vec)	The smaller among Ve and Vec	Specific Sediment Volume	Transportable Sediment(Vec)	The smaller among Ve and Vec	Specific Sediment Volume	
	km2	m3	m3	m3	m3/km2	m3	m3	m3/km2	m3	m3	m3/km2	m3
1	0.16	0	9,591	9,591	59,570	9,299	9,299	57,756	7,751	7,751	48,144	
2	0.99	11,596	58,796	21,117	21,396	25,318	21,117	21,396	21,105	21,105	21,383	
3	0.08	0	4,468	4,468	59,570	3,830	3,830	51,067	3,193	3,193	42,571	
Caurimare 4	6.35	726,522	378,508	331,509	52,173	101,429	101,429	15,963	84,548	84,548	13,306	
Galindo 5	3.85	484,019	229,047	213,920	55,636	58,960	58,960	15,334	49,147	49,147	12,782	
6	0.09	1,613	5,183	6,796	78,115	12,171	6,796	78,115	10,145	6,796	78,115	
7	0.36	26,018	21,445	47,463	131,842	16,314	16,314	45,316	13,029	13,029	36,190	
8	1.14	45,810	68,089	34,169	29,895	35,448	34,169	29,895	28,309	28,309	24,768	13,400
9	0.12	0	6,970	6,970	59,570	16,039	6,970	59,570	12,809	6,970	59,570	
10	0.06	0	3,276	3,276	59,570	9,792	3,276	59,570	7,820	3,276	59,570	
11	0.25	17,199	14,714	31,913	129,201	15,134	15,134	61,270	11,797	11,797	47,763	
12	2.10	403,843	125,097	158,682	75,563	62,947	62,947	29,975	49,070	49,070	23,367	
13	0.33	20,238	19,479	39,717	121,460	50,512	39,717	121,460	39,377	39,377	120,418	
Tocome 14	9.45	1,716,695	562,817	683,854	72,381	152,175	152,175	16,107	118,627	118,627	12,556	
15	1.40	67,151	83,577	45,218	32,230	45,318	45,218	32,230	35,465	35,465	25,278	
16	0.38	9,464	22,637	32,100	84,475	52,003	32,100	84,475	40,698	32,100	84,475	
17	1.57	154,682	93,525	74,462	47,428	48,669	48,669	30,999	38,088	38,088	24,260	10,700
18	0.17	8,346	9,948	18,294	109,544	31,317	18,294	109,544	24,413	18,294	109,544	
19	1.37	128,422	81,849	63,081	45,911	44,718	44,718	32,546	34,996	34,996	25,470	
20	0.11	1,085	6,672	7,757	69,258	23,398	7,757	69,258	18,240	7,757	69,258	2,400
21	0.27	15,243	16,084	31,327	116,025	24,891	24,891	92,187	19,479	19,479	72,146	4,900
22	1.97	102,990	117,532	66,157	33,531	56,156	56,156	28,462	43,948	43,948	22,275	
23	0.78	48,798	46,167	94,964	122,535	30,802	30,802	39,744	24,105	24,105	31,104	
24	0.21	2,759	12,331	15,090	72,900	36,549	15,090	72,900	28,492	15,090	72,900	
Chacaito 25	6.33	428,734	377,197	241,779	38,184	112,394	112,394	17,750	87,960	87,960	13,891	
26	0.16	647	9,412	10,059	63,662	30,085	10,059	63,662	23,453	10,059	63,662	
27	0.25	4,046	15,071	19,118	75,563	42,165	19,118	75,563	32,869	19,118	75,563	
28	1.19	95,641	71,007	49,994	41,942	67,986	49,994	41,942	53,205	49,994	41,942	1,000
29	0.07	0	4,110	4,110	59,570	14,850	4,110	59,570	11,576	4,110	59,570	
30	0.60	21,511	35,623	57,134	95,542	70,924	57,134	95,542	55,505	55,505	92,818	3,800
31	0.24	0	13,999	13,999	59,570	34,374	13,999	59,570	26,881	13,999	59,570	
32	0.06	0	3,395	3,395	59,570	10,539	3,395	59,570	8,241	3,395	59,570	
Mariperez 33	0.70	16,868	41,461	58,328	83,805	26,564	26,564	38,167	20,773	20,773	29,847	
34	0.09	0	5,480	5,480	59,570	17,010	5,480	59,570	13,302	5,480	59,570	
35	0.57	41,973	33,895	75,869	133,337	23,196	23,196	40,767	18,140	18,140	31,880	
36	0.27	1,234	15,846	17,079	64,207	30,780	17,079	64,207	24,604	17,079	64,207	
Gamboa 37	3.07	91,399	182,939	82,302	26,800	71,825	71,825	23,388	73,030	73,030	23,781	
38	0.19	0	11,437	11,437	59,570	24,398	11,437	59,570	19,503	11,437	59,570	
39	0.43	10,855	25,436	36,292	84,993	15,636	15,636	36,618	12,499	12,499	29,271	
40	0.19	0	11,378	11,378	59,570	24,307	11,378	59,570	19,430	11,378	59,570	
Anauco 41	3.69	136,514	219,813	106,898	28,970	233,670	106,898	28,970	179,110	106,898	28,970	68,500
Cotiza 42	3.80	331,373	226,247	167,286	44,046	144,514	144,514	38,050	110,771	110,771	29,166	93,000
43	0.27	3,515	16,024	19,540	72,638	11,326	11,326	42,106	9,054	9,054	33,657	
Catuche 44	4.50	203,068	268,005	141,322	31,412	95,859	95,859	21,307	73,477	73,477	16,332	
45	0.09	0	5,421	5,421	59,570	13,798	5,421	59,570	11,030	5,421	59,570	
46	0.08	0	4,885	4,885	59,570	12,434	4,885	59,570	9,939	4,885	59,570	
47	0.48	18,774	28,474	47,248	98,846	21,708	21,708	45,414	17,352	17,352	36,302	
Total	60.84	5,398,644	3,624,358	3,232,250	−		1,699,240	−		1,454,133		197,700

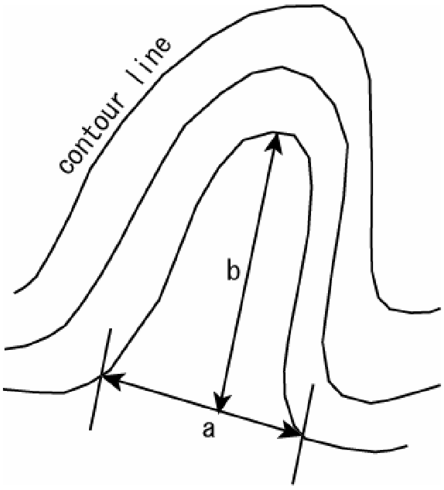


Figure S12-1.2.1 Definition of 1st Order Stream

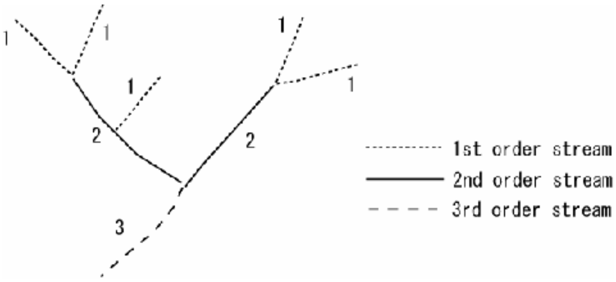


Figure S12-1.2.2 Stream Order Concept of Strahler

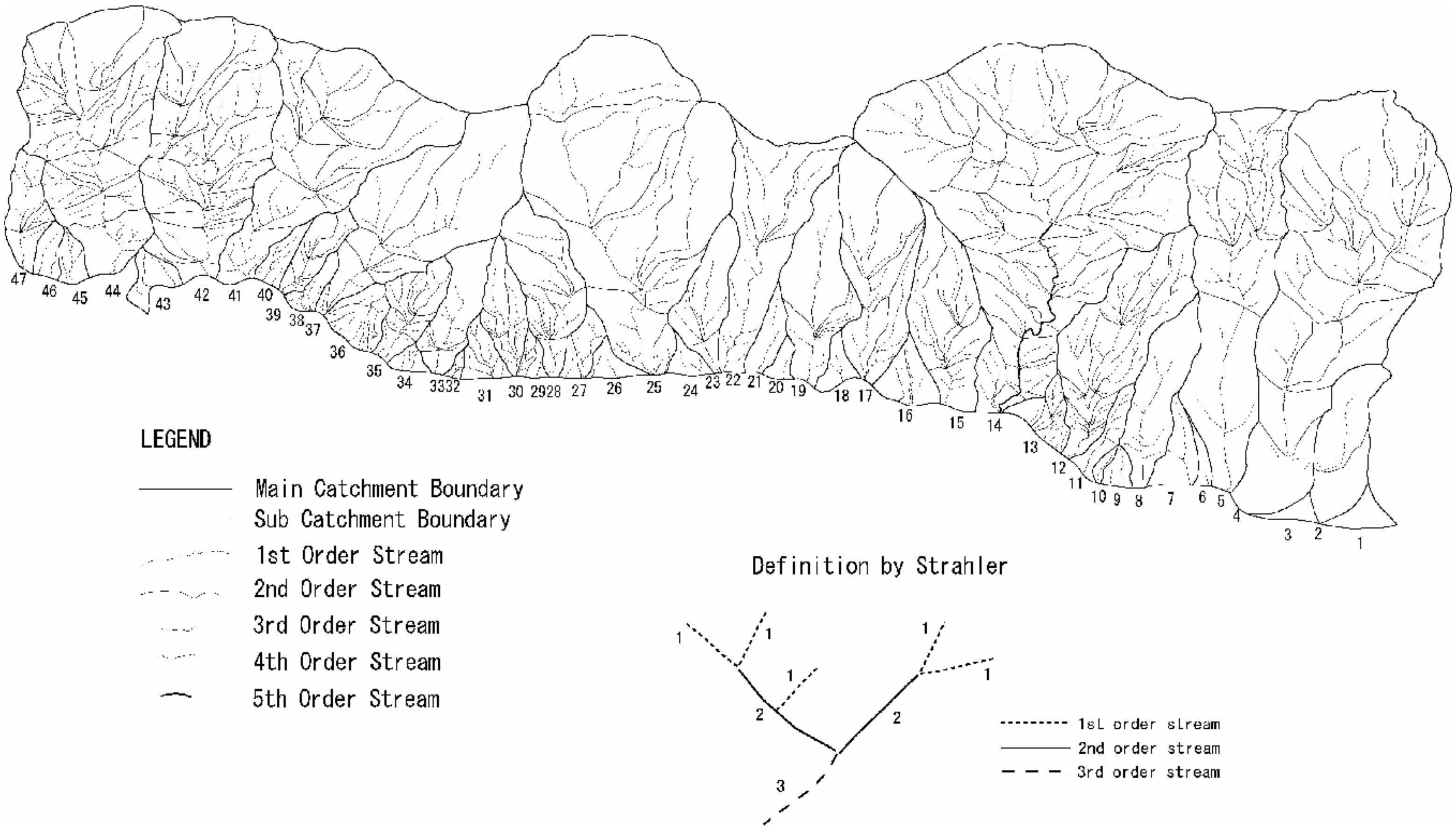


Figure S12-1.2.3 Sub-catchment Boundary for the 2^{nd} Order Stream as Unit Catchment

