SABO in Ecuador

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Layout of presentation:

- 1. First steps of SABO in Ecuador. List of disaster prevention engineering projects.
- 2. Experiences of SABO in Ecuador.
- 2.1. The Guagua Pichincha experience.
- 2.2. The Cotopaxi volcano experience.
- 2.3. HIGEODES

1. First steps of SABO in Ecuador.

- **DEBRIS-MUD FLOWS OF VOLCANIC ORIGIN**
- **Debris and mud flows numerical simulation**
- **Early warning systems – Pichincha volcano**
- **Physical hydraulic models**
- **Hazard maps**
- **Structural and non-structural mitigation measures**
- **DEBRIS-MUD FLOWS OF HYDROMETEOROLOGIC ORIGEN.**
- **HIGEODES –Hydrogeodynamic & Antropogenic Disaster Prevention Research Center.**

- Main disaster prevention Engineering Projects.

a.- Debris- mudflow hazard maps in the western part of the city of Quito.

b.- Physical modeling of deposited volcanic ash.

c.- Mudflow simulation using FLO-2D.

Due to a possible eruption of the Guagua Pichincha volcano, west of Quito.

1, 2, 3, 4, 5, 6

2. SABO IN ECUADOR

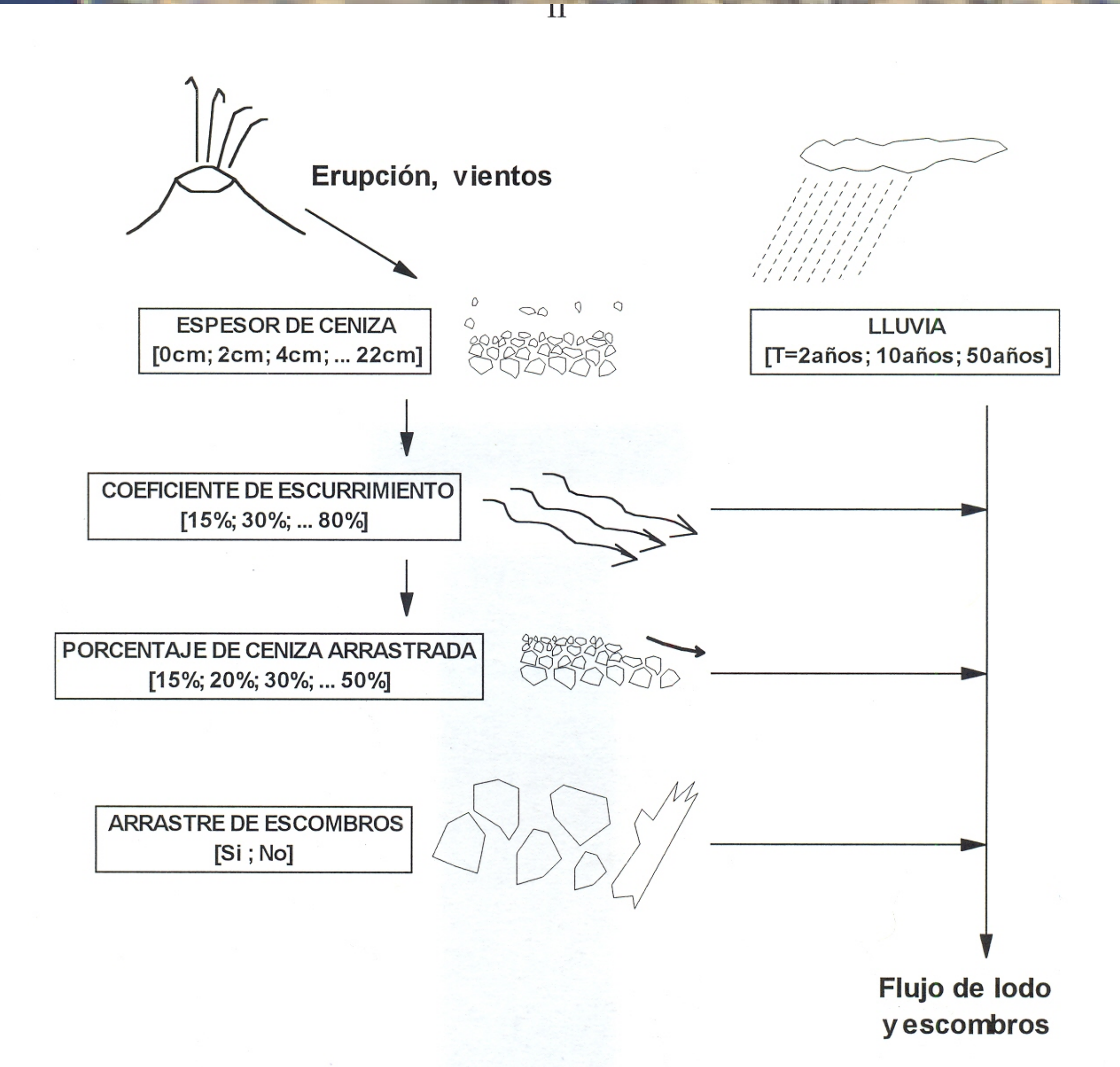
THE GUAGUA PICHINCHA VOLCANO

2.1 The Guagua Pichincha volcano

- **Location:**
  Latitude: 0. 17° S
  Longitude: 78.60° W
- **Basic information**
  Elevation: 4794 m
  Diameter in the base: 12 km N-S
  Type of volcano: Estratovolcano with an avalanche open caldera to the west
- Diameter of the caldera: 1.6 km
  Depth of the caldera: 700 m
  Domo in the caldera, elevation: 400 m

- **GUAGUA PICHINCHA:**
- **First attemp to study debris and mud flows of volcanic origin by numerical simulation both in the sideslopes of the volcano masiff and within the city.**
- **Define hazard maps for secondary mudflows of volcanic origin, based on field work in the routing & impact zones, air photography, and numerical simulation.**
- **(DHRH, IG, UNISIG. COSUDE, PNUD, EMAAPQ, IRD, INAMHI).**

uncertainties in modeling



Volcanic, hydrologic and hydraulic elements to be considered in defining debris-mudflow scenarios

Scenarios

El escenario, llamado número I, consta de las siguientes consideraciones:

1.- Capa de ceniza: 22 cm en las dos cuencas, considerado el evento eruptivo de 980 aAP. Carga de ceniza que puede ser arrastrada: 30% para Rumipamba y 20% para Rumiurcu.

2.- Carga o lámina de agua: se adopta una tormenta con período de retorno de 50 años, y se basa en datos hidrológicos suministrados por el Proyecto Sishilad (estación La Chorrera).

3.- Coeficiente de escorrentía: 80%, definido para toda la cuenca.

4.- Carga o volumen de escombros, calculados de acuerdo a las características propias de geometría y estabilidad de taludes y pendientes en cada cauce.

ESCENARIO II

El escenario, llamado número II, consta de las siguientes consideraciones:

1.- Capa de ceniza: 4 cm en las dos cuencas, considerado el evento eruptivo de 1660 DC. Carga de ceniza que puede ser arrastrada: 30% para Rumipamba y 20% para Rumiurcu.

2.- Carga o lámina de agua: se adopta una tormenta con período de retorno de 2 años, y se basa en datos hidrológicos suministrados por el Proyecto Sishilad (estación La Chorrera).

3.- Coeficiente de escorrentía: 30%, definido para toda la cuenca.

4.- Carga o volumen de escombros, calculados de acuerdo a las características propias de geometría y estabilidad de taludes y pendientes en cada cauce.

ESCENARIO III

El escenario, llamado número III, consta de las siguientes consideraciones:

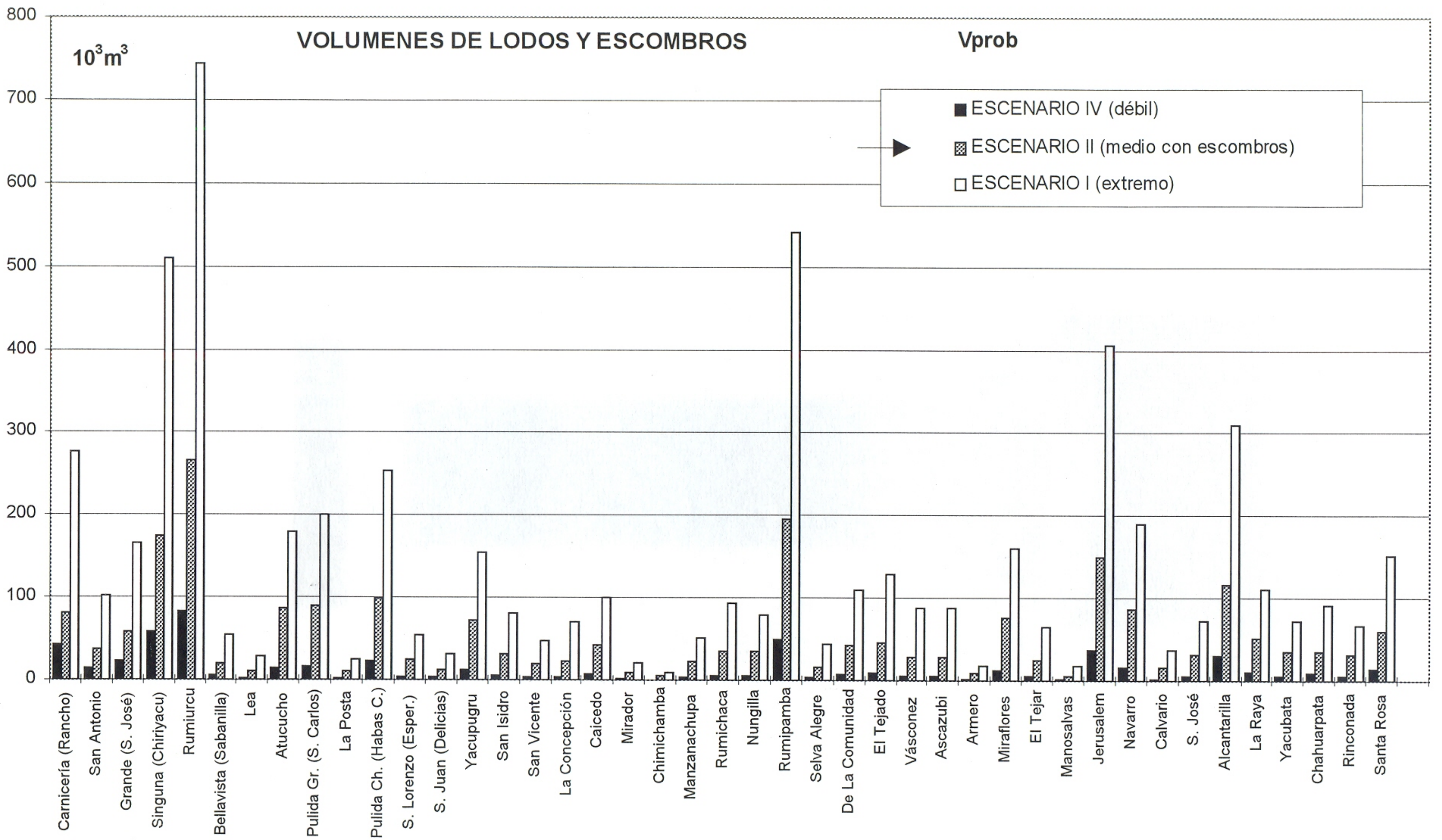
1.- Capa de ceniza: 4 cm en las dos cuencas, considerado el evento eruptivo de 1660 DC. Carga de ceniza que puede ser arrastrada: 30% para Rumipamba y 20% para Rumiurcu.