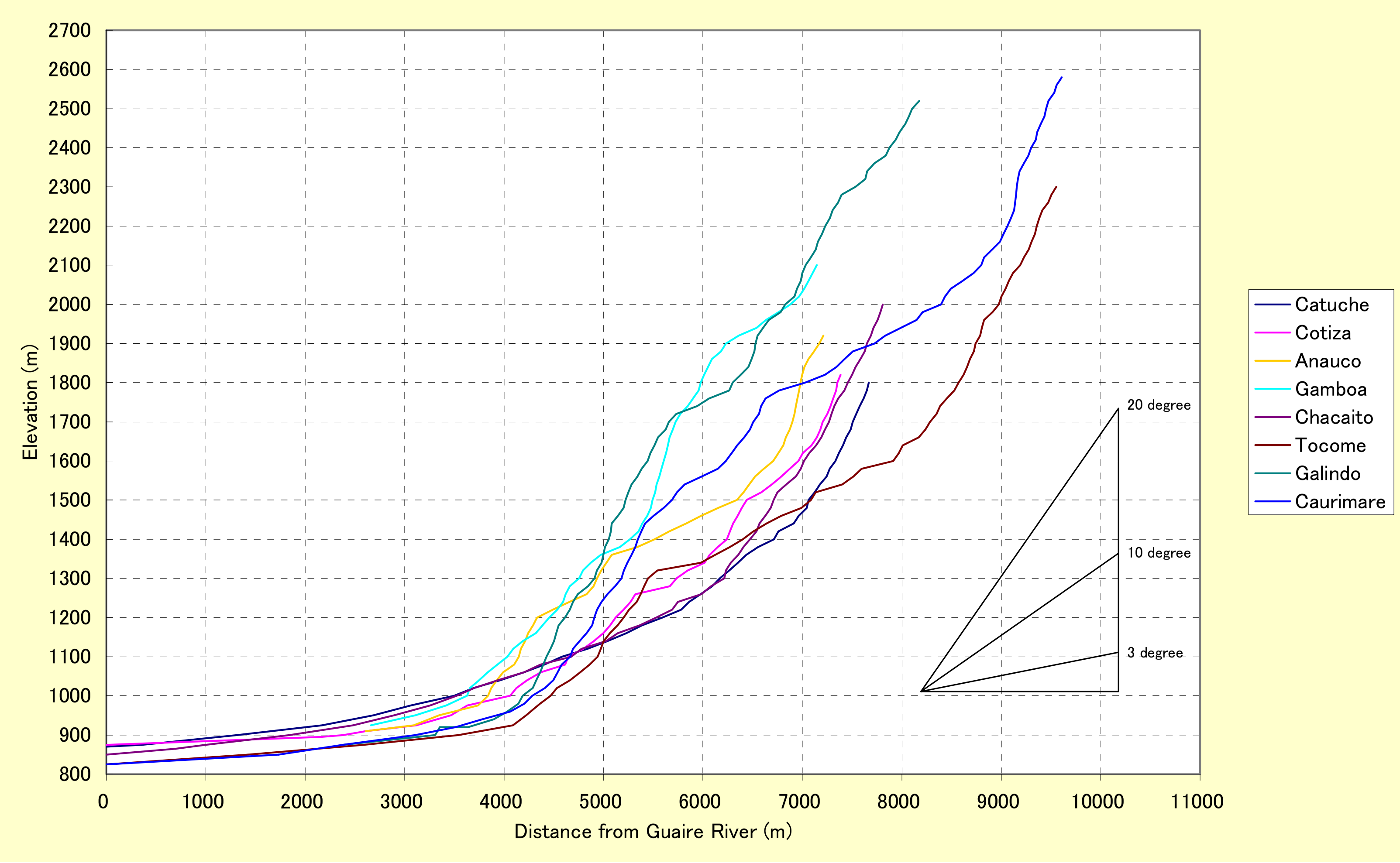


Figure S12-1.5.1 Streambed Profile

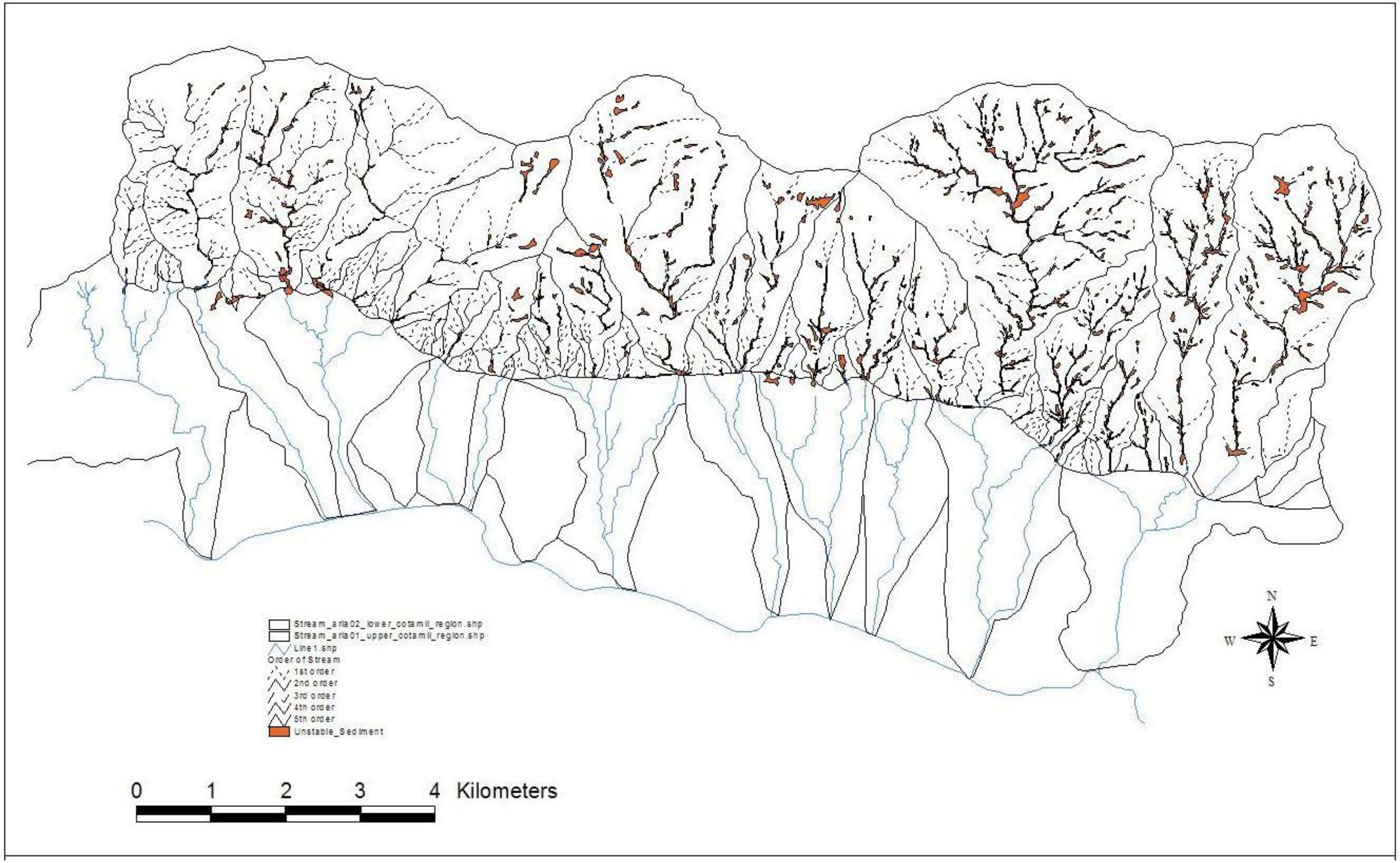


Figure S12-1.5.2 Unstable Sediment on Streambed

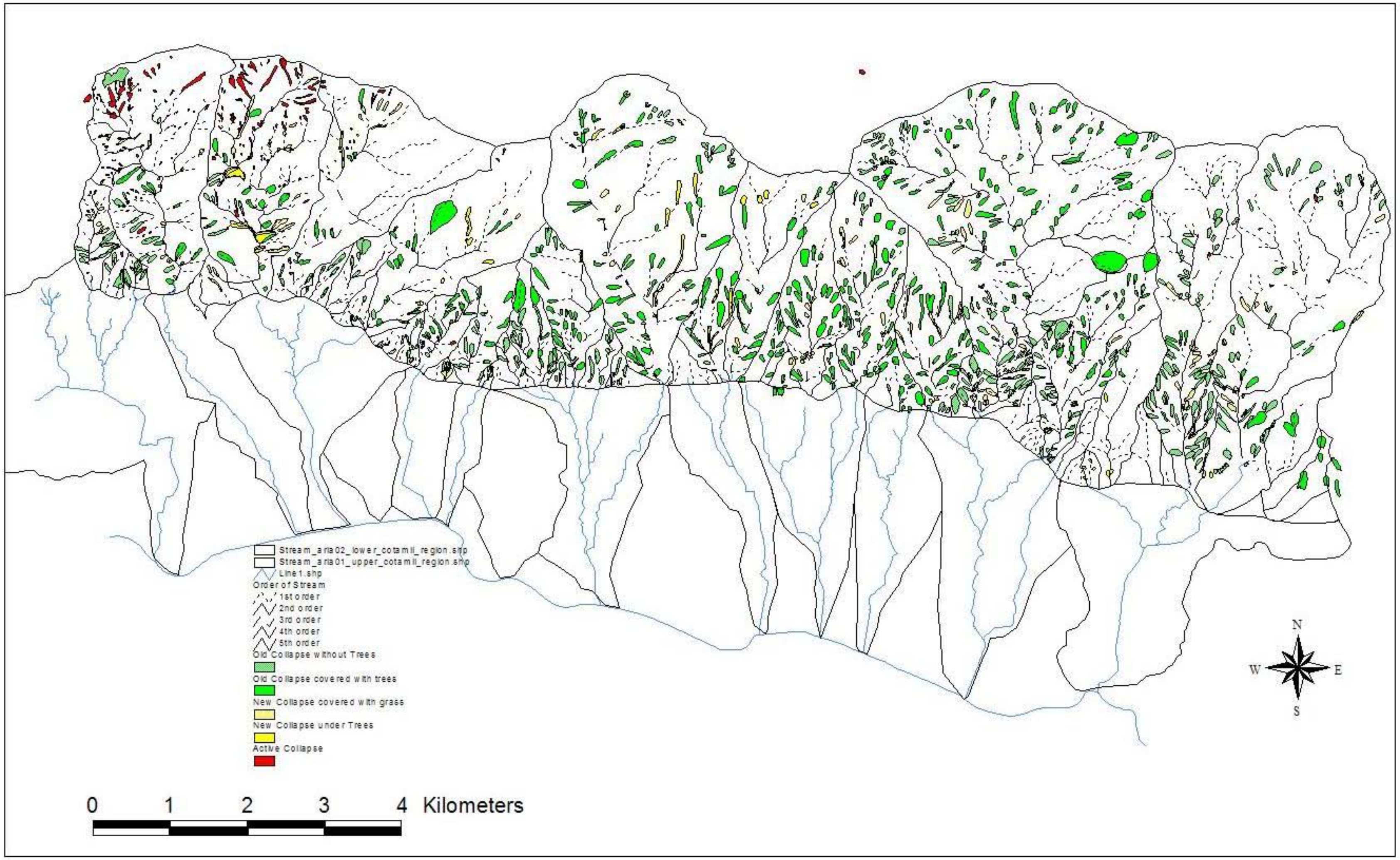


Figure S12-1.5.3 Potential Slope Collapse

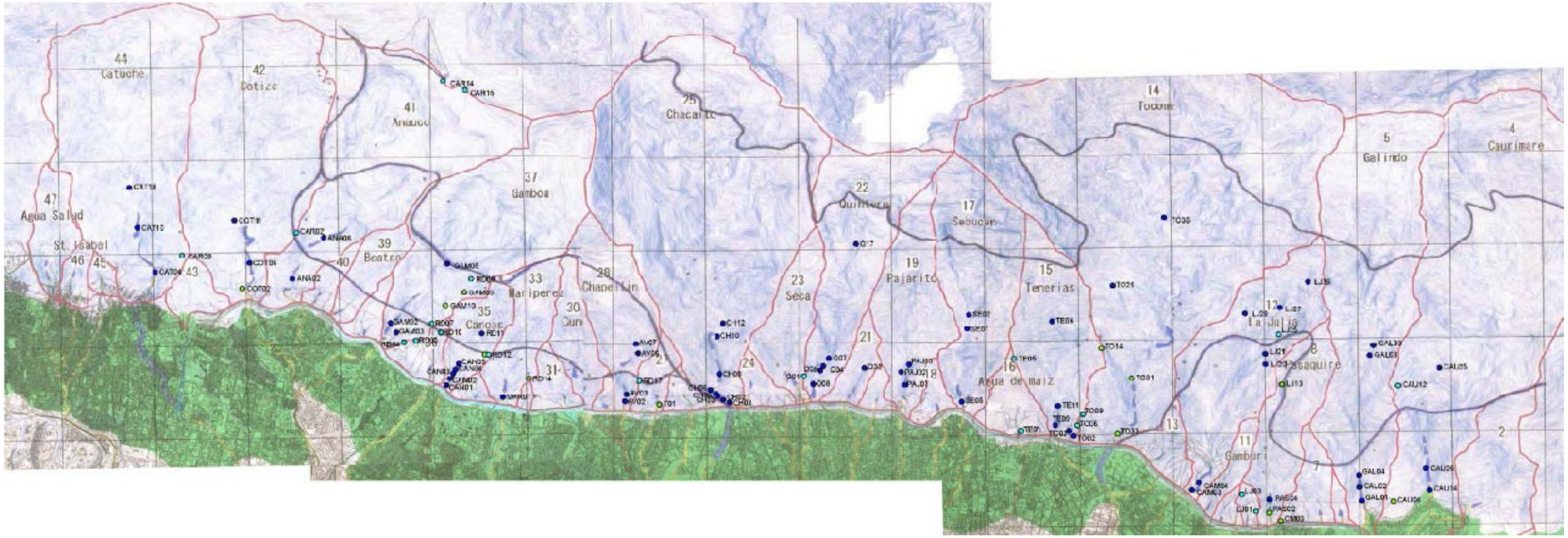


Figure S12-1.6.1 Location of Sketch for Section, Slope and Column

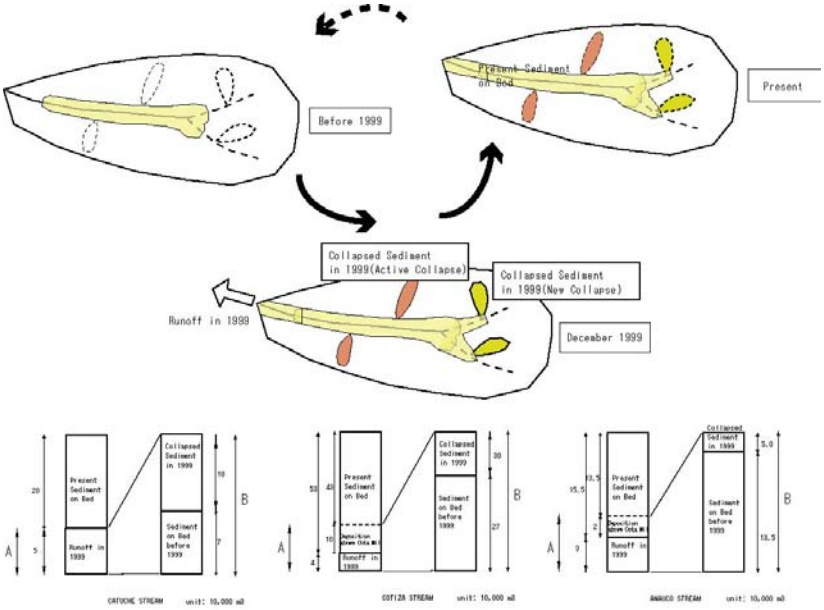


Figure S12-1.7.1 Sediment Movement before and After December 1999 Flood

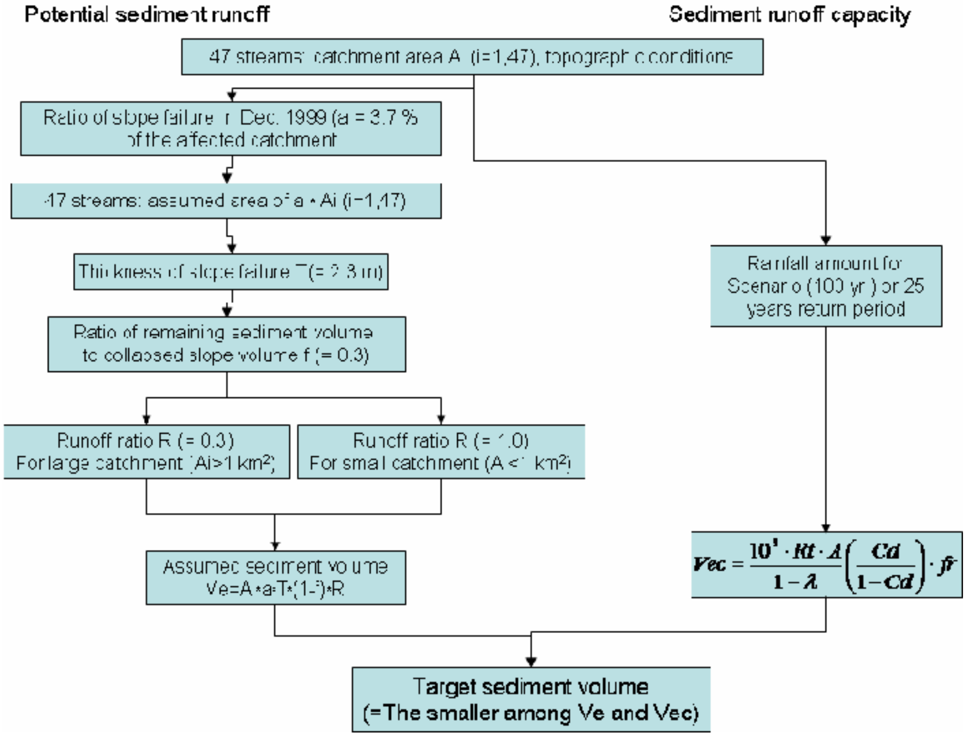


Figure S12-1.7.2 Evaluation Flow for Target Sediment Volume

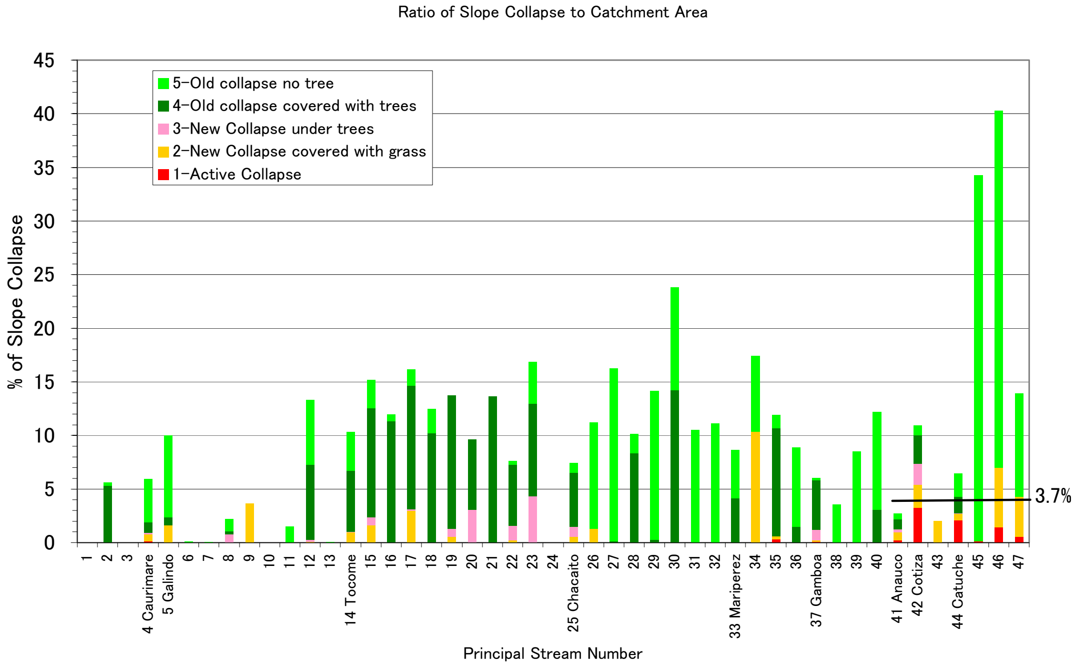


Figure S12-1.7.3　Ratio of Slope Collapse to Catchment Area

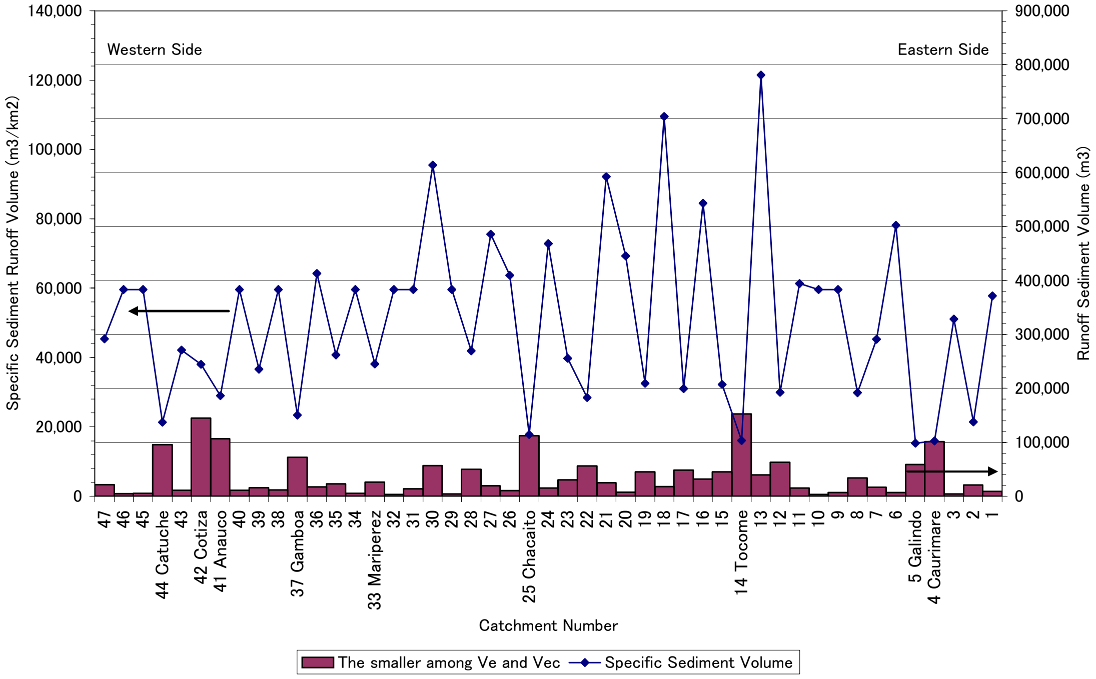


Figure S12-1.7.4　Target Sediment Volume

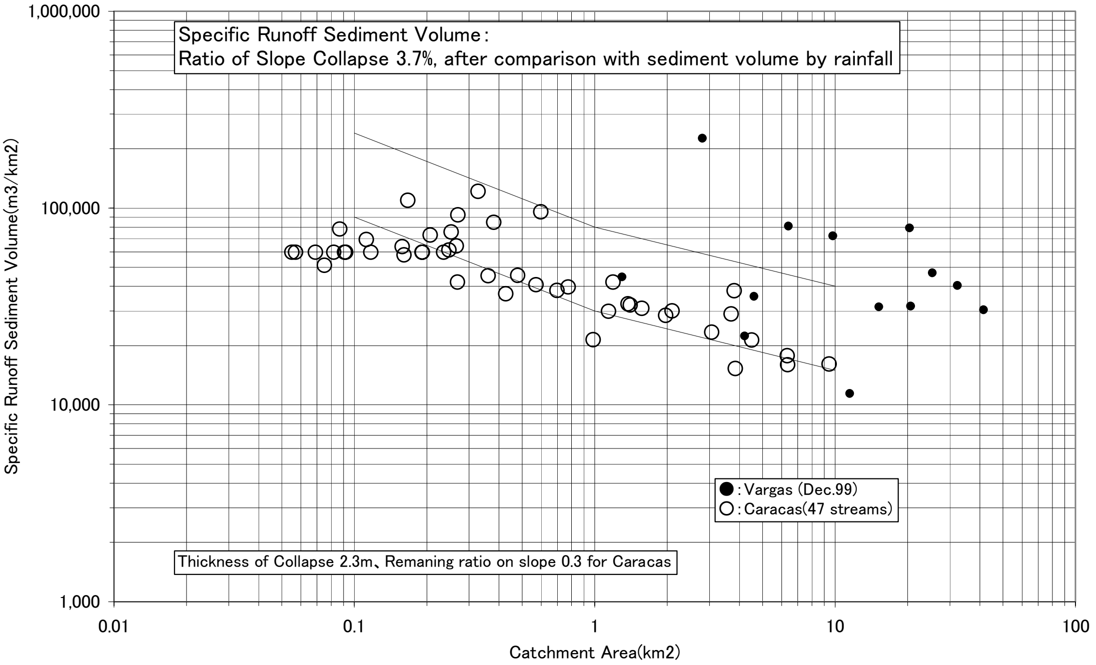


Figure S12-1.7.5　Target Sediment Volume per Catchment Area

CHAPTER 2 DEBRIS FLOW HAZARD / RISK

2. 1 Mapping Streams

In the previous chapter, there were totally forty seven (47) principal streams in the Avila. The scope of works of the JICA study specifies twenty streams (20), which are completely included in the above forty seven (47) principal streams in the Avila. The 20 streams can be grouped into 11 alluvial fans, which are subjective to the hazard and risk mapping in this study. Table S12-2.1.1 shows the relation between the 20 streams and the 11 alluvial fans.

Hazard mapping for the 11 alluvial fans has also been executed by PREVENE, the Avila Project and the Caracas Project in Venezuela. The Table S12-2.1.1 also shows the project names covering these 11 alluvial fans.

Among the above 11 alluvial fans, the Cotiza-Anauco-Gamboa and Tocome-La Julia models were developed by “PREVENE” while the remaining were developed in the “Mapa de Amenaza” by Central University in Venezuela (UCV) except for the Caroata Stream. In addition to the “Mapa de Amenaza”, UCV has been conducting an extensive study of drainage system for the 11 alluvial fans including the Caroata stream to improve the simulation models in the Caracas Project.

2. 2 Methodology

This chapter describes the methodology how to delineate the hazardous / risky area by debris flow for the sediment study area.

The methods of the above PREVENE, Avila Project and Caracas Project can be explained as follows (Table S12-2.2.1).

First of all, the rainfall and runoff simulation for the Avila has difference between the PREVENE, and the Avila Project / Caracas Project. The PREVENE applied unit hydrograph method, whereas the Avila Project / Caracas Project is using the kinematic wave method which was conducted by MARN (CGR Engineers).

Regarding the flood simulation for the Caracas Valley, the FLO-2D model was used by these projects.

The rainfall-runoff simulation by MARN (CGR Engineers) is a comprehensive hydrological study for the entire Avila mountain, while the PREVENE was a kind of pilot study for some specific study areas. The Study Team reviewed the results of rainfall-runoff simulation by MARN (CGR Engineers) and compared with the conventional rational formula as described in Supporting Report S13 (Hydrology). Since the hydrological study by MARN (CGR Engineers) has been the basis in the hazard mapping field in Caracas, the Study Team decided to make use of the results as a runoff (water) data from the Avila. For the debris flow hazard mapping, the Study Team took into consideration of sediment volume based on the filed survey in this study.

For the hydraulic modeling, the Study Team merged the 11 alluvial fans into the west and the east modeled area. For each modeled area, the flood simulation model was made using FLO-2D covering the all 11 alluvial fans. The FLO-2D model by the Study Team was designed in order to analyze the effect of sabo dam in the Avila simply taking into consideration of the Master Plan level.

The difference between the model of the Avila Project and the model by JICA Study Team is shown in Table S12-2.2.2.

The hazard map is created by two (2) methods. Method 1 is by Japanese Law Sediment Disaster Prevention. Method 2 is by FLO-2D Model.

2. 3 Method 1: Method by Japanese Law Sediment Disaster Prevention

The Law of Sediment Disaster Prevention, which was issued in 2000 in Japan, and the related guidelines indicate the methodology to delineate the potential area for debris flow.

2. 3. 1. Peak Discharge and Height of Debris Flow

The potential peak discharge by debris flow can be calculated as follows,

$$Q_{sp} = \frac{0.01 \cdot C_*}{Cd} \cdot V$$

$$Cd = \frac{\rho \cdot \tan\theta}{(\sigma - \rho)(\tan\phi - \tan\theta)}$$

where Qsp : potential peak discharge by debris flow, V : transported sediment volume by debris flow, C* : volumetric concentration of the deposit (= 0.6), Cd : concentration of debris flow after Takahashi, σ : specific density of sediment (t/m^3) (= 2.6), ρ : flow density (t/m^3) (= 1.2), ϕ : internal friction angle (degree) (= 35), theta : slope of stream bed (degree).

The unit weight of debris flow and the velocity of debris flow are as follows,

$$\rho_d = \frac{\rho \cdot \tan\theta}{\tan\phi - \tan\theta}$$

$$U = \frac{h^{2/3} \cdot (\sin\theta)^{1/2}}{n}$$

where row-d : unit weight of debris flow (t/m^3), h : depth of debris flow (m), U : average velocity of debris flow (m/s), n: Manning's roughness (= 0.1 for natural channel).

Therefore, the depth (height) of debris flow can be expressed as

$$h = \frac{Q_{sp}}{B \cdot U} = \left(\frac{n \cdot Q_{sp}}{B \cdot (\sin\theta)^{1/2}} \right)^{3/5}$$

2. 3. 2. Flow Width of Debris Flow (B)

The flow width of debris flow can be evaluated by 2 kinds of approaches, namely Manning method and Regime method.

The Manning method is to calculate the flow width which can satisfy the following equation.

$$Q_{sp} = \frac{1}{n} \left(\frac{A}{S} \right)^{2/3} (\sin\theta)^{1/2} \cdot A$$

where A : flow area (m^2), S : hydraulic radius of the section (m).

In the case of laterally flat alluvial fan, it is difficult to evaluate the flow width from the above formulas. For such case, the regime theory can be applied.

The regime theory is as follows,

$$B = 4\sqrt{Q_{sp}}$$

If both methods can be applicable to evaluate the flow width (B) in a cross section, the smaller width (B) is selected.

2. 3. 3. Longitudinal Change of Debris Flow

The following equations are the relation between the volumetric concentration of debris flow and the peak discharge of debris flow while the debris flow goes downstream.

$$Qsp_i = \frac{C_* - Cd_{i-1}}{C_* - Cd_i} Qsp_{i-1}$$

where suffix (i) and (i-1) indicate downstream and upstream, respectively.

2. 3. 4. Definition of "Red Zone"

The seriously affected area by debris flow so called "Red Zone" can be defined as the section in which the hydraulic force by debris flow is larger than the resistant force of house / building.

The hydraulic force in kN/m^2 is expressed as

$$F_d = \frac{\rho_d}{g} \cdot U^2$$

The resistance force of house / building is

$$P_2 = \frac{35.3}{H(5.6 - H)}$$

where P_2 : resistance force of ordinary house / building in kN/m^2, H : height of debris flow when the force is acted on the house / building by debris flow.

The equation of P_2 has been authorized in Japan by the Law of Sediment Disaster Prevention, however, it is based on the structure of ordinal wooden house in Japan.

In this study, the yield strength for concrete columns against debris flow attack was developed as explained below.

1. Basic Conditions