2.- Carga o lámina de agua: se adopta una tormenta con período de retorno de 2 años, y se basa en datos hidrológicos suministrados por el Proyecto Sishilad (estación La Chorrera).

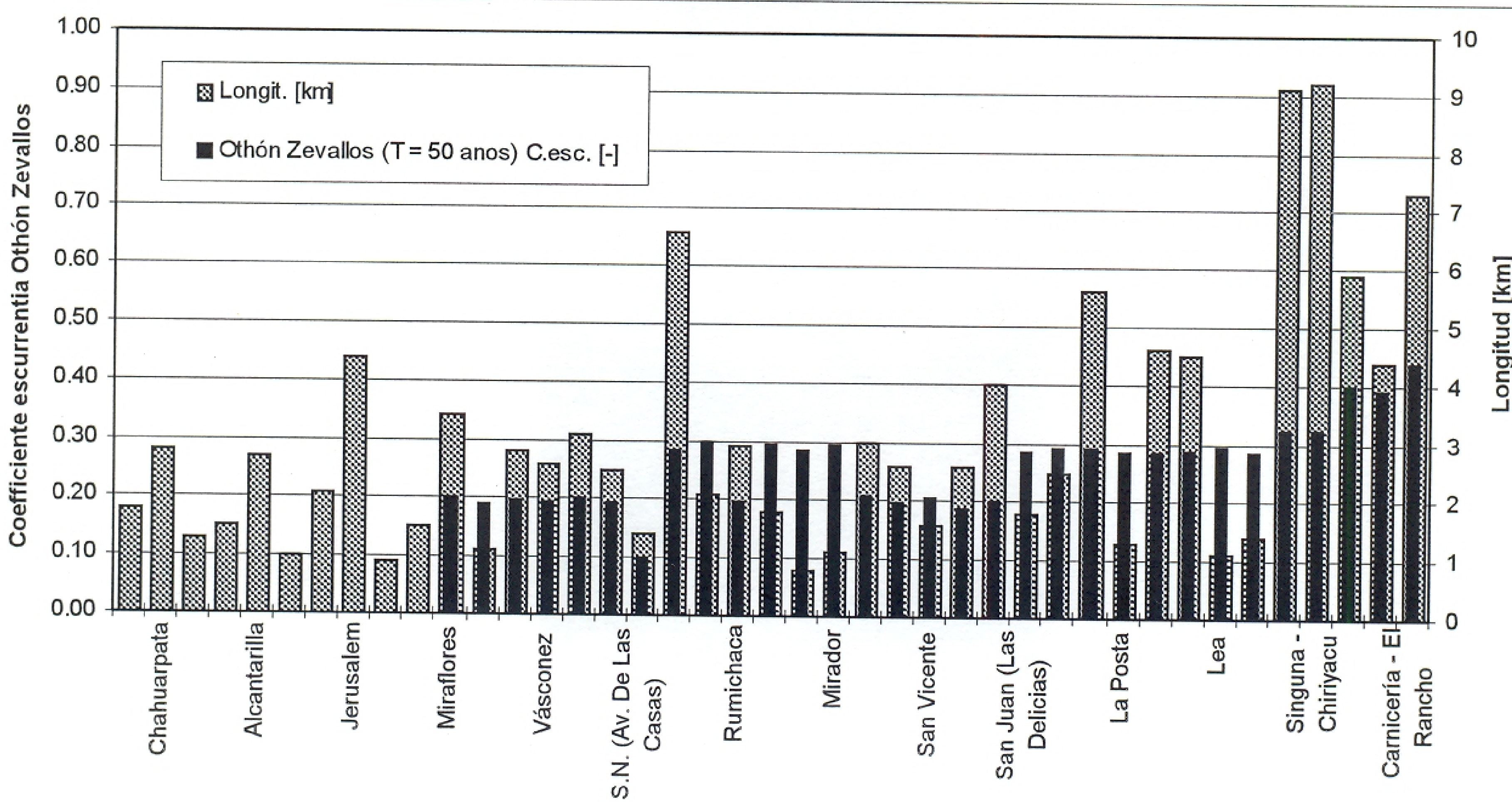
3.- Coeficiente de escorrentía: 30%, definido para toda la cuenca.

4.- Carga o volumen de escombros: no presentes en este escenario.

Debris- mudflows volumes in each quebrada



Runoff coefficient



Actual runoff coef: very low: 2-15%. Values used with ash on the slopes: 20-30% event f 1660. Up to 80% with thick ash deposits (Zevallos, Mothes).

Percentage of ash to be washed away.

- Ash to be washed away=f(Intensity of precipitation, ash thickness, runoff coef.).

Espesor y porcentaje de ceniza que podría movilizarse

		AREA	PEND	Esp. ceniza		T= 2 años			T = 2 años (10 ?)			T = 50 años		
	Coef. de escurr. >					15%	15%	15%	30%	30%	30%	80%	60%	45%
	Caída de ceniza >			*980aa*	*1660*	980aa	1660	½1660	980aa	**1660**	½1660	**980aa**	1660	½1660
N°	QUEBRADA	(km2)	%	*cm*	*cm*	c20cm	c5cm	**c2cm**	c20cm	**c5cm**	c2cm	**c20cm**	c5cm	c2cm
1	Carnicerìa (Rancho)	5.43	12.2	*12*	*3*	10	15	**20**	15	**20**	30	**20**	30	40
2	San Antonio	1.79	15.1	*12*	*2.5*	10	15	**20**	15	**20**	30	**20**	30	40
3	Grande (San José)	2.9	15.2	*13*	*3*	10	15	**20**	15	**20**	30	**20**	30	40
4	Singuna (Chiriyacu)	7.4	17.7	*18*	*4*	15	20	**25**	20	**30**	40	**30**	40	50
5	**Rumiurcu**	**11.1**	**19.5**	*22*	*4*	10	15	**20**	15	**20**	30	**20**	30	40
6	Bellavista (Sabanilla)	0.62	21.6	*13*	*2.5*	50	55	**60**	60	**70**	80	**70**	80	90
7	Lea	0.27	27.6	*13*	*2.5*	50	55	**60**	60	**70**	80	**70**	80	90
8	Atucucho	2.14	27.3	*16*	*3.5*	15	20	**25**	20	**30**	40	**30**	40	50
9	Pulida Grande	2.46	26.8	*17*	*3.5*	15	20	**25**	20	**30**	40	**30**	40	50
10	La Posta	0.29	19.2	*13*	*2.5*	30	40	**50**	40	**60**	70	**50**	70	90
11	Pulida Chico (Habas C)	3.29	22.4	*19*	*4*	15	20	**25**	20	**30**	40	**30**	40	50
12	Sn Lorenzo	0.61	22.2	*15*	*3*	15	20	**25**	20	**30**	40	**30**	40	50
13	Sn. Juan (Delicias)	0.46	16.2	*14*	*3*	15	20	**25**	20	**30**	40	**30**	40	50

Sediment transport in the quebradas

- Amount of sediments along the bottom of the quebradas difficult to assess.
- Debris and mud flows occur on river slopes greater than 35%, soil thickness on the bottom between 1.5 – 6 m. Channel bottom width about 3 m.
- Estimated sediment contribution from the bottom: up to 20 m3 / m.
- Ratio of volume of ash deposited / volume of observed secondary lahar varies between 15-65%

Sediment carried by the lahar

- Based on: topographic maps, field work, debris flow deposits:
- Sediment volume (m3)=sediment on the stream (v1) + collapsable sediments from the slopes (v2).
- v1: (cross section of deposit)(mean width of channel)(length from the basin outlet to the erosión point).
- v2: collapsable sediment from nearby river slopes (unknown). Assess equivalent movable volume: (equivalent cross section)(mean channel width)(mean equivalent sediment thickness in the stream).

Sediments into the hydrogram

- Trigger mechanisms for debris- mud flows:

Progressive increment of sediment concentration. Hyperconcentrade flows (water and volcanic ash) are able to take sediment from the bottom until the concentration is very high and it is able to carry large stones.

Flow initiation by landslides: small landslides deposited in the bottom of the ravines are able to start debris flow once they break and its volume increases downstream.

Sediments into the hydrogram

- Sediments move along the stream from the steepest upstream portion of the basin to the deposition areas well downstream of the basin arriving to the city.
- We assume that the sediment are part of the hydrograph already in the high and middle part of the basin where most of the sediment contribution takes place.

Debris- mudflows routing

- Aim: find the physical characteristics of debris-mudflows (volume, peak discharge, time to the peak, flow duration, velocity and flow depth) at the outlet of the basins, that will serve as initial conditions of the flow in the urban part of the city.
- Model used: a hydrologic model named HEC-1 modifying the channel roughness coefficient.
- PROCEDURE:

a.- Define volcanic ash depth (deposits)

- 980 aAP – 1660 – 2 cm deposit (1/2 of 1660),

Debris- mudflows routing

b.- define precipitation for Tr = 2, 10, 50 yrs.

c.- estimate percentage of ash removal

d.- define routing scheme within the basin. Run HEC-1. Obtain hydrogram in each cross section of the channel. Modify Manning roughness coefficient according to Yoshida´s values between 0.010 and 0.015.

e.- Determine contribution areas within the basins both for sediment in the bottom and landslides.

f.- Run HEC-1 with sediment loads. Find peak discharge & volume at the outlet of the basins. Run HECRAS to find flow velocity & depths.

Debris- mudflows routing

g.- find physical characteristics of flows at the outlet of the basins (total sediment volume, flow depths, velocity).

h.- Define hazard map (high, middle, low impact areas) over Quito based on Zevallos (1995) method, field survey, air photo analysis.

i.-Check defined impact areas in air photo.

Using HEC-1

- Why HEC-1?

Not available debris- mudflow simulation model in EPN.

HEC-1 simulates the precipitation – runoff process.

HEC-1 represents the basin as an inter-connected system of hydrologic and hydraulic components.

Using HEC-1

- HEC-1 provides: flood hydrogram of the mixture water-ash-debris; total volume of the mixture; peak discharge; time duration of the flood; time to the peak.
- Used to simulate the contribution of all subbasins within the basin and determine the flood hydrograph at the outlet of the basin.
- A 2-h precipitation hietogram is used, based on laboratory tests to start debris- mudflow in this areas.
- Manning roughness coefficient is modified to take into account mixture composition.

Routing

1. Define boundaries and subbasins, length of main stream, area, distance from the outlet to the farthest point.
2. Define the basin simulation plan: represent the main hydraulic process present in the basin: rainfall, runoff, channel flow, routing in channels.
3. Simulation time: 5/4 – 3/2 of the total rain to determine the behavior of the mud – debris flood after finishing the rain. Time increment: 5 minutes.

Debris flow simulation

- Debris flood simulation done considering that the volcanic ash as part of the precipitation pattern used.
- Infiltration-interception: SCS curve number based on initial abstractions. Defined base on soil characteristics, soil type, land use and antecedent soil characteristics.
- Runoff: based on Clark´s unit hydrograph. Concentration time: 12-18 min, basin slope & storage coefficient.
- Routing procedure: Muskingum-Cunge: good approach in short distances of modeling.