Concrete compressed strength : "Sigma-c" (kgf/cm^2)
Short-term strength for concrete shear force : Fs =(Sigma-c) / 30 * 3
Size of Concrete Column: D (cm)
Sectional Area of Concrete Column : As = D^2
Yield Shear Strength of Concrete Column : Qdmax=(2/3) * As * Fs

Assuming the uniform load (p) acts on the concrete column of the 1st floor,

$2*Q_d=h_0*p*b$
where h0 is the height of the column (cm), p is the uniform load (kgf/cm^2) and b is the span between 2 columns (cm).

The assumed structure model is shown in Figure S12-2.3.1.

It is assumed that the load by the debris flow acts on the column as the uniform load. The above statically indeterminate beam can be solved as follows,

$$Q_{da} = \frac{pH}{8h_0^3}\left[4\left(H^2\right)h_0 - H^3\right] = \frac{pH^3}{8h_0^3}\left[4h_0 - H \quad\right]$$

$$Q_{db} = \frac{pH}{8h_0^3}\left[8h_0^3 - 4\left(H^2\right)h_0 + H^3\right]$$

Therefore, the uniform load, p, can be expressed as a function of H, as follows,

$$p = \frac{8h_0^3 Q_{db}}{H(8h_0^3 - 4\left(H^2\right)h_0 + H^3)b} = \frac{8h_0^3(Qd_{\max})}{H(8h_0^3 - 4\left(H^2\right)h_0 + H^3)b} \qquad \cdots Eq(1)$$

The applied parameters are as follows,

	Concrete Columns of Barrio Area	Concrete Columns of Urban Area		Wooden Columns in Japan
Height of Columns h0 (cm)	300	300		280
Interval of Columns b (cm)	350	600		91
Area of Column D^2 (cm^2)	20*20	30*30		10.5 * 3.5
Compressed Strength Sigma-c (kgf/cm^2)	80	180		-
Short-term shear strength Fs (kgf/cm^2)	80/30*3=8	180/30*3=18		6*3*(4/3)=24

According to the above structure analysis in this study, the yield strength of concrete columns of barrio house in Caracas is almost same as that of ordinary wooden house in Japan. The concrete column of house in formal area in Caracas has stronger strength than that of ordinary wooden house in Japan (Figure S12-2.3.2).

Figure S12-2.3.3 and Table S12-2.3.2 show an example of calculation. The cross sections on the plane view and the depth and width for each section are shown.

2. 3. 5. Definition of “Yellow Zone”

The normally affected area by debris flow so called “Yellow Zone” can be defined as the section in which the potentially debris flow could reach from the topographical viewpoint. The yellow zone is the basic point downstream and the slope two (2) degree upstream, in principle.

The concept to delineate the yellow zone in the valley shape cross section is illustrated in Figure S12-2.3.4. If the height of red zone is less than 5 m, then the height of the yellow zone will be 5 m. If the height of red zone is more than 5 m, then the height of the yellow zone will be 1 m above the height of the red zone.

“Fan Rule” is applicable when the cross section is flat and the area of 5 m height can not be decided. The fan rule is illustrated in Figure S12-2.3.5. The 40 m length vector (dotted line) is described as the steepest slope direction from each end point of the yellow zone. The vector (non-dotted line) for the yellow zone is described as thirty (30) degrees from the dotted vector. The vector for the yellow zone is repeated until the slope is less than two (2) degrees.

2. 3. 6. Hazard / Risk Map by Method -1

Figure S12-2.3.6 is the debris flow hazard map by the method-1. The number of affected house and the total area of the house in Yellow and Red Zones are shown in Table S12-2.3.3 and Table S12-2.3.4. From the 2,700 houses located in the red zone, 1,300 are barrio houses of which about 1,000 are built in the streams. Therefore, it is recommended that these are relocated.

The former table is the principal stream basis, in which the counted property numbers have duplicated counts in alluvial fans. The former table can be referred when individual principal streams are compared in terms of the potential hazard.