Debris flow simulation. Results

- For the Rumiurcu and Rumipamba Qs.
- Basic data:

	Rurcu	Rpamba
length of stream (Km):	10.5	7.8
Mean width channel (m):	3	3
Depth of erodible Material (m):	3.8	3.8
Debris volume (m3):	118K	88K
Peak discharge (m3/s)		
Scenario: I	179	146
II	70	63
III	33	24

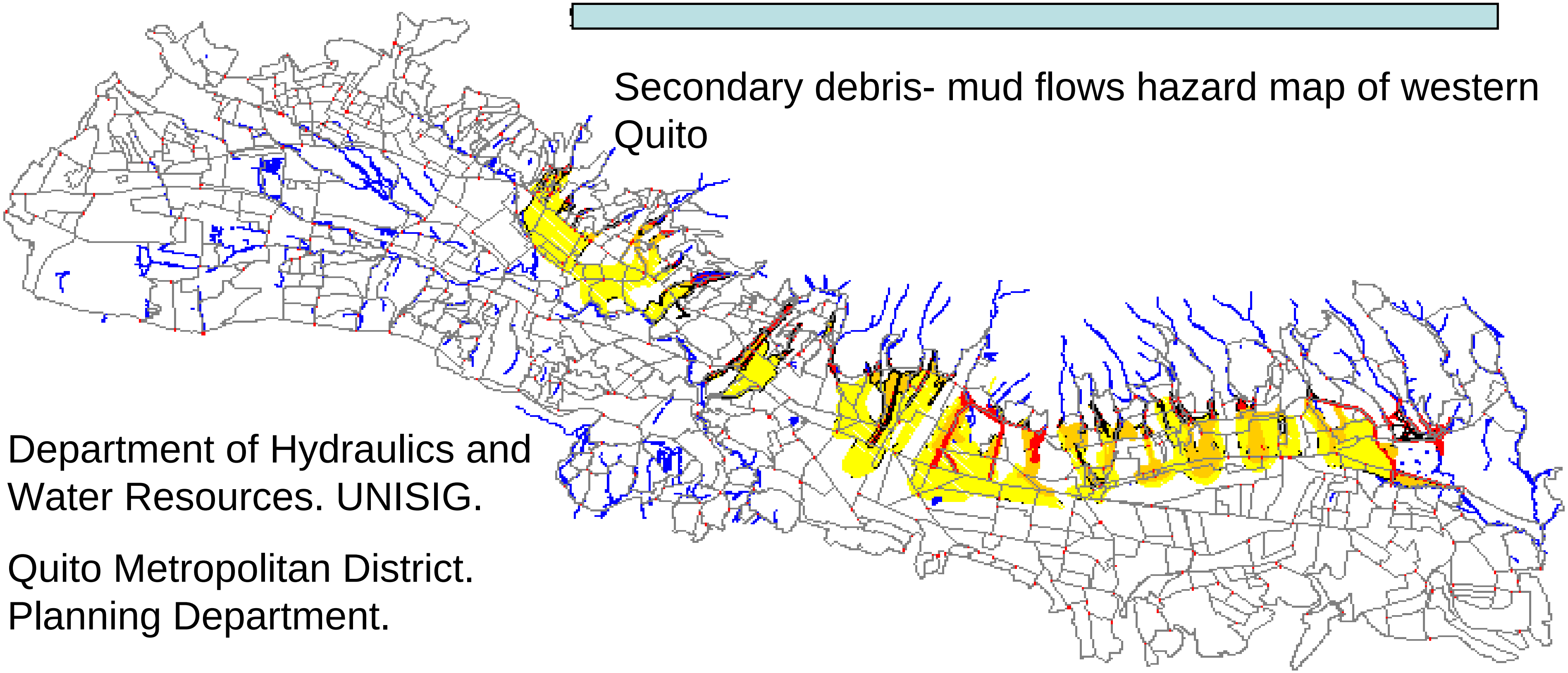
Hazard Mapping

- Aim:

a) Determine affected areas along the routed debris- mud flows, mainly in the urban zone of Quito but also in the bottom of some quebradas where people lives.

b) Estimate possible impacts and their physical characteristics, with regard to: deposited material composition, flow velocities, impact areas, depth of flows, impact in socio-economic population areas.

Hazard map



Secondary debris- mud flows hazard map of western Quito

Department of Hydraulics and Water Resources. UNISIG.

Quito Metropolitan District. Planning Department.

Methodology

- Type of hazards:

1) Extreme danger: direct impact by DMF due to large material and highest flow depths.
2) Mean danger: indirect impact by DMF, mean diameter of materials and mean flow elevations.
3) Mud floods, mainly with shallow water-mud flow depths in flat areas of the city. Mud accumulation

Methodology

- Available information:

Peak DMF discharge

Total volume of DMF runoff

Flow velocity

DMF depths

Direction of mean DMF velocity

Size distribution material

Methodology

- Topographic information

Map scale 1:10000 without infrastructure

Map scale 1:10000 with streets and infrastructure

Maps scale 1:5000 from the slopes

City cadastral maps scale 1:2000

Areal photography of the City and the slopes scales 1:60000, and 1: 30000.

Methodology

- Procedure to estimate impact areas:

1. Take the outlet of a Quebrada. Define 3 most likely flow directions namely: critical, medium, and low.
2. Define preferential flow direction based on past flow paths.
3. Define a “possible” discharge along the main routes (streets) based on the estimated percentage of flow along that path (based on Manning´s).
4. Degree of damage = f(DMF depth, velocity, deposited material).

Methodology

- Model to define hazard areas

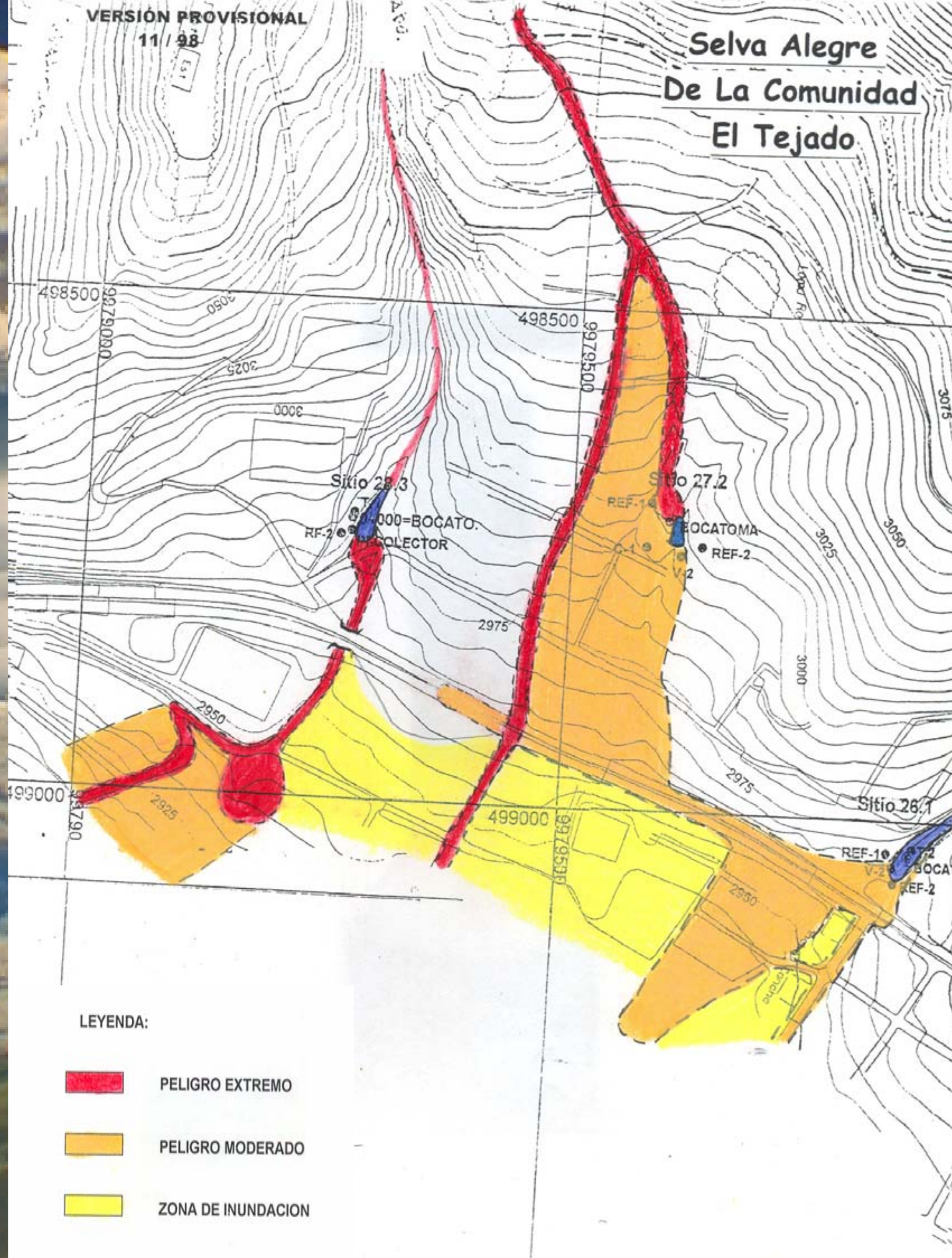
1. Look for possible DMF trajectories,
2. Define longitudinal profiles from the outlet of the contributing basin,
3. Estimate deposition areas as a function of sediment transport:

   a. diameter material g.t. 10 cm (36%)

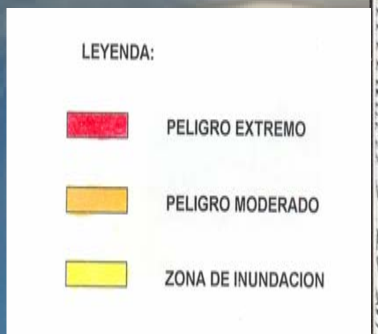
   b. gravel and sand between 0.25 mm to 10 cm (40%)