The latter table is the alluvial fan basis, in which the counted numbers do not have any duplication in alluvial fans. As a scenario case, if debris flows happen in all the principal streams, the hazard area can be shown in the latter table (Figure S12-2.3.7).

The Risk map is shown in Figure S12-2.3.8. This is the map that is classified by the colors according to the density of houses in the hazardous area based on the hazard map.

2. 4 Method 2: Method by FLO-2D Model

2. 4. 1. Hydrological Part

(1) Modeled Area

The hydrological study report “Estudio de Crecidas” is focused on the mountainous area above the 1,000 Meter Road (the Cota Mil) of each stream. The report studied the design rainfall hyetograph by return period for the areas. Also the design discharge is calculated by rainfall-runoff analysis.

The output of the hydrological study is configured as the upstream boundary condition for the hydraulic analysis.

(2) Rainfall Analysis

"Estudio de Crecidas" states that the distribution of monthly rainfall in Caracas Valley is quite different from that in Vargas State, which means that the metereological characteristics are different among them. While the distributions of monthly rainfall within Caracas Valley are similar among the rainfall stations, the aerial distribution in terms of short duration rainfall has a large variation. Hence, five (5) rainfall stations were selected as representative stations for the southern part of El Avila Mountain.

The report pointed out that the heavy rainfall in Caracas did not continue for several days as it happened in Vargas.

(3) Runoff Calculation

For the conversion of the rainfall amount to the runoff discharge, SCS method was used to estimate the effective rainfall amount and the kinematics wave method was applied to produce the runoff hydrographs.

2. 4. 2. Hydraulic Part (FLO-2D)

(1) Applicability for the topography of the area to be modeled

The hydraulic study is focused on the urban area below the 1,000 Meter Road (the Cota Mil) of each stream. The area to be modeled is the alluvial fan that was composed of sediment from El Avila. The slope along the streams is very steep and the contour lines of the area are fan-shape, so that the floodwater tends to flow downward very rapidly and to spread. The floodwater passing the fan apex could distribute into two directions depending on the topography. In the above sense, the use of the 2-dimensional hydraulic model "FLO-2D" is quite appropriate.

(2) Usability in Venezuela

"FLO-2D" is commercial software. It was developed by Dr. Jim O'Brien in the United States of America and by Dr. Reinaldo Garcia in the Central University of Venezuela (UCV). The UCV is one of the counter parts of the Study.

The methodology for the use of FLO-2D was tested in twenty-three sites in the Caracas and Vargas State region by Venezuelan side. The hazard maps of the Vargas State are being used by planners of the Venezuelan Ministry of Environment and Natural Resources and other agencies to design emergency plans and new land use policies. The methodology is being expanded to other flood hazard regions in Venezuela.

(3) Usability in the world

FLO-2D is a hydraulic software officially evaluated as hazard mapping tool by the Federal Emergency Management Agency in the United States. It is widely used for flood hazard mapping in a lot of countries as well as in the USA. This means that there are a lot of users for the software in the world and it has been applied to many practical problems.

(4) Hydraulic Solution Concept

FLO-2D is a two-dimensional flood routing model that is a valuable tool for delineating flood hazards, regulating floodplain zoning and designing flood mitigation. FLO-2D routes a flood hydrograph using the full dynamic wave momentum equations and guaranteeing volume conservation to accurately predict the area of inundation. The fluid viscous and yield stress terms are accounted in the model. The channel and floodplain roughness play a role in the turbulent stresses in the full dynamic wave equation. The model is effective for analyzing river overbank flows, but it is also valuable for analyzing unconventional flooding problems such as unconfined flows over complex topography and roughness, spilt flows, mud / debris flows and urban flooding. The key to the model applicability is volume conservation that tracks the flood wave progression over unconfined surfaces. Flood hazard delineation detail can be enhanced with FLO-2D by modeling rainfall and infiltration, applying bridge, culvert and levee components, simulating hyper-concentrated sediment flows or by modeling the effects of buildings or flow obstructions.

(5) Mathematical Equations and Solution

The governing equations for hydrodynamic computation are as follows,

$$\frac{\partial h}{\partial t} + \frac{\partial h V_x}{\partial x} + \frac{\partial h V_y}{\partial y} = i$$

$$S_{fx} = S_{ox} - \frac{\partial h}{\partial x} - \frac{V_x}{g}\frac{\partial V_x}{\partial x} - \frac{V_y}{g}\frac{\partial V_y}{\partial y} - \frac{1}{g}\frac{\partial V_x}{\partial t} \quad S_{fy} = S_{oy} - \frac{\partial h}{\partial y} - \frac{V_y}{g}\frac{\partial V_y}{\partial y} - \frac{V_x}{g}\frac{\partial V_y}{\partial x} - \frac{1}{g}\frac{\partial V_y}{\partial t}$$

Where h is the flow depth, Vx and Vy are the depth averaged velocity components along the x- and y- coordinates, and I is excess rainfall intensity.

The differential form of the continuity and momentum equations in the FLO-2D model is solved with a central, finite difference scheme. The solution domain is discretized into uniform, square grid elements.

The friction slope components S_{fx} and S_{fy} are composed of yield slope component, viscous slope component and turbulent-dispersive slope component.

$$S_f = S_y + S_v + S_{td}$$

$$S_f : friction\,slope \quad S_y : yield\,slope \quad S_v : viscous\,slope \quad S_{td} : turbulent - dispersive\ \ slope$$

FLO-2D routes hyper-concentrated sediment flows (mud and debris flow) as a fluid continuum by predicting viscous fluid motion. For mudflows, the motion of the fluid matrix is governed by the sediment concentration. A quadratic rheologic model for predicting viscous and yield stresses as function of sediment concentration is employed and sediment volumes are tracked through the system. As sediment concentration changes for a given grid element, dilution effects, mudflow cessation and the remobilization of deposits are simulated.

(6) Criteria of Simulation

The model takes into account the hydraulic structures such as channel, culvert and bridge and existing infrastructure as building density.

The model is the two (2) dimensional and the grid size is 30 m * 30 m except for the Tocome and Anauco models. The hydraulic structure can be modeled within a grid.

The discharge hydrograph for water to be used is based on the study “Estudio de Crecidas”. For the return periods of 10, 100 and 500 years, the hazard maps has been prepared.

The hydrograph for sediment material at the upstream boundary is made to consider the ratio of sediment concentration to water discharge.

The reduction factor on building area, which could affect the depth of water and sediment, is taken into account.

2. 4. 3. FLO-2D Modeling for Caracas

(1) Modeled Area

The 11 alluvial fans were divided into 2 separate modeled areas, namely the east model and the west model. The east model covers the Caurmare, Tocome, Agua de Maiz, Sebucan, Seca and Chacaito alluvial fans. The west model covers the Mariperez, Canoas, Anauco, Catuche and Caroata.

Each model can simulate the floods of all the alluvial fans in one run. So the model can simulate the flood water from 2 alluvial fans to converge and form the contiguous flooded area.

(2) Grid Size and Grid Elevation

The grid size was set to 100 m * 100 m square. It was decided to consider the spatial scale of topography accuracy as well as the modeling work volume. Especially the grid size can affect on the modeling work volume directly because it is necessary to adjust the model data such as elevation, channel section, roughness for each grid cell in the course of repeated simulation runs.

The grid elevation was given by the average elevation of the point elevation data of 5 meter resolution DTM which was generated from the base map (scale 1:5,000) for this study.

(3) Channel

The channel within grid was configured for main streams in both models. All the channels are regarded as open channel with rectangular shape.

(4) Sediment Concentration

Due to the software requirement, for the simulation of debris flow the sediment concentration must be at least 0.20. For the scenario case, the sediment concentration was decided to input the total sediment volume as the portion exceeding the sediment concentration 0.20, equal to the target sediment volume.

Based on the FLO-2D concept, sediment discharge is calculated as follows,

$$Qsp = \frac{Cv}{1 - Cv} Qp$$

$$Cv : volumetric \quad se\dim ent \quad concentration$$

Qp is water discharge given by the rainfall and runoff calculation. As shown in the Figure S12-2.4.1 below, the sediment discharge graph is given by setting of sediment concentration profile (time series). The sediment runoff volume shown in Table S12-2.3.1, for example V=101,400 m3 for the Caurimare catchment, is almost equivalent to the integration of the sediment discharge profile.

The timing of debris flow occurrence was set approximately 30 minutes around the peak of water discharge hydrograph.

2. 4. 4. FLO-2D Model Runs

(1) Case

The simulated cases are 10 years, 100 years in terms of return period of design rainfall under existing condition. The considered sediment conditions are no debris flow happening (Cv = 0.2 constant) for 10 years, sediment runoff volume for 100 years.

As a reference, assuming all the Sabo Dams are constructed in the Avila, one (1) case was simulated for 100 years return period.

(2) Results

Figure S12-2.4.2 and Figure S12-2.4.3 are the depth and velocity for 100 years return period under the existing condition. The values of depth and velocity are the average value for each grid cell.

Figure S12-2.4.4 is the depth for 100 years return period assuming all the Sabo Dam constructed in the future. The peak discharge was reduced because of less sediment concentration, resulting into that the flooded area was also reduced.

Table S12-2.1.1 Subjective Mountain Streams for Debris Flow Hazard Mapping

	20 streams by JICA S/W	**Name of Alluvial Fan**	**Venezuelan Study**
1	Caroata, Agua Salud, Agua Salada	Caroata	“Proyecto Caracas”
2	Catuche	Catuche	“Mapa de Amenaza”
3	Cotiza, Anauco, Gamboa	Cotiza-Anauco-Gamboa	“PREVENE”
4	Sarria (Canoas)	Canoas	“Proyecto Caracas”
5	Mariperez	Mariperez	“Mapa de Amenaza”
6	Chapellin, Chacaito	Chacaito-Chapellin	“Mapa de Amenaza”
7	Quintero	Quebrada Seca	“Mapa de Amenaza”
8	Pajaritos, Sebucan	Pajaritos-Sebucan	“Mapa de Amenaza”
9	Tenería	Agua de Maíz	“Mapa de Amenaza”
10	Tocome, La Julia	Tócome-La Julia	“PREVENE”
11	Pasaquire, Galindo, Caurimare	Caurimare-Galindo-Pasaquire	“Mapa de Amenaza”

Table S12-2.2.1 Model Structure

	PREVENE	Avila / Caracas Project	JICA Study
Rainfall Runoff Model	Unit Hydrograph	Kinematic wave(MARN-CGR report)	Kinematic wave(MARN-CGR report)
Hydraulic Model	FLO-2D (Tocome, Anauco)	FLO-2D (11 alluvial fans, each alluvial fan has a separated model)	FLO-2D (11 alluvial fans, combined as 2 models)
	25 m grid	30 m grid	100m grid