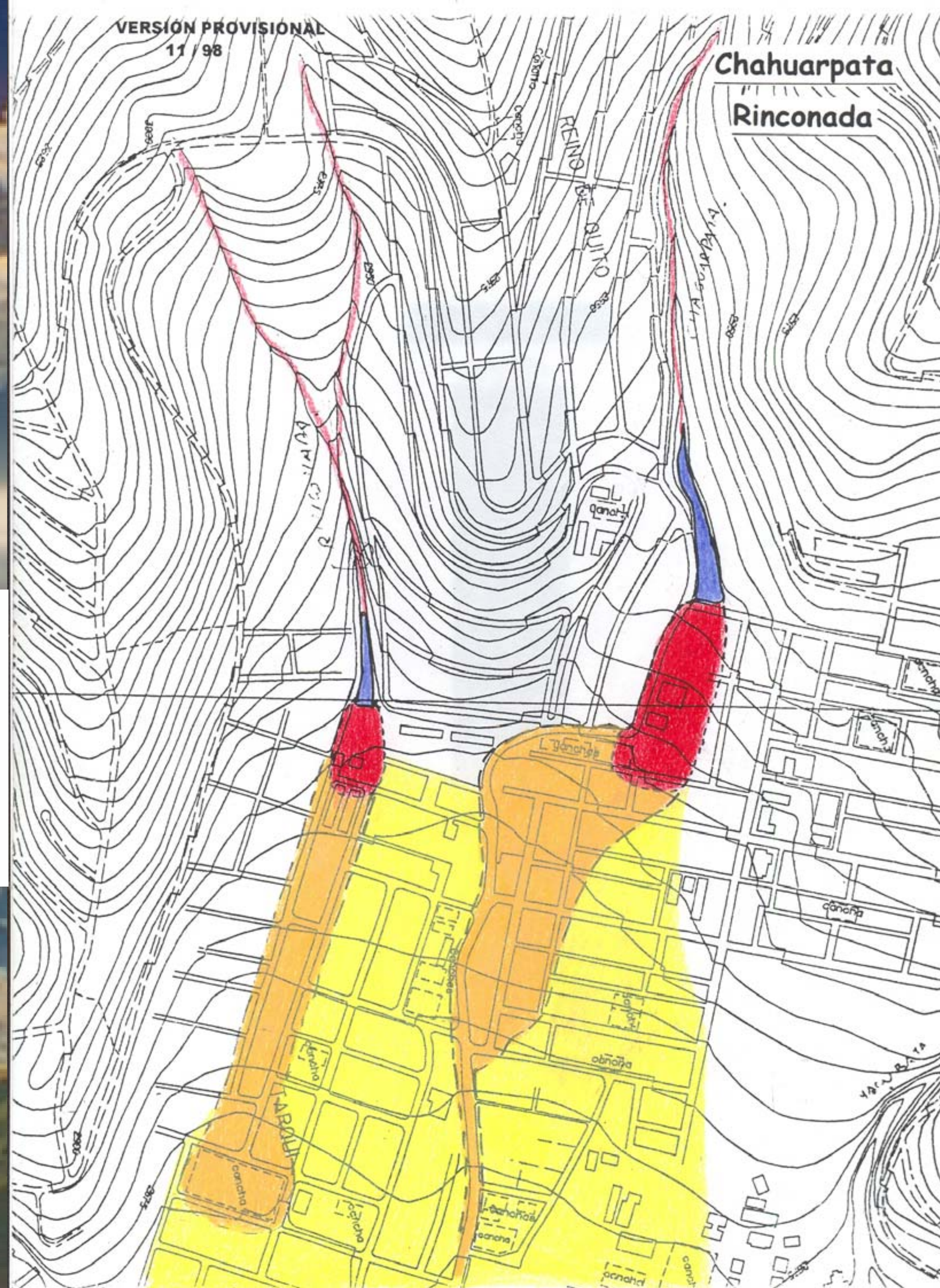
   c. mud flow material – fine material (20%)
4. Draw hazard maps for all types of hazard areas out of the quebradas.

Some hazard maps

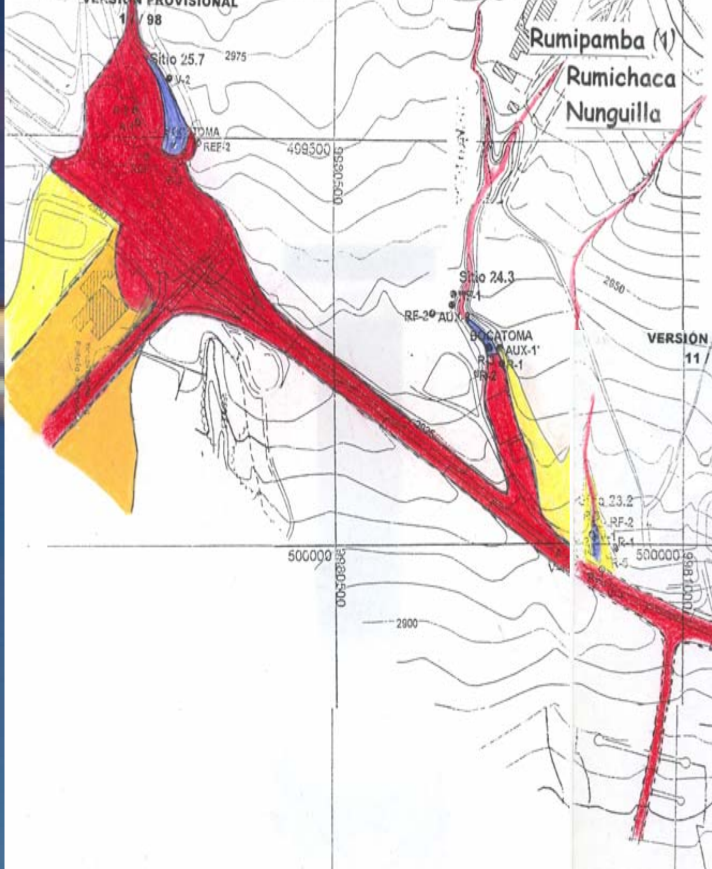


Some hazard maps

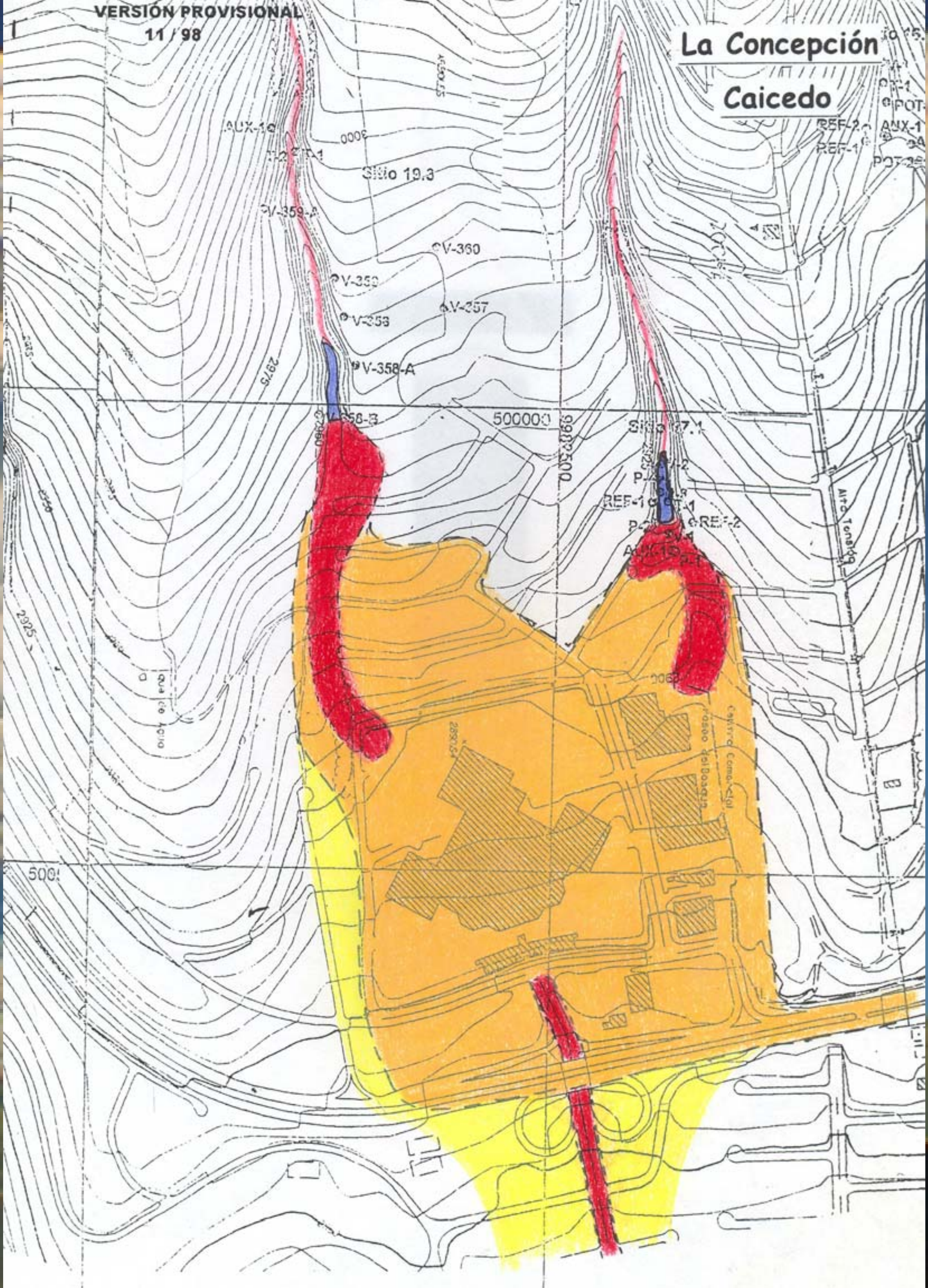




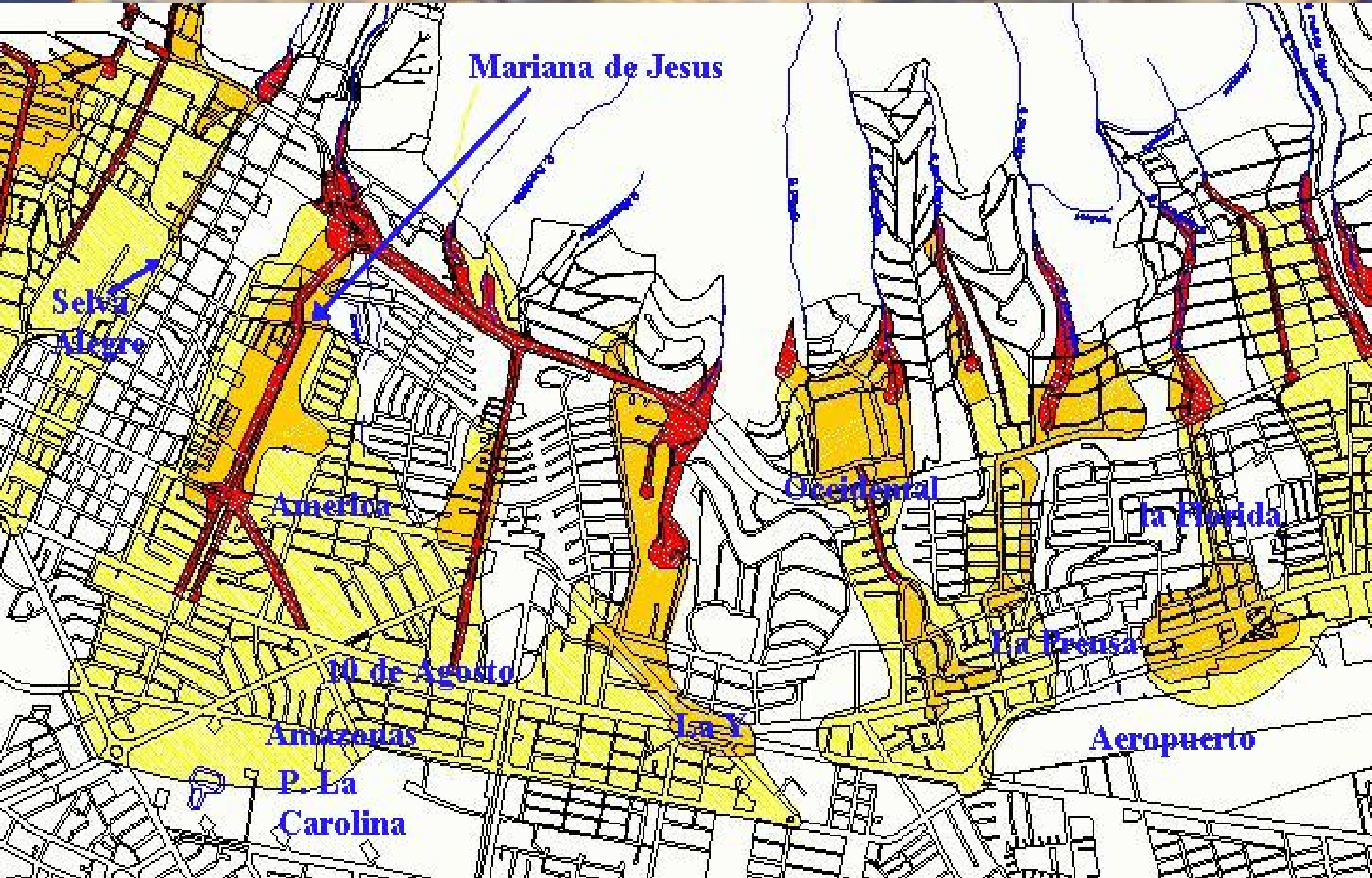
Some hazard maps



Some hazard maps



HAZARD MAP FOR THE WESTERN PART OF THE CITY OF QUITO, ECUADOR



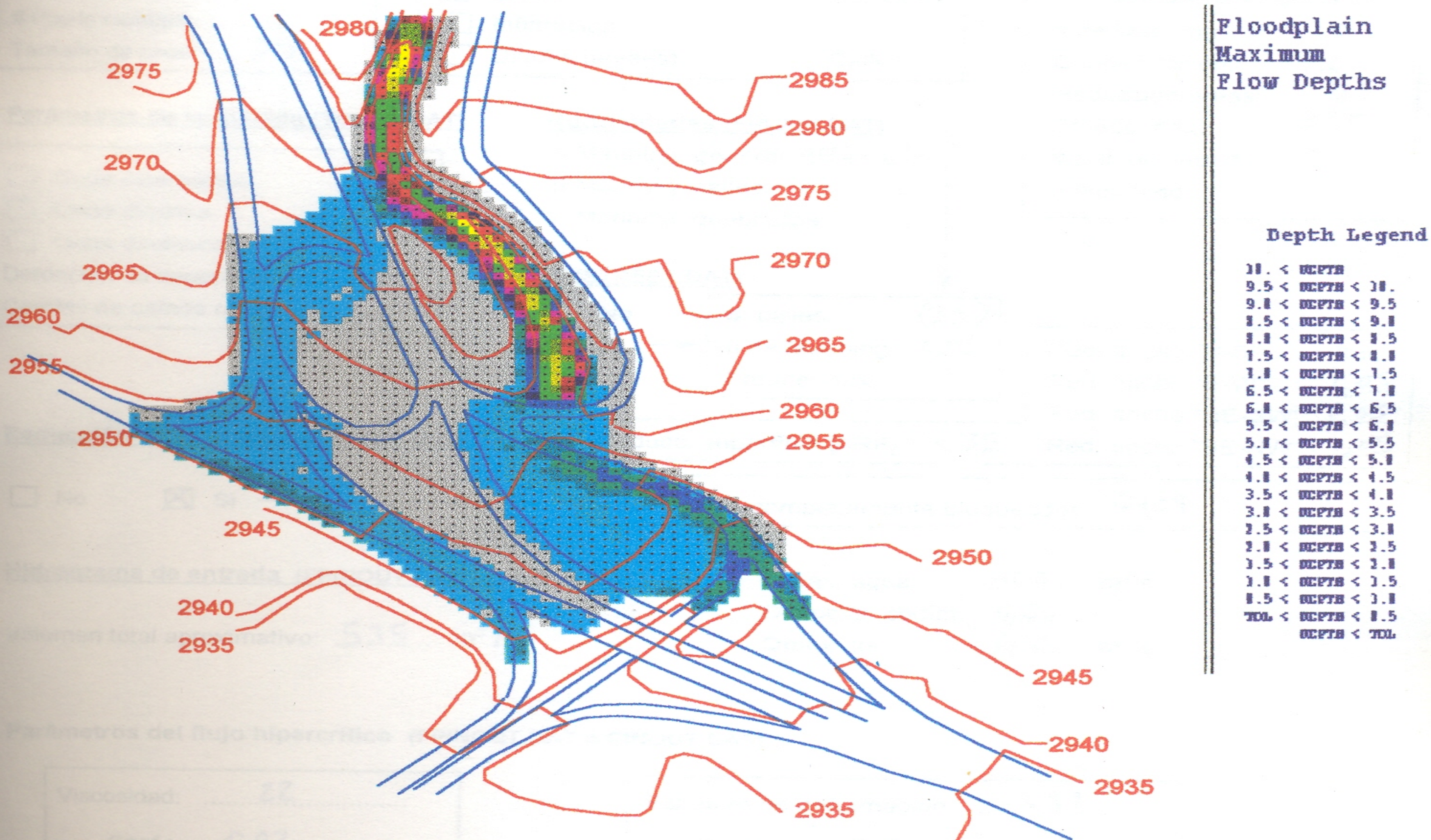
Hazard maps using FLO-2D

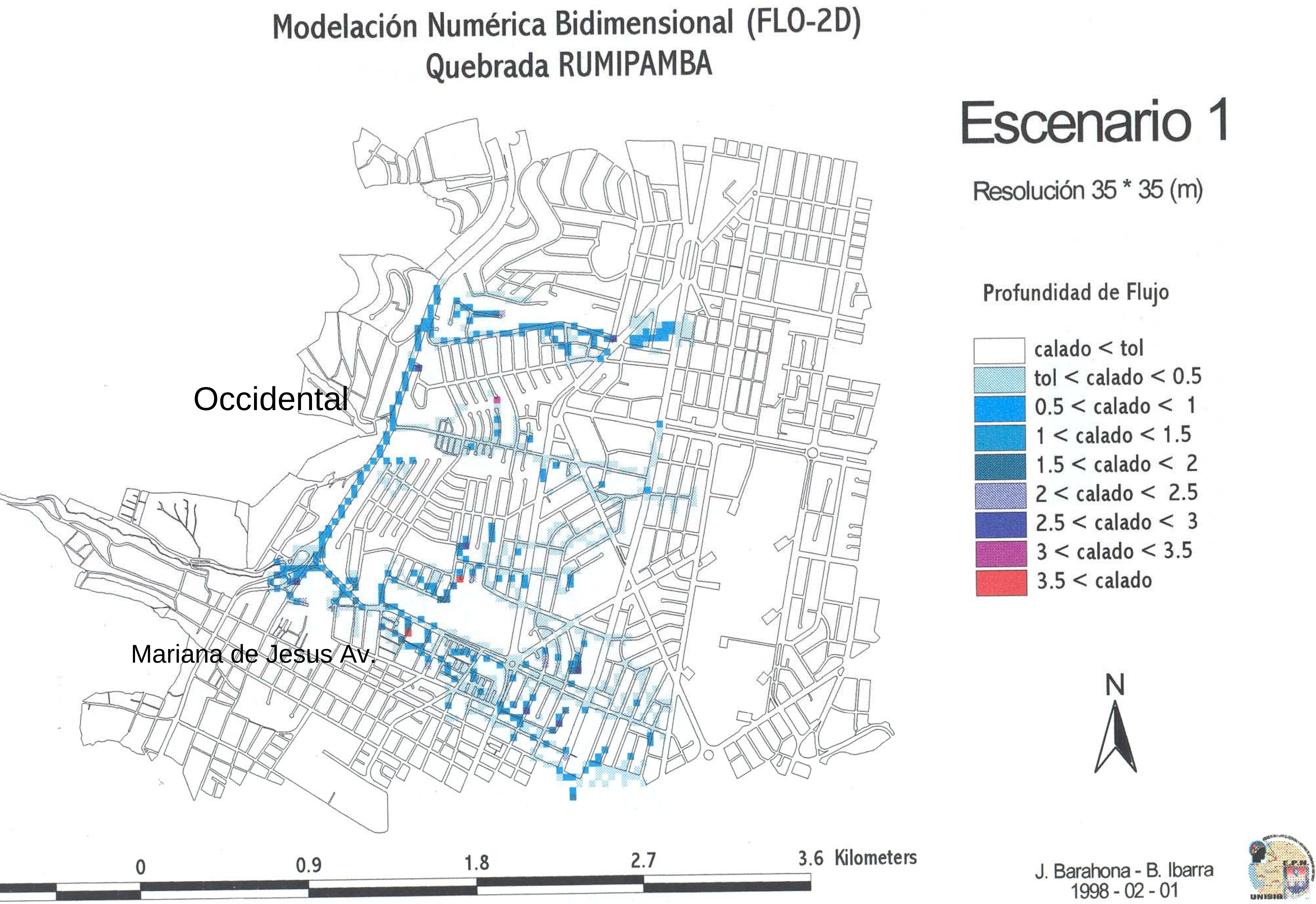
- Development of hazard maps in urban areas.
- FLO-2D: 2D numerical model, finite differences, for debris- mud flow routing.
- Use of DEMs.
- Routing thru streets.
- Data: DEM, viscosity, shear stress, laminar resistance.

Resultados de la modelisación numérica bidimensional (FLO-2D)

Quebrada RUMIPAMBA (salida), pixel 5mx5m, escenario I

Alturas máximas de flujo





Modelación Numérica Bidimensional (FLO-2D)
Quebrada RUMIPAMBA
Escenario 1
Resolución 35 * 35 (m)
Profundidad de Flujo
calado < tol
tol < calado < 0.5
0.5 < calado < 1
1 < calado < 1.5
1.5 < calado < 2
2 < calado < 2.5
2.5 < calado < 3
3 < calado < 3.5
3.5 < calado
Occidental
Mariana de Jesus Av.
N
0
0.9
1.8
2.7
3.6 Kilometers
J. Barahona - B. Ibarra
1998 - 02 - 01

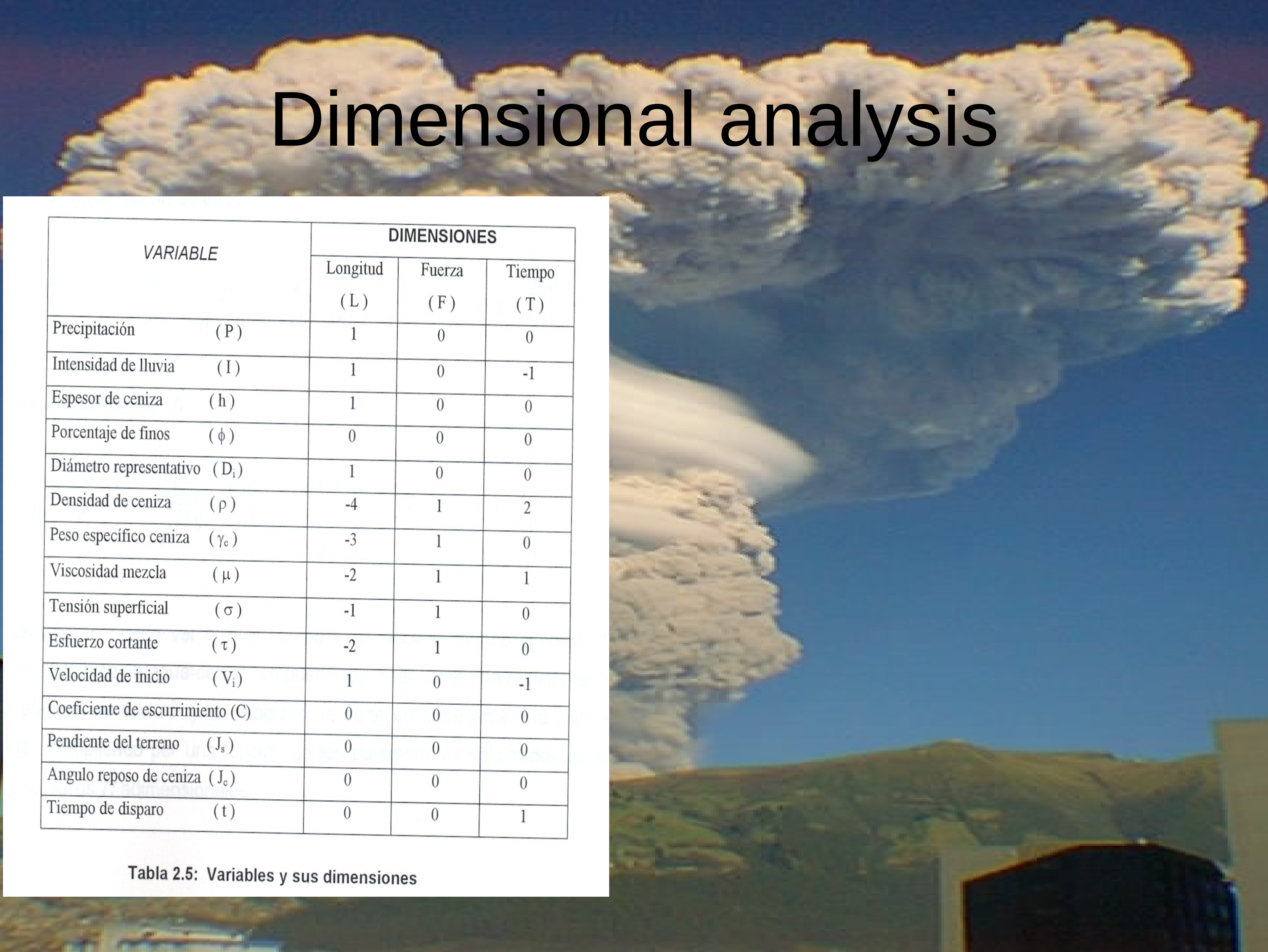
Rain simulation to determine secondary volcanic mud flows trigger time