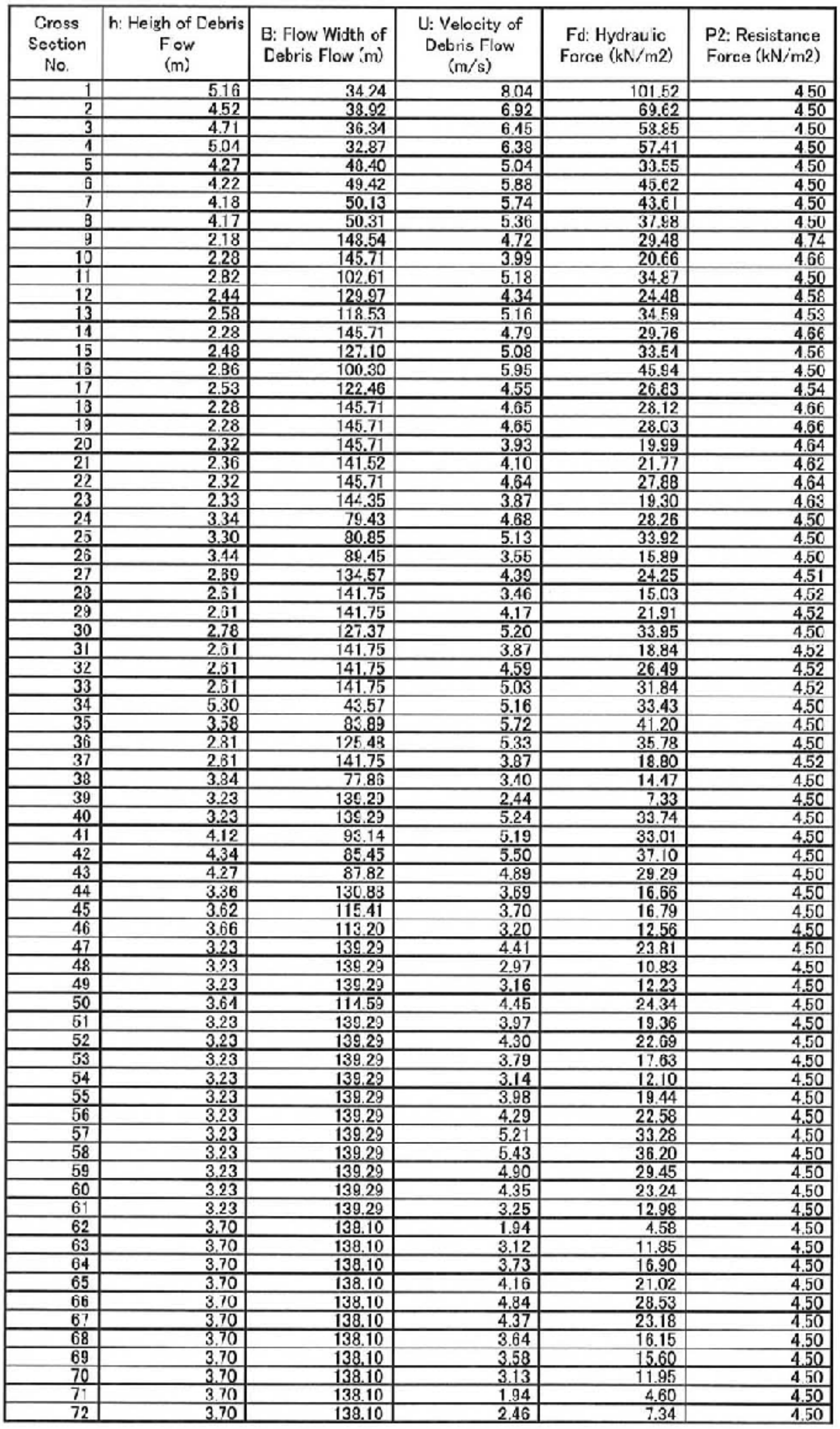
Table S12-2.2.2 Difference Between the FLO-2D Model by the Avila Project and by the Study Team

	Avila / Caracas Project	Study Team
Inflow Hydrograph	Water Hydrograph (CGR report)+ standard sediment concentration value	Water Hydrograph (CGR report)+ proposed sediment volume
Grid size	30 m	100 m
Channel within grid	considered	considered
Culver, Street		

Table S12-2.3.1 Sediment Runoff Volume for Method-1 and Method-2

No of Catchment		Catchment name		Area		Sediment Runoff Volume	adjustment	Cota Mil upstream pocket capacity	Sediment Runoff Volume for Method-1 and 2			Qp for Method- 1
				(km2)		(m3)	(m3)	(m3)	(m3)	(m3/km2)		(m3/s)
1	48		Caurimare	0.161		9,300				58,000	Vec	8.0
2-0	48		Caurimare	0.987	0.107	21,100	2,400			21,000	Ve	24.8
2-1				0.955	0.155		3,400		3,400			
2-2					0.071		1,600		1,600			
2-3					0.622		13,700		13,700			
3	48		Caurimare	0.075		3,800				51,000	Vec	3.7
4	48	Caurimare	Caurimare	6.354		101,400			101,400	16,000	Vec	75.0
5	48	Galindo	Caurimare	3.845		59,000			59,000	15,000	Vec	68.0
6	48		Caurimare	0.087		6,800			6,800	78,000	Ve	3.2
7	48		Caurimare	0.36		16,300			16,300	45,000	Vec	14.4
8	48	Pasaquire	Caurimare	1.143		34,200		13,400	20,800	30,000	Ve	34.0
9	48		Caurimare	0.117		7,000			7,000	60,000	Ve	5.1
10	48		Caurimare	0.055		3,300			3,300	60,000	Ve	2.4
11	50	Gamburi	Tocome	0.247		15,100			15,100	61,000	Vec	10.6
12	50	La Julia	Tocome	2.1		62,900			62,900	30,000	Vec	74.0
13	50		Tocome	0.327	0.142	39,700	17,240		17,240	121,000	Ve	13.9
14	50	Tocome	Tocome	9.448		152,200			152,200	16,000	Vec	182.0
15	50	Tenerias	Tocome	1.403		45,200			45,200	32,000	Ve	47.0
16	52	Agua de maiz	Agua de maiz	0.38	0.142	32,100	12,000		12,000	84,000	Ve	12.0
17	54	Sebucan	Sebucan	1.57		48,700		10,700	38,000	31,000	Vec	53.0
18	54		Sebucan	0.167	0.1	18,300	10,960		10,960	110,000	Ve	7.1
19	54	Pajarito	Sebucan	1.374		44,700			44,700	33,000	Vec	42.0
20	54		Sebucan	0.112		7,800		2,400	5,400	70,000	Ve	4.8
21	54		Sebucan	0.27	0.223	24,900	20,570	4,900	15,670	92,000	Vec	11.5
22	56	Quintero	Seca	1.973		56,200			56,200	28,000	Vec	41.2
23	56	Seca	Seca	0.775		30,800			30,800	40,000	Vec	25.9
24	56		Seca	0.207	0.84	15,100	6,130		6,130	73,000	Ve	8.8
25	58	Chacaito	Chacaito	6.332		112,400			112,400	18,000	Vec	117.0
26	58		Chacaito	0.158		10,100				64,000	Ve	6.7
27	58		Chacaito	0.253	0.18	19,100	13,590		13,590	75,000	Ve	10.3
28	58	Chapellin	Chacaito	1.192		50,000		1,000	49,000	42,000	Ve	40.0
29	58		Chacaito	0.069		4,100				59,000	Ve	3.3
30	58	Cuno	Chacaito	0.598		57,100		3,800	53,300	95,000	Ve	24.5
31	58		Chacaito	0.235	0.136	14,000	8,100		8,100	60,000	Ve	10.9
32	62		Mariperez	0.057		3,400				60,000	Ve	2.7
33	62	Mariperez	Mariperez	0.696		26,600			26,600	38,000	Vec	34.0
34	63		Canoas	0.092	0.034	5,500	2,030		2,030	60,000	Ve	4.3
35	63	Canoas	Canoas	0.569		23,200			23,200	41,000	Vec	28.0
36	66		Anauco	0.266	0.107	17,100	6,880		6,880	64,000	Ve	8.9
37	66	Gamboa	Anauco	3.071		71,800			71,800	23,000	Vec	52.8
38	66		Anauco	0.192		11,400			11,400	59,000	Ve	6.4
39	66	Beatas	Anauco	0.427		15,600			15,600	37,000	Vec	10.0
40	66		Anauco	0.191		11,400			11,400	60,000	Ve	6.4
41	66	Anauco	Anauco	3.69		106,900		68,500	38,400	29,000	Ve	50.0
42	66	Cotiza	Anauco	3.798		144,500		93,000	51,500	38,000	Vec	56.0
43	67		Catuche	0.269		11,300				42,000	Vec	10.4
44	67	Catuche	Catuche	4.499		95,900			95,900	21,000	Vec	59.0
45	69	St.Isabel	Catroata	0.091		5,400			5,400	59,000	Ve	3.0
46	69		Catroata	0.082		4,900			4,900	60,000	Ve	2.7
47	69	Agua Salud	Catroata	0.478		21,700			21,700	45,000	Vec	14.7

Table S12-2.3.2 Example of Calculation Result (Catuche)



Cross Section No.	h: Heigh of Debris Flow (m)	B: Flow Width of Debris Flow (m)	U: Velocity of Debris Flow (m/s)	Fd: Hydraulic Force (kN/m2)	P2: Resistance Force (kN/m2)
1	5.16	34.24	8.04	101.52	4.50
2	4.52	38.92	6.92	69.62	4.50
3	4.71	36.34	6.45	58.85	4.50
4	5.04	32.87	6.38	57.41	4.50
5	4.27	48.40	5.04	33.55	4.50
6	4.22	49.42	5.88	45.62	4.50
7	4.18	50.13	5.74	43.61	4.50
8	4.17	50.31	5.36	37.98	4.50
9	2.18	148.54	4.72	29.48	4.74
10	2.28	145.71	3.99	20.66	4.66
11	2.82	102.61	5.18	34.87	4.50
12	2.44	129.97	4.34	24.48	4.58
13	2.58	118.53	5.16	34.59	4.53
14	2.28	145.71	4.79	29.76	4.66
15	2.48	127.10	5.08	33.54	4.56
16	2.86	100.30	5.95	45.94	4.50
17	2.53	122.46	4.55	26.83	4.54
18	2.28	145.71	4.65	28.12	4.66
19	2.28	145.71	4.65	28.03	4.66
20	2.32	145.71	3.93	19.99	4.64
21	2.36	141.52	4.10	21.77	4.62
22	2.32	145.71	4.64	27.88	4.64
23	2.33	144.35	3.87	19.30	4.63
24	3.34	79.43	4.68	28.26	4.50
25	3.30	80.85	5.13	33.92	4.50
26	3.44	89.45	3.55	15.89	4.50
27	2.89	134.57	4.39	24.25	4.51
28	2.61	141.75	3.46	15.03	4.52
29	2.61	141.75	4.17	21.91	4.52
30	2.78	127.37	5.20	33.95	4.50
31	2.61	141.75	3.87	18.84	4.52
32	2.61	141.75	4.59	26.49	4.52
33	2.61	141.75	5.03	31.84	4.52
34	5.30	43.57	5.16	33.43	4.50
35	3.58	83.89	5.72	41.20	4.50
36	2.81	125.48	5.33	35.78	4.50
37	2.61	141.75	3.87	18.80	4.52
38	3.84	77.86	3.40	14.47	4.50
39	3.23	139.29	2.44	7.33	4.50
40	3.23	139.29	5.24	33.74	4.50
41	4.12	93.14	5.19	33.01	4.50
42	4.34	85.45	5.50	37.10	4.50
43	4.27	87.82	4.89	29.29	4.50
44	3.36	130.88	3.69	16.66	4.50
45	3.62	115.41	3.70	16.79	4.50
46	3.66	113.20	3.20	12.56	4.50
47	3.23	139.29	4.41	23.81	4.50
48	3.23	139.29	2.97	10.83	4.50
49	3.23	139.29	3.16	12.23	4.50
50	3.64	114.59	4.45	24.34	4.50
51	3.23	139.29	3.97	19.36	4.50
52	3.23	139.29	4.30	22.69	4.50
53	3.23	139.29	3.79	17.63	4.50
54	3.23	139.29	3.14	12.10	4.50
55	3.23	139.29	3.98	19.44	4.50
56	3.23	139.29	4.29	22.58	4.50
57	3.23	139.29	5.21	33.28	4.50
58	3.23	139.29	5.43	36.20	4.50
59	3.23	139.29	4.90	29.45	4.50
60	3.23	139.29	4.35	23.24	4.50
61	3.23	139.29	3.25	12.98	4.50
62	3.70	138.10	1.94	4.58	4.50
63	3.70	138.10	3.12	11.85	4.50
64	3.70	138.10	3.73	16.90	4.50
65	3.70	138.10	4.16	21.02	4.50
66	3.70	138.10	4.84	28.53	4.50
67	3.70	138.10	4.37	23.18	4.50
68	3.70	138.10	3.64	16.15	4.50
69	3.70	138.10	3.58	15.60	4.50
70	3.70	138.10	3.13	11.95	4.50
71	3.70	138.10	1.94	4.60	4.50
72	3.70	138.10	2.46	7.34	4.50