- Find trigger time to start secondary debris-mudflows in the eastern slopes of the Guagua Pichincha volcano.
- Find physical factors associated with initiation of secondary mud flows due to ash accumulation on the eastern slopes of the Pichincha massif.
- Parameters: basin slopes, rain intensity, rain duration, time to the beginning of the flows, and infiltration rates.

Rain simulation. Cont.

- Basin slopes:10-80% in field. In model: 25-60%.
- Rain intensity: based on IDF curves: 120 mm/h and 40 mm/h.
- Duration of rain: 4 hours.
- Surface runoff: along the tests to determine the amount of infiltration under normal conditions with ash cover over the soil. Infiltration=total precipitation-surface runoff.

Dimensional analysis



VARIABLE	DIMENSIONES Longitud (L)	Fuerza (F)	Tiempo (T)
Precipitación (P)	1	0	0
Intensidad de lluvia (I)	1	0	-1
Espesor de ceniza (h)	1	0	0
Porcentaje de finos (ϕ)	0	0	0
Diámetro representativo (D_i)	1	0	0
Densidad de ceniza (ρ)	-4	1	2
Peso específico ceniza (γ_c)	-3	1	0
Viscosidad mezcla (μ)	-2	1	1
Tensión superficial (σ)	-1	1	0
Esfuerzo cortante (τ)	-2	1	0
Velocidad de inicio (V_i)	1	0	-1
Coeficiente de escurrimiento (C)	0	0	0
Pendiente del terreno (J_s)	0	0	0
Angulo reposo de ceniza (J_c)	0	0	0
Tiempo de disparo (t)	0	0	1

Tabla 2.5: Variables y sus dimensiones

Rain simulation. Cont.

- Catastrophic debris flow not expected just after an eruption. Ash has high water absorption capacity.
- First rains will saturate and compact the ash. Long term rainfall of low intensity may cause redistribution of the ash. Strong rainfall may trigger possible debris-mudflows.
- During tests no movement of ash is seen. Just fine soil movement during low intensity rainfalls.
- Movement of deposited ash is not continuous but intermittent and slow. Ash slopes do not fail. Ash is compacted by the action of rain over it.
- After fine soils is washed out, erosion chumminess appear.
- Vegetation anchors the soil above it and it does not allow to flow.

Rain simulation. Cont.

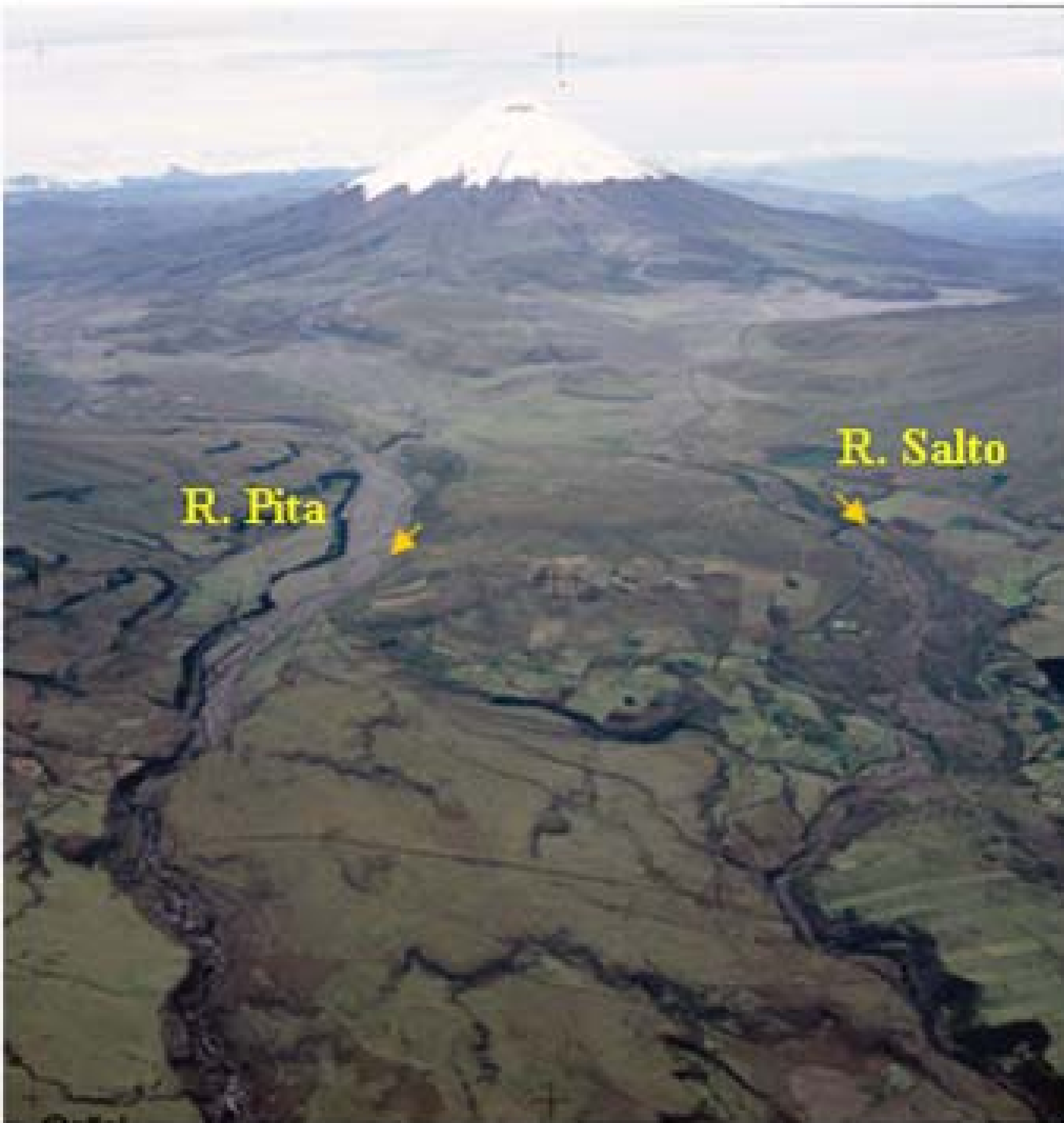
Foto 4.- Simulador de lluvia sobre la estructura de experimentac

Foto 14.- Preparación de la parcela cubierta de ceniza para la prueba 1

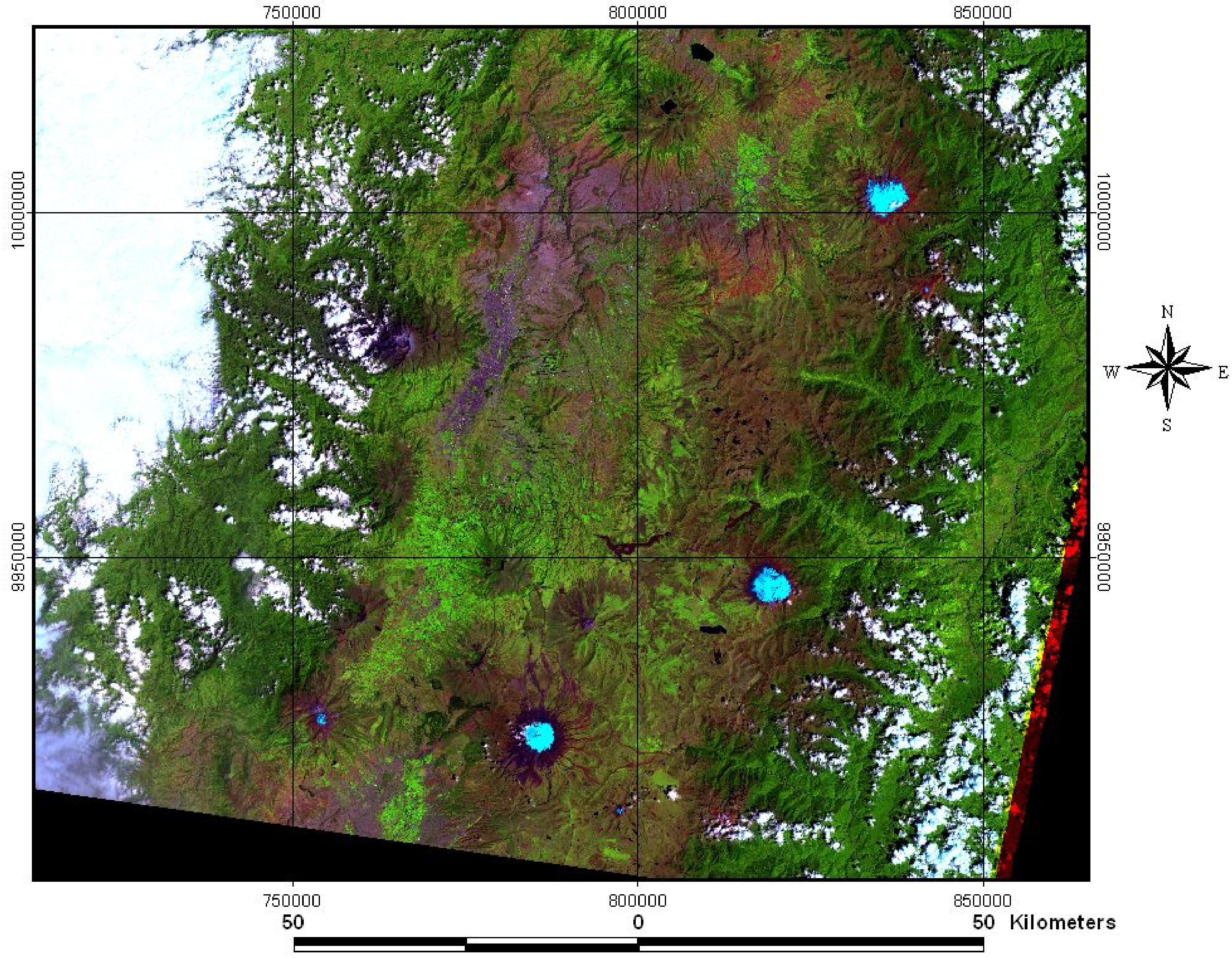
Foto 16: Detalle del material fino colocado sobre el modelo

Foto 22: Formaciones sobre el material por efecto del escurrimiento

2.2 The Cotopaxi volcano hazard map and risk analysis



Satellite image of the study area



Models used

- NWS – FLDWAV. 1-D NON PERMANENT FLOW SIMULATION.
- HYDROLOGIC ENGINEERING CENTER. HEC-RAS: PERMANENT FREE SURFACE ONE-DIMENSION GRADUALLY VARIED FLOW
- Hazard analysis
- Vulnerability analysis for the system
- Risk analysis

Objectives

Determine volcanic MDF depths and velocities for the june 1877 event (Calib.). Hazard maps.

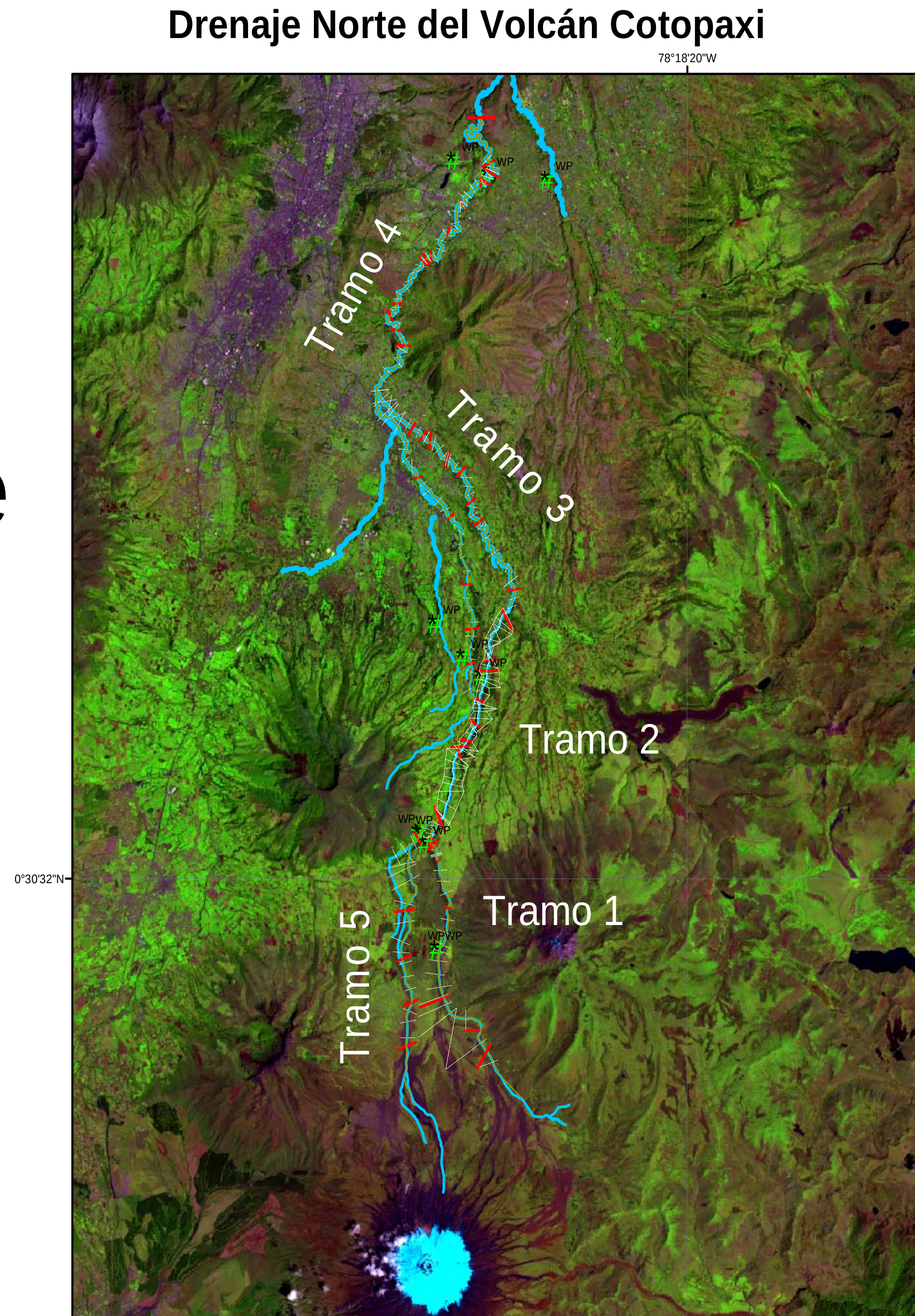
Run calibrated HEC-RAS & FLDWAV for 3 scenarios: LOW, MEDIUM, HISTORICAL.

Find depth and velocity values in EMAAP-Q potable water infrastructure for Quito (intake, aqueducts, populated areas).

Design alternatives works to prevent cutting water to the City of Quito in case of an eruption.

Divide the northern draining system into hydraulic branches to solve the discontinuity given by water falls.

Northern drainage of the Cotopaxi volcano



Hazard map and EMAAP-Q infraestructure.

THREE LARGE POTABLE WATER SUPPLY SUSTEMS FOR QUITO

1.- PITA – TAMBO SYSTEM

2.- LA MICA SYSTEM

3.- PAPALLACTA SYSTEM

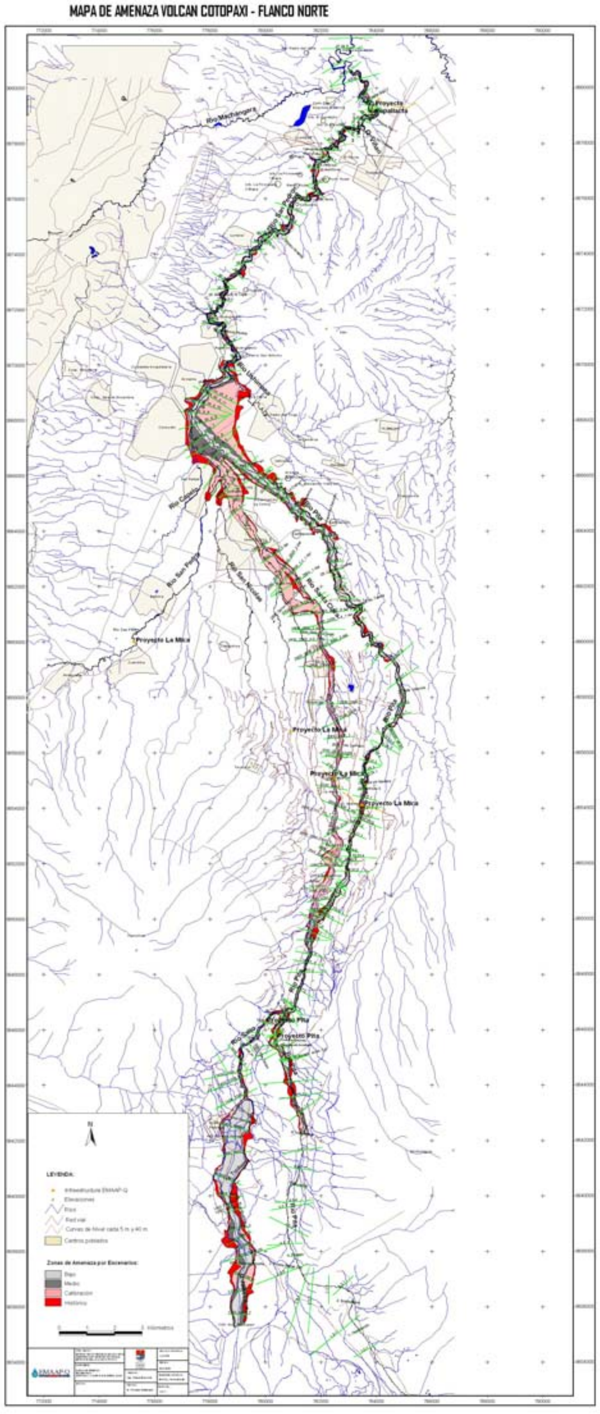
Calibration and scenarios results

Resultados finales para los cuatro escenarios

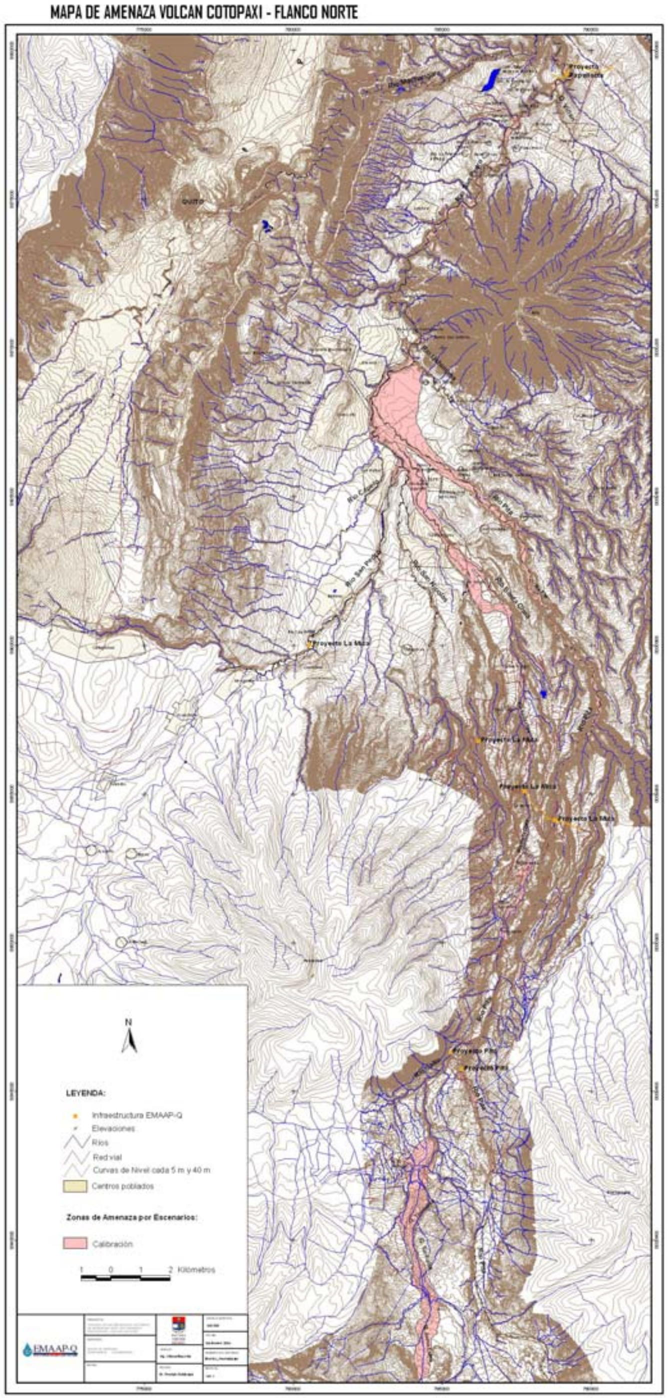
Modelo:	HEC RAS 3.0						
Flujo:	Flujo gradualmente variado						
Modelador:	Xavier Coello						
Revisor:	Remigio Galárraga S.						
Fecha:	Junio 02/2004						