Table S12-2.3.3　Property in Yellow and Red Zones (Principal Stream Basis)

Principal Watershed		Yellow Zone						Red Zone					
		Building Count			Building Area			Building Count			Building Area		
No.	Name	Barrio	Formal	Total	Barrio	Formal	Total	Barrio	Formal	Total	Barrio	Formal	Total
		nos.	nos.	nos.	m2	m2	m2	nos.	nos.	nos.	m2	m2	m2
02_1		46	0	46	2,272	0	2,272		0			0	
02_2		231	168	399	11,312	55,591	66,903		0			0	
02_3		195	96	291	10,348	48,343	58,691	9	27	36	339	10,272	10,610
4	Caurimare	316	271	587	20,981	121,969	142,950	109	103	212	6,107	79,994	86,101
5	Galindo	0	18	18	0	5,702	5,702		0	16		4,733	4,733
6		0	198	198	0	46,569	46,569		0			0	
7		0	90	90	0	21,377	21,377		0	41		5,741	5,741
8	Pasaquire	0	233	233	0	54,548	54,548		0	60		7,355	7,355
9		0	171	171	0	51,812	51,812		0			0	
10		0	336	336	0	141,091	141,091		0			0	
11	Gamburi	0	246	246	0	66,192	66,192		0	12		1,937	1,937
12	La Julia	10	696	706	888	187,272	188,159	8	397	405	838	97,416	98,255
13		0	92	92	0	29,800	29,800		0	9		3,803	3,803
14	Tocome	0	638	638	0	160,183	160,183		42	42		11,909	11,909
15	Tenerias	0	92	92	0	24,275	24,275		0			0	
16	Agua de maiz	115	247	362	5,487	64,580	70,068		0	2		610	610
17	Sebucan	0	742	742	0	255,255	255,255		0			0	
18		0	507	507	0	152,338	152,338		0			0	
19	Pajarito	0	517	517	0	210,755	210,755		1	1		503	503
20		0	805	805	0	352,716	352,716		0	1		460	460
21		0	900	900	0	389,840	389,840		0			0	
22	Quintero	9	1,157	1,166	62	454,710	454,772		0	184		37,703	37,703
23	Seca	24	529	553	683	186,530	187,213		57	57		7,639	7,639
24		69	397	466	6,355	140,453	146,808		0	1		548	548
25	Chacaito	63	454	517	5,487	162,209	167,696	39	209	248	2,635	55,814	58,450
27		303	484	787	23,016	127,160	150,176		4	4		781	781
28	Chapellin	255	139	394	18,325	30,036	48,361		0	2		152	152
29		278	143	421	19,247	26,440	45,687		0			0	
30	Cuno	248	106	354	17,581	21,626	39,207		0	10		1,700	1,700
31		259	105	364	17,843	21,796	39,639		0			0	
33	Mariperez	0	106	106	0	23,550	23,550		3	32		6,545	6,545
34		920	154	1,074	61,584	45,133	106,717		0	1		1	1
35	Canoas(Sarria)	551	341	892	34,297	69,282	103,578	5	5	163	4,471	7,132	11,602
36		463	755	1,218	20,953	174,237	195,190		0			0	
37	Gamboa	83	315	398	11,277	68,997	80,274		2	17		2,179	2,179
38		191	433	624	22,346	99,098	121,444		0			0	
39	Beatas	184	169	353	15,849	28,282	44,131		0			0	
40		319	255	574	28,308	40,941	69,249		8	8		815	815
41	Anauco	339	340	679	32,774	58,615	91,389	290	188	478	26,218	23,045	49,263
42	Cotiza	64	69	133	3,636	12,680	16,316		0			0	
44	Catuche	659	696	1,355	59,691	194,692	254,383	660	399	1,059	59,967	111,363	171,330
45	St. Isabel	224	0	224	13,050	0	13,050		0			0	
46		299	275	574	20,588	26,812	47,400	23	10	33	828	443	1,271
47	Agua Salud	158	224	382	11,774	23,590	35,364	134	0	299	8,665	13,071	21,736

Note: The count and area of building/house were calculated based on the topographical map of scale 1:5,000.

Table S12-2.3.4 Property in Yellow and Red Zones (Alluvial Fan Basis)

Watershed	Yellow Zone							Red Zone						
System	Building Count			Building Area			Zone Area	Building Count			Building Area			Zone Area
No.	Barrio	Urban	Total	Barrio	Urban	Total		Barrio	Urban	Total	Barrio	Urban	Total	
	nos.	nos.	nos.	m2	m2	m2	m2	nos.	nos.	nos.	m2	m2		m2
Caurimare	458	965	1423	27,800	370,200	398,000	1,784,800	118	130	248	6,400	50,000	56,400	595,200
Tocome	10	1,303	1313	900	331,300	332,200	997,500	8	440	448	800	100,000	100,800	394,000
Agua de Maiz	115	415	530	5,500	111,700	117,100	459,800		0	0	0	0	0	4,200
Sebucan	0	1,525	1525	0	524,000	524,000	1,643,600		0	0	0	0	0	22,100
Seca	30	879	909	700	337,100	337,900	1,088,500		50	50	0	38,500	38,500	148,500
Chacaito	483	1,063	1546	37,000	312,200	349,200	1,285,700	39	215	254	2,600	55,000	57,600	353,900
Mariperez	0	106	106	0	23,600	23,600	124,600		3	3	0	600	600	53,800
Canoas	1,270	592	1862	83,300	127,200	210,600	556,600	5	5	10	4,500	700	5,200	36,600
Anauco	688	1,006	1694	56,200	226,100	282,300	867,900	290	190	480	26,200	22,000	48,200	168,300
Catuche	659	502	1161	59,700	164,500	224,200	559,200	660	394	1,054	60,000	111,100	171,100	393,900
Caroata	596	433	1029	39,100	40,800	79,900	172,900	157	10	167	9,500	1,000	10,500	57,200
51	0	4	4	0	300	300	600		0		0	0	0	0
55	0	38	38	0	17,200	17,200	71,300		0		0	0	0	0
57	0	284	284	0	86,500	86,500	268,400	0	1	1	0	0	0	0
64	207	517	724	9,000	104,400	113,400	270,900		0		0	0	0	700
68	0	201	201	0	27,800	27,800	62,500		0		0	0	0	0
Total	4,516	9,833	14,349	319,300	2,804,800	3,124,100	10,214,800	1,277	1,438	2,715	110,100	378,900	489,000	2,228,400

Note: The count and area of building/house were calculated based on the topographical map of scale 1:5,000.

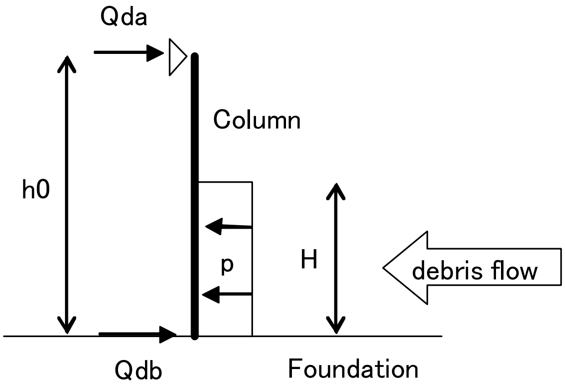


Figure S12-2.3.1 Structure Model for Concrete Column

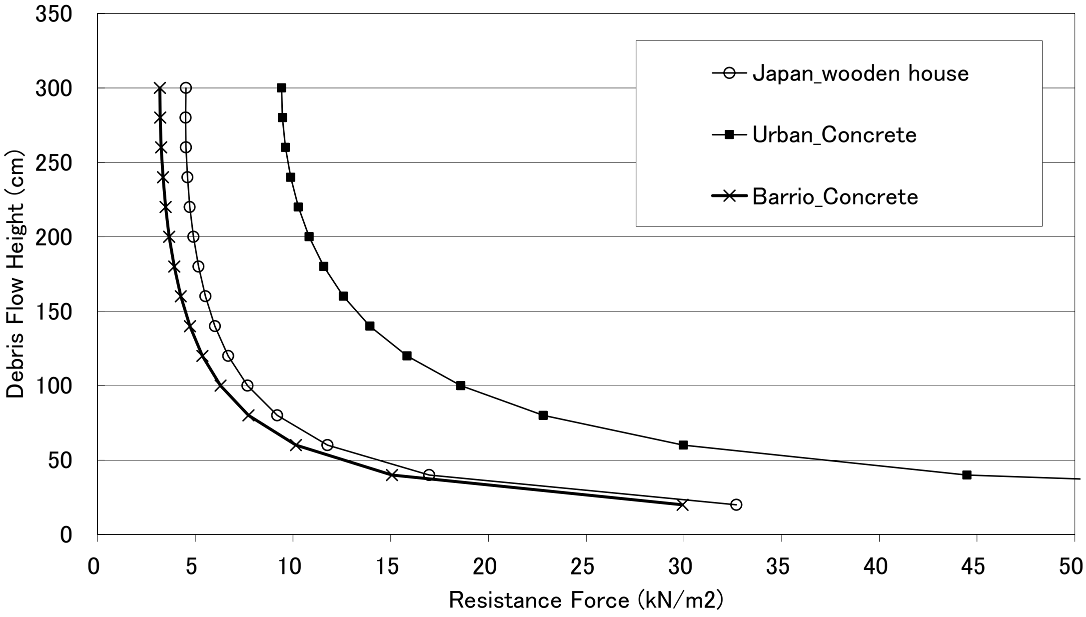


Figure S12-2.3.2 Yield Strength Curves for Red Zone Delineation

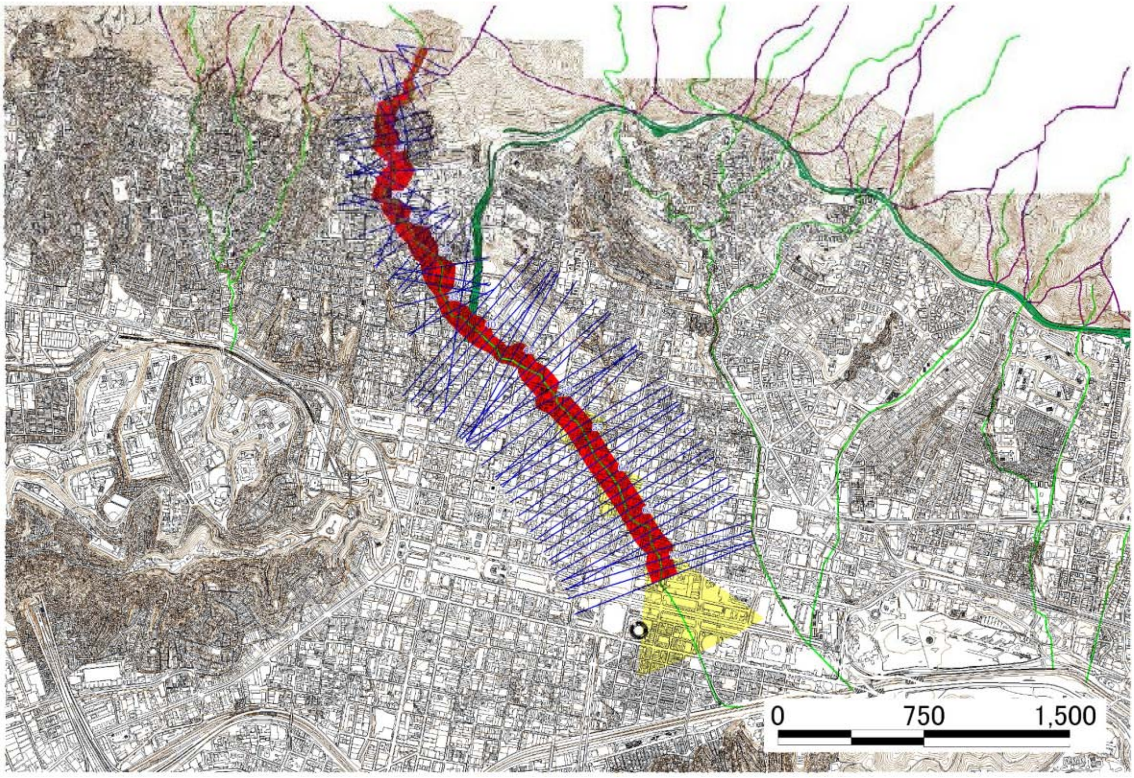


Figure S12-2.3.3　Example of Cross Sections for Method 1

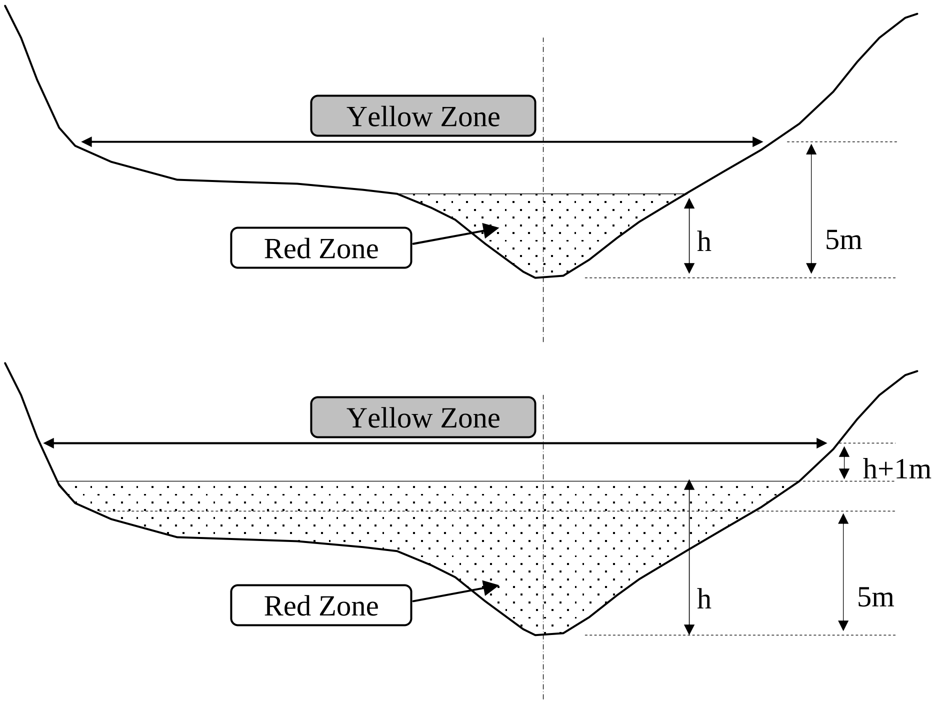


Figure S12-2.3.4　Definition of Yellow Zone

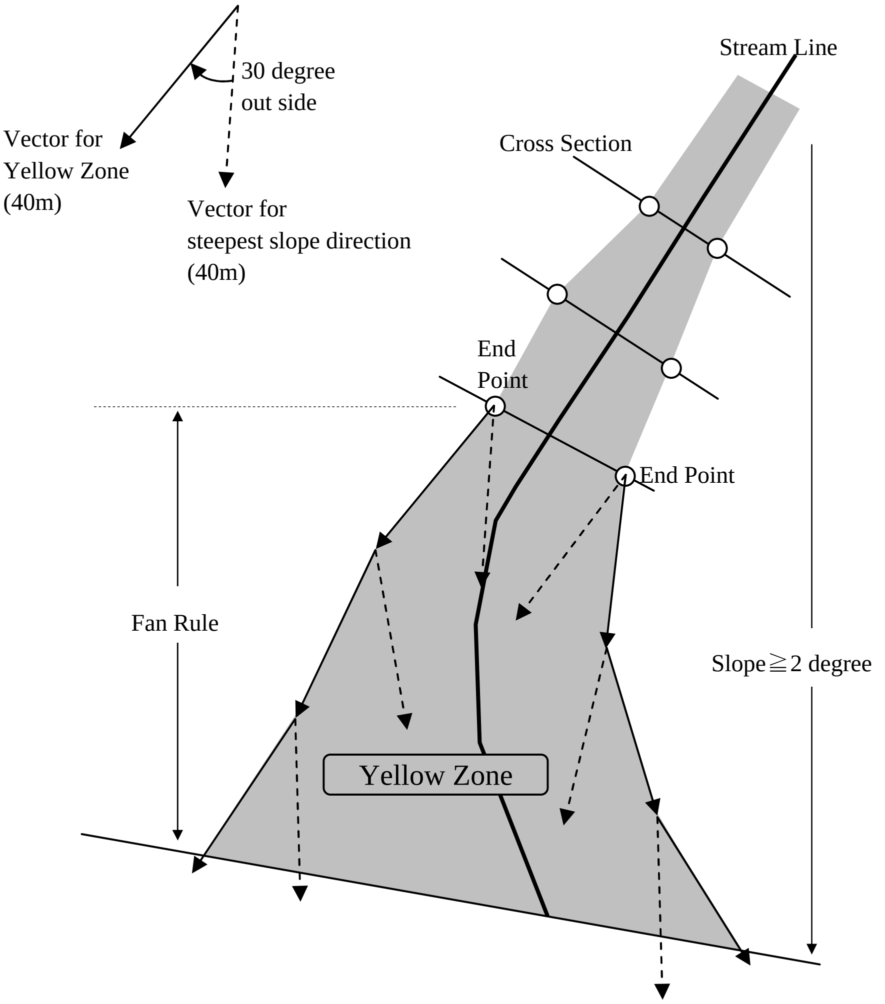


Figure S12-2.3.5　Fan Rule

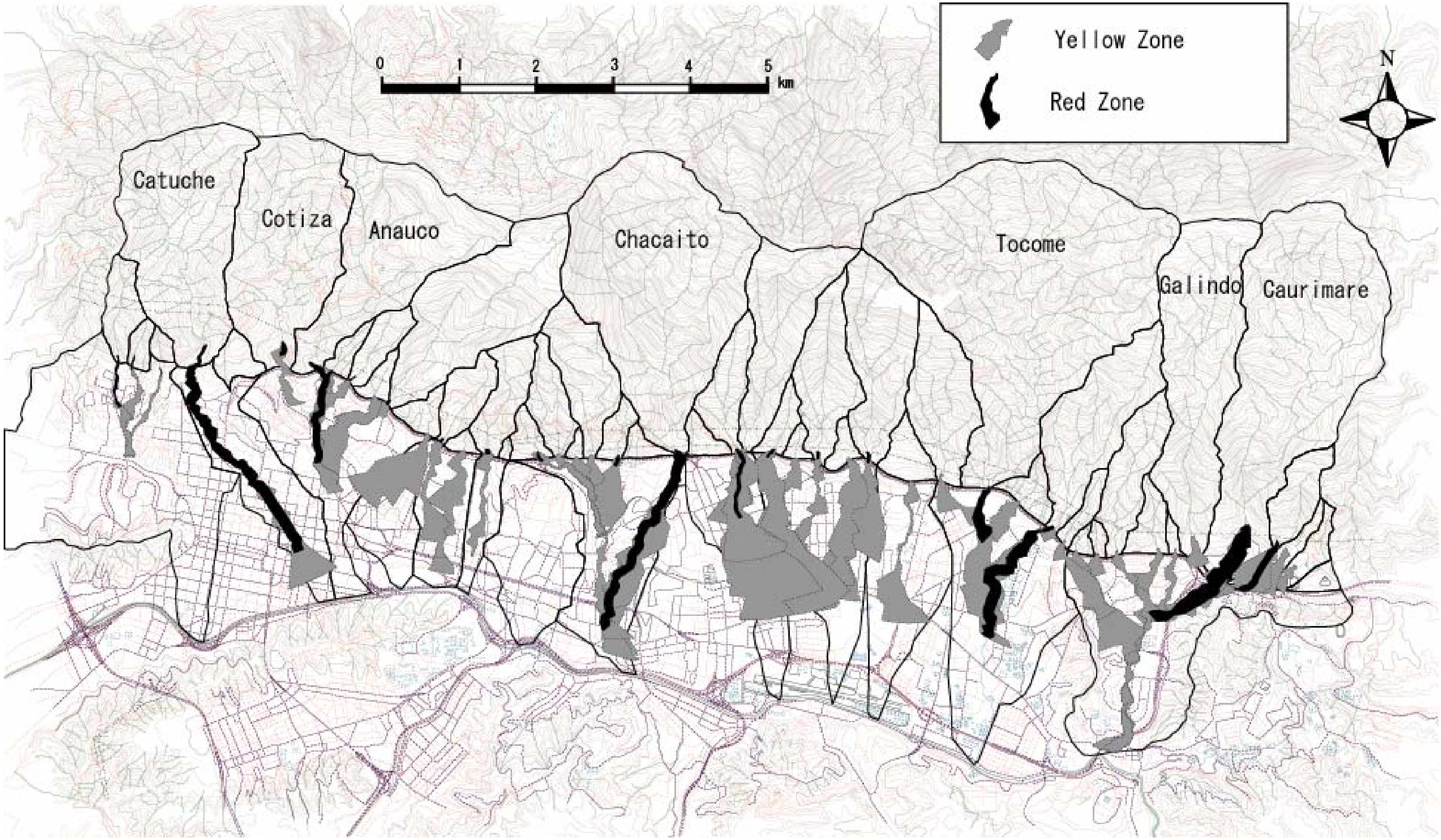


Figure S12-2.3.6 Debris Flow Hazard Map by Method-1

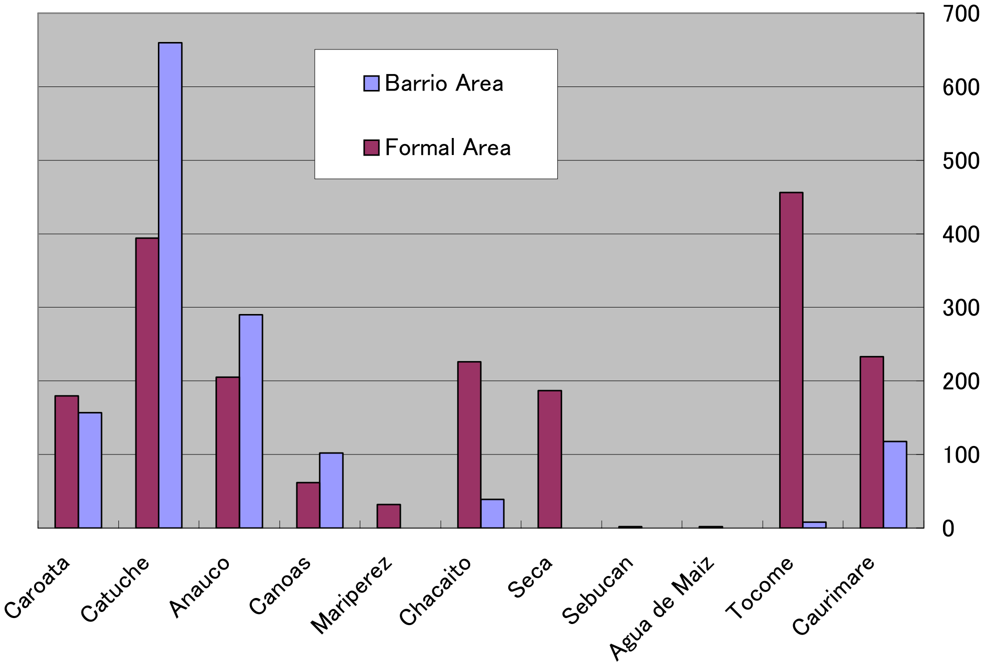


Figure S12-2.3.7 Number of House in Red Zone