Tramo	Sección campo	Sección modelo	Nivel Esc. Bajo (m)	Nivel Esc. Medio (m)	Nivel de campo (m)	Nivel Calibración (m)	Nivel Esc. Antiguo-Histórico (m)
1.1	6	1100	10.12	14.34	*28*	*27.64*	29.40
	7	1000	15.59	17.91	*22*	*20.41*	22.79
1.2	8	950	9.06	11.79		*15.65*	20.62
	9	930	9.11	13.71	*20*	*20.13*	29.77
	10	900	11.12	15.52	*19*	*20.14*	26.52
	11	850	9.92	14.10	*24*	*20.79*	31.44
1.3	13	800	13.90	23.48	*38*	*37.45*	42.78
	14	700	19.42	22.31	*36*	*29.97*	43.64
2.1	17	600	20.23	25.40	*31*	*31.77*	39.94
	19	500	16.41	24.36	*37*	*36.03*	53.25
2.2	20	400	16.93	20.48	*27*	*26.43*	37.55
	21	300	14.02	19.20	*37*	*35.47*	58.26
	22	200	17.02	25.43	*27*	*27.64*	33.23
2.3	24	150	7.93	11.27	*18*	*17.00*	21.64
3	25	1000*	8.71	12.05	*15*	*16.52*	22.20
	27	800*	6.59	9.81	*11*	*14.74*	19.77
	28	700*	8.97	12.21	*15*	*17.67*	27.64
	29	600*	6.94	9.98	*10*	*14.08*	19.60
	30	500*	7.25	9.82			18.84
	32	300*	6.95	8.94	*12*	*11.78*	16.37
	33	200*	5.48	7.59	*13*	*10.54*	14.71
	34	100*	6.42	8.82	*12*	*11.64*	15.74
4	37	110	8.75	12.20	*20*	*17.11*	23.68
	35	100	9.87	13.81	*17*	*17.35*	22.71
	36	98	13.26	16.39	*25*	*21.08*	29.10
	39	95.5	10.72	15.84	*15*	*21.26*	27.21
	38	92	7.26	11.13	*12*	*18.28*	27.39
	40	84	7.62	11.82	*18*	*17.70*	26.08
	41	82	6.79	9.56	*10*	*13.83*	19.00
	42	75	8.76	12.58	*18*	*18.24*	26.65
	43	69	9.59	12.06	*18*	*16.56*	24.94
	45	58	8.17	11.85	*15*	*17.11*	25.10
	46	55	10.58	14.47	*17*	*19.42*	26.06
	47	52	11.10	14.21	*20*	*19.30*	31.03
5.1	1100	10	7.11	9.33	*13*	*11.94*	15.36
	1200	6	6.52	7.35	*11*	*8.62*	10.81

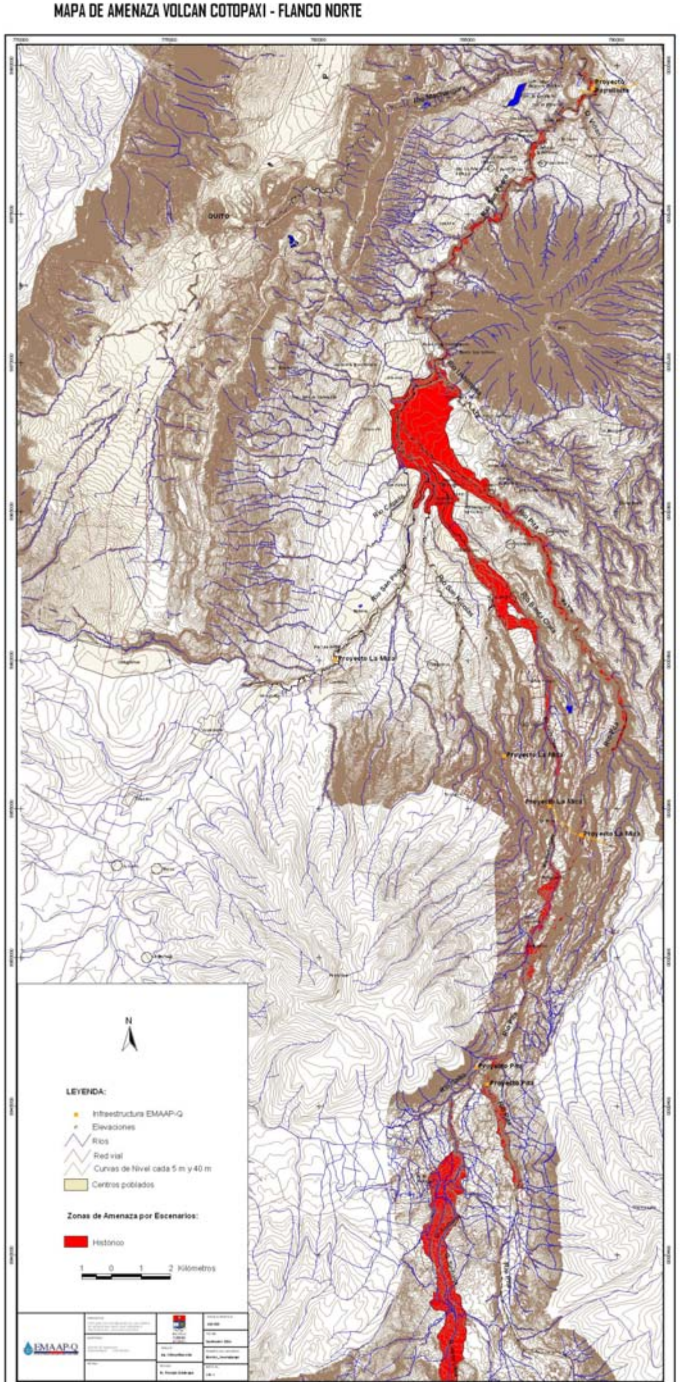
Cross sections defined in the study area from the volcano till the the surroundings of the Tumbaco and Los Chillos valley.



Hazard maps. Calibration stage



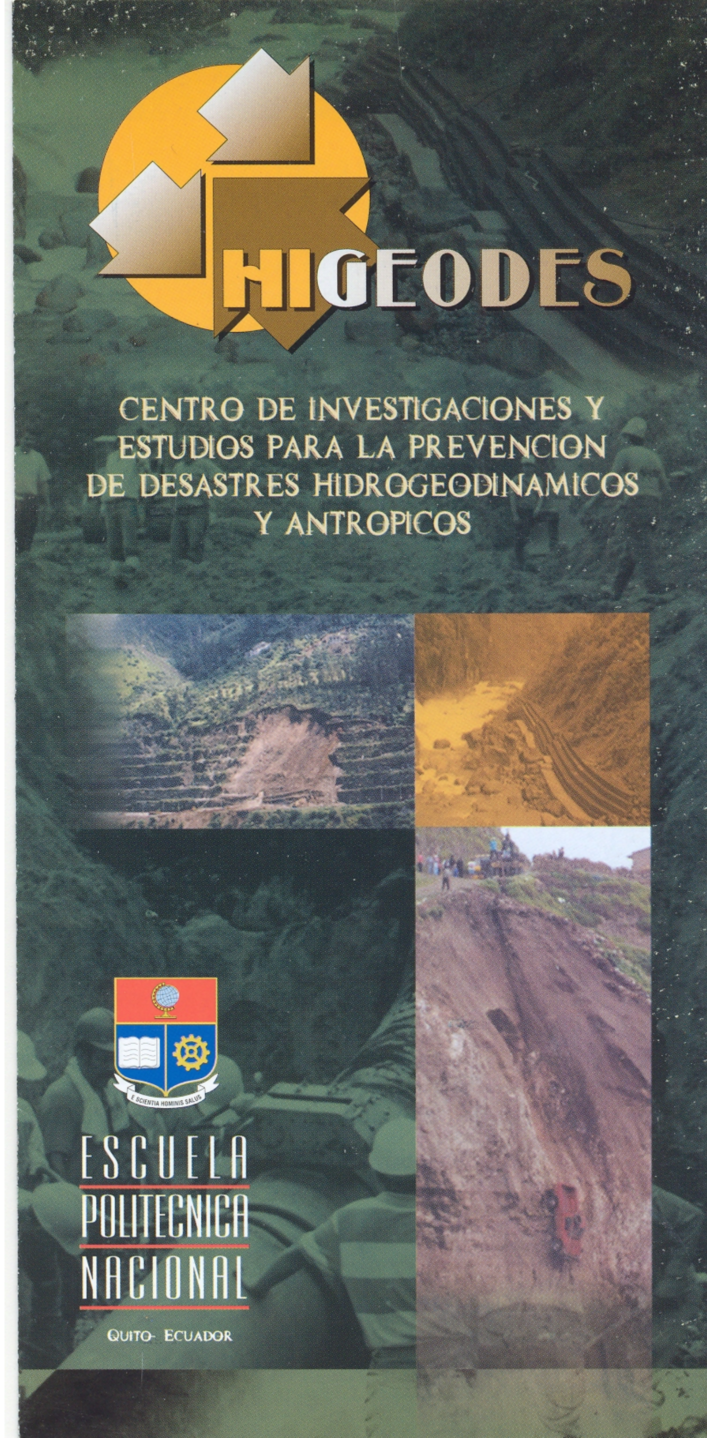
Hazard map. Historical



HIGEODES

Hydrogeodynamic & Antropogenic Disaster Prevention Research Center

It is a technology transfer and development research center, created by the National Technology Transfer Law, which allows universities to create TTC with economical, administrative and financial autonomy.



HIGEODES

- Why a research center on disasters?

Ecuador faces a high vulnerability towards the occurrence of natural and anthropogenic disasters (volcanic origin, debris- mudflows, landslides, floods, oil spills) and therefore it is necessary to undertake necessary actions towards studying and investigating trigger mechanisms, and prevention and mitigation measures for our own economical conditions.

HIGEODES

- Fields of action:

DMF hazard mapping. Identify, design & evaluate prevention and mitigation measures. DMF-flooding- surface / subsurface water- contaminant transport mathematical and physical modeling.

Landslides and slope stability analysis.

Sismogeothecnic & landslide zoning

HIGEODES

Real-time early warning systems

Seismic engineering

GIS applied to disaster prevention Eng.

Watershed management

Environmental impact assessment.

Environmental pollution control

Climate change research.

Department of Hydraulics and Water Resources – EPN and HIGEODES

- Main projects:

Geology, geodynamic, hydrometeorology and DMF hazard studies in the southern slopes of western Quito. Phase 1.

Landslide stabilization studies in the Guazuntos area, Chimborazo Prov.

DMF mathematical modeling & hazard zoning in western Quito.

Seismic, landslide, hydrometeorologic hazard zoning in Bahía de Caráquez, Manabí Prov.

DMF Early warning system in the eastern slopes of the Pichincha massiff, western Quito.

Department of Hydraulics and Water Resources – EPN and HIGEODES

Alternative designs of the Ecuadorian Oil Pipeline System – SOTE - between Papallacta & Baeza. Petrotransporte.

Disaster prevention countermeasures in the rivers Marker, Montana and Reventador. Petrotransporte.

Alternative designs for the Quito Metropolitan Potable Water System due to a possible eruption of the Cotopaxi volcano. EMAAP-Q.